State of the art review
From technology driven invention towards transport demand innovation and integrated application

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Executive Summary

The objective of CityMobil is to achieve a more effective organisation of urban transportation. It will build its research on the results of recent projects\(^1\) and validate and demonstrate the capabilities of new mobility solutions in different European cities.

Urban sprawl and fragmentation of the built up area, enlarges the private car-dependency of the urban society. This is often seen by city governments as unwanted, because of related traffic unsafety, noise disturbance and air pollution and because of intensive land use (car parking included). Automation seems to be a potential solution to handle the new spatial settings in the periphery and in the centre of cities. Besides adapting transport to the new land use patterns, it also seems to be wise to adapt land use pattern as much as possible to match the potentials of newly introduced applications of automated transport.

From a technology driven perspective, innovative transport concepts\(^2\) are being offered as sustainable solutions for both the transport problem, the sustainable city case and the innovation challenge. Feasibility studies demonstrate that automation of transport can provide significant benefits, meet a wide range of policy objectives, can be cheaper to build and operate and provide a level of service which is superior to conventional public transport.

Transport analysis of concepts, focussing on costs and benefits of the automated transport service, results in the determination of system features such as transport demand, peek demand, operational speed, vehicle capacity and frequency of service, that the transport quality depends on. Promising applications derived from this analysis, are mainly related to the length of the track and the given transport demand; a fully automated transport service fits best to a track with a length of 2 to 4 km (one way) and a transport demand of 200 to 400 passengers per hour, one way, on the busiest track, either providing a service as main transport, shuttle service or feeder transport.

Initiators of innovative transport projects often follow a logical approach, starting with an idea, bringing stakeholders together, deciding on plans and finances and making a blueprint to start the construction phase. This logical approach seems to fit with the implementation of one application as part of the mobility system as a whole, but not with the aim to change the system as it is. A transition management approach, a more process-oriented and goal-seeking philosophy, seems to be more sufficient for this, working in parallel in multiple development phases, multiple policy domains and on multiple mandatory levels. In this way one should not be satisfied and lean back having realised one application, but must study the changes in the complex and adaptive social system of sustainable mobility caused by the impact of this success, and prepare for reaction from within the system instead of waiting until ‘things happen’.

\(^1\) Amongst others, the projects from the LUTR cluster, the Netmobil cluster and the CityFreight project.

\(^2\) Cybercars, PRT, high-tech buses, advanced city cars and dual mode vehicles.
Preface

CityMobil did not start from scratch. In the thematic priority of the 5th Framework Program "City of tomorrow and cultural heritage" the seed was planted to develop the technological opportunity of automated transport into an innovative transport concept to serve upcoming needs for niches in transport demand.

In this State-of-the-art deliverable of CityMobil we will reconstruct this change of perspectives: from technology driven invention towards transport demand innovation and integrated application. We will also add the perspective of land use and transport planning, since we know cities adapt to transit and transit adapts to cities.

By doing so, we will leave the stepping stone of successfully implemented niche applications of automated transport and look even further into the future, to draw up the research question: what will be the contribution to urban sustainable mobility of changing the mobility system as a whole because of the introduction of cybercars, personal rapid transit, high-tech buses, advanced city cars and dual mode vehicles?

I like to thanks the co-authors and contributors to the texts in this document and SP2 leader Tony May for reviewing the document. And I want to pay tribute to all partners that contributed to the research over the years, and I look forward to the results of CityMobil in terms of commercial viability and accelerated deployment!

Delft, September 28th, 2006
Marten Janse
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1 General introduction

1.1 Objective of CityMobil

The objective of the CityMobil project is to achieve a more effective organisation of urban transport, resulting in a more rational use of motorised traffic with less congestion and pollution, safer driving, a higher quality of living and an enhanced integration with spatial development. This objective is brought closer by developing integrated traffic solutions: advanced concepts for innovative autonomous and automated road vehicles for passengers and goods, embedded in an advanced spatial setting.

The city of tomorrow is in need of integrated traffic solutions that provide the required mobility in an efficient, safe and economic manner. It is expected that automation, in all possible forms between providing information at one end of the spectrum and fully autonomous driving at the other, will play a major role. We wish to make significant steps forward that will, on the short to medium term, support a sustainable development of European cities.

The CityMobil project will build on the results of recent European and national projects and will validate and demonstrate the capabilities of new mobility solutions in different European cities.

1.2 Supporting European policies

Cities throughout the world are facing numerous challenges in this new century. They are moving towards increased concentration into megalopolises with more than 100 cities expected to have over 10 million inhabitants during the next fifty years while many smaller ones might face a bleak future if they are not “connected” into them.

Freight traffic has increased dramatically in the past decades as well and perspectives for the future indicate that this trend has not come to an end yet. It seems that a strong reduction of urban freight transport will be hard to achieve.

The rise of these megalopolises has been made possible by the development of two forms of transportation. The first was developed in the 19th century with trains and subways. The second has followed from the development of the automobile, in two phases. The first phase occurred in the first half of the 20th century with the development of buses and taxis giving the citizen a new flexibility in their transport not possible with subways and trains, in particular for reaching peripheral locations. The second phase occurred in the second half of the 20th century with the democratisation of the private automobile and the possibility for every citizen to live outside the city, in what became the suburbs.

The consequences of all these innovations in transport have been enormous in terms of urbanism with the freedom for the population to choose where to live, to work and to pursue other activities. It has also led to problems concerning safety and quality of life factors for citizens including pollution, noise, excessive travel times, and more and more difficulties to move around without access to an automobile. Another problem concerns the excessive energy cost resulting from the massive utilisation of fossil fuels by vehicles with the associated problems of oil dependency and global warming.

At the Lisbon European Council in March 2000, a new strategic goal was set for the European Union for the coming decade and this goal concerns directly our urban organisation: to become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and social cohesion.3

It is now widely accepted that the trend of urbanism brought by massive use of the private automobile is not sustainable and goes against social cohesion. In the 12 Prescriptions for a European Sustainable Mobility Policy, the EPC Task Force on Transport has stated that: *Europe should use its potential to become a global leader in the development of a knowledge-based transport sector. Modern technology can help in creating a safer, more secure, customer friendly and efficient European transport system. The challenges resulting from climate change call for increased investment in transport-related R&D. ... European transport solutions should firstly focus on those areas with the biggest problems, including urban areas. Sound, well-managed and well-planned infrastructure would greatly contribute to the reduction of congestion in densely populated urban areas. It is particularly important to make more efficient use of existing urban space by encouraging personal travel in safer, more energy efficient and environmentally friendly ways*.

And, in 2004, in a communication to the Parliament, the Commission has clearly stated that: *Urban mobility needs to be rethought to tackle these negative effects while retaining the potential for economic growth and supporting the freedom of movement and quality of life of urban citizens. A framework at the European level promoting sustainable urban transport seems therefore necessary*.

**1.3 Taking further the results of European research projects**

A sustainable transport system has been defined by the European Transport Council in 2001 as a system that:

- allows the basic access needs and development of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between generations;
- is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy, and regional development;
- limits emissions and waste within the planet’s ability to absorb them, uses renewable resources at or below their rates of generation, and, uses non-renewable resources at or below the rates of development of renewable substitutes and minimises the use of land and the generation of noise.

Several recent European Projects have been funded to face these challenges. Numerous solutions for passenger transport have been proposed and they can be lined up into two approaches:

- A regulation of the demand for transport through a better use of the land (land-use approach) and conventional transport policies with projects some of which have been grouped into the LUTR cluster ([http://www.lutr.net](http://www.lutr.net));
- New forms of urban transport which are more sustainable and offer a better mobility to the whole of the population with also a number of projects grouped into the NetMobil cluster ([http://www.netmobil.org](http://www.netmobil.org)).

The transportation of goods and distribution within the city centres has been researched in the CityFreight project ([http://www.cityfreight.eu](http://www.cityfreight.eu)). Its objective was to identify and analyse innovative and promising logistics schemes in Europe.

**1.3.1 Passenger transport**

The two clusters mentioned above, have identified problems to be solved and have issued recommendations that are important for CityMobil.

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5 A thematic strategy on the urban environment. Communication from the EC to the Parliament (2004).
This is the analysis of the LUTR cluster:

Across Europe there is a common challenge to improve the quality of life in urban communities, and to ensure the competitiveness of cities, whilst promoting sustainable development. All cities face common challenges relating to air quality, noise, urban sprawl, traffic congestion, waste, economic competitiveness, job creation, security, social inclusion, and maintaining the built environment, cultural heritage, and a deteriorating infrastructure.

And through annual State of the Art Reviews, LUTR researchers have brought to light the following directions for moving towards more sustainable cities: These passenger and freight transport trends and projections point to the following land use and transport policy instruments and processes being in place by 2030:

- Travel Demand Management;
- Parking controls;
- Road user charging for passenger and freight vehicles;
- Public transport development;
- Innovative modes;
- Home delivery and services;
- Air transport developments;
- Freight transport regulations;
- Rail freight;
- Urban distribution centres;
- New technology;
- Properly integrated land use and transport planning;
- Land use planning that favours urban regeneration and polycentric development;
- More harmonised land use and transport strategy development, forecasting, appraisal and implementation to promote sustainability and quality of life;
- Targets and indicators to support the above;
- Public participation.

From the perspective of citizens, all this means that many will live in densely populated urban areas at various points throughout their lives, notably, between leaving home and starting families, and again in older age. Some families will also continue to live in these urban areas where polycentric development creates family friendly regeneration, i.e., including local schools, play groups, leisure destinations catering for children etc, as well as creating urban villages where people know each other, creating a safe environment for children to grow up in. Such environments also provide a better quality of life for everybody, especially single person households (be they young or old), those with mobility impairments, and those on a low income. Urbanites will have shorter everyday travel distances, many of which will be undertaken by public transport (including innovative modes), on foot or, where terrain and weather permits, by bicycle.

The propositions clearly call for a strong reduction of private car use to be achieved through a better structuring of the city (involving a polycentric organisation for the largest ones), through better use of soft modes such as cycling or walking, and through better public transport, in particular with new technologies. Soft modes are also wanted because of the health issue for end users.

It was the focus of the NetMobil cluster to examine how new technologies could improve the sustainability of European cities. These technologies concerned new public modes such as guided buses to form high capacity networks similar to light rail but at a lower cost and with better flexibility, PRT (Personal Rapid Transit) and CTS (Cybernetic Transport Systems based on cybercars, small urban vehicles with fully automatic driving capabilities, mostly as a complement to mass transport). They also concerned private vehicles with ADAS (Advanced
Driver Assistance Systems) technologies which could improve the efficiency of the vehicles as well as their safety (examples: intelligent speed adaptation, adaptive cruise control, Stop&Go, lane keeping).

The conclusions of this cluster can be found in their final document: Recommendations for the implementation of potentially sustainable personal urban transportation systems through 2 approaches have been described. The first exploits developments of ADAS systems in car share schemes and private fleets to win the benefits of cleaner, greener, safer and more efficient vehicles as they become available from the vehicle manufacturers. The second promotes PRT/CTS systems which similarly provide cleaner, greener, safer and more efficient transport but through a public transport approach. Both provide alternatives to the use of private cars in urban areas through exploiting automatic vehicle technologies. Both appear to offer cost effective solutions to sustainable urban transportation, and offer different and complementary solutions. Both approaches will lead ultimately to fully automatic vehicles (or dual-mode vehicles), but progress will depend on a range of factors including user acceptance, risks, legal and institutional aspects, and social and market forces.

1.3.2 Transportation of goods
Road freight transport has increased dramatically in the past decades within the urban conglomeration, and prognoses for the future indicate that the growth has not come to an end. The negative aspects of urban freight growth are most visible in all European urban areas: congestion to which lorries and small delivery vehicles contribute; noise emissions, emission of pollutants and accidents are problems that decrease the quality of the urban environment substantially.

Driving factors for freight growth are the liberalization of the transport market and the progressive harmonization of the regulatory environment created by the European Union; the internationalization and globalization of manufacturing and of trade and logistics; the consumers’ increasing demand for customized and frequently changing product assortments. The resulting economy of scale on the production side and on the retail side (e.g. shopping centres) significantly increase the number of commuting trips and shopping trips made by private car and so reinforce the urban and suburban transport problems.

To mitigate the negative impacts of urban freight transport a series of instruments are suggested: time windows and weight restrictions for deliveries; urban freight distribution centres; congestion charging; environmentally friendly vehicles; improvement of information and communication technologies (ICT), etc. Although most of the developments mentioned above have started only recently, first results can still be identified. Moreover, some first results seem very counterintuitive: instead of reducing congestion, some Urban Distribution Centres generate more freight vehicle movements than before. Therefore a successful implementation of instruments to deliver the desired effects has to be accompanied by appropriate adaptations of regulatory frameworks, too. For example, when local authorities impose time frames and weight restrictions they must prevent through adapted land use regulations the relocation of retail shops to the city or town outskirts in the long term.

The objective of the CityFreight project was to identify and analyse innovative and promising logistics schemes in Europe. It provides guidance to a range of interested stakeholders (government, regional, or local authorities, network operators, shippers and consignees) on the ‘best practices’ for analyzing their city freight problems as well as for designing and implementing integrated strategies to solve them.

Each of the solutions/scenarios was judged on four categories:
1. the results achieved by implementing the solution
2. approaches followed by each scenario
3. the kind of policy instruments used
4. the stakeholders directly or indirectly affected by each solution.

The innovative logistic concepts or new transport technologies in this project include:
Urban distribution centres, the use of electric vehicles, the use of rail transport, separation of different types of traffic and creating a process of bringing together all relevant actors.

Automatic modes of urban freight transport have not been tested.

The conclusions of the CityFreight project can be found in their final document:

- *the solution chosen for a certain problem related to urban freight distribution influences and therefore take into account, the interrelationships that exist between actors, the urban context and the distribution model;*

- *there are no best practice solutions for problems related to urban freight, however there are recommendations for a best practice project and process approach.*

In the Netherlands there have been initiatives for underground transport with automated vehicles in city centres and for the establishment of a connection between the flower auction in Aalsmeer and Schiphol Airport. The high investment costs for this dedicated infrastructure, however, did stop these plans.

### 1.4 The CityMobil approach

While the problems of mobility in cities have been clearly identified, the solutions to be put in place are still in their infancy. It is clear that a mix of land-use policies and a shift from the private automobile to a multi-modal approach is the preferred trend. The solution for implementing the multi-modal approach (including and encouraging soft modes, such as walking or cycling) must recognise the need for both high speed scheduled mass transport and individualised on-demand short distance transport. However, these individual on-demand trips should not use the private automobile, in particular in the densest parts of the cities which are not well adapted for the private automobile in terms of space, energy and safety. This is why we have to test new solutions based on advanced city vehicles in car-sharing or public mode, on fully automated vehicles running on new infrastructure (personal rapid transit) and, as a transition path to fully automated road transport, on dual-mode vehicles: traditional vehicles which can be driven manually in mixed traffic or run automatically in dedicated areas.

Similar technologies can be adapted for freight transport in cities with a multimodal approach using dispatch centres outside the cities with clean vehicles running inside (in manual or automatic modes). The initiatives undertaken until now in the public area are in manual mode, while automatic modes are only being used on closed industrial sites.

Thus, the CityMobil Project is perfectly in line with the recommendations concerning urban transport issued in 2001 by the Commission⁶:

- *support (using Community funds) for pioneering towns and cities;*

- *increased use of clean vehicles and of forms of public transport accessible to all users, including people with reduced mobility;*

- *identification and dissemination of best transport system practice.*

The objective of the CityMobil project is to focus on a number of cities in Europe and, by careful study of their requirements, design, evaluate and test sustainable transport innovations. At the end of the project, there will be a better understanding of the capabilities of the new technologies and of what gains there are to be expected in the various city agglomerations.

### 1.5 Modelling of innovative transport concepts

Modelling innovative transport concepts might be a great help to study and detail any expectations about the capabilities of new services. Though very limited, there is some

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experience in this area based on feasibility studies, e.g. on the PRT-case in Cardiff (UK) within the Edict project, and based on micro-simulation, e.g. in the cybercars case in Antibes (France) in the CyberMove project.

But any model is supposed to be a simplification of the system being studied. It is not designed, and should not try to account for everything. It should instead be a well-made resemblance of reality, outlined on discriminating features between possible implementations. The more transparent the model, the easier understood by its end users and the more trusted its output.

In order to help decision making (predicting impacts, optimising solutions, evaluating initial and ex-ante) five types of models are to be distinguished:

- Policy explorers
- Sketch planning models
- Network models
- Transport planning models
- Land use and transport interaction models

**Policy explorers**
These models provide a simplified representation of a hypothetical city configuration and will help to understand the types of impacts a policy or package deal might have, for example road pricing.

**Sketch planning models**
These types of models do represent the city itself, but at a strategic level, and show the main interactions between demand, supply and land use, without giving detailed information. These models are to be used especially in developing strategies or in the pre-design phase of a project.

**Network models**
Network models render the behaviour of vehicles, in most cases by micro-simulation. In the CyberMove project a micro-simulation has been developed to calculate the transport quality at the Antibes site as a part of the ex-post evaluation.

**Transport planning models**
In transport planning models, not the vehicles themselves are being modelled, but the transport services provided by the system. These services are described with functional parameters like: commercial speed, frequency and the service network.

**Land use and transport interaction models**
These complex models represent transport networks and land use patterns and their interaction in detail. They not only predict impacts on traffic and transport, but also economic and ecological impacts, completing the overall sustainability picture. An example of such a model is the ISHTAR Suite7.

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7 The FP5 ISHTAR Project has provided an innovative decision support tool for advanced urban planning and management through the integrated analysis of the various environmental effects of technical and non technical measures. The suite includes both existing and newly developed models, covering the areas of citizens behaviour, transport, vehicles safety and emissions of pollutants and noise, pollutants dispersion and noise propagation, exposure to pollutants, noise and accident and related risk assessment, impacts on monuments assessment and a tool for the overall analysis. These modules are integrated by a software Manager, a Suite Data Base, a commercial Geographic information System and a user-friendly interface. This integration represents a significant technical achievement. Standard models suites normally include only a few of these models. The suite
Modelling of innovative transport concepts does not necessarily call for new types of models to be developed as long as one is keen on the specific performances.

For example, automated transport supply can easily be modelled with a transport planning model, because the functional parameters are exactly the same as the parameters of conventional transport. Only the values of the parameters might be different because of the automation, e.g. higher frequency, lower speed, smaller vehicle capacities, et cetera.

The only item to reconsider, however, is the fact that transport models contain some parameters based on transport behaviour of travellers, among others: choice of transport mode. The willingness of potential passengers to use a certain transport mode is estimated, based on empirical data in relation to travel costs. Such empirical evidence for innovative transport modes is not available. To deal with this lack of information, one could consider a stated preference survey in which potential passengers are presented with a number of situations to chose from. A well performed stated preference survey can give an insight into passenger willingness to use that transport mode.

In the CyberMove project an ex-ante evaluation has been carried out, based on a regular transport modelling approach, in which the service offered to the public with cybercars, had been described with functional parameters. A typical approach in which both transport planning models and network models are being used, is the case in Almere (NL). In this study the transport demand is determined by a classic four step network model in which the supply is being modelled as an extension to the private car traffic at an expected quality of service. Knowing the number of passengers at the site, the network model is being used to calculate the related quality of service. These steps are to be repeated a number of times to determine an equilibrium situation between the quality of service and the number of passengers.

represents a strong enlargement of the applicability area of urban planning tools, since with this kind of ‘multi-impacts’ software tool the user is able to analyse in an integrated and ‘coherent’ way the various aspects of ‘global’ urban policies, without having to perform separate studies relying on different input information and so providing less credible conclusions. Besides the modelling and software integration, the scientific core value of the ISHTAR Suite is represented by a few crucial modelling developments that can be summarized as: prediction of the effects of citizens reaction to postulated measures; improvement of the vehicle emissions modelling; development of an urban road safety model; detailed estimate of pollution effects on citizens health based on the analysis of population groups movements during the day and the temporal-spatial maps of air pollution and noise.
2 Transport in the city of tomorrow

New automated transport modes are developed for the future. Hence, a reflection on the potential of new means of transport needs to take into account future transport supply and future transport demand. The aim of this chapter is to give an outline of possible futures and an analysis as to the extent automated transport fits in. The emphasis is on changes in the spatial structure of cities and the challenges that result from it.

Current land use developments are usually not supportive to public transport exploitation. Urban sprawl and fragmentation of the built up area, makes it difficult to provide public transport services and therefore enlarges the private car-dependency of the urban society. This is often seen by city governments as unwanted, because car transport in an urban environment is unsafe, results in much noise disturbance and air pollution and is very land intensive. Some city authorities therefore try to influence the travel behaviour of their citizens and try to regulate the spatial pattern of mobility. Cervero (1998) identified in his book ‘The Transit Metropolis’ two strategies to cope with the challenges in the area of transport that emerge from the ongoing economic and spatial restructuring of urban areas. Firstly, cities can try to influence the urban development. For instance, they try to arrange that new residential areas and new working locations are located around existing or new public transport lines. Cervero calls these cities ‘adaptive cities’ since they try to adapt the urban landscape to the structure of the public transport system. An alternative strategy that cities adopt is the innovation of the public transport system. Instead of adapting the land use pattern to the structure of the public transport system, this strategy tries to adapt the public transport system to the changing land use pattern. Cervero calls this strategy ‘adaptive transit’.

The automation of transport belongs clearly to the latter strategy, the ‘adaptive transit strategy’. Therefore, this chapter starts in the first section with an assessment of the most important societal trends and spatial developments and an analysis of the role that automated transport can play in the future urban environment. It is outlined how new automated transport modes might provide solutions for the challenges of the future. Then the chapter continues with an assessment of the ‘adaptive cities strategy’ and the opportunities for automated transport. It is argued that although new transit means need to fit in the restructuring urban landscape, they can only succeed when city authorities try to influence the land use developments in such a way that the development and exploitation of these new transport means are optimally supported. Therefore, the second section provides an overview on land use and transport interaction and provides a few guidelines with regard to land use planning from the perspective of automated transport means.

2.1 The need for adaptive transit

2.1.1 The spatial pattern of cities

In a single millennium Europe has become urban (Hohenberg and Lees, 1985). It is especially in the last century that cities have changed dramatically. One of the areas where this change has manifested itself is in the urban structure. Whereas the spatial structure of cities had remained relatively stable for centuries, the 20th century saw important changes take place due to strong population growth, increased prosperity and new means of transport. It is in particular the latter part of the 20th century in which the spatial dimension of many cities multiplied.

Prior to 1850, all cities were based on pedestrians and animal power. Cities were therefore limited in size. The introduction of motorised transport did start a range of fundamental changes in the land use system of cities. One of the first spatial types of deconcentration due to motorised transport was the emergence of the suburb. Semi-urban or suburban areas first formed around horse and cart tracks, then around stations on tracks carrying steam trains.
and by the late 1800s there were suburbs around "commuter" trains and electric trolleys (Risse, 1989).

In the fifties car ownership and the development of the road network, including highways, made it possible for workers to disconnect, at least to some extent, the place of work and the place to live. A lot of households made use of this new freedom to escape the crowded cities. They settled down in settlements that were too small and had too low a density to call them urban but at the same time they were too large and well-structured to call them rural. This process of outward urban expansion is explained by the monocentric model of urban development. Land use, rent, intensity of land use, population and employment are a function of distance to the central business district of the city in the model. This is the foundation of what later is called the monocentric model of the city (Anas, 1998). The monocentric model assumes that regional functions, like jobs, are concentrated in the inner city while residential areas are clustered around this centre. A bid-rent function generates equilibrium between land values and transport costs and thereby structures the urban space. The transport systems in such cities were designed to connect the residential (sub)urban areas to the inner city. Public transport usually consisted of a radial system of heavy rail lines accompanied by feeder bus lines. In case of urban expansion the length of the radials was simply extended. Hence, urban expansion did not imply fundamental change in the structure of the public transport system or public transport technologies.

Most contemporary cities are badly explained by this monocentric model of urban development. Ewing (1997) for example concludes that monocentric development in the United States context is an anachronism, as downtowns have become just one of many centres in large metropolitan areas. Anas and Small (1998) argue that the urban structure of cities is undergoing qualitative change because employment is increasingly decentralised and the inner city is no longer the only major destination area of a city.

There are two major spatial trends. First, there is a general tendency of deconcentration and dispersion. Whereas the first suburbs were well structured along the density and rent gradient, later on in the 20th century suburbanisation of the settlement pattern in the urban periphery became more chaotic and could not be explained by density of rent gradients. In the late 1950s and the early 1960s the term ‘sprawl’ entered the literature to describe this spatial pattern (Burchell et al, 1998). Since this period, sprawl is often used in literature to refer to a dispersed urban development. Sprawl is the result of the decline of agglomeration economies. It appears that the accessibility benefit of spatial clustering no longer outweighs the increasing costs of such clustering, such as congestion, loss of quality of life etc. The centripetal tendencies produced by agglomeration economies are losing power against the centrifugal tendencies produced by a decreasing spatial variation in accessibility (Gordon and Richardson, 1996b; Sudjic, 1992).

The second spatial trend, however, seems to restore, at least partially, the dominance of centripetal tendencies as a force that structures space. At the urban periphery new centres are emerging that concentrate again the employment that was previously concentrated in the inner cities. These new concentration nodes outside the historic central cities are sometimes called ‘Edge Cities’, in particular in North-American literature. Garreau (1991) argues that these new centres qualify as separate ‘cities’ when they contain a full arsenal of urban functions and certain thresholds concerning their dimensions are passed. This is confirmed by Ingram, who gives an overview of observed patterns of metropolitan dynamics in many world cities (Ingram 1998). He describes how large metropolitan areas are converging to similar decentralised structures with multiple sub centres, decentralised manufacturing and more centralised service employment.

The resulting polycentric model has, similar to the monocentric model, its foundations in the theory of agglomeration economies. Agglomeration economies create a centripetal tendency in cities, causing agents to cluster in either large or small groups to facilitate interaction and save costs. Anas and Small (1998) show with the use of simulation models that the interacting centripetal and centrifugal tendencies logically result into sub centre formation and, if cities grow, an evolution of a monocentric urban structure towards a polycentric urban
structure. If a monocentric city grows, the demand and consequently the costs of locations in the inner city increase. The high costs influence the location decisions of businesses. First, businesses that are land extensive and businesses that do not need frequent interaction with other businesses (back office functions) move out and settle down at the urban fringe. Later, when costs of inner cities locations increase, both in terms of rent prices as well as in terms of accessibility, other businesses follow. Within the urban periphery, the still existing centripetal tendencies make businesses cluster in peripheral sub centres. These sub centres may in time rival the city centre. Some argue even that this change of the spatial configuration of workplaces reflects a paradigm change in the economy. Beckouche and Veltz (quoted in Graham and Healey, 1999) claim that ‘the old geography, which linked businesses to the sources of raw materials and to consumer markets is being thrown into disarray at the expense of a more complex geographical arrangement. Hereby, the production-distribution system can fight it out for space using the length of the infrastructure and communication networks on a national, even planetary level’. It is assumed that Christallerian territorial hierarchies and traditional core-periphery hierarchical relations are superseded by a new network development, which rejects the idea that the organisation of the territory is based solely on relations of spatial proximity (Dematteis, 2000).

The originating transport problem

This fundamental change in the spatial configuration of cities does result in new challenges for transport planning. The change in the settlement pattern is driven by the increased mobility of people. The suburb and also the development of a network city with decentralised cores of employment, are the result of an increase in car availability and car use. The spatial setting, however, is not flexible enough to change as fast as is needed to cope with this increasing car mobility.

Also the delivery and distribution of goods to shops cause problems, especially in the inner cities of European towns because of their historical (medieval) character, meaning that they are not designed for lorry and truck mobility. In the more dispersed and polycentric spatial setting, freight distribution seems to be a less severe problem.

2.1.2 Passenger transport

There are a few reasons why public transport is still needed within an urban environment. Firstly, car transport produces considerable environmental side effects, like air pollution, noise and vibration, smell, energy consumption and global warming. Some of these side effects will be solved by technical means. Emissions from motors have decreased considerably and this has resulted in a net decrease in emissions in recent decades. The OECD (1999) reports that emissions per capita of NOx, VOC, particulates, CO and SOx by transport decreased since 1980 by 20% to 40%, in the United States as well as in most Western European countries. Other side effects, however, are much harder to solve, such as the consumption of scarce energy resources and global warming, i.e. the emission of CO2. Both side effects can only decrease when the number of car kilometres per capita decreases, when cars make more kilometres per litre of petrol or when cars use other propulsion fuels like the hydrogen fuel cell. Since this is not the case yet, most countries have seen an increase in the emission of CO2. The IEA (2003) reports that in the Western European countries the CO2-emissions per capita from transport have risen by 40% to 80% in the period 1973-1998 to arrive at a value around 0.4 tons per capita in the late-1990s. Over the same period the CO2-emission per capita from transport in the United States has only slightly increased (almost entirely due to increased air travel), although the absolute volume is still three times higher than in Europe. Also with regard to noise, the outlook is not positive. It is estimated that approximately 32 % of the EU population is exposed during the day to road noise levels exceeding 55 dB directly in front of their homes and this will continue to increase due to the expected growth in freight traffic and the dominance of tyre noise offsetting the effect of the expected reduction of engine noise (EEA, 1999).
Secondly, car transport requires much land. Although the structure of cities has changed enormously over the last decades, the speed of change is relatively slow compared to the changes in mobility levels. In particular the historic parts of cities have difficulties in accommodating the traffic growth. Land use is related to car ownership; the more cars per capita, the more land used for parking and driving. The OECD reports that in the period 1980-1996 the total stock of motor vehicles in the EU15 increased by 62% and in the USA by 35%. The land used for transport and parking is likewise to increase as well.

Thirdly, car transport results in many accidents and traffic casualties, in particular in the urban environment due to the concentration of many activities. However, there have been ways to decouple traffic growth and traffic accidents. Over 39 thousand people died in 2001 in Western Europe from injuries of road accidents. Whereas this is still a significant figure, it is approximately 50% less than in 1970, while mobility grew over the same period by 250% (ECMT, 2003). Nevertheless, 39 thousand people are still a small city.

Fourthly, and last but not least, public transport is also needed out of social considerations. The emergence of the motorised transport modes has changed human life fundamentally. The increased mobility of almost all citizens has had far-reaching effects on social and economic life. Those with good access to transport modes have profited most. Differences in transport access have resulted in differences in economic and social opportunities. For example, several social studies have shown that female participation in the work force has been hindered by a lack of access to mobility (Root et al., 2002). Mobility is usually not perceived as a constitutional right, like the right to education or health care. However, mobility is often a condition to realise these constitutional rights. When an individual has no means to transport, the existence of a good hospital or school becomes irrelevant. And it is easy to extend this argument to almost all activities of social and economic life. Consequently, governments may want to provide alternative transport to enable all citizens to take part in society.

The need for good public transport is particular urgent for European cities since European cities rely much more strongly on public transport than North American cities. The share of car travel in cities in the United States ranged in 1990 from 62% (New York) to 93% (Detroit). In Western Europe levels in between 35% (e.g. Freiburg, Amsterdam, Munich) and 60% (e.g. Paris, Bordeaux, Trondheim) are more common. In many large American cities public transport counts for only 2% to 5% while in large European cities the market share of public transports counts for 10% up to 30% percent (Paris, Rome) of the modal split (Pucher and Lefevre, 1996). If European cities want to keep these high public transport market shares than they will have to adapt their public transport system to the emerging more dispersed and polycentric spatial setting.

Automation seems to be a potential solution to handle the new spatial settings. These spatial settings occur in the periphery and in the city centre.

**Public transport at the urban periphery**

For the outskirts of towns a few main trends are identified and the potential chances for automation of public transport have been formulated. The first trend is urban sprawl, this not only lowers density, it also increases the distance between the different activity centres of citizens. The other main trend concerns the change in user needs and change in social activities. The car dependency (rising car ownership and growing work participation by women) is a second large trend which is important to realize. Keeping in mind especially the growing group of travellers who are depending on public transport, the public transport system should fulfil this function.

For the first trend, urban sprawl which is causing the increase of travel distances, a chance for automated public transport lies in the feeder function it could fulfil. This increase of distances makes it necessary to create a coarse network for the main public transport to allow higher speeds for the connection between nodes. These nodes on this network still need to be accessible for passengers. The connection of passengers to the nodes on the network is an opportunity for automated public transport, it serves as feeders for the main...
network. This feeder function allows a greater area around the node to be accessible from the node, since not only walking but also for example a fully automated vehicle is an option to get to and from the destination.

Related to this is the development of network cities. This trend creates a need for connection of the new centres, which are not always connected to the current public transport network, to the current network and to the other different centres. These centres can basically serve again as centre for feeders, however one of the feeders will form a connection to the existing public transport network.

The second consequence of urban sprawl is the decrease in density of people per square kilometre, and therefore the decrease in use of public transport (per square kilometre). This decrease is directly related to the cost effectiveness of the transport supply. If the occupancy degree is expected to be too low and therefore the operating costs would be too high, the introduction of automated transport might be a solution. Operating costs of automated transport are lower, compared to conventional public transport. Therefore, looking at urban sprawl, there are several chances for automation of public transport to be implemented, if the spatial effects need to be challenged by public transport.

The third identifiable trend is the rise of mega-complexes for shopping, entertainment and other activities. These mega-complexes require frequent public transport allowing people to travel to these centres. People wishing to travel to these activity centres have different expectations for public transport compared to commuters or children travelling to school.

From a users' point of view two trends can be identified looking at the change of user needs. This change in user needs occurs in several ways. The first one is the aging of the population, there will be a growing group of seniors who will have time and money to travel. This group of people is willing to pay for a comfortable ride and demand a higher quality of public transport compared to that which is delivered currently. This is another chance for automation of public transport, although exploitation costs of automated transport are low, the comfort level is increasing and they can be adapted easily to demands of the seniors using this means of transportation. The second trend involving change in user needs is the increasing wish for freedom of people. This increase could be translated to an increase in frequency to satisfy this wish. This increase in frequency is difficult to solve with conventional public transport, for automated transport however this is not a problem at all. Especially when this automated transport is made on demand and therefore creating the largest freedom possible for users.

The last trend which is visible is the trend of uncertain development of all current urban complexes. There are expectations for certain built up suburbs which will be deserted within 10 to 15 years, therefore it is not an option to integrate heavy rail into these new suburbs. Another form of flexibility is actually demanded from public transport. Conventional heavy rail or even light rail is not really an option if it is implemented, automated public transport which can be used on already available infrastructure creates larger flexibility and is more adaptive to changes in demand and density. This is another big chance for automated public transport, its flexibility.

**Public transport in the inner city**

For the inner cities different trends can be identified. A very important issue is the liveability of city centres (sustainability). Citizens request more quality of life in the city centre, this means abandoning the car outside of the centre and replacing it for example with a fully automated vehicle. Another important issue here is appeal of the current car, which is still seen as an important psychological issue for human beings.

The quality of the air in urban centres is considered important, especially after the introduction of the new EU-standards concerning the air quality. This asks for different forms of transport in the inner city, for example vehicles which are sized to fit. These sized to fit vehicles can be electrically driven and therefore will contribute to cleaner air. The automation
of public transport in the inner cities therefore will contribute to a greater sustainability. Abandonment of the car and replacement with a fully automated vehicle might be very interesting in the coming years.

A second important issue about travelling is the appeal of the mode of transport. Public transport is nowadays associated with low appeal and is not considered to be of high standard. Introducing a fully automated vehicle might be a possibility to change the appeal currently associated with public transport. If the change in appeal can be realized another big chance for fully automated vehicles is identified and the current issue of declining use can be solved.

The trend already identified in the previous section about the change in user demands is also valid for the inner city or city centres. Adapting to the spatial patterns currently identified there is a large potential for automation of public transport. Especially when current amounts of public transport travel in European travel cities need to be maintained.

2.1.3 Freight transport

Freight transport at the urban periphery
Besides public transport there is also a need for urban freight transport to deliver goods to the shops. Problems exist especially in the inner cities of European towns. In the emerging more dispersed and polycentric spatial setting freight distribution is a less severe problem. Urban sprawl for the transport of goods is not a negative trend. In the designing phase of the development of the area the demands for freight transport could be kept in consideration. Most of the new areas are located close to major roads so there are fewer difficulties to reach the stores compared with stores in the historical inner city.

The size of sites and the character of companies at the urban periphery can make automated transport of freight within the company’s site possible. The technique for automatic guided vehicles is developed far enough and already implemented for several kinds of jobs. These automated vehicles are used at locations where the public can not enter so the risk of collisions is lower and the safety norms are lower.

Although there are high investment costs at the start, savings on wages of personnel can make the automatic guided vehicles profitable in the long run.

Freight transport in the inner city
The same problems exist for freight transport in the inner city as for public transport. For the sake of liveability the entrance of freight trucks in city centres is limited with time windows or other restrictions. The emissions and the size of the trucks are perceived by the shopping public as main problems.

To solve these problems new logistic schemes are developed for the distribution of the goods in the shopping area. One solution, often mentioned, is the use of small electric vehicles delivering goods from a distribution centre just outside the shopping area to the shops. In several European cities pilot project are conducted.

The costs of these electric vehicles are at this moment the main disadvantage. Further developments could permit these vehicles to drive automatically without a driver in the future. This could even make transport of very small amounts remunerative.

2.2 Adaptive cities

2.2.1 Integrated land use and transport planning
Besides adapting the public transport to the new land use patterns, it seems also wise to adapt the land use pattern as much as possible to match the potentials of newly introduced applications of automated transport.

In the United States the integration of land use and transport planning is more recently called “smart growth”, which can be considered to be a nice shorthand for transport and land-use
integration, aimed at reducing mobility (Cervero, 2000). By coordinating land use planning and transport planning at the regional level cities can try to adapt the urban structure, i.e. match the land use pattern and the transport system, in such a way that mobility is thought to change in a preferred direction.

Land use planning and transport planning are traditionally separated, both in practice and in academic discourses. This is seen not only in vocabularies and theories, but also in many practical examples of planning. It is not uncommon that land use investment is not accompanied by adequate transport investment. For many years two of the airports in Paris lacked adequate public transport. Orly airport was built in the 1960s, but a connecting automatic train (OrlyVal) was only realised in 1991. Roissy airport was built in the 1970s, but the direct connection with the city centre was not established until 1984. A more recent example is the development of new large-scale residential areas in the Netherlands under the framework of the Netherlands Fourth Document on Spatial Planning (VINEX). Snellen et al (2005) calculated that 42% of the houses in these new neighbourhoods lack good public transport access, which is higher than the Dutch average. This is primarily caused by differences in strategy and timing of the ministry responsible for transport and the ministry responsible for housing.

Additionally, the proliferation of large out-of-town shopping malls in many European countries, especially in France, during the 1990s is symptomatic of the failure to adequately integrate land use and transport planning. Nowadays, some countries have imposed blanket bans on developments of this kind until more effective policy options are formulated (ECMT, 2001).

Integrated land use and transport planning is, in essence, a matter of policy integration and institutional reform (Hägerstrand and Clark, 1998). This management of cross-cutting issues asks for more than just having a meeting once in a while and informing each other of ongoing activities. Integrated policy making is more than policy coordination or policy cooperation. The main differences relate to the interaction and the output (Stead, 2004). Coordination means that different sector policies are coordinated in order to overcome possible mismatches, and cooperation merely means that different departments work together in order to increase efficiency. Integrated policy-making goes further; it produces one joint policy and starts with a shared policy objective that goes beyond the objectives of the individual departments.

2.2.2 Policies to favour public transport use

The method to increase public transport usage in the long run is to cluster land use around the stops. It is often shown that people or employees who live or work around a public transport stop use this facility more frequently (Hilbers, 1997; Van Wee, 1997). This conclusion is also valid for new public transport modes.

8 For instance, the Netherlands had between 1990 and 2000 a location policy for employment. This so-called ABC-location policy aimed, among other things, to concentrate businesses around public transport nodes. There are various examples of companies that did move towards a location around a public transport station and where this move did indeed change in a significant way the travel behaviour of its employees. For instance, the move of the Chamber of Commerce in Amsterdam towards the area around the central station decreased the share of car travel in the modal split of its employees by 50%. The move of the ministry of Housing, Spatial Planning and the Environment to a location near the central station of The Hague decreased the share of car travel by 30%. Although, there are also examples where the expected mobility impact did not manifest itself, the overall conclusion of many authors is that concentration of residents and employment around public transport stops does result in a higher usage of public transport.
A fully automated vehicle, or any other form of automated transport, will perform better when it is embedded in the existing spatial structure and when new urban developments are located around its stops.

2.2.3 New challenges

The speed of spatial change in cities does however result in additional challenges. In the past urban planners could try to locate employment around train or metro stations since they could assume that both the infrastructure as well as the employment would remain at that location for decades to come. Location decisions were therefore very important since they determined the urban structure for many years to come.

Nowadays, it seems that the land use and transport system has become much more dynamic. The lifetime of an office building has decreased enormously and location decisions have therefore a smaller impact that previously. As described above, public transport will also have to react to this higher spatial dynamic in urban areas and will have to increase its ability to adapt to new spatial settings, for instance by means of automated transport modes such as fully automated vehicles. Firstly, the introduction of public transport modes that make use of existing road infrastructure enlarges the flexibility of public transport companies. In the past they could only respond to changes in the land use pattern by changing the frequencies on public transport lines. Changing the exact location of these lines was difficult due to the rail infrastructure. By introducing new transport modes that make use of the extensive road network of cities, public transport companies have much more flexibility. Secondly, the introduction of automated public transport may enable companies to exploit public transport in the rapidly developing low density areas at the urban fringe.

However, if both land use patterns and public transport networks become more dynamic, there are important implications for land use and transport planning. On the one hand, the high dynamics are a threat to integrated land use and transport planning, since a good location decision will impact over a shorter time. Consequently, the net impact of policies that try to match land use to the public transport network becomes smaller.

On the other hand, the high dynamics also result in new opportunities for urban planners. Simply because it is easier to change the public transport network and because land use patterns change faster, there are more possibilities to match land use and public transport. While in the past it took cities 20 to 40 year to develop a particular urban structure (for instance the finger structure of Stockholm), now they may reach a good match within 10 to 20 years.
3 Technology driven inventions...

Visioning the future from a technology point of view makes it easy to imagine flying cars, monorail, driverless container transport, high speed buses, and the like. But when it comes down to solving transport problems, a system innovation of the mobility market requires more than a technical approach—not to mention investments in infrastructure and maintenance costs. The FP5 Netmobil cluster merged the results of four projects on innovative transport concepts: CyberCars, CyberMove, Edict and Stardust.

3.1 Promising solutions

Table 1: Different approaches of innovations in passenger transport

<table>
<thead>
<tr>
<th>Innovative transport concepts</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cybercars are fully automatic, clean, driverless vehicles that run on guide ways, and will evolve to operate on street in mixed traffic, starting with traffic at low speed (pedestrians, bicycles) and traffic with professional drivers (taxis, buses).</td>
<td><img src="image1" alt="Cybercar Image" /></td>
</tr>
<tr>
<td>Personal Rapid Transit (PRT) is a system of fully automatic clean, driverless vehicles that run on guide ways to segregate them from other traffic and pedestrians;</td>
<td><img src="image2" alt="PRT Image" /></td>
</tr>
<tr>
<td>High-tech Buses run automatically on guide ways and can dock precisely, but need a driver on city streets.</td>
<td><img src="image3" alt="High-tech Bus Image" /></td>
</tr>
<tr>
<td>Advanced City Cars provide cleaner, safer and more efficient vehicles, but ultimate control remains with a driver; they are equipped with advanced driver assistance systems.</td>
<td><img src="image4" alt="Advanced City Car Image" /></td>
</tr>
<tr>
<td>Dual Mode Vehicles combine the advantages of a fully automated mode wherever possible, with a manually driven mode wherever necessary.</td>
<td><img src="image5" alt="Dual Mode Vehicle Image" /></td>
</tr>
</tbody>
</table>

9 This chapter summarises the work and results of the FP5 Netmobil cluster as presented at the final conference held in Rotterdam, June 2005, “New Transit in Town”.

State of the art review 25
The issue for the Netmobil cluster has been to show how the different approaches of innovations in passenger transport (Table 1) can be exploited to best effect by communities seeking sustainable solutions for the future.

### 3.2 Policy and application areas

Within the Netmobil cluster, three main policy drivers have been identified for the implementation of new transport systems with automated vehicles or advanced driver assistance. These are:

- the “transport problem” case, where there are identified existing problems of increasing traffic congestion, accidents, pollution, lack of flexibility, integration and accessibility in the transport network;
- the “sustainable city” case, where the project is not problem driven, but driven by environmental and lifestyle goals and local development plans which derive from the vision of a sustainable “City of Tomorrow”;
- the “innovation policy” case, where the project is not problem driven but driven by the goal of creating new opportunities through launching an innovation process.

The systems have been shown to offer the potential for cost effective and sustainable solutions to particular problems, whilst at the same time demonstrating innovation policy. For instance: advanced driver assistance systems include ACC (adaptive cruise control), lane keeping assist, ISA (intelligent speed adaptation) and Stop&Go (automatic queuing in congested traffic). By themselves they provide opportunities for improved efficiency and safety of operations of vehicles, including buses, in urban areas. They can be exploited, for example, in an ‘advanced car share application’ that will discourage private car ownership and use in cities, and promote shared use of cleaner, safer vehicles.

#### Table 2: Promising applications in summary

<table>
<thead>
<tr>
<th>Problem / driver</th>
<th>Application type</th>
<th>Technological concept</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cybecars</td>
</tr>
<tr>
<td>Transport problem</td>
<td>Interconnect modal interchanges</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Feeder to retail/business/leisure developments</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Flexible links between major services (e.g. hospitals, universities) and transport</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Connect car parks with transport system</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Short distance, on-demand, door-to-door travel</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Low density transport demand</td>
<td>X</td>
</tr>
<tr>
<td>Sustainable city</td>
<td>Clean, safe road vehicles</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Clean, safe vehicles on segregated track</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Using cars in a better, more efficient way</td>
<td>X</td>
</tr>
<tr>
<td>Innovation policy</td>
<td>Short links to develop (part of) the city’s image as a leading city of technology and innovation</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Innovative way of introducing new mobility management</td>
<td>X</td>
</tr>
</tbody>
</table>
PRT and cybercars transport systems can be used to provide short flexible links between major attraction points. They are preferred to solve a particular public transport problem e.g. to extend services from an existing train or metro station to serve a new business park or regeneration area. These systems also complement innovation processes.

Summarized in Table 2, these solutions can meet the requirements of a number of policies and types of application areas.

**Logistic applications**

Apart from these passenger transport applications, it is relevant to list logistic applications in the freight sector to handle goods with robotic applications. A well known showcase in the Port of Rotterdam that has been a source of inspiration to work on passenger transport with automated vehicles as well, is the European Container Terminal (ECT).

Since 1993 The ECT terminal in the Port of Rotterdam has used automatically guided vehicles for the loading and unloading of containers from cargo ships at the terminal. The objective for introducing this kind of handling, has been: the rise of the capacity of the terminal and the speeding up of the loading and unloading process at lower costs. The terminal is a closed industrial site, so there are no problems with transport legislation and there is no risk of collisions with other transport modes.

These container carriers are capable of transporting either a single 40ft. or two 20ft. containers. Both active and passive restraints are used to secure the containers with a maximum load of 60t in its position while travelling.

The automatic guided vehicles are equipped with all-wheel steering enabling tight turns. The vehicle is entirely symmetrical, without any difference in forward/reverse speed limit (11km/h). It has powered wheels on both axles and is equipped with a diesel engine. Safety is among others ensured by means of laser obstacle detection scanners.

The same automatic container carriers are now also used in the Ports of Hamburg and Antwerp.

**Figure 1: Fully automated vehicles at the ECT terminal.**

3.3 **Driver assistance and cybercar technologies**

The 5th Framework Program has brought many improvements to the technologies for automated transport. Two parallel development lines are being explored, one on driver
assistance systems in the ADASE projects and one on fully automated vehicles in the CyberCars project. The main difference between these two lines is the operational context: whereas driver assistance systems are developed in full traffic, fully automated vehicles are developed in protected environments segregated from other traffic.

3.3.1 Driver assistance
ADASE ([http://www.adase2.net](http://www.adase2.net)) aimed at paving the road for the introduction of the advanced driver assistance systems for passenger cars in Europe by coordinating existing studies, by developing scenarios for the introduction of these systems and by initiating new innovative European projects.

The introduction of advanced driver assistance is characterized by an evolutionary or step-by-step introduction and development of these systems. Each step enables the next step on the roadmap. This is due to the limitations of technology, the users and the costs. An evolutionary introduction will allow the users to understand the reactions of advanced driver assistance systems better, gain experience and confidence, and so raise the acceptance of these new systems. Where the costs are concerned, no supplier is going to offer a new advanced driver assistance system, if no customer is willing to pay for too expensive a service.

In 2004 the ADASE roadmap (Figure 2) was updated. The technological focus was extended in many other aspects of driver assistance like legal aspects, political and societal aspects, etc. In each case the complexities of the system concerning these aspects are shown by the size of the dots. The overall consideration of all these aspects and the functionality of the systems should lead to an assessment of the estimated safety benefit.

Figure 2: ADASE roadmap

3.3.2 Cybercar technologies
In contrast with the ADASE roadmap in which fully automated vehicles appear in the end of an evolutionary process of motorcar development, the CyberCars project ([http://www.cybercars.org](http://www.cybercars.org)) developed automatic vehicles as a starting point. This has meant
that the environment in which they can be tested has had to be
controlled and kept clear of other traffic. The technologies that have been tested are
described below.

Fleet management
Industrial companies have developed management software based on a centralised system
and communications. These systems now offer a very flexible operation and can implement a
demand responsive transportation system with minimum waiting times and a low number of
vehicles.
At the research level, new techniques have been developed for the optimisation of large
scale systems.

Communications
Good communication between the vehicles and the infrastructure and between infrastructure
and the users is essential for any good transportation system. In the case of cybercars where
the vehicles are run according to demand, this is even more essential. During the project,
various communication schemes have been used and are now operational on various
systems: GSM and GPRS mostly for communicating with the users through their mobile
phones, and Wi-Fi (IEEE 802.11) for the communication between vehicles and infrastructure.
High bandwidth communication is needed in case of transfer of images, for example for
remote control of the vehicles.

Energy
Cybercars offer the unique opportunity to turn away from internal combustion engines and
inherent local pollution and noise in the cities. All the cybercars available now run on
batteries and electric motors, because the cities require it. Due to the low energy capacity of
the batteries, the management of the energy is crucial for an efficient operation of the
system. Various optimisation algorithms have been developed in the project for the optimum
battery capacity and recharging strategy. Also, techniques for automatic recharging and for
energy transfer through induction have been developed and tested.

HMI
Human machine interfaces (HMI) are also one of the key elements for the ease of use of the
system and hence for its acceptance. Various developments have been done in the project to
work on simple but powerful interfaces inside or outside of the vehicle. It has been accepted
now that the most convenient way to request the vehicles is either through simple call
buttons (such as for elevators) or, when this is not possible due to a very large number of
pick-up points, through a mobile phone. More advanced interfaces have also been explored
in the context of another European project, OZONE, which develops a generic framework for
consumer oriented ambient intelligence applications10. Cybercars are used in this project as
a test case.

Control
Cybercars are precursors of drive-by-wire vehicles since acceleration, braking and steering
are be controlled by computers. During the project, participants have developed new
hardware for the safe implementation of these functions. However, the main focus has been
on the development of safe software. To reach a high level of safety in a complex computer
environment, often with distributed processing, a new tool has been developed which has
been extensively used and validated by several partners. This is the SynDEx approach which
allows the development and certification of distributed real time software.

10 http://www.hitech-projects.com/euprojects/ozone/
Obstacle avoidance
Obstacle avoidance is the main difficulty in the deployment of cybercars. Considerable research work has been carried out in this domain by the partners. Now available on industrial vehicles are systems based on scanning laser rangefinders complemented by ultra-sounds and sensing bumpers. These sensors are associated with advanced control software to anticipate potential collision while ignoring obstacles which are not in the path of the vehicles.

Other collision avoidance techniques based on radar and on vision have been researched. They are not yet certified but offer great promise for lowering the cost and improving the performance. These researches are conducted in close cooperation with the automobile industry which is looking for similar devices for avoiding vulnerable users in urban environments.

Platooning
Platooning techniques are needed for the operation of several vehicles closely spaced. The first vehicle of this platoon may or may not be automatic depending on the application. Two techniques have been developed in the project. One relies on the scanning laser sensor used for obstacle avoidance and the other is based on the development of a linear camera using low cost components. Both approaches give good results but the linear camera has the potential for very low gap and high speed operation.

Navigation
The first automated vehicles used an infrastructure-based approach with electric wires or transponders. During the project, Frog improved its navigation technique, based on dead-reckoning associated with localisation on magnets widely spaced and hence implemented at low cost. This technique allows for fine tuning the exact path of the vehicles and is available on the ParkShuttle II, the system that is operational in Capelle aan den IJssel/Rotterdam.

Other techniques based on localisation by laser or natural features in the environment or on vision have been demonstrated. These techniques, which require no modification of the environment, are still to be industrialised. Advanced techniques for path generation in complex and dynamic environments have also been explored successfully.

3.4 Netmobil conclusions and recommendations

The feasibility studies and trials undertaken in the Netmobil cluster projects demonstrate that cybercars and PRT:

- can provide significant benefits and meet a wide range of needs and policy objectives within different urban environments;
- can be cheaper to build and operate than conventional forms of guided public transport;
- provide a level of service which is superior to that available from conventional public transport because there is very little waiting time, travel is essentially private and is non-stop direct from origin station to destination;
- integrate well with other forms of public transport;
- are well received by the public – end users perceive advantages in view of enhanced traffic safety, personal security and environmental benefits. There are issues of

11 Since the objective of the Netmobil cluster aimed at the potentials for deployment of innovative transport concepts, taking them one step further along their development lines, not that much has been concluded in terms of sustainability impacts which is an issue in the CityMobil project. See also footnote 9.
concern relating to technical reliability and legal aspects which can be proved by a real demonstration;

• are likely to receive mixed responses from stakeholders with some resistance because technology is new and untried. Main issues of concern relate to visual intrusion and technical reliability;

• promote the social inclusion of certain groups especially disabled and elderly persons by increasing their access to cities and key services e.g. retail, recreation, hospitals, stations and vehicles are also proved more accessible than conventional modes;

• are regarded as a quiet, safe, convenient and efficient means of public transport with potential to replace car trips;

• can enhance the image of cities, attract inward investment, and increase the economic value of land and premises.

Simulation studies of Advanced Car Sharing systems have shown:

• significant reductions in traffic-related pollutant emissions can be achieved within a city (as found in the AMICA study);

• the Praxitéle example proved the technical feasibility of the scheme;

• there is a high user acceptance of car sharing. The number of users doubled from 400 to 800 in 12 months in the Praxitéle experiment. The use of public transport is also found to increase with car sharing usage;

• there are certain vehicle design features to consider in meeting user needs for short trips within cities. For example, making the system easy and convenient to use through ticketing access, route guidance, reservation;

• car sharing scheme results in societal benefits providing it achieves a modal shift and replaces existing private car journeys;

• as realised in the Praxitéle example it is unlikely that, in the present stage of development, an advanced car sharing scheme would be economically feasible. The current cost of producing electric vehicles is too high to cover costs, especially for a scheme with less than a few hundred vehicles.

Potential for integrated transport:

• cybercars and PRT can provide flexible links to public transport interchanges and park and ride facilities. It works best when integrated with the transport network, thus improving overall network efficiency, journey quality and reducing the need for car journeys. Research also suggests that people use public transport more frequently with PRT and CTS systems, as the overall public transport network can be improved;

• car sharing is designed to complement public transport. User trials indicate that users are likely to use public transport more frequently as a result of car sharing. Integrated ticketing can encourage multi-modal journeys by public transport and make car sharing attractive. Season tickets for public transport may include special discounts on car sharing. The examples in Zurich, Bremen, Aachen, Hanover and other cities show that integrated ticketing of public transport and car sharing options greatly encourage use and frequency of use during peak and off peak periods. Other services could also be included to improve mobility within cities e.g. taxis and car hire.

Since the combination of technological concept and transport supply service in the definitions of promising solutions sometimes seems to be confusing, one of the overall challenges for CityMobil to work on, are more generic descriptions that will be comprehensible to the public to understand what automated transport really offers.
4 Transport analysis of concepts

The first developments of fully automated vehicles were focused mainly on improving the technology of automatic driving. Recently the focus has started to shift to the transport application: where and under what circumstances can fully automated vehicles be a useful addition to the existing range of transport modes? And can they in some respects even replace certain parts of the existing range?

This shift of focus can be considered a step towards maturity: from a technology driven invention towards a transport demand innovation and integrated application. The aim of this chapter is to get a general insight of the transportation possibilities of the promising solutions introduced in chapter 3. This will be achieved by logical reasoning, supported with some basic calculations and assumptions.

The emphasis in this analysis will be on public transport applications, taking advantage of the natural plus points of collective transport to solve congestion problems in built up areas and enhance the quality of life. Car sharing schemes and mass transport supply match the need for city mobility to be serviced partly by collective transport and offer alternatives for individual private car use. In this sense, it does not matter whether the service is carried out by supplying a cybercar, PRT, high-tech bus, advanced city car or dual mode vehicle.

The special advantages of (fully) automating the vehicles are:

- saving personnel costs of the driver;
- scheduling at high frequencies with smaller units at relatively low cost;
- more possibilities for on demand services because of smaller units and therefore also useful in cases and time frames of a low transportation demand;
- saving energy and vehicles being quiet, clean, and economic;
- an innovative image.

To determine the prospects of innovative transport applications, two discriminating factors have to be taken into account: benefits in relation to the number of transported passengers, and operational costs of the vehicles. First we will look at the automated transport service itself. Secondly we will compare the automated mode to regular modes.

4.1 The automated transport service

There has been a number of case studies looking at costs and benefits of automated systems, including the Edict project which conducted feasibility studies to show the potentials of implementing PRT in several European cities. In the next paragraphs, we take our experience from the only operational system in Europe so far: the ParkShuttle system between metro station Kralingse Zoom (Rotterdam) and business park Rivium (Capelle aan den IJssel).

We look at the fully automated vehicle transport system as a stand alone system and use transportation demand as a given fact. The success of its service depends both on the transportation demand and the operational concept. Based on ex-ante data from the CyberMove project, we can draw up a balance sheet and start analyzing.

4.1.1 Balance sheet

Table 3 indicates the total operational costs of the Rivium ParkShuttle, on an annual basis. Supervision is needed during the entire operating period. It is assumed that supervision can be combined with other tasks, like the managing of the parking facilities. Calculations are based on an operating period of 12 hours per day (1.5 FTE), of which only 0.4 FTE is attributed to the Rivium ParkShuttle.
Table 3: Operational costs per year (based on CyberMove reports)

<table>
<thead>
<tr>
<th>Operational costs per year</th>
<th>€</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supervision 12h/day (0.4 FTE attributed to ParkShuttle)</td>
<td>48,000</td>
</tr>
<tr>
<td>Other costs for exploitation (maintenance, energy, etc.)</td>
<td>168,000</td>
</tr>
<tr>
<td>Vehicles and control centre (depreciation 8 year)</td>
<td>327,000</td>
</tr>
<tr>
<td>Infrastructure not taken into account</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>543,000</strong></td>
</tr>
</tbody>
</table>

Noteworthy is the structure of the energy costs. According to data from the Coimbra case in the CyberMove project, the particular vehicle (a 2-passenger fully automated vehicle) consumes 0.11 kWh/km, which at € 18 ct/kWh comes down to a subtotal of € 2 ct/km -a very decent price compared to the cost of a combustion engine. However, replacing the batteries will cost € 1,500 per year per vehicle. If a vehicle were in operation for about 24,000 km a year, this results in € 6 ct/km. Thus, the battery price is the dominant component in the cost of the energy.

Table 4 shows, based on a few assumptions, an estimate of the balance sheet of the Rivium ParkShuttle.

Table 4: Costs and benefits (based on CyberMove reports)

<table>
<thead>
<tr>
<th>Description</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of persons transported per day</td>
<td>3,677</td>
</tr>
<tr>
<td>(prognosis of the public transport company)</td>
<td></td>
</tr>
<tr>
<td>Number of persons transported per year</td>
<td>735,400</td>
</tr>
<tr>
<td>(200 days/year)</td>
<td></td>
</tr>
<tr>
<td>Cost of 1 person being transported</td>
<td>€ 74 ct</td>
</tr>
<tr>
<td>(€ 543,000 / 735,400)</td>
<td></td>
</tr>
<tr>
<td>Revenues of 1 person being transported</td>
<td>€ 85 ct</td>
</tr>
<tr>
<td>(1 tariff zone, sold in advance)</td>
<td></td>
</tr>
<tr>
<td>Ratio of revenues and costs</td>
<td>115%</td>
</tr>
</tbody>
</table>

A few remarks on these rough calculations:

- the estimated revenue of 1 tariff zone per ride is somehow optimistic. In reality, many people use a season ticket, which generates less revenue per ride. Moreover, many people use the fully automated vehicle in combination with another mode of transport, e.g. metro, whereas they do not pay for each ride separately. So, only a part of the revenue of 1 tariff zone can be assigned to the ParkShuttle;
- the estimate for the cost of supervision (0.4 FTE attributed to the fully automated vehicle), has been made for a small system in steady state, i.e. a system which has grown beyond its introductory phase. For larger systems and systems in their introductory phase, the cost would eventually be higher;
- the feature “vehicles and control centre” could, in case of a large-scale system, be somewhat lower;
- the cost of the infrastructure is not taken into account, which is standard procedure in case of public transport. However, an infrastructure tax could be taken into account.

4.1.2 System features

The calculations above lean on a specific combination of transport demand, track, and service concept as it occurs in the Rivium case. Let us zoom in on the features of this system.
The track is 2 km long. The vehicles ride with a speed of 16 km/h, including five stops. This means that one vehicle can ride the entire track, back and forth, in 15 minutes. The system uses 6 vehicles. The maximum frequency is therefore: one vehicle every 2.5 minutes. Each vehicle has a capacity for 20 passengers. In theory, in case of a maximum frequency and a maximum use of capacity, 480 passengers can be transported each way, on the busiest part of the track. In practice, the reduction of capacity that occurs because of inconsistencies in both demand and supply (estimated at about 25 %) is compensated by the fact that in reality, during rush hours, vehicles contain more than 20 passengers each.

Table 5 shows the specification of the transportation demand (both directions) during the day. The demand is very sensitive to rush hours: in the morning peak hour, mainly from metro station Kralingse Zoom in the direction of business park Rivium, and in the evening peak hour vice versa. The maximum number of passengers transported per hour in one direction is: 400 passengers.

Because of the high frequency of the subway, the transportation demand is spread out over the hour: evenly.

### Table 5: Specification of transportation demand in the Rivium case

<table>
<thead>
<tr>
<th>Period</th>
<th>Service concept</th>
<th>Number of passengers transported</th>
<th>Number of passengers transported per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:00 - 7:30</td>
<td>On demand</td>
<td>226</td>
<td>151</td>
</tr>
<tr>
<td>7:30 - 9:30</td>
<td>fixed, every 2.5 min.</td>
<td>1,000</td>
<td>500*</td>
</tr>
<tr>
<td>9:30 - 12:00</td>
<td>On demand</td>
<td>254</td>
<td>102</td>
</tr>
<tr>
<td>12:00 - 15:30</td>
<td>On demand</td>
<td>593</td>
<td>169</td>
</tr>
<tr>
<td>15:30 - 18:00</td>
<td>fixed, every 2.5 min.</td>
<td>1,254</td>
<td>500*</td>
</tr>
<tr>
<td>18:00 - 21:30</td>
<td>On demand</td>
<td>350</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>3,677</td>
<td></td>
</tr>
</tbody>
</table>

* out of which 400 on the busiest track (determining the capacity)

### 4.1.3 Interdependencies between system features, costs and benefits

Let us try to find the dependency of costs and benefits on fluctuations in the transport demand. A decrease of the total transport demand would lead to proportionally less revenue. The cost, however, would decrease less than proportionally, since there would be a need for fewer vehicles, whereas the fixed costs such as supervision, control centre and infrastructure would remain constant. In short, a decrease in transport demand leads to a lower ratio of benefits and costs. An increase in transport demand, on the other hand, would result in a higher ratio. In the case of Rivium, a (much) larger capacity is hardly realistic. In case of a completely two-lane track, and a lower amount of stops, the capacity does increase somewhat. However, the more vehicles using the track, the more disturbances of the operational scheme with levelled intersections and, in the future, merging with other traffic.

Another important operational issue of the fully automated vehicle service is the spreading of the demand over the hour. If the transport demand is evenly spread out in time -as it is with the Rivium ParkShuttle, due to the high frequency of the metro- this results in an even utilization of the capacity, which is profitable when taking into account the cost and benefits. A transport demand that is concentrated in peaks, is less profitable from an operational point of view. Either larger vehicles must be used (which results in a lower frequency in the other direction and therefore in a lower quality for the passenger), or the vehicles have to be clustered (which has as a side-effect that some vehicles are necessarily ‘unemployed’).

A longer track leads to a more profitable exploitation, since the system, even with the extra vehicles needed for operation, still does not need more than one supervisor. This lowers the cost per passenger.
A higher operational speed, of course, is profitable as well. On the one hand, fewer vehicles are needed because of their higher speed; on the other hand, the quality increases for the passenger, which may result in extra revenues. The average operational speed is mainly dependent of the distance between stops; the maximum speed of the vehicle is much less influential.

An important advantage of the fully automated vehicle is that it can function on demand; i.e. the vehicle operates only when there is a demand for it. However, the question is: how profitable is this aspect when put into practice? From an end users perspective, an on demand service is worthwhile if it results in a waiting period that is shorter than in the case of a scheduled service. The success of an on demand service depends on the criteria used for the start of a vehicle from its ‘central location’ (which is metro station Kralingse Zoom in the Rivium case): how many passengers have to gather before the vehicle is allowed to depart? When this number is too low, some vehicles will depart with only a few passengers and soon the point will be reached where there are no more vehicles available for the remaining travellers. These travellers will have to wait for the first vehicle to complete its entire cycle. But when the criteria for departure are too high, this will result in longer waiting times, since passengers will have to wait in the empty vehicle before departure.

The criteria for departure can be optimized by virtually spreading the passengers evenly over the vehicles. This optimum occurs in a system with a fixed frequency. Only if the average number of passengers per vehicles would decrease to less than one passenger, an operation on demand will be more profitable. These are intensities of a few passenger per hour. Taking the cost and benefits into account, this would be profitable only if this low transport demand in off-peak hours is compensated by a more substantial transport demand in peak hours.

Another potential advantage of fully automated vehicle transport systems is the possibility of deploying relatively small vehicles, e.g. with a capacity of 4 passengers. But how advantageous are small vehicles actually? Small vehicles are definitely practical in urban areas, especially in pedestrian zones. But, another argument that is used in favour of small vehicles, is that people prefer riding in vehicles the size of their own car, rather than in larger vehicles like the bus or train. This argument, however, is: false! People do not prefer a car because it is a small vehicle, but because it is their own ‘private space’ – their ‘territory’. In case of collective transport (i.e. being transported together with ‘strangers’), the case can be said to be inverse; people do not like it when the space is too small, since it would result in the violation of their territory by others.

From an operational point of view, the rules behind successful applications with fully automated vehicle transport systems are the same as for services with regular modes: transporting large numbers in large vehicles is more efficient than transporting small numbers in small vehicles. Only the differences are less extreme, because of the absence of a driver and his wages. That is why the extra cost to offer the passenger a higher frequency, and therefore a higher quality, are much lower than with conventional modes. Combined with advantages of quality, such as a high frequency, and a better match with existing infrastructure, the option of smaller vehicles seems to be more interesting.

4.2 Comparison with regular modes

In this paragraph, fully automated vehicles are compared to traditional public transport on the same route. We assume that traditional public transport can be replaced by a fully automated vehicle, ignoring the fact this is not yet possible today due to technical reasons.

4.2.1 Transport capacities

First of all, we want to have some idea of the numbers of passengers that can be transported. Table 6 indicates the capacity per transport service; Table 7 starts with the transport demand and links this to possible transport services.
Table 6: Capacity per transport service

<table>
<thead>
<tr>
<th>Supply</th>
<th>Capacity of vehicle</th>
<th>Vehicles per hour</th>
<th>Effective utilization</th>
<th>Capacity per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metro, 2 minutes service</td>
<td>750</td>
<td>30</td>
<td>75%</td>
<td>16,800</td>
</tr>
<tr>
<td>Articulated bus, 5 minutes service</td>
<td>125</td>
<td>12</td>
<td>75%</td>
<td>1,125</td>
</tr>
<tr>
<td>Fully automated vehicle, 20 passengers, 2 minutes service</td>
<td>20</td>
<td>30</td>
<td>75%</td>
<td>450</td>
</tr>
<tr>
<td>Bus, 15 minutes service</td>
<td>75</td>
<td>4</td>
<td>75%</td>
<td>225</td>
</tr>
<tr>
<td>Fully automated vehicle, 4 passengers, 2 minutes service</td>
<td>4</td>
<td>30</td>
<td>75%</td>
<td>90</td>
</tr>
</tbody>
</table>

Table 7: Transport demand linked with transport service capacities

<table>
<thead>
<tr>
<th>Peak Intensity</th>
<th>Bus service</th>
<th>Fully automated service</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 persons</td>
<td>every 15 minutes, 2-3 passengers per bus</td>
<td>on demand every 5-15 min, 1 passenger per vehicle</td>
</tr>
<tr>
<td></td>
<td>every hour, 10 passengers per bus</td>
<td></td>
</tr>
<tr>
<td>30 persons</td>
<td>every 15 minutes, 5-10 passengers per bus</td>
<td>on demand every 3-8 min, 1-3 passengers per vehicle</td>
</tr>
<tr>
<td></td>
<td>every hour, 30 passengers per bus</td>
<td></td>
</tr>
<tr>
<td>100 persons</td>
<td>every 15 minutes, 20-30 passengers per bus</td>
<td>on demand every 3-8 min, 3-10 passengers per vehicle</td>
</tr>
<tr>
<td></td>
<td>scheduled every 2 minutes, 2-4 passengers per vehicle</td>
<td></td>
</tr>
<tr>
<td>300 persons</td>
<td>every 10 minutes, 40-60 passengers per bus</td>
<td>scheduled every 2 minutes, 8-12 passengers per vehicle</td>
</tr>
<tr>
<td></td>
<td>every 5 minutes, 20-30 passengers per bus</td>
<td></td>
</tr>
</tbody>
</table>

A point of attention is the occurrence of peak intensities; this is when, for whatever reason, a large number of passengers plan to use the service in a short period of time. Examples of such a peak are: the transport demand from a train station shortly after the arrival of a train, or transportation after a large public event. Services with smaller vehicles can lead to longer waiting times. Table 8 gives an indication of these waiting times. It is assumed that a shortage of vehicles does not occur.

Table 8: Waiting times at peak intensities

<table>
<thead>
<tr>
<th>Peak intensity</th>
<th>Bus service (75 or 125 passengers) departure every 2 minutes</th>
<th>Fully automated service: 20 passengers departure every minute</th>
<th>Fully automated service: 4 passengers departure every 30 sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 persons</td>
<td>no waiting time (1 bus)</td>
<td>no waiting time (1 vehicle)</td>
<td>1 minute waiting time (3 vehicles)</td>
</tr>
<tr>
<td>30 persons</td>
<td>no waiting time (1 bus)</td>
<td>1 minute waiting time (2 vehicles)</td>
<td>3.5 minutes waiting time (8 vehicles)</td>
</tr>
<tr>
<td>100 persons</td>
<td>no waiting time (1 articulated bus)</td>
<td>4 minutes waiting time (5 vehicles)</td>
<td>12 minutes waiting time (25 vehicles)</td>
</tr>
<tr>
<td>300 persons</td>
<td>4 minutes waiting time (3 articulated buses)</td>
<td>14 minutes waiting time (15 vehicles)</td>
<td>37 minutes waiting time (75 vehicles)</td>
</tr>
<tr>
<td></td>
<td>6 minutes waiting time (4 buses)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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4.2.2 Production Costs

Deploying fully automated vehicles on an existing public transport track can lead to lower production costs.

Table 9 compares the cost of the ParkShuttle to a similar system that uses minibuses and a driver. The infrastructure is not incorporated in the comparison, since its costs are considered to be indifferent in the two situations. From these calculations it can be deduced that the exploitation by minibuses is over 60% more expensive than exploitation by fully automated vehicles.

Taking a broader view on the balance sheet of the fully automated vehicle versus that of the traditional bus, the fully automated service proves (not taking into account the cost of infrastructure) to be structurally cheaper than a bus. Besides that, the advantage of the fully automated vehicle increases as the frequency increases. Low cost of personnel is the main reason for this. Also on a short track, the fully automated services bypasses the bus, since the cycle becomes too short to efficiently deploy a large bus.

Table 9: Costs of automated service and minibus (based on CyberMove reports).

<table>
<thead>
<tr>
<th></th>
<th>ParkShuttle 6 vehicles</th>
<th>Minibus 6 vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost staff</td>
<td>Supervision 0.4 FTE, €40/u, 261 days €48,000</td>
<td>Drivers 6 x 1.5 FTE, €40/u, 250 days €720,000</td>
</tr>
<tr>
<td>Other exploitation costs</td>
<td>Maintenance, Energy, Various €168,000</td>
<td>Maintenance, Fuel, Insurance Depreciation €180,000</td>
</tr>
<tr>
<td>Vehicles</td>
<td>Depreciation (8 years) €327,000</td>
<td></td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Indifferent</td>
<td>Indifferent</td>
</tr>
<tr>
<td>Total</td>
<td>€543,000</td>
<td>€900,000</td>
</tr>
</tbody>
</table>

4.2.3 Improving quality

Deploying fully automated vehicles can lead not only to lower production costs, but also to an enhanced quality, which can result in an increase of passengers, and therefore in higher revenues.

The transport quality can be improved by deploying fully automated vehicles at higher frequencies. One example is replacing buses that employ a fifteen minute service, with fully automated vehicles (of the same capacity) that employ a three minute service. The average waiting time then decreases from 7.5 minutes to 1.5 minute. Assuming the total travel time is 7.5 minutes (both by bus and fully automated vehicle), the travel time elasticity of demand is 1.0 % (long-term effect), and a waiting time penalty according to Wardman [2001] is 2.5 minutes per minute, the result would be an increased demand by more than 50 %.

It would be wise, in the fully automated vehicles’ introductory phase, to take this potential increase in demand into account. Extra vehicles, or larger vehicles, should be on hand and deployable in order to meet this increase. Introducing a system that is not flexible at this point, is running a risk.

An increased demand will have a positive impact on the balance sheet of the fully automated service as well. Production costs will rise because either larger vehicles or higher frequencies have to be provided to meet the demand. But at the same time, these higher costs are compensated by extra revenues from end users.
4.3 Promising applications

Coming from the promising solutions in chapter 3 and finishing our analysis of transport concepts, we may now conclude on promising applications. The applicability of fully automated transport services is mainly related to two factors:

- the length of the track: when a track is too short, people might prefer to walk, and when a track is too long, the fully automated vehicle is, in spite of its high frequency, too slow to compete with traditional forms of public transport.
- the transport demand: when the transport demand is too low, maintaining the fully automated vehicle system is too expensive; when this demand is too high, the advantage of automatic driving is cancelled, since the effect of saving the driver’s wages in relation to the cost per passenger is minimal. Moreover, a small-scale fully automated vehicle system would then have reached its maximum capacity.

Based on this observation, a fully automated transport service fits best to a track with a length of 2 to 4 km (one way) and a transport demand of 200 to 400 passengers per hour, one way, on the busiest track. For such an application, there are three scenarios:

- the fully automated vehicles provide a service as the main mode of transport, i.e. the mode of transport for the entire, or biggest part, of the trip;
- the fully automated vehicles provide a shuttle service to a ‘distant’ parking lot;
- the fully automated vehicles provide feeder transport to a train station, metro or other ‘fast’ mode of public transport.

When designing a site, one can of course also create combinations of these application scenarios.

4.3.1 Main mode of transport

The most important application of a fully automated vehicle lies in the local transport within medium-sized cities, with suburbs 2 to 4 km from the city centre. A fully automated transport service can connect such a suburb to the city centre. As shown in § 4.2, the fully automated vehicle is in such situations an effective alternative for the regular city bus, both financially and in terms of transport quality. The transport demand in this case matches also the transport service capacity of the fully automated vehicles.

However, current technology does not yet allow large-scale mixing with other traffic. The necessity of dedicated infrastructure for the fully automated vehicle limits the possibilities of applications considerably: the construction costs of the necessary infrastructure will presumably not be compensated by the money saved during exploitation (including the possible extra proceeds from an increase in passengers). Only when dedicated infrastructure is considered for reasons other than the fully automated vehicle, does the application of a fully automated vehicle become a realistic option.

It is exactly because of this barrier that the application of dual mode vehicles or high-tech buses could be promoted to fill this gap in the development line of fully automated services.

4.3.2 Shuttle service

One of the best potential applications for fully automated vehicles is a shuttle service to connect an attraction point to a ‘distant’ car park when parking at the destination is undesirable because of economic reasons or reasons of inaccessibility. Especially in medium-sized cities, the distances and the number of passengers are very well suited to the operation of such a fully automated service. Operating an automated shuttle service can be combined with the operation of the car park.

From a technology point of view in this transport application scenario, a dedicated lane for the shuttle service might be combined with other professionally driven vehicles like buses and taxis or slow traffic such as cyclists. Merging with professionally driven vehicles is considered to be a next step in the roadmap for fully automated vehicles. The cost of the
infrastructure would be more profitable than being used by the shuttle service as sole transport mode.

4.3.3 Feeder transport
By deploying a fully automated vehicle as a feeder to a train station, metro or other ‘fast’ mode of public transport, the catchments area of that particular station can be enlarged. This will lead to an increased transport demand for these existing modes. The automated service is mostly profitable when the station is a certain distance from the attraction points.

Applications at the destination end of the trip seems to be most promising. Here we have concentrated streams of transport, with passengers who in principle cannot make use of their own vehicle (car or bicycle), and who are therefore dependent on public transport. But also at the origin side of the trip there are opportunities: connecting suburbs that are relatively far from the city centre. However, the amount of passengers would then be lower. A combination of origin and destination transport demand would be best.

4.4 Streamlining the public transport network
Having put into words the three promising applications mentioned in § 4.3, it is easy to understand that the introduction of these innovative transport concepts will have an influence on city planning. Both in terms of adaptive cities and adaptive transit, the toolbox for land use and transport research has been enriched with these promising applications.

Figure 3: Illustration of streamlining the public transport network

One of the challenging ideas that occurs in relation to the near future, is the streamlining of the existing public transport network as shown in Figure 3. In general terms, this would come down to the following:

- by introducing fully automated feeder services, it is no longer essential to situate a public transport stop at walking distance from origin and destination;
- therefore, less stops are needed in the main lines of the network resulting in less density; also avoiding the necessity for detours to reach various origin and destination areas;
- the result of this enhancement is a faster performance of the main lines in the network, which again will lead to a higher transport quality for the passengers; at the same time exploitation costs are being lowered; a less dense network can also provide higher frequencies for the same costs.

Cybercars, PRT, high-tech buses, advanced city cars and dual mode vehicles will pave the way to a system innovation on both passenger and freight transportation. Looking at the mobility system as a whole, niche applications, experiments pilots and demonstration will precede this change of paradigm… but only if we are keen enough to learn from it.

In the next chapter we will have a look into the decision making processes.
5 Implementing system changes

There is a need for a sharp eye during the process to discriminate between what is helpful and what is essential to deal with. There is a need for a deep breath to persevere in the process of introducing innovative transport solutions. And there is a need for a brave heart to decide on something completely new.

If a local authority likes the idea of an innovative transport application, at least a three stage process has to be followed: pre-design, design and construction. In each of these phases, comparable decisions should be prepared on vantages and needs, financial perspectives, policy impacts and opportunities. The decision making process during the pre-design phase should lead to a go/no-go decision to start the design phase. The same process precedes the start of the construction phase.

However, the decision making process on land use and transport planning is not a linear and not necessarily a logical process. Seldom is it clear who the decision makers are, what power they have, mandate based or dependent on public acceptance, and how long they still will be in charge… And what about shifting the scene from public to private, putting stakeholders and financers in the front line of co-operation and leaving the authorities in their role of preserving rules and setting up new regulations?

5.1 A logical approach

Local authorities often seem to follow a logical approach, building consensus along the way, and using regional or national policy frameworks to determine their territories and achieve co-financing.

Along the way, there has to be found agreement on:

- the existing situation, both from a sustainable transport point of view, a traffic perspective and a spatial development vision; also legal barriers and constraints have to be taken into account;
- the ideas and expectations for building and operating an innovative transport application, respecting the interests of people and/or parties that have to live with the impacts of realising these plans, now and in the future;
- expected enhancements in terms of accessibility, sustainability and/or vitality of the area and its next door neighbourhoods that the innovative transport application is going to serve;
- a balance between the provided transport quality, financial investments and the exploitation costs (and revenues), both by simulating the (sub)system and optimizing the operating scenarios, and by contracting founding fathers and exploitation mothers; and
- a final blueprint, including a kind of (self)certification to take full responsibility for the safety and robustness of the transport system.

If the process is successful and first ideas become plans and lead to a project, the local authority will be the proud owner of a niche application that by its potential in the long term may (or may not) change the mobility system.

5.2 Transition management

Transition management breaks with the planning-and-implementation model aimed at achieving particular outcomes. It is based on a different, more process-oriented and goal-seeking philosophy (Figure 4) which helps to deal with complexity and uncertainty in a constructive way.
5.2.1 Conceptual model

The mobility system can be looked upon as a complex and adaptive social system. This complexity is caused by several means, one of them being the differences in scope of time and place. For example, not only national policy developments make the social system adjust itself, but also developments on local/regional level and/or on the European level. And, for a large part, these developments 'happen' in parallel and do not necessarily work in the same directions.

In the same way, it is nearly impossible to narrow the introduction of an innovative transport concept that may (or may not) change the system, to one domain, e.g. the policy domain of a ministry of transport, since there is a lot of impact on other domains as well as soon as the social system starts to adapt itself. Moreover, domains are not static; the throughput of research results, social and/or political debates, trends or changes in the contextual environment of a domain, or, simply, things that happen... will show the dynamic side and continues interaction with other domains. Most of the time -and when by exception there is one, he/she will only be there for a moment- no actor involved is controlling the social system or knows how it is to be controlled. By nature, mankind is limited by its perception, its motives and its interests.

Taking further this concept of a complex and adaptive social system, mobility is a coherent conglomerate of components that evolves in the interaction between the system and the social environment. According to Jan Rotmans, transition management professor at the Dutch Research Institute For Transitions at the Erasmus University of Rotterdam, key features are:

- Co-evolution, which means that the system co-evolves with its environment;
- Emergence, the spontaneous development of repeating mechanisms; and
- Self-organisation, the power to rearrange the system from within because of its internal constitution.

Innovations to optimize the system itself (or components of the system), so-called incremental innovations, will lead to system developments and a better fit with the social environment. But after a while, these incremental innovations are no longer sufficient to bridge the gap with the social environment. By then, a more rigorous system innovation has to take place. This is what we call: a transition.

What are the chances for managing transitions? The simple answer to this question is that transitions cannot be managed, at least not in the traditional way. The reason for this is, that transitions are the result of the interaction between many processes, several of which are
beyond the scope of management (e.g. cultural change). What can be done, however, is to attempt to control the direction and speed of a transition with various types of (direct and indirect) intervention and coordination actions (Rotmans and Loorbach, 2006, Rotmans, 2005; Rotmans, Loorbach, van der Brugge, 2005).

With transition management there are three hooks for co-ordination: markets, plans and institutions. Transition management uses markets by relying on price mechanisms and decentralized decision making in choosing products and services. It makes use of planning in the form of transition goals, policy strategies and objectives that coordinate economic activities. And it uses institutions by offering new models for policy making: the development of transition arenas, agendas and goals, the fostering of new networks and a focus on learning processes.

5.2.2 Transition management put into practice

The basic steering philosophy underlying transition management is: anticipation and adaptation. The aim is to start from a macro vision and build upon bottom-up (micro) initiatives, meanwhile influencing the meso regime. Goals are chosen by society (often more or less implicitly through debates and opinions) and the mechanisms designed to fulfil these goals are accordingly created through a bottom up approach. These mechanisms are not set into stone but are constantly assessed and periodically adjusted in development rounds.

Transition management can be described as a cyclical and iterative process, organised in so-called development rounds. One round (represented in Figure 5) consists of four main activities (Loorbach, 2002; Rotmans, 2005):

- establishing a transition arena;
- developing a long-term vision and a common transition agenda;
- initiation and execution of transition experiments; and
- monitoring and evaluation of the transition process.

Figure 5: Transition management development circle (Loorbach, 2002)

Participants in these development rounds come from so-called transition arenas, that play a crucial role in transition management. Transition arenas are networks of innovators and visionaries that develop long term visions and images that, in turn, are the basis for the development of transition-agendas and transition-experiments, involving growing numbers of actors. Key elements of thinking are (Loorbach, 2002, 2004; Rotmans, 2005):

- system thinking in terms of more than one domain, different actors and at different scale levels; analysing how developments in one domain or level gel with
developments in other domains or levels; trying to change
the strategic orientation of regime actors;

- long-term thinking (at least 25 years) as a framework for shaping short term policy;
- back- and fore-casting: the setting of short-term and longer term goals based on long-
term sustainability visions, scenario-studies, trend-analyses and short-term possibilities;
- a focus on learning and the use of a special learning philosophy of learning-by-doing
and doing-by-learning;
- an orientation towards system innovation and experimentation;
- learning about a variety of options (which requires a wide playing field);
- participation from and interaction between stakeholders.

Figure 6: Transition management multi phase concept (Rotmans et al., 2001)

Transition management works with three main topics in parallel:
- multi phase;
- multi domain; and
- multi level.

The multi-phase concept indicates that transition paths are highly non-linear with different
phases, shifting from one dynamic equilibrium to another. In general, we presuppose that a
transition takes place through the stages of the so-called “F-curve” with: (1) a pre-
development phase where there is very little visible change at the systems-level but a great
deal of experimentation at the individual level; (2) a take-off phase where the process of
change starts to build up and the state of the system begins to shift because of different
reinforcing innovations or surprises; (3) an acceleration phase in which structural changes
occur in a visible way through an accumulation and implementation of socio-cultural,
ecological, national and institutional changes; and (4) a stabilization phase where the
speed of societal change decreases and a new dynamic equilibrium is reached (Rotmans
2000, Rotmans 2005).
The multi domain concept (Figure 7) covers the interaction between components in the economic, the ecological and in the social domain (profit, planet, people) and can be used to distinguish between these three perspectives (Rotmans et al., 1998; Grosskurth and Rotmans, 2003; Van de Lindt and Rijkens, 2004).

The multi-level concept (Figure 8) describes a transition in terms of different scale dynamics, which are interlinked. The multi-level concept makes a distinction between niches, regimes and the socio-technical landscape at three interacting scale levels: the micro, meso and macro level. At the macro level the societal landscape is determined by slow changes in society. Operating at the meso level are the social norms, interests, rules and belief systems that underlie companies', organisations' and institutions' strategies and political institutions' policies. Acting at the micro level (niche applications) are individual actors, technologies and local practices. At this level, variations to and deviations from the status quo can occur as a result of new ideas and new initiatives such as new techniques, alternative technologies and different social practices (Geels and Kemp, 2000, Rotmans et al., 2005).

5.3 Promising developments

CityMobil does not start from scratch. The first reference, for example, to a cybercar dates from December 19th, 1957 in the comic story “Tintin a essayé le cybercar” (Tintin Journal nr. 478). In the 5th Framework Program the technology driven invention of automated
vehicles for the transportation of people and goods, has been matched with transport demand and turned into transport services at the level of niche applications. The aim now is to take this further and start working on integrated applications.

We ought to be led by a vision at the macro level that we need innovative solutions to solve traffic and transport problems in the urban area. And we have to make sure that we know that in the end transport problems will have an ongoing negative impact on the social, environmental and economical domain as well.

Therefore we need to:

- expand our research;
- intensify our research; and
- up scale our research.

Expanding our research means that we have to widen our research scope and take into account other experiments and niche applications in the transport sector as well. It is not wise to start a debate on the pro’s and con’s of cybercars versus PRT or discuss whether or not investments in shuttle services should be public or private, but we have to learn from all experiments and translate our progress to the meso level of the regime.

Intensifying our research means that we have to deepen our knowledge on the experiments we are working on. We should not be satisfied and lean back when we have realised one application, but we will have to study the changes in the complex and adaptive social system that will be the impact of our success. We have to be prepared for reaction from within the system and other domains instead of waiting until ‘things happen’.

Up scaling our research is one of the potential certainties in the CityMobil project because of the project structure and the variety of partners in the consortium. The three demonstration sites in Rome, Castellon and at Heathrow Airport, guarantee the real implementation at (sub)system level and since we have other cities gathered in the Reference Group, we must be able to apply learning points and tools to other sites as well. This will enable the discourse on innovative transport concepts on meso and macro level and take the longed for sustainable system innovation one step closer from pre-development phase to take-off.
6 Sources

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