UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENGINEERING, SCIENCE AND MATHEMATICS
SCHOOL OF CIVIL ENGINEERING AND THE ENVIRONMENT

AUTOMATED TRANSPORT SYSTEMS FOR SUSTAINABLE URBAN MOBILITY

By
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ABSTRACT

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The thesis has as a general aim to analyse if and to what extent automated urban transport systems (AUTS) can provide more sustainable mobility in urban areas. AUTS is defined as a transport system with the following properties. AUTS consist of a fleet of road vehicles with fully automated driving capabilities for passenger transport on a network of roads with on-demand and door-to-door capability. The vehicle fleet is under control of a central management system in order to meet a particular demand in a particular environment. Key Findings are that various related systems and technologies which provide one or more of the functionalities of AUTS have proven to be feasible and to provide some of the benefits anticipated for AUTS. A number of early AUTS applications have already been used or tested since 1997; these systems have proven to be safe and reliable, but various perceived risks so far delayed a wider implementation. Users and stakeholders were able to envisage the potential of AUTS to improve urban mobility, but some concerns remained at this stage over technology being mature enough for systems in mixed traffic. After having used the system, public acceptance increased, as due to the innovative characteristics of AUTS, users who had no direct experience with the system before, developed a different attitude. AUTS vehicle performance parameters including acceleration, deceleration, and jerk are below benchmark values for comparable systems in terms of comfort and safety levels for passengers. AUTS as part of the multi-modal public transport system and with accompanying measures can improve network efficiency and reduce travel times. The research has shown that there is large potential for AUTS to provide more sustainable mobility in urban areas. But a number of implementation barriers have been identified, which so far have hindered a more wide-spread and large-scale implementation of AUTS. Future work in this field therefore has to address these issues and to develop means to overcome these barriers in order to realise the potentials of AUTS. Furthermore sensor technologies and robotics algorithms have to be further improved, and new vehicle, infrastructure and operational concepts have to be developed for larger and more advanced systems.

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1 INTRODUCTION

1.1 Background

Urban Design and Planning

As the design of urban environments evolves very slowly, most patterns to be observed in modern cities are still based on design principles from the early 20th century. The 'Athens Charter', a groundbreaking document on urban design, was developed in 1933, following the fourth CIAM (Congres Internationaux d'Architecture Moderne) conference with the theme 'The Functional City'.

The main principle of this document was the radical reshaping of urban environments to create a 'zoned city' with a clear spatial separation of the main activities in cities, leading to separate areas for work, home and leisure (Hall, 2002). The aim of this was to alleviate the appalling conditions in mainly poor working-class urban areas, suffering from the proximity of the workers' homes to the factories they were employed in, which produced large amounts of pollution, by creating clean and healthy living conditions away from factories in green and more rural settings (Le Corbusier, 1987).

In contrast to these developments based on the implementation of rather theoretical design principles, urban design can also be influenced by socio-economic factors, e.g. in the case of 'Urban Sprawl'. Urban sprawl was formed through the building of highways following World War II, which through shorter travel times for commuting allowed the development of homes in more rural areas, where land was cheaper. This led to urban environments surrounded by large belts of sprawling low-density communities of homes, out-of-town business parks and shopping centres (Marshall, A., 2001).

These two examples for urban planning and development, the separation of working and living and urban sprawl, in addition to disadvantages of the public transport system and the generally low image of public transport in a 'private car society', have resulted in a strong private car dependency in urban areas. This private car dependency has huge negative impacts on cities, including the degradation of urban environments through parked cars and the land take to provide road space, the pollution and noise generated by internal combustion engines (ICE), safety issues through road accidents, congestion and wider effects on the economy and societal issues.

Environment and Sustainability

The concept of sustainable development was brought to wide recognition following the publication of 'Our Common Future', a report by the World Commission on Environment and Development commonly referred to as the Brundtland Report. This report has introduced a general definition of sustainable development as "... development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Tomlinson, C., 1987). In order to achieve this very broad goal, economic and financial, environmental and ecological, and social sustainability has to be ensured (UN, 1996).

Based on this general concept of sustainable development, the World Business Council for Sustainable Development defines sustainable mobility as "... the ability to meet the needs of society to move freely, gain access, trade, and establish relationships without sacrificing other essential human or ecological values today or in the future" (WBCSD, 2001). Sustainable mobility therefore tries to balance economy, society and the environment; Kennedy et al suggest that this can be achieved through four main issues, governance, financing, infrastructure, and neighbourhoods (Kennedy, C., 2005).

Potential areas for further research and development work are therefore implementing innovative technologies, pricing and financing, and integrated transport and land use planning (Greene, D., 1997). Therefore the two main elements to achieve more sustainable urban mobility are (in view of the transport system) to make public transport a better alternative to the private car and (in view of urban planning) to decrease trip distances through more sensitive location of activity centres.

In view of transport systems, the concept of more sustainable transport through discouraging private car use and encouraging public transport use has been incorporated into various policy documents (see e.g. DETR, 1998 for UK transport policy or EC, 2001 for transport policy on an EU-wide level or DFT, 2000 for special guidance on preventing social exclusion through a more sensitive design of public transport services).

In view of land use planning, a number of initiatives were aimed at influencing urban developments, e.g. through mixed-use developments to counteract the separation of working and living, or through more sensitive design of urban environments to make urban living more desirable, ideally leading to 'an urban renaissance' (UTF, 1999).

On a more global level the Habitat conferences organised by the UN aimed at solving transport problems in the worlds 'mega-cities' (UN, 1996). A number of non-governmental organisations (NGOs), especially environmental groups have also used their power to lobby for more sustainable urban transport, in view of local effects on noise and pollution in communities and more global effects of CO_2-emission and climate change (see for example WWF, 2001 or FOE, 2000).

Another important issue to address in view of sustainable mobility is social exclusion. This will become even more important with the increasing ageing of society, as a growing part of the population will be unable to use private cars or even conventional public transport systems; e.g. the proportion of the population aged 60 or over in the EU has risen from 15.4% in 1958 to 21.9% in 2001 (EC, 2002). The above issues show the strong need for more sustainable urban mobility.

Social exclusion can generally be defined as certain parts of the community being excluded from participating in activities spatially, temporally, financially or personally (DFT, 2000). In more detail social exclusion can be split into physical exclusion, geographical exclusion, exclusion from facilities, economic exclusion, time-based exclusion, fear-based exclusion, and space exclusion (Church, A., 2000)

The issues described above, including the general concept of sustainable development, transport and land use planning policies and the influence of NGOs, have resulted in changes to decision-making processes and design principles, favouring sustainable urban mobility and funding-resources for targeted research and development (R&D) activities in the field of innovative urban transport systems and technologies (see for example the EC's 'City of tomorrow and Cultural Heritage' initiative).

These changes in policy and design principles in combination with R&D can form the basis for efforts to create more sustainable urban mobility. R&D work for sustainable urban mobility has resulted in a variety of innovative systems and technologies, which have the potential to alleviate some of the issues in urban transport as described above, and which can be used by urban planners and decision-makers as a tool to achieve a safer, less polluted, more inclusive and generally more desirable urban environment.

Systems and Technology

An early example of a radical idea to provide more sustainable urban mobility was the personal rapid transit (PRT) concept in the 1960s/ 70s, which was to provide individual on-demand transport through a system of small vehicles on a network of monorails. In this period of time the US government provided huge funding for the PRT concept, and following the enthusiasm of the successful Moon Landing Program, President Nixon said in his budget speech to the Congress in 1972 "If we can send 3 men to the moon 200,000 miles away, we should be able to move 200,000 people to work 3 miles away."

But history proved the introduction of PRT to be more problematic, with only few small-scale niche applications implemented. The main barriers to the wide-spread introduction of PRT were the lack of maturity of the technology involved, the need to radically reshape urban environments (e.g. visual intrusion through elevated tracks, and the vision of PRT not complementing but replacing the convention multi-modal public transport system in urban areas (Rydell, E. W., 2000).

Various studies have been carried out more recently to compile descriptions of developments in innovative transport systems (see for example Andreasson, I., 2001 or RECONNECT, 1999). These systems include e.g. carsharing/ carpooling, demand-responsive transport (DRT), automated people mover (APM), advanced driver assistance systems (ADAS) and automated highway systems (AHS).

The functionalities and efficiency of most of these systems was further enhanced in recent years through the use of intelligent transport systems (ITS). The term ITS relates to developments in computer/ information processing and sensor technology and their use in transport telematics to e.g. more efficiently manage traffic, improve safety and security, or provide assistance functionalities to drivers.

While APM, like PRT, traditionally requires rail infrastructure and is mainly used for transport within large airport and in theme parks, the use of various ITS applications and system components (e.g. vehicle navigation, obstacle detection, vehicle localisation, etc.) for this technology enables the same concept to be realised without rail infrastructure. It is therefore now possible to design a public transport system potentially offering the advantages of PRT without its disadvantages.

This system could potentially provide individual, on demand, and direct point-to-point transport without requiring additional infrastructure, in particular no elevated rail structures (resulting in huge cost savings and less visual intrusion or risk of community severance) and with additional system flexibility and improved system performance in view of safety, security and reliability.

First examples of the small-scale application of this technology are the systems on the long-stay car park at Schiphol airport and at a business park near Rotterdam. Both systems operate within a shared environment on conventional roads to provide on-demand transport and are proven to be safe, reliable and accepted by the system-user (Bootsma, G. and Koolen, R., 2001).

Based on these systems the concept of automated urban transport systems (AUTS) will be developed for this research to investigate the potential of this technology to provide more sustainable urban mobility. This relates to a more large-scale implementation of these systems, using it for various urban public transport applications. Based on research on related technologies the following positive impacts are expected.

The automated vehicle operation will be safer, more environmentally friendly and provide more network/ link capacity, as seen in research work carried out on AHS and ADAS (for safety of AHS/ ADAS see Carsten, O. M. J. and Nilsson, L., 2001, for capacity see Carbaugh, J., Godbole, D. N. and Sengupta, R., 1998, for network effects see Golias, J., Yannis, G. and Antoniou, C., 2001, for environmental issue see Barth, M. J., 1997).

The system will also be socially inclusive as neither a private car nor the ability to drive a car is required. Furthermore as the use of electric vehicles will be assumed no noise will be generated and there will be no emission at the point of use in addition to the generally higher energy-efficiency of electric engines (Funk, K. and Rabl, A., 1999).

In the following sections the detailed objectives of this study on the use of AUTS to provide more sustainable urban mobility will be described, followed by the methodology to be used in order to meet these objectives, including an overview of all analysis activities and the structure of the study and the structure of the thesis.

Related EC-funded Research

Two large scale EC-funded research projects relating to AUTS, CyberCars and CyberMove, have been running in parallel with the work on this thesis. Data collected through my work as a Research Fellow, that were part of these projects have formed the basis of the main data analysis chapters of the thesis. In the following an outline of these two projects and a description of my role within the projects, the influence of this on the PhD design, and the original contributions independent from the projects will be given.

Both CyberCars and CyberMove were parallel 3-year project funded by the EC under Framework Programme (FP) 5, running from 2001 to 2004. The main aim of both projects was to test and analyse the state-of-the-art of AUTS technologies and to enable a wider implementation of these system. The focus of the CyberCars project was on technologies and system components, whereas the focus of the CyberMove project was on the AUTS concept generally and its potential for wider implementation.

My role within the CyberCars and CyberMove projects was workpackage leader for the user needs analysis and the project evaluation. This included defining and organising all individual activities for these research areas, coordinating and overseeing the work carried out by all partners according to the predefined specifications, and the analysis of all data collected. These projects provided funding required for most of the data collection activities, including the market research and the public system test sites.

The specifications of methods of data collection (e.g. questionnaire design, focus group format, specification of vehicle data log procedure) as part of these projects were in general accepted by the project consortium and are original contributions. However, in practice some limitations were imposed, as e.g. it was only possible to carry out an ex-post user need analysis at one of the two test sites due to internal issues.

The background literature review on AUTS-related systems and technologies and the modelling of network-wide impacts of a large scale AUTS application were carried out independently of the CyberCars and CyberMove projects. Data for the ex-ante and ex post user needs analysis, for the state-of-the-art survey, and for the assessment of performance was collected as part of the project, but design of the data collection procedure and the data analysis were independent original contributions.

1.2 Objectives

Experience with Related Systems and Technologies

To review the experience with various related systems and technologies and to analyse their implications for AUTS:

No AUTS applications are implemented yet, therefore no actual experience with AUTS technology is available for this analysis to be based on. But as described in the background section, a number of systems and technologies closely related to AUTS already exist. More detailed research questions are:

i) What transport systems exist that share some of the characteristics of AUTS?

ii) Have applications of these technologies been successful/ economically viable?

iii) What can be learnt from these systems in terms of overcoming risks/ barriers?

iv) What service parameters/ system functionalities have implications for AUTS?

Experience with First Small AUTS Applications and Tests

To review the state-of-the-art of first developments of AUTS based on the work on applications, tests, and studies:

A number of technology providers have developed their respective systems and have tested them on private sites. They have also carried out studies for applications of their technology. A number of sites have been studied as part of the CyberCars and CyberMove projects. More detailed research questions are:

i) What infrastructure technologies (e.g. guideway, navigation, control) are in use?

ii) What vehicle technologies (e.g. size, type, number of passengers) are in use?

iii) For what type of application and in what environments is AUTS implemented?

iv) Are the existing systems convenient, safe, reliable, and accepted by the public?

Public Acceptance of the General AUTS Concept

To analyse requirements/ perceptions of the AUTS concept for all users involved in using, operating, supplying, and deciding over implementation:

The overall aim of this research is the analysis of a system to create more sustainable urban mobility, thus being a real improvement to existing public transport as well as a real alternative to the private car. For a system like this to be successful, the design has to be based on user requirements. More detailed research questions are:

i) Which different (non-)user groups can be identified to be covered by this analysis?

ii) What are the general views on transport in urban areas and its wider implications?

iii) What are the perceptions of AUTS and its potential for sustainable urban mobility?

iv) What are specific requirements the system has to meet in order to be accepted?

Public Acceptance after having used an AUTS Application

To analyse the level of public acceptance of an AUTS application by system end-users based on a small-scale test/ demonstration site:

In contrast to the user needs analysis above, where no personal experience was required, this evaluation of the user satisfaction is based on experience with a small-scale AUTS application. The analysis has focused on the AUTS concept in general and various technology issues. More detailed research questions are:

i) Is the system perceived to be safe in terms of personal security and traffic safety?

ii) Is performance of the system in terms of comfort comparable to existing systems?

iii) Is the concept sufficiently advanced to improve modal share of public transport?

iv) What other application areas for which AUTS would be suitable can be identified?

Performance of the System (Safety, Reliability, Comfort)

To analyse the performance of an AUTS application in terms of safety, reliability, and comfort based on a small-scale test/ demonstration site:

Before implementation of AUTS can be considered, safety and the level of reliability has to be proven. The results from analysing vehicle data collected at the sites can be compared to public acceptance and to benchmark values from conventional public transport systems. More detailed research questions are:

i) Is the performance comparable/ superior to existing systems in terms of safety?

ii) Is the performance comparable/ superior to existing systems in terms of comfort?

iii) How accurate is the navigation system, what are implications for performance?

iv) Are the user ratings reflected by the actual measured vehicle performance data?

Network Benefits of a City Centre wide AUTS Application

To analyse the network-wide benefits and impacts of a large-scale implementation of the AUTS concept based on modelling/ simulation tools:

In contrast to the small-scale application this analysis activity is aimed at examining the impacts of large-scale applications of AUTS. As it is not possible to implement an application of that scale in this early phase of the research process, the analysis has to be based modelling. More detailed research questions are:

i) What are the key characteristics of an ideal large-scale implementation of AUTS?

ii) What impacts would this large-scale application have on a network-wide level?

iii) What impacts would this large-scale application have on a corridor/ route level?

iv) What are the costs and benefits of this compared to a more conventional system?

Based on the six main objectives described above, this study follows a four step process as shown below in figure 1.1. The first step is the general research background including an analysis of experience with related systems and with first small scale applications and tests. The second step is the development of a generic concept, where the public acceptance of the general system is to be analysed. The third step is the testing of a small scale system, including analysis of the public acceptance of a specific application, and analysis of the performance of this system application. The fourth and final step is the simulation of a large-scale application, where the network-wide benefits are to be studied. In the following these six main objectives are described in more detail. This is then followed by the methodology section, where for each of these six main objectives the methodology to meet these objectives are described in more detail.

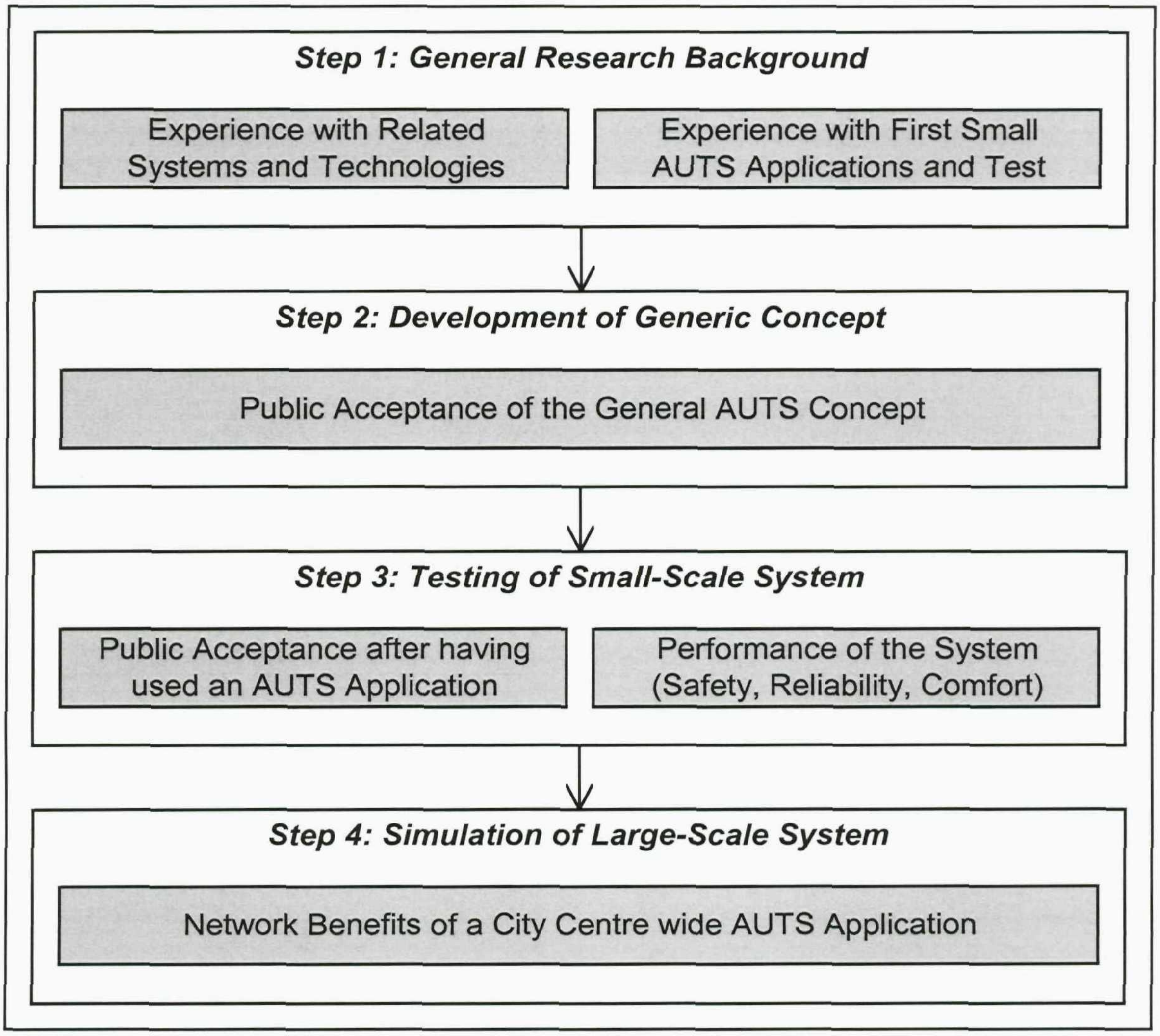


Figure 1.1: Structure of the Study

1.3 Methodology

Experience with Related Systems and Technologies

Literature Review of Related Systems: The methodology used for this objective and to answer the more detailed questions posed in the last section has as a starting point a general definition of AUTS to be used for the whole research work. Based on this an analysis framework of potential AUTS user groups and possible AUTS application areas has been developed. This leads to the description of a generic AUTS concept, which is used for the first stage of the 4-step-analysis process. After these preliminary activities, the main task is to carry out a literature review of AUTS-related existing innovative transport systems and technologies to answer the more detailed questions of this objective and to assess the relevance of these results for AUTS. After having analysed and defined the key operating characteristics of AUTS, the main relating existing advanced transport systems, which share some of these characteristics, can be identified. Based on this, the systems to be examined for the literature review of related systems and technologies therefore are car sharing organisation (CSO), demand-responsive transport (DRT), automated people mover (APM), personal rapid transit (PRT), and automated highway systems (AHS).

Experience with First Small AUTS Applications and Tests

AUTS State-of-the-Art Survey: The methodology used for this is to carry out a survey of experts from industry and academia, who are involved in the testing and development of AUTS technology and applications, in securing funding and support for small scale demonstration sites and in carrying out detailed feasibility studies. As this is mainly an information gathering exercise, only qualitative survey techniques will be considered. Because the experts identified for this are located all over Europe, face-to-face interviews were not practical. And as the descriptions of technologies and systems are required in a reasonable level of detail for this analysis, a paper based survey was chosen instead of interviews. Two different forms are to be designed for specific sites and for individual AUTS technologies. The identified key experts for this state-of-the-art survey will be contacted and sent an electronic version of the survey form to fill in. The analysis of the compiled results from this, in addition to the previous literature review of related systems, gives a further insight into the first experience with these very innovative transport systems and also provides vital input for the next stage of this research, the development of a generic AUTS concept.

Public Acceptance of the General AUTS Concept

Ex-Ante User Needs Analysis: As no experience with AUTS exists for the user, it was felt that the use of a quantitative survey would not be appropriate at this stage of the research, because the proposed answers in a stated-preference questionnaire would be solely based on the researchers' expectations and not on the users' initial reaction. Furthermore predetermined questionnaires generally have the disadvantage of unintentionally influencing the interviewees' responses (Krueger, R. A., 1988). Therefore the methodology used for this objective and to answer the more detailed questions posed in the last section is based on qualitative research, using market research techniques, including focus groups and structured interviews. A focus group can be defined as a group discussion of ca. 90-120 minutes, led by a trained moderator, involving 8-10 participants, who are recruited for the session based on certain predefined characteristics (Greenbaum, T. L., 1998). This technique has been used for 'end-user'. For all other user groups one-to-one interviews based on the focus group outline were used, as it was felt, that they would be less prepared to discuss their views openly.

Public Acceptance after having used an AUTS Application

Ex-Post User Needs Analysis: In contrast to the user needs analysis in the first stage of this research, where qualitative research is to be carried out, here participants can be interviewed directly after using the system, thus having direct experience. This allows the use of a stated preference survey with quantitative results. The advantages of survey research include comprehensiveness i.e. being able to analyse complex issues, such as attitudes or preferences and efficiency i.e. being able to obtain information about an extremely large population from a relatively small sample of people (Alreck, P. L. and Settle, R. B., 1985). A questionnaire has been designed, followed by a statistical analysis. Generally attitudes can be measured through questions with open-answer formats and closed answer formats, and questions in closed answer-formats can either include a variety of given answers to choose from or use a numerical rating system (Sudman, S. and Bradburn, N. M., 1982). But in this case there was an emphasis on questions with closed answer-format in view of the quantitative nature of this analysis, with only a small number of questions in open-answer format as a qualitative background. This also gives the opportunity to identify changes in responses due to the change from AUTS only being a theoretical subject to participants having direct experience with the technology.

Performance of the System (Safety, Reliability, Comfort)

Assessment of AUTS Performance: The safety and reliability assessment of AUTS technology is based on two small-scale demonstrations of AUTS applications in urban areas. These test-sites were designed as simple line or loop systems with a number of stops, operated on-demand by the user. At the demonstration site AUTS vehicles were operated using a vehicle guidance system based on a combination of electro-magnetic markers underneath the road surface and a digital map of the track. The operating environment was shared with pedestrians and cyclists, therefore the vehicles were also equipped with a laser-based obstacle detection system. In case of an obstacle in the vehicle path, the vehicle would slow down to a stop until the path is cleared or carry out an emergency stop, based on the distance to the obstacle. Vehicle performance data was collected on operation of the system, giving an amount of data, which allowed a statistically-significant quantitative analysis. The vehicle performance data was collected in log files on a tenth of a second basis. Vehicle performance parameters included in the data collection and consequent analysis included vehicle speeds, acceleration/ deceleration, jerk, and positioning errors in relation to the pre-defined vehicle path (lateral error, longitudinal error, and orientation error).

Network Benefits of a City Centre wide AUTS Application

Modelling of Network Impacts: Following on from the previous research activities, in the final step of the four-step process of this analysis, the impacts of a large scale city-wide AUTS application were studied. As it would currently not be feasible to implement a system on this scale, the only option to gain an understanding of this was to use modelling and simulation techniques. As a basis for decision-making processes in transportation planning, analytical models are used to test solutions or schemes proposed and to estimate their respective performances and impacts (Ortuzar, J. de D. and Willumsen, L. G., 1998). The AUTS impact assessment was carried out using a network simulation model for the city of Southampton. This network model has been developed by TRG through previous research and is based on the simulation software package CONTRAM. For this analysis activity a large-scale network-wide application of AUTS technology has been devised. The scale of the system, the application area, the service performance, and the role of AUTS as part of an urban multi-modal public transport system were based on the results and findings from all previous research activities as described above.

The following figure shows the structure of the thesis. The six main objectives as detailed above have here been translated into chapters of the thesis, based on the methodology developed to meet the key objectives.

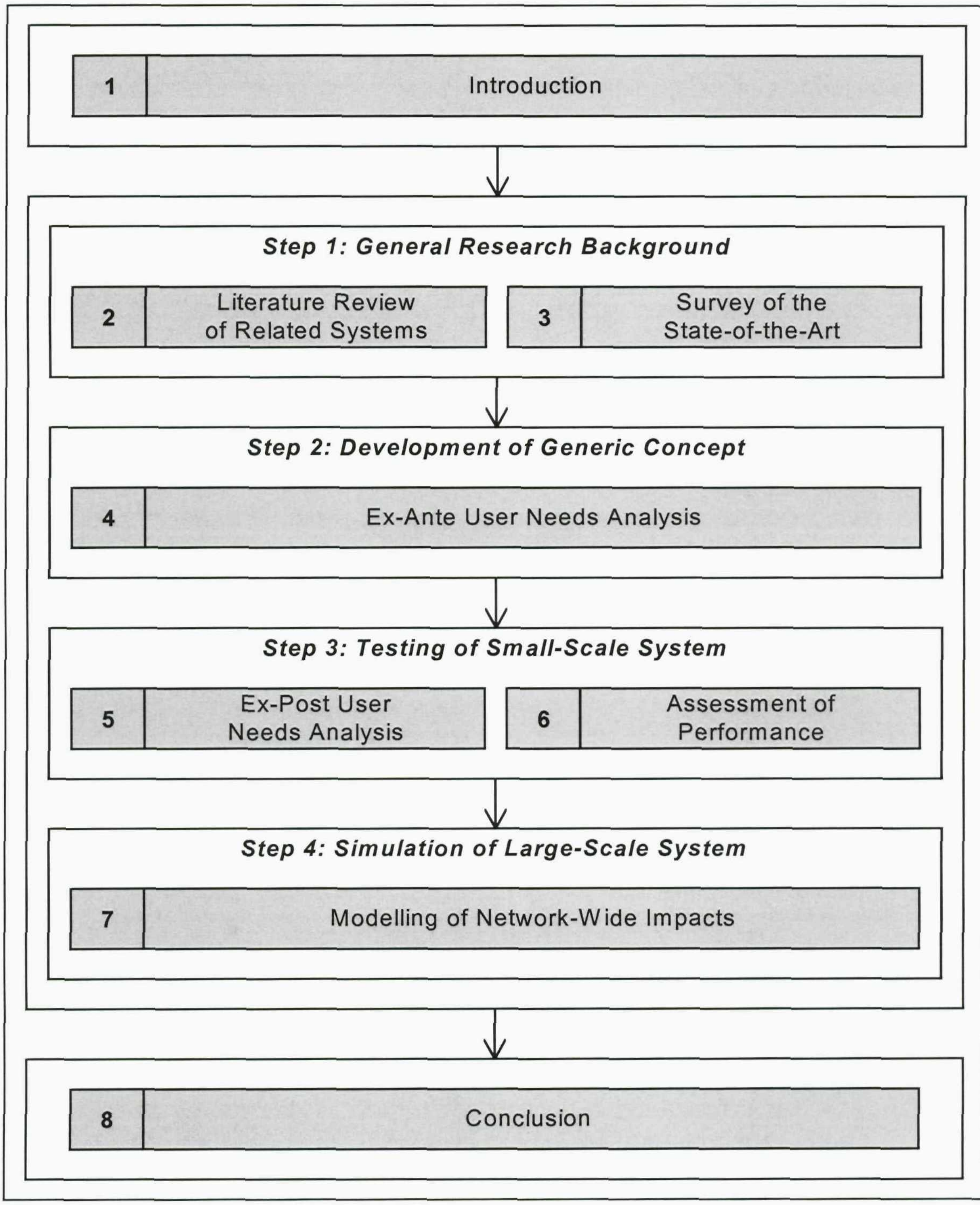


Figure 1.2: Structure of the Thesis

2 LITERATURE REVIEW OF RELATED SYSTEMS

2.1 Introduction

2.1.1 Background

As a first step in this analysis into the potential of AUTS for providing more sustainable mobility in urban areas, a review of related systems has been carried out. This together with the survey of the state-of-the-art of AUTS has formed the first stage of the four stage analysis process of this study. The results of both of these background analysis activities have consequently formed an input into the next stage of the analysis process, where the user needs has been analysed based on a generic AUTS concept.

As the development process of AUTS is still at a very early stage, there is only limited published information available. Furthermore any current knowledge of and experience with the first developments of AUTS has been covered by the state-of-the-art survey. But due to this lack of published information on AUTS, this literature review has focused on closely related systems that share some of the characteristics and functionalities of AUTS and how experiences with these technologies relate to them.

2.1.2 Objectives

The objectives of this literature review of AUTS related systems and technologies are therefore to identify existing innovative transport systems that have the potential to provide more sustainable urban mobility and which share some of the main characteristics and functionalities of AUTS. For these systems literature has been reviewed in order to gather information on system performance and operating characteristics. This information was then analysed in view of how it relates to AUTS

A first step for this literature review of related systems is therefore to specify a general AUTS definition. This specification outlines the key operating characteristics that are necessary in view of its potential for providing a more sustainable mode of transport in urban areas. Based on this definition the identification of related systems was then carried out. In the following section the general AUTS definition and the related systems identified for this literature review are described in more detail.

2.1.3 Methodology

AUTS Definition

For the purpose of this research AUTS is defined generally as a transport system with the following main operating characteristics and functionalities:

- Fleet of Road Vehicles
- Automated Driving Capabilities
- For Passenger Transport
- On a Network of Roads
- On-Demand Transport
- Door-to-Door Transport
- Central Control System
- Meet particular Demands
- In particular Environment

At the initial stages, AUTS is designed for short trips at low speed in an urban environment or in private grounds. In the long term, AUTS could also run autonomously at high speed on dedicated tracks. AUTS are members of the general family of people movers and close to personal rapid transit but they offer the advantage of being able to run on any ground infrastructure, which means they are cheaper and more flexible, as AUTS is operated under the control of a computer control system

General AUTS system characteristics assumed include vehicle guidance for the completely autonomous operation (under central control system) of vehicles, obstacle avoidance for a safe and secure operation on a mixed infrastructure with e.g. cyclists, pedestrians, and manually operated vehicles, platooning and road trains for the potential of a semi-automated operation where just the first vehicle is operated manually and other vehicles follow automatically, and fleet management to coordinate a number of automated vehicles.

According to these descriptions of the general AUTS concept and of the more detailed system components necessary, as mentioned above, the key system characteristics of an AUTS application can be summarised as: fully automated, on-road capabilities, demand-responsive, potential for door-to-door transport, individual transport (i.e. only one passenger or a group wishing to travel together), and the potential for dynamic routing of vehicles (if the systems is implemented on a network-wide level).

Identification of Related Systems

The literature review has been carried out in order to gain a better understanding of the key technologies to be used for AUTS and of systems already implemented, which are closely related to AUTS. These closely related systems and technologies, which share some of the main operating characteristics include:

- Car Sharing Organisation (CSO)
- Demand Responsive Transport (DRT)
- Automated People Mover (APM)
- Automated Highway System (AHS)

Table 2.1 below shows a comparison of the four main AUTS-related systems identified for this study as mentioned above in relation to the main operating characteristics of AUTS, including full automation, on-road capabilities, demand-responsive operation, door-to-door individual transport and dynamic routing.

Comparison of AUTS-Related Systems				
AUTS-Characteristics	AUTS-Related Transport Systems			
	CSO	DRT	APM	AHS
Fully Automated	–	–	X	X
On-Road Capabilities	X	X	(X)[3]	X
Demand-Responsive	X	X	(X)[4]	X
Door-to-Door	(X)[1]	X	–	–
Individual Transport	X	(X)[2]	(X)[5]	X
Dynamic Routing	X	X	(X)[6]	(X)[7]

1) Door-to-door capability depends on the number of and the locations of vehicle access and drop-off points
2) DRT can vary from individual to collective transport depending on the systems or peak/ off-peak operation
3) Some applications require rail infrastructure but through recent developments road-capabilities are possible
4) APM can operate demand-responsive, but at high demand (airports, metro) continuous system operation
5) Depending on the application APM can provide either individual or group transport, but not mass transport
6) Depending on the scale of the application APM can be a single line or a network allowing dynamic routing
7) Depending on the scale AHS can be on a segment of a motorway or on a network allowing dynamic routing

Table 2.1:Comparison of AUTS-Related Systems

2.2 Analysis

2.2.1 Car Sharing Organisation

Introduction and Background

Sperling et al give the following general definition: Carsharing is based on the principle of a collective and therefore more efficient use of cars. In contrast to the concept of carpooling people do not use the vehicles at the same time, but individually. Carsharing usually begins as a small local cooperative with one or two vehicles in a residential neighbourhood, which then spreads out over bigger parts of the city. Subscribers of a car-sharing programme can then use these vehicles by renting them for a short period of time. The rental period ends consequently, when the user returns the vehicle.

Car sharing allows households access, as needed, to a fleet of shared-use vehicles. Alternatively, it could be privately owned vehicles that are used to share trip costs. Early examples were Sefage in Zurich, Switzerland, in 1948 and Protocip in Montpellier, France, in 1971 (Sperling et al, 2000). Modern car sharing began in Switzerland in 1987 and shortly afterwards in Berlin, Germany. Between two companies, after 10 years, Switzerland now has 20,000 participants in organised car sharing. One of the benefits of car sharing is that users are more inclined to use public transport for leisure trips and business travel outside the peak hours (Muheim, 1998).

The concept of carsharing has been known in Europe since the 1970s. Most of the first initiatives however failed. More successful experiences began in the late 1980s, though until the late 1990s, virtually all start-ups of carsharing were subsidised with public funding. In 1999, ca. 200 car-sharing organisations were active in 450 cities throughout Switzerland, Germany, Austria, the Netherlands, Denmark, Sweden, Norway, UK, France, with over 130,000 participants (Sperling and Shaheen, 1999).

A special type of carsharing is the station car concept, which consists of cars parked at central locations (e.g. public transport stations, business-parks, high-density residential areas, etc.), which can be hired and driven by subscribers for any type of short trip. After a trip, the user can leave the vehicle at any station designed for the station car vehicles in the network, where any other user can pick it up. Station cars are typically small electric vehicles (environmental reasons), although other types can be used (Shaheen et al., 2000).

System Characteristics

Most of the calculations show that carsharing becomes an economically attractive alternative for people who do not necessarily need a car every day and who normally drive their cars less than a certain number of kilometres in a year (less than 10.000km). Typically, members of a carsharing cooperative pay a membership fee and a refundable deposit. Cars are reserved by telephone or in some cases on the Internet.

Users are charged per hour and per kilometre. Insurance, fuel, maintenance and often parking in designated places are included in the fee. Some carsharing organisations are now entering a modernisation phase, moving from manual key based operations to a system of smart card technologies for making automatic and advanced reservations, accessing vehicle keys, securing vehicles from theft, and facilitating billing.

The shift to smart cards simplifies vehicle access for customers and eases the administration and management of large systems. However, the large investment required for the new communication and reservation technologies puts pressure on these organisations to continue expanding to pay off these investments.

Operating Environment

Most surveys characterise carsharing as a predominantly inner urban phenomenon. This can be explained by the fact that sharing instead of owning a car becomes economically attractive for people who do not necessarily need a car every day. This is more likely to be the case in the inner urban area.

In the periphery people are more often dependent on the car due to less nearby activities and less alternative transport modes. Trips from the periphery will often also cover longer distances. Because costs for longer trips tend to increase quickly, carsharing only seems suitable for short or middle range trips.

For trips longer than 40 kilometres car rental seems the more economical option (Orski, 2001). Another point in favour of carsharing in inner urban area is the poor availability of parking for private cars. The projects that do arise in the periphery usually have a more informal and cooperative character and are often used as substitution for the purchase of a second vehicle.

Performance and Findings

Several surveys of users have been conducted in Europe and North America by carsharing organizations. A brief summary of the findings is reported by Sperling and Shaheen (Sperling and Shaheen, 1999). While several studies paid attention to person characteristics of carsharing users, much less information is known about the activities for which carsharing is used. The concept of carsharing seems however less attractive for regular work-related trips because the vehicle is not used during the work day and costs mount up quickly when a car is used for a longer period.

A Dutch study has shown that only 3% of carsharing members use a shared car for work purpose. It is assumed shared cars are being used for all activities except commuting. The effects of carsharing on the travelling behaviour were examined as part of this study (Meijkamp and Theunissen, 1997). Their first rather logical conclusion is the reduction of the amount of cars. In practice, the average ratio of shared cars per number of participating households is 1:12. However the actual reduction in the amount of cars depends on actual consumer behaviour, as the reduction in the amount of cars depends on the extent to which people substitute their private car for a shared car.

The study showed that carsharing primarily (71%) functions as an addition to available transport services, and that 9% use it as a second car alternative. So only 21% of people substitute their private car for a shared car. The total number of cars does however reduce. The study among carsharing participants also showed a strong decrease of car use. The average car mileage of former car-owners went down from 15.899 to 10.080 kilometres a year (-37%). The car mileage of former car-less (hiring or borrowing a car) reduced from 5.360 to 3.820 a year (-29%).

According to the Dutch survey of carsharing users, the main motivations to join a carsharing organisation are based on disadvantages of the private car: high costs and poor availability of parking space and of public transportation (e.g. long travel time). Important conditions for participation are reliable availability of vehicles and convenient nearby neighbourhood locations. The average distance to a carsharing location in the Netherlands is 1700 meters. A distance of more than 1900 meters is valued as less attractive by carsharing members (Meijkamp and Theunissen, 1997).

Despite the benefits of carsharing, it still does not account for even 1% of travel in any region. In another European study (Sperling and Shaheen, 1999) it was found that the principal reasons for not participating were the unprofessional image of many car sharing organisations, an insufficient variety of products and services offered, high costs compared to transit, too complicated, impractical and time consuming and poor availability of vehicles near home.

Sperling and Shaheen also state that people use and view their cars in many different ways that are poorly understood. They value them not only for utilitarian travel, but also for storage, quiet time away from family and work, and office space. Carsharing will not be successful everywhere at all times.

It is more likely to thrive when environmental consciousness is high, when driving disincentives such as high parking costs and traffic congestion are pervasive, when car ownership costs are rather high and when alternative modes of transportation are easily accessible.

The Paraxitele trial has shown that dispersed demands, in view of timings as well as locations do not pose any insuperable problems in terms of the required fleet management of individual vehicles (Blosseville et al, 2000).

Furthermore such a system can be operated with relatively limited human resources for the redistributions of vehicle within the network. An economic assessment of Car Sharing Organisations (CSO) has shown that potential benefits of an application of this concept can be similar to a major road scheme, but at a fraction of the cost (Fellows and Pitfield, 2000)

But despite encouraging results for the potential of car sharing applications, in order to guarantee their success, further improvements are necessary. Various ITS technologies, such as e.g. smart cards for vehicle access can make system operations both more efficient for the operator and more user-friendly for customers (Wagner, 1999).

Moreover, car sharing should not be seen as stand-alone system, but should be implemented as part of urban or regional combined mobility solution in order to achieve the maximum potential of this concept (Huwer, 2004).

Implications for AUTS

In the section above an introduction and background, the system characteristics, the operating environment, and the performance and finding of the car sharing concept was described. Car sharing is one of the four main innovative transport systems which were identified as sharing some of the characteristics/ functionalities of AUTS. In the following a summary of the main findings that have direct implications for AUTS is given. These points will input into the next research activities.

The car sharing concept can provide individual, demand-responsive, on-road, individual transport, but the system is not automated, although with increasing implementation of ADAS some driver assistance functionalities will be possible. Due to having these general characteristics and functionalities in common with AUTS, the larger experience with this concept because of the much earlier implementation, can then be analysed in view of the implications it has for the development of AUTS.

The literature review of the car sharing concept has shown a number of clear benefits of this system. These system benefits relate to cost savings for end-users compared to owning a vehicle, cost savings on an economic level (in terms of the capital costs and the operating costs) compared to a major road scheme (whilst providing comparable benefits), reduction of the number of vehicles in use (on the road network and parked), and modal shift to other forms of public transport.

But despite these benefits uptake of the car sharing concept has been slow and many schemes rely on subsidies from central government or local authorities. But there is potential for large improvements to the system through implementation of various ITS technologies, including smart-cards, driver assistance systems, and automated (or platooning) vehicle redistribution. Furthermore the concept should not be seen as a stand-alone system, but as part of a multi-modal solution.

2.2.2 Demand-Responsive Transport

Introduction and Background

Demand responsive transport (DRT) is an intermediate form of transport between a bus and a taxi (Mageean and Nelson, 2001). DRT can either be fully demand responsive or patrol a route and transport people who wish to use it, but at the same time be available for people who book a journey.

It was traditionally primarily used to increase the mobility of those without access to private transport (often mainly for disabled and elderly). Telematics are employed through travel dispatch centres (TDC) to optimise routes while automatic vehicle location (AVL) devices provide information on the status and location of the vehicle. Routes operated by DRT can either be fixed, timetabled, roving or door-to-door (Horn, 2000).

DRT is a flexible public transport service, combining the service characteristics of buses and taxis. It can be used in areas of low demand (e.g. rural areas), where conventional public transport service cannot be operated economically viable and to accommodate the needs of special users (e.g. disabled or elderly).

DRT can be characterised as a system, which is operated in response to calls from passengers or their agents to the operator, who then dispatches a vehicle to collect the passengers and transports them to their requested destination. Unlike a conventional bus service DRT does not operate on a fixed route or to a fixed schedule and unlike a conventional taxi service the vehicle might serve more than one request at a time, as it can be dispatched to pick up and deliver several passengers at different points.

DRT is a public transport system in which the planning and use of the service depends on requests made by customers, because unlike traditional public transport, booking or reservation of the trip is always compulsory. Generally when reserving a seat the user has to specify the leaving point and the destination, and either the time at which he wishes to be picked up or when he desires to arrive.

The provider can then either accept or refuse this request or suggest changes, so that there can be a degree of negotiation between the two parties. The system will also specify the time at which the customer will be picked up, if the customer has given the desired time of arrival at the destination, or specify the arrival time if the pickup time has been given by the customer.

System Characteristics

According to an analysis framework developed in context of the SAMPO (System for Advanced Management of Public Transport Operations) different DRTS concepts can be specified by the following main characteristics: route type, schedule, method of collection and quality of service (SAMPO, 1996).

The operation of a DRT system consists of the following main steps. Registration of the customers: In most of the systems, people willing to use the service must be registered. This simplifies many tasks, from the reservation to billing, especially if a smart card is used. The customer has to give a personal code whenever he wishes to use the service. For the reservation of a trip, the customer needs to contact the travel dispatch centre to request a service.

This can be traditionally done by phone, but also by using e.g. email, SMS, WAP, Internet, etc. if the system can support this. In the case of these more advanced booking systems, system operators often discourage the use of the phone, as it is more labour intensive and less efficient. But it would not be feasible to use a system in which no reservations can be made by phone, as most of the potential DRT customers (e.g. elderly) often cannot use other communication tools

When all customer requests have been collected the travel dispatch centre schedules the service. Most systems have a daily planning horizon (e.g. until 17:00 or 18:00 hrs they accept reservations for the following day, and then they schedule the service trying to fulfil all the requests with the available vehicle fleet). This had to be carried out manually in the past, but now there are various software packages that allow the management of the whole process (from reservation to billing) with a computer.

The scheduling phase includes the customer requests, the characteristics of the road network (length and/ or travel times) and of the fleet (number of vehicles, number of seats, facilities for e.g. disabled, etc.), and which will result in the service plan for the following day. This is a balancing process, which takes time and in practice the optimum is never completely achieved. The travel dispatch centre calls the customers back to confirm (or reject) the reservation and to specify either the pickup time or the arrival time, when the service plan has been finalised.

Operating Environment

DRT can be divided into systems for the general public or for specific user groups, as mentioned above. While the former were most common until the 1980s and included specific characteristics (e.g. fleets of relevant size, high number of requests served daily, service covering a whole metropolitan area with millions of potential users), currently services more oriented towards specific user groups (e.g. elderly and disabled) dominate the DRT market, although almost all of these applications are heavily subsidised.

There are also examples of DRT for particular attraction centres such as airports, serving customers with a high willingness to pay for a bespoke service. There can be a varying degree of flexibility in the planning of the routes. Most of the systems do not have predefined routes/ stops and can therefore be defined as free services, because the routes are designed only on the basis of customer requests.

More recently, corridor services have been proposed, in which the vehicles follow a predefined route but are allowed to make deviations within a certain range. In this way, attempts have been made to make the system more attractive for the user, but some passengers may feel more at ease in conventional public transport services. These systems do not strictly operate on-demand, as the vehicles are largely independent of the number of calls, and a reservation of the trip cannot not be requested if the pickup point is on the predefined route.

Another distinction can be made in view of the type of travel patterns. This allows dial-a-ride transport to be divided in the following categories. Many-to-many (several origins and destinations), every node coincides with a collection area and the node can be both origin and destination. Many-to-one (several origins and only one destination), the destination is one single node of the network and all others can be only origin nodes. Many-to-few (several origins and selected destinations), all nodes can be origins, of them only a few can also be destination.

One-to-many and few-to-many can of course be associated with the last two cases, featuring the return trip to previous origin stops. Many-to-many systems have historically been implemented initially in large metropolitan areas. They are the most versatile, but even harder to manage in an efficient way. On the other hand, in many situations in which DRT is used, many-to-one or many-to-few services can be well suited.

Performance and Findings

DRT has quite a long history, and early systems date back to the 1970s. After an initial period of enthusiasm, most of these were closed or radically changed, due to financial problems. The main reason often being that planners ignored the fundamental fact that DRT only works in very specific cases. There is no doubt that the market niche for these systems is quite limited, as on one hand they can be used only in particular situations, on the other hand the economic balance is always critical.

Allowing customers to reserve trips shortly in advance, like in taxi services, is the real challenge and can increase the potential attraction of DRT, making them a true alternative of conventional public transport. Real-time systems could hugely increase the situations in which a DRT becomes competitive, well beyond the cases described.

The first field trials of these new systems have been set up and there are some encouraging results. One of the weaknesses of current systems is their rigidity, i.e. the difficulty they have in operating in contexts different from those planned, breakdowns either of the vehicles and of the information processing equipment, anomalies on the network due to special events (streets closed, traffic jams), user behaviours or requests that had not been forecasted.

Within the DGXIII-funded SAMPLUS project, DRT was demonstrated within the Florence metropolitan area by PersonalBus (Mageean and Nelson, 2001). This used 5 minibuses and 2 buses equipped with AVL and chip card ticketing machines. Provision was made for low floor and wheelchair capabilities. Users could book a trip by calling a free number or ask drivers for the next time of departure. The service for the disabled was door-to-door while the remaining services used an increased number of service stop points.

The Ruf-Bus in Friederichshafen, Germany, is a bus transit operation that incorporates route deviations (Blackwelder and Loukakos, 2000). Requests for services are made at kiosks which would return the next available bus times. On accepting the bus, a vehicle was assigned to pick up the passenger. In the 1980s this service was replaced by the flexible operations command and control service.

Nevertheless, to make the system more appealing, especially in rural areas, door-to-door services have been proposed, which like a taxi can pickup and deliver passengers to their real origins and destinations, avoiding or minimising movements any walking distances.

This can also be appropriate for night services in urban areas with crime problems, especially for women. The drawback is that the operation of such a system, if made by a computerised tool, is hugely complicated as it becomes quite hard to preview the travel times during the planning phase.

In an online system the planning horizon is open, as requests concerning any moment in the future can be accepted, but of course the scheduling process is more focused on events in the near future. Dynamic systems are not only more difficult to manage, but require the use of advanced ITS technologies, but on the other hand, they are far more appealing for customers, as they can often accept travel bookings just a little in advance of the required service.

Thus a policy underpinning these systems, just as for traditional public transport, is essential if they are to be successful. Nevertheless, the extensive adoption of ITS technologies that are becoming quite common and cheap could greatly benefit DRT, even more than conventional transit. Devices such as automatic vehicle locating (AVL) or new telecommunication tools permit a continuous monitoring of the fleet, facilitating the implementation of online systems.

In some advanced applications researchers are trying to design algorithms which logic imitates in various situations the behaviour of expert human schedulers observed in different contexts, in order to increase the capability of the computerised system to react to an event that was not foreseen in the planning phase.

Another active research field is the development of efficient algorithms for scheduling the requests and routing the vehicles. In the last decade some theoretical advances and the increasing performances of computers allowed the implementation of artificial intelligence techniques to improve the quality of the solutions (i.e. satisfying all the requests with the minimum number of vehicles or with minimum ride time).

Implications for AUTS

In the section above an introduction and background, the system characteristics, the operating environment, and the performance and findings of the DRT concept were described. DRT is one of the four main innovative transport systems which were identified as sharing some of the characteristics/ functionalities of AUTS. In the following a summary of the main findings that have direct implications for AUTS is given. These points will input into the next research activities.

The DRT concept can provide demand-responsive door-to-door transport on the existing road network and has dynamic routing capabilities. Depending on the operating characteristics individual transport is possible, but the system is not automated. Due to having these general functionalities in common with AUTS, the much larger experience with this concept because of the much earlier implementation, can be analysed in view of the implications it has for the development of AUTS.

The literature review of the DRT concept has shown a number of clear benefits of this system. These system benefits relate to being able to provide transport where more conventional systems are not viable (in low-demand areas or at low-demand time periods), being able to provide transport to those who are unable to use conventional public transport systems (disabled and elderly), and being able to offer highly personalised transport (similar to taxis) at lower costs.

But despite these benefits implementation of the DRT concept has mainly been limited to small targeted application for disabled and elderly and most of these system rely heavily on subsidies from central government and local authorities. But there is a potential for improvements and larger applications, aimed at the general public through the use of various ITS technologies (including automatic vehicle locating, system control algorithms, online applications) for real-time dynamic scheduling.

2.2.3 Automated People Mover

Introduction and Background

Automated people movers (APM) are similar to mini-buses, except that they have no driver. They operate on dedicated paths. As of June 2000, there were 23 APM operating at airports, 24 at leisure sites and 21 at institutional systems, such as at subways, malls or universities (Swedetrack, 2000).

In addition to APM, another in many respects very similar innovative transport system is personal rapid transit (PRT). PRT is primarily an automated, low polluting, demand-responsive form of transport. The first PRT initiatives were in the mid-seventies, motivated mainly by the sharp increase in oil price and the sudden necessity for solutions with existing technology.

This specific form of an automated people mover is very similar to the general concept of AUTS, as it potentially can provide individual, on-demand, door-to-door transport, the main difference though is that it requires a segregated guideway as this technology is not capable utilising the existing road network. This is mainly due to technology constraints at the time when these systems were first investigated.

But to some extent AUTS is a continuation of this concept at a time when due to innovation in the necessary technology an operation without a guideway using the existing road network is possible. Therefore PRT will be also be reviewed here in addition the conventional APM. PRT is expected to be cheaper to construct, operate or modify than conventional road or underground transport (Electric Bikes, 2001).

It is environmentally sound, reducing energy use and harmful emissions by a factor of ten over the private car. An example is the urban light transport system (ULTra), which is described as an automatically controlled personal taxi system running on its own guide-way network (Lowson, 2001).

Customers determine the destination of the journey and algorithms determine the route taken. The striking visual feature of PRT is the elevated guide-way. Cabs may ride on top of this guide-way (e.g. ULTra) or be suspended from it (e.g. FLYWAY). To maintain minimum headways, stations are off-line and merging is controlled by the system.

System Characteristics

Nearly all APM are kept separated from conventional traffic on some form of guide-way or track. The notable exceptions are the Schiphol Airport ParkingHopper and the Rivium business ParkShuttle. Tracks have electromagnetic markers or buried cable built into the pathway to direct the vehicle. Guideways physically constrain the path of the vehicle. These methods determine the route that the vehicle takes, allow smaller headways and yet increase safety.

APM can operate on an elevated, below ground or at grade track. They can also combine track characteristics. The VAL in Lille, France, is largely an underground system although it also has elevated viaducts and a small section at grade (Marino, 1996). For personal rapid transit, at grade guideways have to be fenced off and bridged over for cross traffic, which is rarely practical (Anderson, 2000). Elevated systems are cheaper than underground systems (Anderson, 1997).

Operating Environment

Automated vehicles can be either mass transit or for individual use. For mass transit, the possibility of severance from the remaining traffic, particularly for multi-modal journeys, means that at grade transport might be preferable. People movers, such as the ParkShuttle in Rotterdam, Holland, operate at grade (Bootsma and Koolen, 2001). Mass transit vehicles are larger and so require greater support if they are to be elevated. This increases visual intrusion. Personal transport allows for smaller vehicles, reducing cost and visual intrusion.

APM can either operate as demand responsive or route specific transport. The first is a form of mass transit and the second may be more individual, automatic people movers may continue to operate over a route, regardless of the number of people waiting to use the system, even if there is no demand. Personal rapid transit is designed to take control of the vehicle away from the individual, but allows a vehicle to be booked and origins and destinations to be decided by the traveller.

Performance and Findings

ULTra has been well documented (see papers by Martin Lowson, the Advanced Transport Group website http://atg.fen.bris.ac.uk, the Advanced Transport Systems Ltd. website http://www.atsltd.co.uk and Andréasson, 2001). The system is designed to have battery-operated cabs that can accommodate four passengers or two passengers and luggage. There is also room for wheelchairs. It runs on rubber tyres on a guideway that is partly elevated and partly at grade. It is expected to run at 40 km/hr with 1sec headways.

Taxi 2000 (http://www.taxi2000.com) uses vehicles that can seat 3 adults, all facing forwards. The cabs get power from an electric rail on the guide-way. This means that braking is not dependent on the tyres, due to the use of linear motors. A demonstration of 3 cabs running is available from Taxi 2000. Papers by Edward Anderson describe the technical aspects, which are beyond the scope of this review (see http://www.taxi2000.com/pubs/transitpapers.htm).

One possibility for maintaining ownership of the vehicle while getting the benefits of public transport, is by driving cars onto a public transportation system, but allowing that system to take control for the bulk of the journey. Autoshuttle in Braunschweig, Germany, is a system, which would place cars into cabins for the main leg of a journey and transport them very quickly using magnetic levitation technology (Steingröver et al, 2001).

Cars drive into the cabins, are transported along a guide-way on the median and then drive out to continue with the journey. The technology behind maglev systems are beyond the scope of this review, but a short test track has been built at the Technical University of Braunschweig. One of the options for this system is the possibility of platooning or uniting several cabins into a chain, controlled by the lead vehicle. This becomes more like the automated people movers.

Another form of privately owned vehicle is the RUF (Rapid Urban Flexible). This is a battery-operated car that can run on the road, but which has a slot on the underside for connection to a monorail guide-way (Andréasson 2001). There is a MaxiRUF version for 10 passengers, which is then an automated people mover. There is a test track at the Danish Institute of Technology (see http://www.ruf.dk/).

A different form of APM is the Serpentine (from Saugy et al, 1997). This has autonomous, electrically powered shuttles, which are guided by means of a magnetic track integrated into the road pavement (Gillet and Chevroulet, 1999). They can link together to form a platoon. Each shuttle can carry up to 5 people.

The Parking Hopper at Amsterdam Airport Schiphol (Netherlands) provides passenger transport to and from the long-stay car park P3. Since December 1997 four Parking Hoppers have been operational at Schiphol. The service is available around the clock, seven days a week and is free of charge for users of the long-stay car park. The route on car park P3 is divided into two one-kilometre loops, each of which has three stops.

The Rivium ParkShuttle is an automated guided vehicle with a capacity of 12 persons and a maximum speed of 30 km/h. The people mover drives on a dedicated infrastructure. The vehicle is unmanned, operation and guidance is electronic using beacons in the road and sensors in the vehicles. The vehicle stops automatically when it detects an object on its path.

One early example of the APM is that in Morgantown, USA, connecting various parts of the University of West Virginia campus with the central business district. It began operating in 1975 and has carried 50 million people without incident. The VAL (Villeneuve d'Assq-Lille) has carried fare-paying passengers since 1983. It has a guide-way length of 15.8 miles, of which two-thirds is underground and the rest is mostly elevated. It has 36 stations, 83 vehicles and carries 50 million passengers a year (Marino, 19963).

The cars run on pneumatic tyres and have guide-wheels, which bear onto two guide rails. Power comes from a third rail, with D.C. motors under the cars, which can be recharged during breaking. It is basically a metro system without a driver. However, being computer controlled it has proved cheaper and safer than comparable manually driven systems. It averages 97% of trips on time.

Dallas/Fort Worth International Airport is installing an APM, which is expected to begin service in 2005 (Nicholas et al, 2001). This is projected to move 8,500 passengers per hour per direction. It will connect 12 stations on a guide-way, travel at 37 mph and enable passengers to get across the airport in 9 minutes.

Implications for AUTS

In the section above an introduction and background, the system characteristics, the operating environment, and the performance and findings of the APM concepts were described. APM is one of the four main innovative transport systems which were identified as sharing some of the characteristics/ functionalities of AUTS. In the following a summary of the main findings that have direct implications for AUTS is given. These points will input into the next research activities.

The APM concept can provide fully automated operation and is, depending on characteristics of the application, capable of demand-responsive individual transport (but not door-to-door), dynamic routing and operating on the existing road network. Due to having these general functionalities in common with AUTS, the much larger experience with this concept because of the much earlier implementation, can be analysed in view of the implications it has for the development of AUTS.

The literature review of the DRT concept has shown a number of clear benefits of this system. These system benefits relate to high system flexibility, large savings in staff costs compared to a manually operated shuttle due to the fully automated system operation, improved traffic safety when compared to manual operation, and the system providing convenient user-friendly transport using an innovative high-profile technology, which can address the generally low perception of public transport.

But despite these benefits most applications are so far confined to small-scale systems implemented on private sites (e.g. in airports, theme parks, etc.). The APM concept is very similar to AUTS, with the main difference being the reliance on a fully segregated guideway. People movers in airports are now common in large airports all over the world and a wealth of experience exists. Therefore further potential of this mainly relate to the implementation of AUTS or other related technologies.

2.2.4 *Automated Highway System*

Introduction and Background

Research in the area of automated highway systems has been lead by the PATH consortium in California, which has undertaken some of the most high profile work in vehicle to vehicle communications. The program, dedicated to the construction and test of a range of cooperative prototypes effectively culminated in a major demo of differing vehicle platforms and communication technologies.

Despite large technical and public relations success of the demonstration, the NAHSC project was discontinued, with research now focussing on particular niche applications such as snow plough control and automated busses in dedicated lanes.

Since that time several high profile demonstrations have been undertaken, including events showcasing developments in Japanese research programs, however advances in the EU have been mostly restricted to investigating the potential for truck platooning as part of the Daimler-Chrysler led CHAUFFEUR projects.

System Characteristics

AHS, at its most extreme limit assumes a system where vehicles are electronically linked, allowing the formation of closely packed groups of vehicles or 'platoons'. The speed, acceleration, and inter-vehicle separation of each vehicle is measured on-board, and then transmitted to neighbouring vehicles and/or a roadside processor. With the increased accuracy and reliability of data obtained, it is possible to automate vehicle throttle and brakes to achieve much closer following distances hence forming so-called 'road trains' where vehicles in theory may have spacing down to the meter level (Chang et. Al., 1994).

While a number of vehicles may form a platoon, individual platoons are separated from each other by a larger spacing of the order of 50-100m. In order for such a system to function at full efficiency however, control must be performed flawlessly, with the driver therefore entirely removed from the vehicle control loop. Similarly, in order to allow for full predictability of vehicle movements, vehicles must operate in a dedicated right of way, ideally in their own lanes, barrier separated from non-equipped vehicles.

Operating Environment

As mentioned above, a full AHS requires the vehicles to operate in dedicated lanes, with dedicated entry and exit facilities in order to ensure that equipped and non-equipped vehicles may be separated and subsequently 're-mixed' with minimum risk and disruption to flow.

Although the AHS technology is applicable to both lorries and cars current implementation strategy assumes platoons of a single vehicle type. An additional safety restriction imposed is that ideally all vehicles would pass some manner of 'certification'/health check before entering the system to ensure the vehicle is able to respond accurately and quickly to external vehicle dynamics commands.

Performance and Findings

Cooperative/AHS systems have always been associated with the provision of significantly higher capacity increases (typically estimated as being >300%). Most investigation for these systems have been undertaken by PATH using the SmartAHS simulation tool, designed to be able to incorporate a wide range of sensor, communication, control policy and human driver models into an integrated simulation environment.

Recent work however (Michael et al, 1998), has shown how this 300% figure may vary according to operational constraints. Some conditions, such as the use of an AHS system allowing HGVs, can reduce maximum throughput from 7000vph/lane to 1500vph/lane or less, while the characteristics of each platoon can be managed to increase capacity further (more vehicles per platoon and smaller intra platoon gaps).

Still further increase may in-turn be possible by the barring of vehicles with low maximum braking capacities, with the elimination of the worst 4% of the vehicle population potentially increasing throughput by 14%. Additionally, through microscopic modelling, it is possible to consider the effect that such convoy systems may have on emissions, and with the elimination of stop-go driving, it is clear that savings and decreases in fuel consumption will become apparent.

For equipped vehicles it is estimated that this may be of the order of 10%, with reductions in Hydrocarbon and NOX emissions of 48% and 37% respectively, having been calculated. Other investigations have identified concerns that may reduce the maximum achievable capacity substantially (Rao and Varaiya, 1994).

For example the expected increases may be tempered by a range of other problems that would be induced in the adjacent non-equipped traffic, particularly as part of the merge/ de-merge processes. In such situations, it is quite possible for the demand for merging 'places' to outstrip the supply provided by passing platoons, restricting capacity to a practical maximum of 2700 per lane, little higher than that currently attainable.

One potential solution may be to increase the speed of merging vehicles, or alternatively introducing a degree of 'pre-platooning', releasing vehicles in synchronisation with arriving platoons, or slowing of the mainline platoon may reduce capacity losses to the order of 25%. For cooperative systems, 'safety' has been a major concern, voiced by both public and manufacturer alike, (though from the public point of view, this may be a misplaced concern associated with abdicating control at what would normally be viewed as a high risk headway).

The potential for injury should the system fail is likely to be low, as the reaction between vehicle actuators is so rapid and the spacing so small, that the relative speed between vehicles in any platoon is unlikely to reach more than 1 m/s. Thus, even if an accident was to occur within a platoon, a spacing of ~100m between platoons would allow sufficient safety distance for a following platoon to decelerate to a total stop.

This has been illustrated by Carbaugh et al. (1998), who have shown that platooning can reduce the probability of a collision occurring from 0.87 with manual driving to 0.028 within a platoon, and assuming a lead vehicle deceleration of –7 m/s2. Relative speed on impact would also fall from around 8.3 to 7.5 m/s.

The characteristics of a platoon can obviously be affected to change these parameters and, for example, the total collision probability in a platoon can be reduced from 0.76 at a 1m inter-vehicle spacing, down to 0.36 at 10m, although the collision speed rises from 1.7 m/s to 5.5 m/s.

Few research findings are publicly available in the area of component reliability, sensor validation and fail safe software design required for the successful implementation of any cooperative system although work has undoubtedly been performed by car manufacturers.

One of the principal problems is that in order to understand failure rates, the systems under test must have been examined in sufficient quantity to allow 'test to failure' routines to be performed, and with the rarity and cost of AHS prototypes (both components and full systems) this has not been possible.

It is however highly likely that double/ triple backups would be required (e.g. if 6 subsystems of an AHS are critical, and each has the standard reliability of 0.9999, the overall reliability is ~0.9995). This corresponds to 1 failure every 13.7 vehicle years, or for a fully operational AHS lane, to 1 vehicle failure every 3.33 hours (Rillings, 1998).

Implications for AUTS

The AHS concept can provide fully automated operation on the existing road network (on specific sections equipped with the necessary infrastructure), as it involves private vehicles it is also an individual and demand-responsive form of transport, and depending on the scale of the application can also include dynamic routing.

The literature review of the AHS concept has shown a number of clear benefits of this system. These system benefits include largely increased motorway capacity, safety improvements due to reductions in accidents, and decrease in emissions through smoother vehicle operation and elimination of stop-and-go driving.

But despite these benefits no applications have been implemented yet, and funding for large scale trials has been cancelled. The AHS concept is very similar to AUTS with the main difference being the limitation to specific lanes on motorways. The experience with AHS shows the difficulties of overcoming implementation barriers.

2.3 Conclusion

2.3.1 Summary

As a first step in this analysis into the potential of AUTS for providing more sustainable mobility in urban areas, a review of related systems has been carried out; which together with the survey of the state-of-the-art of AUTS forms the first stage of the four stage analysis process used for this study.

As the development process of AUTS is still at a very early stage, there is only limited published information available. Furthermore any current knowledge of and experience with the first developments of AUTS has been covered by the state-of-the-art survey. But due to this lack of published information on AUTS, this literature review has focused on a number of closely related systems.

The objectives of this literature review of AUTS related systems and technologies are therefore to identify existing innovative transport systems that have the potential to provide more sustainable urban mobility and which share some of the main characteristics and functionalities of AUTS.

For these systems literature has been reviewed in order to gather information on system performance and operating characteristics. This information was then analysed in view of how it relates to AUTS. A first step for this literature review of related systems was therefore to specify a general AUTS definition. This specification has outlined the key operating characteristics that are necessary in view of its potential of providing more sustainable transport in urban areas.

According to these descriptions of the general AUTS concept and of the more detailed system components necessary, as mentioned above, the key system characteristics of an AUTS application can be summarised as: fully automated, on-road capabilities, demand-responsive, potential for door-to-door transport, individual transport, and the potential for dynamic routing of a vehicle fleet.

The literature review has been carried out in order to gain a better understanding of the key technologies to be used for AUTS and of systems already implemented. These closely related systems and technologies, which share some of the main operating characteristics include car sharing organisation, demand responsive transport, automated people mover, and automated highway.

2.3.2 Key Findings

In the case of car sharing concepts, subscribers of all projects were highly satisfied with the service. The self-service concept, which made the vehicles available by smartcard was a success in all cases. Most feedback of subscribers concerned the limited opening hours and the small number of stations. However only a few projects are still in operation. The customers were satisfied, but as the systems were not economiccally viable, the financing stopped. The high costs are mainly due to the still rather expensive technology needed for monitoring the vehicles, and the labour intensive redistribution of vehicles

Demand-responsive transport systems and services as a concept are still in their infancy, and it is difficult at this point to foresee to what extent these systems could be a true alternative to the private car. Specific services (for elderly and disabled) are nowadays quite common in many countries. Services for the general public will be feasible if the service provided is of high quality. Therefore they could attract some of the car users that are not using conventional public transport because of its poor performance. However that is not yet a well researched subject. Experience shows that there are many critical issues that must be anticipated, e.g. economic issues, service, technology, etc.

Automated people movers share most of the system operating characteristics and functionalities of AUTS as described before, including the fully automated capabilities, but unlike automated highway systems, which have only been demonstrated on test sites, these systems have been in operation for a considerable amount of time. This has to some extent been possible because most applications are on private sites (e.g. airport people movers), where less deployment barriers to these innovative systems and technologies exist. These systems have proven to be reliable and user friendly. The main challenge therefore is to use this technology in less controlled environment at public sites.

Research on automated highway systems has been carried out mainly by PATH in the late 1990s, but despite technical and public relations success the project has been discontinued and research has been targeted towards smaller niche applications since. It has been shown that capacity and safety can be highly increased, technology reliability has been proven and driver opinion has been found to be in favour of the technology. Further fields of research in context of AHS applications were integrated deployment planning and the functional requirements for various individual system components.

2.3.3 Discussion

For innovative transport systems in general formulating and following objectives is important for the success of a project, since communication of goals to users and other target groups is crucial to projects and how they are perceived. Successful communication is also a key to success in a project. It is therefore crucial for project managers to effectively communicate the goals and means of a project, and to stand by them when needed, but also to revise them when needed. Too many objectives in a single pilot can cause problems (e.g. new mobility concept with prototype vehicle).

There should be a distinction between social and technical objectives. Therefore not too many concepts and technologies should be introduced at the same time. Another important feature is whether the experiment is seen as the last step towards implementation or commercialisation or whether it is only a step in a longer process of exploration. In the first case, all social and technical elements should have been proven independently before and there should be a considerable emphasis on the economic feasibility. In the latter case, more elements are considered uncertain and there is little sense to look at economic viability of technologies/ concepts still to be defined.

All experiments are carried out by a heterogeneous network of stakeholders. This is an important condition for success as it creates commitment and a broad base of resources. Support from politicians as well as from the involved industry is also an important issue. Niches are protected application areas in which certain factors in the selection-environment have a decreased effect. There have been many proposals for new traffic and transport concepts that, at least in theory, would be far more efficient and social-inclusive and environment-friendly, than the current conventional systems. The single largest barrier to implementation is the strong position of the private car.

Large incentives are needed to gain popularity and public support. An innovative transport concept should demonstrate its potential in an identified and targeted specific niche area. Systematic problems with vehicles or the concept can be very costly, thus technology testing should not be mixed with large-scale introduction. Innovations form part of a larger system. New alternatives have little chance of success if they do not have a logical place in the existing larger system and policy context, or if they do not generate a new demand that can sustain the implemented technology innovation.

3 SURVEY OF THE STATE-OF-THE-ART

3.1 Introduction

3.1.1 Background

In the literature review of related systems (see chapter 2) system characteristics and results from research and implementations of advanced transport systems that share some of the key functionalities of AUTS were reviewed and analysed in view of their implications for AUTS. Following on from this, first small-scale applications of these technologies that have been implemented both on private test as well as on public demonstration sites and studies that have been carried out, were surveyed.

This analysis of the state-of-the-art of AUTS concepts has therefore investigated the knowledge and experience that technology developers and providers, system operators, and researchers already have through studies, system testing and experiments, planning of real applications and operation of existing systems. For this two different types of systems/ sites were identified, existing AUTS concepts (e.g. concepts, studies, test sites, and applications) and planned AUTS pilot applications.

3.1.2 Objectives

The survey of existing AUTS concepts has focused on the experience of those providing AUTS technology, in view of their proposed systems (general idea, infrastructure/ vehicle technology, etc.), various studies carried out (application areas, stakeholder involvement, securing funding, etc.) and system testing either through existing applications using their technology (user acceptance, feasibility, technology results, etc.) or through specific tests (system/ component performance, reliability, safety, etc.).

The survey of planned AUTS pilot applications has focused on the experience of those proposing test sites/ feasibility studies (application area, demand characteristics, proposed route/ facilities, etc.) and working on the detailed system design (infrastructure/ vehicle technology, land-use planning) and the interaction with authorities, system operators and the public in the planning process (funding/ political support, identify the commercial risk, and assess end-user acceptance, etc.).

3.1.3 Methodology

General Approach

Identified key stakeholders representing technology provider/ system operator and/ or working on the design of one or more of the proposed test sites and feasibility studies for the CyberCars and CyberMove projects were sent a questionnaire in order for them to report on their experiences with AUTS technology.

The questionnaire survey for existing AUTS concepts (see Annex A) included information on the knowledge participants have in case of their on-going research and development work (either through operative systems, tests and experiments or through more theoretical studies and simulations/ modelling) for the following systems:

- FROG (Free Ranging On Grid)
- ROBOSOFT
- RUF (Rapid Urban Flexible)
- SERPENTINE
- ULTra (Urban Light Transport)

These are the systems developed by the main AUTS Technology providers in Europe, which were all members of the project consortium.

The questionnaire survey for AUTS pilot applications (se Annex B) included information on the knowledge participants have through work on their proposals for test sites and feasibility studies (in view of the analysis of the respective sites, detailed system design and the planning process) for the following sites:

- Coimbra (Portugal), 2 Sites:
  - Historic City Centre
  - Redevelopment Area
- Rome (Italy), 2 Sites:
  - Historic City Centre
  - Exhibition Centre
- Antibes (France)
- Lausanne-Crissier (Switzerland)
- Nancy (France)

Questionnaire Design

A common questionnaire was developed to ensure comparable results and to enable a consistent similar analysis of these results. There are separate frameworks for the survey of existing systems and of pilot applications. The following shows the framework used to structure the questionnaire survey.

- Existing Systems
  - General System Description:
    - Infrastructure Technology
    - Vehicle Technology
    - Advantages of System
    - Possible Application Areas
  - Description of Studies:
    - No. of Studies and Overview
    - Application Areas
    - Detailed System Description
    - Experiences with Planning Process
  - Description of Operating Systems:
    - No. of Systems and Overview
    - Application Areas
    - Detailed System Description
    - Experience with Planning/ Operation
- Pilot Applications
  - General Topics:
    - Site/ Application Area
    - Existing Transport System
    - Demand Characteristics
    - Planning Details
  - System Description:
    - Infrastructure Technology
    - Vehicle Technology
    - Proposed Route/ Facilities
    - Advantage of System
  - Planning Process:
    - Availability of Funding
    - Stakeholder Involvement
    - Land-Use Planning
    - Local Authority Interest

3.2 Analysis

3.2.1 Overview

The reviewed systems include in terms of infrastructure technology dual-mode operation (fully automated and manually operated on different sections of the motorway), requiring a dedicated infrastructure and having the potential of using the existing road network, based on route guidance and obstacle detection technology.

The vehicles used also differ in size from individual to group transport, but not exceeding a maximum number of 20 seats, therefore not providing mass transport. Advantages include low infrastructure/ implementation costs and increased convenience. Possible applications are feeder, historic city centres, and private sites.

Various studies have been carried out, which have shown the need to explain the advantages and to educate the market. The systems are in different stages of development, some being operational, and some only with a test track. Application areas include an airport car park, a business park and a theme park.

On most of the reviewed sites various conventional public transport systems exist, in most cases AUTS will not substitute these, but complement them as part of a multi-modal system. The planning process is at different stages of seeking funding, determining the demand characteristics and carrying out detailed system planning.

In most cases the use of fully automated shuttles is planned with the exception of a semi-automated system (both automated and manual system operation is possible, and as a first stage only the manual operation will be carried out) and a platooning system (the first vehicle is driven manually and the other vehicle follow automated).

The anticipated advantages of these studies carried out include increased network and link capacity, higher convenience for end-users, and lower implementation and operating costs (due to the automated operation). At this early stage of the planning process the funding still remains a problem for all sites due to a perceived high risk.

Table 3.1 below shows an overview of the main existing AUTS application and sites/ studies that have been analysed as part of this state-of-the-art survey. This overview includes brief descriptions of the infrastructure technology, the vehicle technology, and the type of application, which are either in operation or have been undergoing feasibility studies and depending on their outcome detailed system design. This is then followed by a detailed description of the findings of the survey.

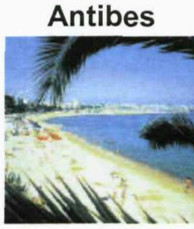
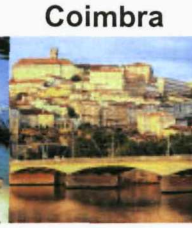
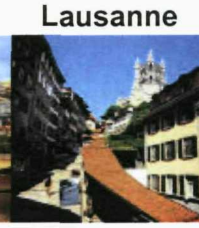
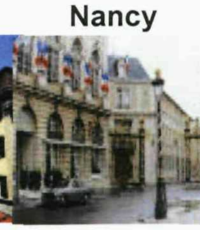
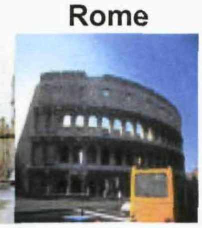
Description	**Existing System Applications analysed**				
	FROG	**RoboSoft**	**RUF**	**Serpentine**	**ULTra**
					
Infrastructure	System uses existing road network	System uses existing road network	Auto on rail, manual on road	System uses existing road network	Requires a segregated guideway
Vehicles	Varies from 4 to 10 to 20 seat vehicles	Vehicle for 22 seated passengers	Varies from 2 to 6 to 10 seat vehicles	Platform for 4 standing passengers	2 permanent and 2 flip-down seats
Application	Car-park, business-park	Ride within a historic theme park	Only test-track for the system	Only test-track for the system	Only test-track for the system
Description	**Location of Sites and Studies analysed**				
	Antibes	**Coimbra**	**Lausanne**	**Nancy**	**Rome**
					
Infrastructure	Transponder or wire-guidance	Transponder navigation technology	Semi-automated operation	No details decided yet for this site	No details decided yet for this site
Vehicles	Electric, 20 passengers, 20km/hr	Zero-emission, 4 passengers	Electric, 8 passengers, platooning	No details decided yet for this site	Electric, 15 passengers, 10km/hr
Application	Connects a car-park with the marina	Development area and city-centre	Peripheral area of the city	Development area close to city-centre	City-centre, exhibition centre

Table 3.1:Overview of Systems and Sites/ Studies analysed

3.2.2 Existing Systems

System Description

The five reviewed systems differ in terms of their infrastructure technology. The RUF system is dual-mode, thus being able to use the road network in manual mode, but requiring (mono-) rail infrastructure for automated operation. The ULTra system also requires a segregated guideway network. The three other systems are able to make use of the existing road network.

The vehicles from FROG are operated through a supervisory control system, which handles traffic control, transportation request dispatching and manages status information from the vehicle; mixing with pedestrians and manually operated vehicles is possible on certain parts of the track, as the vehicles are equipped with an obstacle detection system, which detects other traffic and consequently slows down or stops the vehicle to avoid a collision.

The SERPENTINE system uses their 'MagnetoGlisseur' technology for energy transmission, lateral and longitudinal control and exchange of information, The ROBO system is based on wire-guidance and transponder technology and a wireless communication system. The vehicles for the dual-mode system from RUF can be in various different sizes, including a 2-seater, a midi version for 6 passengers and a maxi vehicle for 10 passengers; in all cases the vehicles need a slot in the middle to enable them to use the mono-rail infrastructure for the automated operation.

The SERPENTINE vehicle uses a platform for 4 standing passengers. ULTra vehicles use conventional rubber tyres, though requiring a separate infrastructure, the vehicles has space for two permanent and two flip-down seats. The FROG vehicles are available as 10/ 20-seater (ParkShuttle) or 4-seater (CyberCab). The ROBO vehicle looks like a trailer with 2 front steering wheels and 2 rear passive wheels and there is space for 22 seated passengers.

The advantages of the FROG system include low operating costs and investment for implementation compared to conventional systems, convenient transport system with short passenger waiting times, environmentally friendly and safe.

The ROBOSOFT system promises very accurate positioning even at high speeds, efficient fleet management and allowing manual operation. Advantage of the RUF system are related to the dual-mode concept, allowing manual on-road operation and safe and environmentally friendly automated operation on a mono-rail infrastructure, leading potentially to a city-wide door-to-door transport system, without the need for interchanges.

The SERPENTINE can also provide within an application area (not city-wide) a network-wide origin-to-destination transport on a marked track, with the additional benefit of low energy consumption. ULTra can provide on-demand (only very short waiting times), non-stop, point-to-point network-based transport. All systems use battery powered electric vehicles, providing the environmental benefits of no noise and pollution at the point of use, which is very important for urban applications.

Possible application areas include feeder to public transport or the sole public transport mode, e.g. in residential areas, and transport on various private sites (FROG); theme-parks, museums, leisure areas, business parks and automated buses in urban areas, where conventional vehicles are restricted (ROBOSOFT); potential to substitute buses, trains and private cars in urban areas, when implemented on a city-wide scale or targeted applications, e.g. park&ride, when implemented on a smaller scale (RUF).

Access to the existing public transport systems, e.g. as a feeder application, internal transport system in e.g. shopping centres or airports, micro-cars in city-centres, especially in historic city-centres, where conventional systems cannot be used or are restricted for environmental reasons (SERPENTINE);

Although original design was targeted at an urban application, the flexibility of the system permits consideration for various applications, including airports, business parks, large business, university campus, new commercial or residential developments or private vehicles, inter-city transport or freight transport applications (ULTra).

Description of Studies

For the FROG system various studies were carried out to assess if the technology is suitable for sites where it is under consideration over the last two years 35 studies have been carried out to promote the system, these were done mainly for transportation systems between car parks and public transport interchanges or other points of interest, including e.g. business parks or theme parks.

A total of seven studies have been carried out for the RUF system, including Copenhagen, Paris, Los Angeles, Seattle and San Antonio, where in most cases the use of the system as an extension to the existing public transport system was analysed, but in two cases a city-wide system was considered.

SERPENTINE carried out five studies, including applications for the Ouchy quays in Lausanne, the campus of the EPFL University in Lausanne, Werfenweng, Antibes and Nancy. The initial proposed application for ULTra is in Cardiff as a connection between a re-development area and the city-centre.

Application areas for RUF studies were public transport feeder systems or city-wide systems. Application areas using the SERPENTINE system included, urban transport for targeted users (tourists), university campus, tourist resort, connection to park&ride and access to new development sites.

Application areas considered through the work on system studies using the FROG technology include transport from a car park to a recreational site, e.g. theme park or zoo (5 studies), park&ride to the city centre (2 studies), public transport station to business park (3 studies), station to city-centre (3 studies), station to shopping centre (1 study), station to stadium (1 study) and on private grounds/ exhibition centre/ resort (3 studies).

Only one study has been carried out for the ULTra system so far. This application is planned to be operated between a re-development site, the former industrial area of the docks in Cardiff and the city-centre, as journeys between these two sites currently cause a variety of difficulties. The study has shown that by complementing the existing public transport network, ULTra can provide an effective solution to these problems.

The studies using the RUF system were mainly line systems, but in two cases network solutions were examined. The studies for Los Angeles and Seattle were networks covering large areas. In Los Angeles the system used the available right of way in the wide streets, where streetcars had been running in the past. In Seattle the network was created to meet the pre-defined objective of providing a transport system, which offers 60% of the population a drive of less than 10min on the road network to reach an access point to the RUF network.

The concept for the SERPENTINE technology is to surround buildings and facilities with a mesh of 200m to 400m with a lane similar to a cycle track, using traffic circles in the main intersections to allow exchange between the meshes, cross walks or traffic areas are protected. The first stage of the proposed ULTra application in Cardiff is to connect a public transport interchange and the harbour for transport within the re-development site of the docks and to work in parallel on the extension, which would connect the bay area with the city-centre.

Experience through the work for studies using the FROG technology included the need to describe CTS not as a solution to all transport related problems or as something, which would replace the existing conventional public transport system, but to describe the specific advantages of CTS for specific targeted application areas. Furthermore, due to the innovative character of CTS, there has to be a certain degree of education of the potential market for CTS, to overcome scepticism of the stakeholders.

In the case of the ROBOSOFT system, it was noted, that in the case of a targeted private application, once there is consensus by all stake holders, the whole development process including infrastructure, vehicles, hardware and software can be achieved in less than a year.

For the studies of the RUF system it was found that, though dual-mode offers various benefits for sustainable mobility in urban areas, there is a lot of reluctance of the involved stakeholders to commit to this technology, due to the innovative character and the lack of experience with real-size applications. In the case of the ULTra system, there is strong political support from the relevant authorities, but also various barriers to be overcome, including regulations for safety or disabilities discrimination.

Operational Systems

There are currently three operating systems using the FROG technology, the ParkingHoppper at Shiphol Airport Amsterdam, the Rivium business park ParkShuttle near Rotterdam and the CyberCabs (only operated by FROG, but using YAMAHA technology) at the Floriade flower show in Amsterdam.

One operational system based on the ROBOSOFT technology is operated at a historical fort in Simserhof. For the RUF/ SERPENTINE/ ULTra system currently only test-tracks exist (RUF in Copenhagen, SERPENTINE in Yverdon and Ouchy, and ULTra in Bristol).

In the case of the FROG technology applications the Shiphol Airport system operates on a car park, transporting passengers from a pick-up point close to their cars to a central point on the car park, where a manually driven bus brings them to the main terminal building, the Rivium business park systems provide transport between a public transport interchange and the business park and the Floriade system transported visitors on the top of an artificial hill at the flower show. The test tracks of the three other systems are on private sites to carry out experiments with the technology.

The infrastructure for the FROG Shiphol application is a double loop track. Each loop is one kilometer long and has 3 stops. At any given time there are three vehicles in operation. Meanwhile, the additional vehicles are being charged. The vehicles space themselves along the track to ensure minimal waiting times at each stop. The ParkShuttle project in the city of Capelle a/d Ijssel connects the Rivium business park to a PT interchange, a 1300m journey over a single lane track with three passing locations. On demand operation in off-peak hours ensures maximum service for passengers.

At the Floriade during operation from April to October, 25 CyberCabs provided transportation to the top of the observation point. The vehicles use a track constructed to spiral up the hill. The electric CyberCabs drove at a max speed of 11 km/hr and a max capacity of 600 passengers/hr/direction. The ROBO system uses 5 vehicles and wire guidance for automatically visiting the gallery inside the fort. The visit lasts 30min, the track is 800m long and the show indoors is synchronized with the motions of the vehicle.

Surveys prove that the FROG Shiphol system is well used and greatly appreciated. The Floriade demonstrated that in order to operate a system, an operator will need to have a degree of certainty. The Floriade organisation conducted extensive research to establish the number of visitors they could expect.

All operations were advised to be based on 2.7 million visitors. Due to unknown circumstances, only 2.1 million visitors visited the Floriade. All operations had to adjust to the new circumstances. In order to establish projects and to attract an operator, it is thus important to consider how operational income is going to be generated. And it is important to create certainty for the operator regarding the minimal income that can be generated.

The experience in the case of the ROBOSOFT application is that this type of system is restricted to private and very contained areas, due to certification issues and speed limits. Even though the RUF test track is very basic, it attracted a lot of media attention and furthermore the tests have proven the basic functionality of the system.

The test of the SERPENTINE system showed the interest of the users, the difficulty in obtaining authorisation in mixed sites and the long period, which is necessary for measurements in real sites in view of e.g. specific obstacles, user behaviour or sensitivity to the specific climate. The initial results of the ULTra test have been positive as vehicle and track have been successfully integrated and multiple circuits of the complex guideway have been completed under fully automatic control.

3.2.3 Pilot Applications

Site Description

Amongst the eight proposed test-sites and feasibility-studies various different AUTS application areas are covered. The two sites in Coimbra (Portugal) are in the city centre as a connection to a market supply and in a large re-development area. In Antibes the proposed system will connect a car park and the marina close to the city centre.

The application area of the Lausanne-Crissier system is a public transport system in a city peripheral area. In the Nancy site AUTS will complement public transport in a large new urban development. The two sites proposed for Rome are a public transport system in the city centre and connection between a public transport station and a newly build exhibition centre in the periphery of the city. In all cases the AUTS applications will not necessarily substitute any existing transport systems, but only try to make public transport as a whole more convenient by complementing it.

At all sites a variety of conventional public transport systems (including e.g. buses, light rail, heavy rail, underground, tram, etc.) exist, but the use of private vehicles is favoured, therefore different application of AUTS are going to offer a more convenient and flexible mode of public transport for targeted application to address the problems of private car use in urban areas.

According to the different AUTS application areas covered by the proposed test-sites and feasibility studies, there is also a variety of different demand characteristics, the proposed systems have to respond to. In the case of the two sites in Coimbra, the demand characteristics are supply for the businesses in the city centre and access for staff and customers, and targeted users in the re-development site, including e.g. tourists, children, disabled and elderly.

At the Antibes site the demand consists mainly of tourists visiting the historical city centre and visitors coming to various cultural events. In Crissier the forecasted demand is composed of local user travelling short distances, as well as commuters to and from Lausanne.

At the Nancy site the demand will consist mainly of short trips between a tram station and a cinema. In the Rome city centre site the demand characteristics are very broad, as it is planned as a public transport system targeting all user groups, whereas at the Rome exhibition centre site the system will only be used by visitors of the exhibition for the way from either the nearest public transport station or the car park to the main entrance of the exhibition centre.

As the planning of the test-sites and feasibility-studies are at different stages, the amount of information available on the detailed planning details also varies. At the two sites in Coimbra only a basic concept exists to use a freight delivery system in the city centre, which could be expanded to transport staff and customers as well and to use individual automated vehicles to complement conventional public transport systems in the re-development area.

At the Antibes site the strategy is to restrict vehicle access to the historic city centre and to reclaim public spaces used for parking before, therefore the proposed AUTS application will provide transport from the car park to and within the restricted area. In Lausanne-Crissier individual semi-automated vehicles are to be operated within the area of Crissier to relieve congestion and to provide a more convenient mode of public transport.

At the Nancy site a number of alternatives for the use of AUTS on the development site are examined. At the Rome city-centre site fully automated shuttles are to be operated on protected lanes and at the exhibition centre a AUTS network would be created on the main car park and a line from car park and public transport station to the exhibition centre.

System Description

Although all applications proposed for the test-sites and feasibility-studies are based on the technologies provided by the project partners, as reviewed in the first section of the experience report activities, the limited scale and the nature of all sites does not allow dual-mode systems or the use of additional elevated (mono-) rail infrastructure.

All proposed systems therefore make use of an existing road network. At the Coimbra sites transponder technology is to be used for vehicle guidance and wireless communication for fleet management. For the Antibes site the alternatives of transponder or wire guidance are still being considered and for high system flexibility the track for the AUTS vehicles is shared with bicycles and will be used by a manually driven shuttle bus, when the automated system is not in operation.

The system proposed for Lausanne-Crissier will use manually operated vehicles initially, so no special infrastructure will be required in this case. The planning of the Nancy site is at an early stage, therefore different concepts (lines or network) are considered, based on automated vehicles using the existing road network, based on vehicle guidance and obstacle detection technologies.

In Rome the AUTS vehicles will also use the existing road network, shared with trams and on most parts with cyclists and pedestrians. The Rome exhibition centre site will use an automated system, which is operated on the car park shared with manually driven cars and pedestrians, but which uses a dedicated lane for the connection to the main entrance to the exhibition centre.

The vehicle technology to be used for the two Coimbra sites is zero-emissions-vehicles, GPS technology and provision for fully automated operation and semi-autonomous operation, where human intervention is only needed in special situations. In Antibes four electric vehicles for 20 passengers each, with a maximum speed of 20 km/hr are used.

In Lausanne-Crissier electric vehicles for up to 8 passengers are used, a number of them can form a platoon, of which only the first vehicle is driven manually and the other follow the leading vehicle automated (semi-automated operation). For the Nancy site no vehicle details are chosen yet. In Rome electric vehicles for 15 passengers with an average speed of 10 km/hr are to be used.

For the Coimbra city centre site no route details are specified yet, for the re-development area the only detail specified is that the infrastructure is to be shared with an already planned cable electric tram. The principal design characteristics for the Antibes system are: Distance: 1.400m with an added 350m option for the Opera events; on demand service, 24 hours a day, ca. 5min maximum waiting time; reorganise the traffic and reserve one way road for AUTS.

This way integrating AUTS should minimise the demonstration costs, method to call AUTS is needed but it is also an occasion to experiment on demand calls by mobile phone. On board vocal and display information in order to deliver explanations on the automated operation. Possibility of multimedia messages to test city oriented advertisement. A direct vocal link with the supervisor should be accessible; specific parking policies along the harbour and combined tickets for specials exhibitions.

As the Lausanne-Crissier system is not operated automatically the existing road network can be used without any alterations. The route length is 2.5km, the number of convoys is 2 and the commercial speed is ca. 20 km/hr. For the Nancy system no details about the proposed route are agreed yet. The Rome city centre system is supposed to run on the same route as an existing bus line, length 3.25km. The Rome exhibition centre site will have a network length of 4.54km, expected average travel time 3min, maximum travel time 6min and expected average waiting time 2min, maximum waiting time 4min.

The proposed systems are to provide various advantages for the targeted applications they are used for. These advantages include increase in network/ link capacity through fleet management and platooning, more convenient public transport (e.g. on-demand, point-to-point without interchanges, short waiting times, individual transport, etc.), high system flexibility (time of operation, route, type of vehicle, etc.), lower implementation cost (compared to conventional alternatives, e.g. light rail), lower operation costs through automation, high potential when used in new developments (green field or brown field) or in re-development schemes.

Planning Process

According to the different stages of planning for the proposed test-sites and feasibility-studies, the process of securing funding for the respective systems is also at different levels. For the Coimbra city centre site there is some support by the local authority, but a feasibility study has to be carried out to prove that an economically viable operation is possible, for the re-development area a private investor has to be found to implement and operate the system.

For the Antibes and Lausanne-Crissier sites the availability of funding is not known yet, financial partnership with local and regional authorities is applied for and an additional partnership with industry sponsor and operators will be considered. In case of the Nancy site the political situation is not clear yet. No funding is yet available for both sites in Rome, for the exhibition centre site a feasibility study has to be carried out as a basis for a decision by a private investor.

The involvement of any stakeholders in the planning and design process varies between the different sites. In case of the Antibes site the mobility department is leading the project in collaboration with other departments (environment, economy, culture, etc.). In Lausanne-Crissier the local operators and the industry have followed earlier similar projects since 1998, therefore there is a high level interest for this project especially by a city car operator, transport of Lausanne and public transport of Geneva.

For the Rome city centre site a user needs analysis has been carried, revealing a certain level of scepticism towards an automated system operating in the city centre. Potential system operators were positive about the proposed system in view of operating cost savings through the automated operation.

For the Rome exhibition centre site no user needs analysis has been carried out, as the only stakeholder involved is the company responsible for the development of the exhibition centre. They would be interested in the project if a feasibility study can prove that CTS would be the best investment for them to secure a fast, convenient and safe connection to the exhibition centre from the car park and the public transport station.

The scale and specific characteristics of all proposed sites require different level of considerations about the land-use transport interaction. In the case of the Coimbra application, no alterations of the current land-use planning have to be carried out and no effects on it are foreseen.

The Antibes and Lausanne-Crissier projects are in tune with regional and national guidelines on urban mobility plans and various environmental issues. In the case of the Nancy system, the new development has the potential not to design CTS into an existing structure, but to plan land-use and the transport system together in a coordinated way.

In addition to the essential issue of securing funding for the test-sites and feasibility-studies, the interest and level of participation of the local authority in the initial planning process is also very important for a successful implementation. For the Antibes site great interest is shown for the trial period and the planning has been accepted by the authority.

In the case of the Lausanne-Crissier system the local authorities have been strongly involved and supportive for recent similar systems, but have not been able to provide the necessary funding. The municipal authority of Rome is the main promoter of the site in view of a study or a small scale trial, but although they are concerned about the full automation, they would support and fund such a system, if certification is given and it is proven to be economically viable.

3.3 Conclusion

3.3.1 Summary

This analysis of the state-of-the-art of AUTS concepts has investigated the knowledge and experience that technology developers and providers, system operators, and researchers already have through studies, system testing and experiments, planning of real applications and operation of existing systems. For this two different types of systems/ sites were identified, existing AUTS concepts (e.g. concepts, studies, test sites, and applications) and planned AUTS pilot applications.

The survey of existing AUTS concepts has focused on the experience of those providing AUTS technology, in view of their proposed systems (general idea, infrastructure/ vehicle technology, etc.), various studies carried out (application areas, stakeholder involvement, securing funding, etc.) and system testing either through existing applications using their technology (user acceptance, feasibility, technology results, etc.) or through specific tests (system/ component performance, reliability, safety, etc.).

The survey of planned AUTS pilot applications has focused on the experience of those proposing test sites/ feasibility studies (application area, demand characteristics, proposed route/ facilities, etc.) and working on the detailed system design (infrastructure/ vehicle technology, land-use planning) and the interaction with authorities, system operators and the public in the planning process (funding/ political support, identify the commercial risk, and assess end-user acceptance, etc.).

Identified key stakeholders involved in planning, studying, operating and testing AUTS technology have provided details on their experiences with their respective applications/ studies by participating in a questionnaire survey. This survey was carried out for existing systems and for pilot applications. The reviewed systems included FROG, ROBOSOFT, RUF, SERPENTINE and ULTra. And the reviewed AUTS demonstration sites included Coimbra, Antibes, Lausanne-Crissier, Nancy and Rome.

3.3.2 Key Findings

In the following the key findings of the analysis of the questionnaire survey on the state-of-the-art of AUTS will be summarised. Table 3.2 shows the results for existing applications, and table 3.3 shows the results for AUTS pilot applications.

Details	Existing AUTS Applications				
	FROG	RoboSoft	RUF	Serpentine	ULTra
Infrastructure Technology	System uses existing road network	System uses existing road network	Automated on rail, manual on road	System uses existing road network	Requires a segregated guideway
Vehicle Technology	Varies from 4 to 10 to 20 seat vehicles	Vehicle for 22 seated passengers	Varies from 2 to 6 to 10 seat vehicles	Platform for 4 standing passengers	2 permanent and 2 flip-down seats
Application Areas (Study)	Park&Ride and private applications	-	Citywide and PT feeder applications	Park & Ride and private applications	City-centre application in Cardiff
Operation (Study)	Simple line and loop systems	-	Line and network-wide systems	Mesh around buildings with intersections	Line with a number of off-line stops
Experience (Study)	Need to educate the market	-	No experience with dual-mode system	Institutional and legal barriers	Political support, but barriers
Application Areas (System)	Car-park, business-park, flower show	Ride within a historic theme park	Only test-track for the system	Only test-track for the system	Only test-track for the system
Operation (System)	Double-loop, single line, single line	Single line outside and inside fort	-	-	-
Experience (System)	Well used, appreciated and reliable	Restricted to small private applications	-	-	-

Table 3.2:Summary of Existing AUTS Applications

Details	AUTS Pilot Sites				
	Antibes	Coimbra	Lausanne	Nancy	Rome
Application Area	Connects a car-park with the marina	Development area and city-centre	Peripheral area of the city	Development area close to city-centre	City-centre, exhibition centre
Demand Characteristic	Tourists for historic city and marina	System for the general public	Local user travelling short distances	Coverage of development area	System for the general public
Transport System	In all cases the AUTS applications will not replace the existing conventional public transport system but will improve the convenience of public transport by providing an additional individualised mode of transport in the respective areas				
Infrastructure Technology	Transponder or wire-guidance	Transponder navigation technology	Semi-automated operation	No details decided yet for this site	No details decided yet for this site
Vehicle Technology	Electric, 20 passengers, 20km/hr max	Zero-emission, 4 passengers	Electric, 8 passengers, platooning	No details decided yet for this site	Electric, 15 passengers, 10km/hr max
System Advantages	The AUTS application will increase network and link capacity through fleet management and platooning, provide more convenient public transport, high system flexibility and lower initial implementation and system operating costs				
Availability of Funding	Financial partnership with authority	Support depends on feasibility	Financial partnership with authority	No detail about funding known yet	Support depends on feasibility
Stakeholder Involvement	The mobility dept. leads the project	Currently low levels of involvement	Earlier project has led to high interest	Currently low levels of involvement	User needs analysis carried out
Authority Interest	High interest for a first trial period	Currently low levels of interest	Supportive but no funding available	Currently low levels of interest	Based on feasibility study

Table 3.3:Summary of AUTS Pilot Sites

3.3.3 Discussion

The reviewed systems included FROG, ROBOSOFT, RUF, SERPENTINE and ULTra. The main differences of the systems are, that RUF is a dual-mode system, that RUF and ULTra require a dedicated infrastructure and that the other systems can use the existing road network, based on route guidance and obstacle detection technology. The vehicles used also differ in size from individual to group transport, but not exceeding a maximum number of 20 seats, therefore not providing mass transport systems.

Advantages include low infrastructure/ implementation costs and increased convenience. Possible applications are feeder to public transport, historic city centres, and private sites. Various studies have been carried out, which have shown the need to explain the advantages and to educate the market. The systems are in different stages of development, some being operational, and some only with a test track. Application areas include an airport car park, a business park and a theme park.

The reviewed AUTS sites included Coimbra, Antibes, Lausanne-Crissier, Nancy and Rome, covering various application areas, e.g. city centre, re-development area, connection to an exhibition-centre and park&ride. On most sites various conventional public transport systems exist, but in most cases AUTS will not substitute these. The planning process for the sites is at different stages of seeking funding, determining the demand characteristics and carrying out the detailed system planning.

In most cases the use of fully automated shuttles is planned with the exception of a semi-automated system and a platooning system, where the first vehicle is driven manually and the other vehicle follow automated in Lausanne-Crissier. The anticipated advantages include increased network and link capacity, higher convenience for end-user, and lower implementation and operating costs. At this early stage of the planning process the funding still remains a problem for all sites due to a perceived high risk.

From the results of this state-of-the-art review it can be seen that in most cases the technology required for AUTS is mature enough for targeted small-scale niche applications, but that the main barrier to a more widespread implementation is that local authorities feel that there is not yet sufficient proof of the system's reliability, economic efficiency and that the case for implementing AUTS is still unclear. Therefore further research into user (including decision makers) requirements is vital.

4 EX-ANTE USER NEEDS ANALYSIS

4.1 Introduction

4.1.1 Background

As described before, more targeted research into analysing the perception and requirements of all potential AUTS users is required in order to overcome the initial barriers of deployment of these very innovative and advanced systems and technologies. Based on the results from this analysis system characteristics and operating conditions can be further specified in order to meet the identified user requirements. Furthermore strategies for market education should be developed.

Therefore user perceptions and requirements for AUTS have to be analysed as part of a successful wide-spread implementation of the technology. In the case of this analysis, qualitative market research was chosen as a first step, as because AUTS is a very innovative technology, most of the users do not have any direct experience with or even any basic knowledge of. Analysis activities chosen for this qualitative market research include focus groups and structured interviews to be used according to the different AUTS user group characteristics identified.

A first step for this analysis is to determine the range of user groups involved in implementing, operating, using, and being affected by AUTS. The different market research activities were then aimed at covering all these main user groups in order to gain a representative picture of user perceptions and requirements. Different market research techniques were then used for the different AUTS user groups identified, e.g. group discussions with members of the public (system end-user) and interviews with experts representing the other main user groups.

Following this first qualitative analysis of user requirements and perceptions, in a later stage of this research a quantitative analysis has been carried out in conjunction with a small-scale public demonstration of the AUTS concept. Thus the direct experience with the system the respondents had enabled a more quantitative analysis of their perceptions. In addition to allowing a statistical quantitative analysis, the data collected has also been used to study changes in perception when comparing the ex-ante and following the ex-post user needs analyses.

AUTS User Groups

In the context of implementing, operating and using AUTS the following three general user groups were identified, which consist of further sub-groups.

- Decision-maker: Decide over implementation of AUTS
- Operator: Operate/ provide services for AUTS
- End-user: use or are affected by AUTS

This is the case for all public applications, but in the special case of a private application, although there is also a decision-making body and a system operator, they are part of the same institution. According to this the site classification will distinguish between public and private applications leading to four main user groups.

AUTS User Groups			
End-user	Potential User	Special Needs	Elderly, Disabled Motorists Cyclists PT User
		General Needs	
	Non-user	Residents Shops& Businesses Other Road Users	
Decision maker (Public)	Non-elected	National Level Regional Level Local Level	
	Elected	National Level Regional Level Local Level	
Operator (Public)	Public Transport Operator General Service Provider		
Decision maker& Operator (Private)	Airport, Theme Park, Large Businesses, University Campus, etc.		

Table 4.1:AUTS User Groups

AUTS Application Areas

As mentioned above, the site and application categories relate to the user groups. Therefore, according to the user groups identified, there should be a distinction on the highest level between the following two applications.

- Public Application: Decision-maker, Operator and End-user
- Private Application: Decision-maker/ Operator combined and End-user

Based on this, the following matrix of site and application categories was defined for the analysis of user needs and perceptions for AUTS.

AUTS Application Areas			
Area Characteristics		User Characteristics	
Public/ Private	Location/ Size	General/ Special	Targeted User
Public Application	Citywide		
	City Centre	General User	
		Special User	Tourists Business Etc.
	Periphery	General User	
		Special User	Business Shopping Etc.
Private Application	Airport Theme Park Large Business University Campus Etc.		

Table 4.2:AUTS Application Areas

4.1.2 Objectives

The key objectives of this analysis are to analyse the perceptions and requirements of all AUTS users. This user needs analysis has been based on the generic concept as developed in the first step of the analysis process. Both the small-scale as well as the network-wide system have to be designed to meet the needs of the user, whilst achieving more sustainable urban mobility, thus being a real improvement to existing public transport and a real alternative to the private car. Furthermore any further analysis of AUTS has to be based on broad public acceptance of the proposed technology.

A focus group is a market research tool for obtaining qualitative responses on perception and requirements of targeted consumers (in this case the end-user of AUTS) for a given product (in this case AUTS). For the purpose of this analysis, a focus group has been defined as a moderated group discussion with 6-12 participants, lasting for 90-120min. When planning focus group activities, the group participant characteristics, the stimulus material (presentation material used to introduce the topic of the discussion the group participants) and the topic guide have to be specified.

After having specified the target group for the focus group all possible characteristics (e.g. age group, gender, social background, etc.) had to be considered to get a representative response. A presentation was developed to introduce the topic of the discussion to the group participants. This material had to be objective, to prevent biasing the group and their responses. A topic guide had to be developed to specify the timings for the use of the stimulus material, the moderation techniques to be used and the important topics to be covered in the discussion.

The focus group technique was used to obtain responses on user perceptions and requirements for AUTS from the user group end-user, as this is the user group which has the least knowledge of AUTS and transport policy and wider sustainability issues. This technique was only used for this user group, as for all other user groups structured interviews were assumed to be a more suitable technique. According to the framework of AUTS user groups and application areas, as mentioned above the user group end-user can be split up into a number of further sub-groups.

End users were defined within the framework as being either potential system users or non-users affected by AUTS. A system user can be either a user with general or special needs. A non-user can be e.g. residents or shops and businesses close to AUTS. They might be affected by the system in a positive or a negative way. The focus groups activities only consider the system user/ non-user with general needs

After having covered the user group end-user for the analysis on user needs and perceptions for AUTS by using the focus group technique, for all remaining user groups and their respective sub-groups, structured interviews with selected representatives of interest group, authorities on various levels, institutions, companies (e.g. public transport operator or service provider), etc. were carried out.

As the focus groups activities only considered the end user with general needs, structured interviews were used to obtain responses from end user/ non-user with special needs. The structured interview approach was used for all these user groups and sub-groups, according to the common agreement, that the focus group technique is only suitable for covering responses from the end-user with general needs.

It was assumed that a free conversation with only a topic checklist to make sure that all important topics are covered in the conversation is preferable to the use of a questionnaire in meeting the objectives to obtain response on the general perception and on specific user requirements for AUTS by all user groups involved in the process of using, operating or deciding over the implementation of AUTS.

Therefore a topic checklist had to be developed, specifying all the important topics to be covered in the conversation in general terms for all user groups involved and possible specific issues for interviews with specific user groups or sub-groups. Furthermore presentation material had to be used to introduce the topic of the interview, the concept and possible applications of AUTS, to the interviewees.

4.1.3 Methodology

Focus Groups

For the group recruitment three participants characteristics categories were considered, age, gender and car-ownership. Within these categories further sub-categories were defined: three different age groups (20-35, 35-50, 50-65), male, female and mixed gender group and car-owners, non car-owners and group with mixed car-ownership. The recruitment of participants for the group was supposed to cover all characteristics within all focus groups carried out in each country.

The stimulus material used in the focus groups to present AUTS as the topic for the group discussion contained 14 slides to be printed on A3 boards (see Annex C) for the moderation. The material consisted of three sections: existing AUTS related systems, the short-term scenario, and the long-term scenario.

The aim of the section 'Existing AUTS related Systems' was to show that AUTS technology is not something futuristic, that the technology is available and that AUTS related systems are already implemented. The material contained descriptions, illustrations and videos for the Schiphol and Rivium systems

The objective of the section 'Short-term Scenario' was to describe what level of technology is possible in three years time, as a basis for the discussion on user requirements for this scenario. The material contained descriptions and illustrations for the Rivium extension and the Copenhagen test site

The intention of the section 'Long-term Scenario' was to describe the level of technology envisaged for the long-term, as a basis for the discussion on user requirements for this scenario. The material consisted of written description of the vision (demand-responsive, door-to-door) and a video of the RUF system as an example.

The topic guide specified the structure of the discussion, the moderation techniques to be used for the investigation of user needs and perceptions for AUTS in view of the short-term and the long-term scenario and the topics to be covered in the group discussion. In the following these parts of the topic guide are explained in more detail.

The discussion consisted of three stages. The group discussion started with a warm-up and introduction, where the moderator and all group participants introduce themselves. The next stage was a free discussion about experience with the existing urban transport system, slowly leading to the main theme of the discussion. The last stage consisted of the presentation of the stimulus material, with free discussions on each part of the material, where the moderator makes sure that all topics specified in the topic guide are covered in the discussion.

For the discussion on general urban transport issues and on the short-term scenario no special moderation techniques were used. For the long-term scenario, where responses had to be more imaginative, special techniques were used in addition to a free discussion. Participants were given a map of an imaginary city and were asked to indicate a possible AUTS network (single connection, single line and real network) and necessary facilities (e.g. depot, maintenance, parking, etc.) on it.

Although the discussion in the focus group was supposed to be as freely flowing as possible, the moderator had to make sure, that certain important topics were covered. These topics included general issues and location-related issues for the present urban transport situation and general issues, operation issues and possible applications of AUTS systems in view of the short-term and the long-term scenario. The operation issues were split up into system, vehicle, safety, security, access, payment and system/ vehicle features.

After developing a common procedure for planning and carrying out the focus groups, to ensure comparable results of all focus groups done by partners involved in this activity, a common structure for organising the results, reporting and analysing them was developed. This structure was based on the topics to be covered developed for the focus group topic guide. All focus groups results were analysed using this structure.

The analysis of user requirements and perception could only be carried out by drawing together all results achieved by partners as being representative for the targeted user group end-user. An analysis of results for each characteristic within the user group end-user (age, gender, car-ownership) or an analysis for each country in which focus groups were carried out by partners is not possible, as more groups would have to be carried out to obtain representative results on this level.

The focus group activities were aimed at covering all user characteristics, that were established and all countries involved in the project to get results, which are representative for the user group end-user on an European level. The following figure shows the analysis framework used to draw together all focus group results for the analysis of user requirements for AUTS.

Focus Group Analysis Framework		
Present urban transport issues	General issues	
	Location-related issues	
User perception/ requirements for the short-term scenario	General issues	
	Operation Issues	System Vehicle Safety Security Access Payment Features
	Possible applications	
User perception/ requirements for the long-term scenario	General issues	
	Operational Issues	System Vehicle Safety Security Access Payment Features
	Possible applications	
Additional issues		
Issues relating to user characteristics		

Table 4.3:Analysis Framework for Focus Groups

Structured Interviews

A topic checklist was developed to specify topics to be covered in the interview. It includes lists of topics for three different main user characteristics, which were identified to require different approaches, authorities, interest groups and operator/ service provider. The following table shows the topics to be covered for each of the respective main user characteristics.

Authorities	Interest Groups	Operator/ Service Provider
Comment/ views on AUTS	Comment/ views on AUTS	Comment/ views on AUTS
- Would they support it?	- Can they meet their special needs?	- Would they consider use of AUTS?
- Supported by decision-maker?	- More suitable than current systems?	- Potential application for AUTS?
Main Transport Problems	Main Problems with current Systems	Current Transport Problems
- Description of problems	- Relating to system	- Description of problems
- Could AUTS be a solution?	- Relating to vehicle	- Could AUTS be a solution?
What Systems currently in Use	- Relating to infrastructure	What Systems currently in Use
- Description of systems	- Relating to operation	- Description of systems
- Why have they chosen it?	-Relating to information systems	- What alternatives were available?
- What initial/ current problems?	- Could AUTS be a solution?	- Why have they chosen it?
- What land-use implications?	What Requirements for AUTS	- What initial/ current problems?
Plans for future Systems	- For safety and security	Plans for future Systems
- Description of plans	- For accessibility and availability	- Description of plans
- Would they implement AUTS?	- For comfort and convenience	- Would they implement AUTS?
- What land-use implications?	- For booking and information systems	- For which application?
- Which criteria for decision?	- Additional topics/ issues?	- Which criteria for decision?

Table 4.4:Topic List for Structured Interviews

The material used for the structured interviews to present the AUTS concept as a basis for the interview, was the same as used for the focus groups (consisting of slides with text and illustration and short video clips, showing existing AUTS related systems, the short-term scenario and the long-term scenario), for a consistency between procedures, leading to comparable results.

After developing a common procedure for planning and carrying out the structured interviews, to ensure comparable results of all structured interviews carried out by partners involved in this activity, a common structure for organising the results, reporting and analysing them was developed. This structure was based on the topic guide developed for carrying out the interviews.

The analysis structure contained an analysis of responses under the following four headings.

- Awareness of AUTS Technology
- Comments/ Views on AUTS Technology
- Current Problems in View of Transport
- Future Plans in View of Transport

The analysis has been carried out for these four issues with regard to each of the four main user groups covered: end-user, decision-maker (public application), operator (public application) and decision-maker/ operator combined (private application). The analysis will not be carried out on a lower level for the sub-groups as the number of interviews carried out in context of the user needs analysis for AUTS is too small to allow a representative analysis on this level.

The sub-groups were established in order to ensure that all sub-groups expressing special views or requirements are covered, so that the final results give a complete picture for each of the four main user groups. In addition to this analysis of the results of the interview there has also been an analysis of the results of the questionnaires on the importance of given criteria for the decision on AUTS.

Analysis Activities

- Focus Groups

A total of 23 focus groups were carried out in 6 countries. All focus groups were carried out and analysed according to a common and agreed structure for comparable results. The following table shows the number of focus groups carried out in each country.

Distribution of Focus Groups	
Country	No. of Focus Groups
Italy	6
France	2
Portugal	4
Netherlands	4
UK	4
Israel	3
Σ	23

Table 4.5:Distribution of Focus Groups

- Structured Interviews

In the context of the formal interviews as part of the structured interview activities 27 interviews have been carried out in 6 countries. The following table shows the number of formal interviews carried out in each country, separated for user groups covered.

Distribution of Structured Interviews				
Country	Number of Structured Interviews per User-group			
	End-user	Decision-maker	Operator	Decision-Maker/Operator
Switzerland	1	1	2	-
Italy	-	1	2	-
France	-	1	-	-
Netherlands	2	1	3	1
UK	1	4	-	1
Israel	3	2	-	1
Σ	7	10	7	3
	27			

Table 4.6:Distribution of Structured Interviews

4.2 Analysis

4.2.1 Results from Focus Groups

Current Urban Transport Issues

The general issues, which were nearly uniformly mentioned in all focus groups in all countries related to the road network, private car usage and public transport. The existing road network was described as badly maintained, highly congested in peak hours and providing an insufficient number of parking spaces.

The private car was perceived as being convenient, as a way of expressing ones personality and as a status symbol, although it was acknowledged, that driving in cities can be a stressful experience, that it results in higher costs compared to using public transport, that parking is often very complicated and that private car usage results in environmental problems, like pollution or noise – though in most cases this does not influence their mode choice.

The public transport system in general was described negatively, mentioning unreliability, inflexibility, low service frequency, overcrowding, use of old vehicles, quality and cleanliness of the interior, insufficient co-ordination of modes and services, lack of information, transfers leading to additional waiting times and network design not meeting user needs and demand.

When going into more detail about specific modes buses are described as the cheapest mode, but also the one providing the lowest quality. Underground is rated higher, because of a high service frequency, fast connections, but the high construction costs as a drawback for a new implementation is also noted.

Trains were also rated higher, but being more suitable for long-distance trips, but quality of service relies on sufficient provision of travel information and there is concern about personal safety when travelling late at night. Taxi was described as the most convenient, especially when transporting luggage, but also the most expensive public transport mode. Walking and cycling was also mentioned, but not always being practical for all trips. When cycling is to be encouraged, then the provision of dedicated cycle lanes is crucial.

Specific location related issues were mentioned in the focus groups for the cities of Antibes (France), Amersfoort (the Netherlands), Southampton (UK) and Haifa (Israel). In Antibes the cape situation of the historical city centre and the difference in demand between low and high season result in problems for parking, general traffic and public transport.

The general trend is to restrict the use of private vehicles. Parking is a big problem, as public space is very rare and is for 120 days a year used for various events (markets, exhibitions, concerts, etc.), so that city centre parking spaces are occupied without any replacement solution for a third of the year.

There are unused parking spaces at a distance of 1 km from the city centre. In Amersfoort traffic is described as illogical, chaotic, busy and dangerous. A new ring road, bus lanes into the city centre and a car-free city centre has improved urban traffic conditions, but not sufficiently.

In Southampton the traffic situation in the city centre is describes as very problematic, because of high level of congestion, due to a new pedestrian area and major developments (e.g. shopping centre). In Haifa there are specific transport problems in context of the Technion campus. There are parking problems, because of limited car access to the campus and remote parking spaces, leading to long walking distances to university facilities – especially problematic due to the hilly topography of the campus.

The Short-term Scenario

Low vehicle speeds were perceived as positive and as negative, positive as contributing to safety and negative in terms of travel time. There were concerns of not being in control in case of using automated transport systems, although technology was perceived to be safer than manual operation. Even if a driver is not needed for the vehicle operation, he also provides a reassuring presence for passengers, leading to concern about personal safety. There were doubts on the feasibility of operating AUTS mixed with car traffic or pedestrians.

The benefits of AUTS were not obvious enough, though the environmental benefits of using a zero emission vehicle were acknowledged. There were mixed reaction towards AUTS complementing or replacing existing public transport systems. There were also worries about AUTS leading to unemployment in the community and about the very high costs for implementing AUTS. The conflict between a system targeting the decrease of walking distance and the personal health benefits of walking was also mentioned.

AUTS was perceived as being only suitable for very short distances for a targeted application and on a dedicated lane or using an elevated structure, to prevent mixing with car traffic and pedestrians. There was also concern about insufficient space in urban areas for the provision of dedicated lanes or elevated structures. Furthermore the vehicle speed seems too low for efficient operation.

AUTS has to provide a high level of flexibility, to be able to adapt to changing patterns of demand. High service frequency or on-demand operation is important. The system has to be fine-tuned in terms of short waiting times, short distances between stops and careful network design (network solution better than lines).

Vehicles should be ordered using mobile phones and the waiting time for the vehicle should not exceed 5min. There was concern about overcrowding of vehicles, and the solutions proposed were either individual vehicle or access control systems. There is a conflict between the system being child proof in case of misuse, but also being usable by children to prevent the system from being socially-exclusive.

The vehicle size should depend on application demand characteristics (e.g. individual, small groups, mass transport). The use of environmentally friendly vehicles (e.g. zero emission and low noise levels through electric operation) is important. For safety reasons the vehicles should not allow speeds exceeding 80 km/hr.

The vehicle should be comfortable, be highly visible and provide space for wheelchairs, pushchairs, luggage or bulky items. Seating for passengers is necessary, especially for elderly users. In terms of the appearance, the vehicles should look like mini-vans or existing shuttles, avoiding unusual shapes or forms. In the case of a public application the vehicle interior has to be vandalism proof.

Depending on the location of the system heating and air-condition is also important. The vehicle has to be clean, e.g. through monitoring of cleanliness and possibly cleaning between trips. There is concern about the engine of the vehicles being able to cope with a hilly topography in terms of necessary acceleration.

There was concern about traffic safety when mixing AUTS vehicles with car traffic or pedestrians. AUTS vehicle must have a proven higher level of traffic safety than existing manually operated transport systems. In emergency situations a manual system override function, emergency stop or a door-opening device has to be available.

But it was also acknowledged that the safety perception might change with a growing experience with automated systems. For safety reasons all passengers have to sit in the vehicle, possibly also wearing safety belts. There were also worries about safety issues when using an elevated structure (e.g. monorail). An alternative manually operated system has to be available for cases of system breakdown of the automated system.

There was much concern about personal security in the vehicle, especially at night and when sharing it with others. Therefore there should be a CCTV system and phone link to a staffed operations centre for emergencies, assaults or vandalism for crime prevention, proof and notification for emergency services. In cases of emergency the vehicle should automatically be directed to a hospital in the case of medical emergencies. Bigger vehicles, high level of transparency and doors only on one side of the vehicle can also create a safer environment.

The topic 'Access' can be interpreted as access to the vehicle or to AUTS in general. In the case of access to the vehicles, low-floor vehicles with large sliding doors and ramp should be used to facilitate the access, especially for elderly, disabled, wheelchair, pushchair and transporting luggage or bulky items.

An access control system should be used to avoid overcrowding of the vehicles. In the case of access to AUTS, integration of AUTS with all other modes of the existing multi-modal urban public transport system is important to ensure access by all parts of the population to make the system socially-inclusive.

In some groups it was assumed that use of these systems would be free, as the systems were mainly envisaged to be used for private applications, where the payment would be hidden in other fees (e.g. parking or theme park). Suggestion for methods of payment included conventional public transport tickets, individual ticket, season tickets and tokens.

The ticket for AUTS should be integrated with all other modes/ services/ operators of public transport systems in the region and parking. The actual transaction was envisaged using credit cards or SmartCard technology, but cash payment in case of infrequent users has to be possible. But in view of the driverless aspect there was also concern about abusing the system. In terms of cost of the ticket, it was stated that it should not exceed tariffs usual for other public transport modes.

Features foreseen for the vehicles included on-board multi-media systems as the human machine interface to operate the vehicle, for travel information, route planning and showing vehicle location and next stops. There should be entertainment/ information devices for passengers, e.g. Internet access, music and video systems.

A system producing warning noises when approaching an obstacle, as well as a system for recharging batteries on downhill sections were also envisaged. In case of group travel there should be swivel chairs in order to make the space inside the vehicle more comfortable and user friendly.

Most possible applications mentioned are very limited and in contained areas, reflecting the concern about using AUTS in connection with car traffic and pedestrians. The envisaged applications include airport, stadium, PT in suburbs, historic city centre, business park, shopping centre, theme park, P&R, feeder to PT, campus and freight.

The Long-term Scenario

There was much concern about the use of AUTS as an individual transport system because it could lead to replacing car congestion by 'AUTS congestion' and there might be insufficient space for the operation of AUTS and for facilities (e.g. parking), due to existing levels of traffic and congestion. Therefore implementation would only be possible if general traffic would be restricted.

To make the system successful it would need to be implemented on governmental level and standardisation would also be crucial, to be able to connect systems. There was concern about visual intrusion in the case of using elevated structures (e.g. monorail). For some participants the benefits of such a system were not clear enough (e.g. similar to a bus-way network, only without drivers).

The system is perceived as a solution between a taxi and a mini-shuttle. It is considered to be suitable only for specific applications, but there is also concern about the cost for using the system, as it is envisaged as being more expensive then an ordinary taxi and having the additional disadvantage of not being picked up at the trip origin.

There were mixed opinions about the end-user characteristics targeted by the system, including only business travel or commuting. Also the perceived costs for implementing the system were judged to be too high for an economically efficient operation. In terms of system operation, it was envisaged, that the vehicles will be located on a central base, called using mobile phones and then the vehicles will park automatically. For some participants the technology seemed too futuristic.

There have to be clear benefits compared to existing modes of public transport or the private car, especially in view of cost for using the system and vehicle speed. The fare for using a demand-responsive door-to-door system should not exceed fuel cost for using the private car for a comparable trip.

The vehicles have to be faster then ordinary transport modes (e.g. bus). In the case of privately owned vehicles (as presented in the RUF-video) choice is very important. This includes vehicle size, special features and the ability to express ones personality, showing that a transport system can only be a real alternative to the private car, if it provides most or all of the advantages of the private car. The vehicles also have to provide a good quality of journey and a smooth and quiet ride.

Additional issues raised in context of the long-term scenario compared to the short-term scenario include concerns about traffic safety issues in view of using an elevated structure (e.g. monorail). This included the automatic guidance from the road network to a monorail access point and problems of leaving the vehicle or infrastructure in cases of accidents or emergencies.

Furthermore the participants repeated the issues relating to vehicle and system access and social-inclusion as described above. This included convenient access for elderly, disabled, wheelchairs and pushchairs using low-floor vehicles and ramps and the system being as social-inclusive as possible through integration with public transport.

In addition it was found that it might be acceptable, though personal transport is favoured, to share a vehicle with others, if this would decrease the fare. A number of possible applications for AUTS in view of the long-term scenario were mentioned, including inter-urban traffic, using high-speed rail links, historic city centres, feeder to existing public transport services and connection to suburbs.

Additional Results/ Issues

Respondents, who own or use a car, look at AUTS from a different perspective, AUTS has to meet higher standards to be considered an attractive alternative. Cyclists think that they have taken an important step with respect to an environmentally friendly approach to transport and will have to be convinced by more compelling arguments than the motorist who is not only confronted with problems in accessibility and parking, but is also aware that he is not the most ecologically sound or socially conscious road user.

For the youngest members of the focus groups, AUTS also seems to have an image problem. The age group 50-65 is more concerned with cost and difficulties in implementing AUTS and is very environmentally aware. The age group 35-40 is more worried about the concept and the technology. The age group 20-35 has the least concern about the technology, but safety and security is very important. They have a very low expectation of governmental support for AUTS.

4.2.2 Results from Interviews

Awareness of AUTS Technology

The replies on the awareness of AUTS technology, after having seen the presentation, were mixed. Some were aware of certain systems (Schiphol and/ or Rivium), especially interviewees in the Netherlands for obvious reasons and representative of authorities or companies who work in transport related areas and therefore need to be aware of emerging technologies.

Most interviewees mentioned related systems, including airport people mover, LRT schemes, guide bus-ways or on-board, in-vehicle telematics systems (e.g. guidance and navigation systems, travel and traffic information systems, collision avoidance systems, autonomous driving, platooning, etc.).

Comments/ Views on AUTS Technology

The reaction of the interviewees representing the user group end-user was positive, acknowledging a high potential for AUTS for meeting their special needs. The use of this technology could enhance the mobility of disabled, provide a more convenient public transport system, targeting existing and potential public transport user, provide better access to facilities for motorists in case of remote parking and it could decrease congestion in city centres, leading to better and more convenient access to shops and businesses.

There was a general confidence in the technology. But there was also some concern about the success of AUTS in our 'private car society', the funding, the possibility to operate in mixed traffic with cars and/ or pedestrians and the general opinion was that the best solution would be a network-wide and demand-responsive door-to-door system.

The interviewees representing the user group decision-maker (public application) were more sceptical about the AUTS concept. They were able to see some potential of the technology for targeted applications, including feeder to other public transport modes or interchanges or historic city centres, but clearly favouring applications in more contained environments, including parking, airports and exhibitions.

There was concern about funding, mixed traffic, user acceptance, experience and reliability of the system. They tended to take a more holistic approach, questioning the added value of AUTS and the socio-economic impacts and where AUTS would fit into an overall transport planning and policy strategy.

The interviewees representing the user group operator (public application) were positive about the potential of AUTS technology, but they were doubtful, that the technology is sophisticated enough to be implemented economically efficiently. They expressed the view that the implementation and operation of AUTS would be a high risk for them as private companies due to the lack of experience with the technology.

The interviewees representing the user group decision-maker/ operator combined (private application) were very positive about the potential of AUTS technology for tackling site-specific freight and passenger transport problems. Main advantages were the lower operating costs, as compared to manually driven systems (e.g. shuttle-bus), due to no labour costs for the vehicle operation.

In the special case of the use of AUTS for an airport, it would be more useful for departure (trickle-feed), then for arrival (peak demand). Potential application included connection from the main terminal building to parking, hotels, conference centre and public transport interchange, ideally leading to a remote vehicle access point separated from the terminals to leave vehicle out of the main airport area.

Current Transport Problems

The problems mentioned by the user group end-user were mainly in view of existing public transport system, which do not provide sufficient access to individual vehicles or the system in general, which is not flexible enough (e.g. point-to-point not door-to-door or rigid schedules not on-demand) and in view of problems with car usage in urban areas, including congestion, parking and pollution.

The problems mentioned by the user group decision-maker are mainly in view of the conflict between the low image of public transport and the 'private car society', the often-insufficient service provision of public transport and the negative effects of car usage, including congestion, pollution, parking problems and social exclusion.

The problems mentioned by the user group operator (public application) include the implications of an ageing population, growth in demand for mobility, rigid public transport system, due to demand characteristics and political issues, the amount of labour costs involved (50% of the operational costs), that not enough parking spaces are provided for new developments and the level of congestion in urban areas.

The problems mentioned by the user group decision-maker/ operator combined are, that the location of building/ facilities/ attractions and the desire to restrict vehicle access, leading to remote parking areas results in long walking distances, possibly with adverse weather conditions and a steep topography and that public transport is insufficient for access to the site.

When providing means of transport there are concerns, especially about the labour costs involved and the costs for the provision of vehicles to cater for peak demand, which are unused in off-peak periods.

Future Plans for Transport

End-users felt, that in view of future development, there should be more emphasis on walking and cycling, a strong increase in comfort and convenience of public transport services and improvement of the road network in terms of road maintenance and capacity. AUTS might be a solution for improving public transport as feeder applications, but there is concern about funding.

Future plans of decision-makers included provision of new public transport service (e.g. LRT schemes), P&R schemes, work travel plans, integrated transport policy initiatives, provision of real-time public transport information, use of SmartCard technology, extension of pedestrian areas to encourage the use of alternatives to the private car, to tackle negative effects, as congestion, pollution and social exclusion.

AUTS could be envisaged as providing solutions in context of these plans, e.g. as feeder to public transport, shuttle for connection between P&R and city centre and use in pedestrian areas where other vehicles are restricted.

Future plans of operators envisaging the use of AUTS included feeder applications to existing public transport modes/ services or interchanges in public applications or when operating the system on a private site (e.g. hospital, university, market, parking or exhibition) as the sole mode of transport and to cover the 'last mile', which cannot be served by public transport. But AUTS need to be tested for safety and reliability.

Future plans of the combined decision-maker/ operator user group include the study of a new high-speed rail for access to a flower auction in the Netherlands from Amsterdam Airport Schiphol (potential use of AUTS for connections), a new airport people mover system in connection with the extension of the London/ Heathrow airport (no potential for AUTS, due to good experience and low costs of existing automated people movers), a new cable car to connect the Technion campus in Haifa to the bay area and the university (potential use of AUTS for connection on the campus) and a new transport system for a archaeological park in Israel with train, shuttle bus or AUTS as potential alternatives.

Additional Results/ Issues

Additional results included concern over finding political consensus for AUTS, the effects of the ageing population on travel demand characteristics, the ability of AUTS to cope with peak demand at major public transport interchanges, visual impact of elevated structures (e.g. monorail), the conflict between AUTS targeting the avoidance of walking and the benefits of walking, the necessity for a gradual introduction of AUTS technology for user acceptance and that after more and more systems get automated, there might be a renaissance of personal service provision – possibly at a very high price.

4.3 Conclusion

4.3.1 Summary

From the results of the state-of-the-art review it could be seen that in most cases the technology required for AUTS is mature enough for targeted small-scale niche applications, but that the main barrier to a more widespread implementation is that local authorities feel that there is not yet sufficient proof of the systems reliability, economic efficiency and that the case for implementing AUTS is still unclear. Therefore further research into user (including decision makers) requirements is vital.

The key objectives of this analysis were to analyse the perceptions and requirements of all AUTS users. This user needs analysis was based on the generic AUTS concept. Both the small-scale as well as the network-wide system have to be designed to meet the needs of the user, whilst achieving more sustainable urban mobility, thus being a real improvement to existing public transport and a real alternative to the private car. Furthermore any further analysis of AUTS has to be based on broad public acceptance.

In order to obtain user requirements and perception of all user groups involved in the use, implementation, operation, planning and decision-making process for AUTS on various levels focus groups and structured interviews were carried out. In the following the results of these market research activities for the user needs analysis are summarised. The focus group activities were targeted at investigating user requirements and perceptions from the user group end-user with general needs.

The group discussion aimed at gaining responses on current urban transport issues and on AUTS, distinguishing between the short-term and the long-term scenario. The short-term scenario was closely related to the small-scale demo sites and what technology level is possible in a time-span of approximately three years. The long-term scenario gave an outlook to what might be possible in thirty years time, realising the overall AUTS concept of individual, on-demand, door-to-door transport.

4.3.2 Key Findings

In the following the key findings of the analysis of the market research activities for the user needs analysis for AUTS are summarised. Table 4.7 shows the results of the structured interviews, and table 4.8 shows the results of the focus groups.

Issues	User Groups			
	End-user	Decision-maker	Operator	Decision-maker & Operator
Awareness of CTS Technology	Mixed, especially interviewees in the Netherlands and interviewees working in very transport related areas were aware of existing and closely related systems. Systems mentioned included airport people mover, LRT schemes, guided bus-ways and on-board in-vehicle telematics systems (e.g. guidance, collision avoidance, autonomous driving, etc.)			
Comment on CTS Technology	Potential for meeting special needs Provide convenient access to facilities Concern about AUTS in private car society Concern about AUTS in mixed traffic	Potential for targeted applications only Favouring application in contained area Concern about AUTS in mixed traffic, user acceptance, funding, experience with and reliability of CTS	Doubtful about level of technology for economic operation Implementing AUTS would be a risk for them without more experience with the technology	Potential for site-specific problems Main advantage of AUTS is the lower labour costs
Current Transport Problems	Existing PT system (access, flexibility) Private car usage (congestion, parking and pollution)	Conflict between the private car society, low image of PT, insufficient PT service and negative effects of car usage	Implications of ageing population on demand Growth in desire for mobility Parking, congestion, rigid PT network	Location of buildings, facilities and desire to restrict car access, result in long walking distances Concern about labour cost for shuttle
Future Transport Plans	More emphasis on walking/ cycling PT more convenient and comfortable Improve road network maintenance/ capacity AUTS potential as a feeder to PT Concerned about the funding for AUTS	New and improved PT services Park&Ride schemes Integrated transport policy Real-time PT info Use of SmartCard for PT integration AUTS potential as a feeder to PT, shuttle for connection to P&R	AUTS needs to be tested for reliability and safety AUTS potential as a feeder to PT for public applications and as the sole mode for private application	Upgrade to a high-speed rail link for a flower auction in the Netherlands A new airport people mover system for the planned extension of the London/ Heathrow airport. A new cable-car solution for transport in Haifa Plans for a shuttle service for an archaeological park in Israel
Additional Results	Concern over finding political consensus for the implementation of AUTS, the effects of an ageing population on travel demand patterns, the ability of AUTS to cope with peak demand, the conflict between AUTS trying to avoid walking and the benefits of walking, the necessity of a gradual introduction of AUTS for user acceptance and a possible renaissance of personal service.			

Table 4.7:Summary of Structured Interview Results

Topic Category			Summary of Results
Present urban transport issues	General issues		Badly maintained and highly congested road network Car convenient, express personality and status symbol *Environment issue of cars do no influence mode choice* Unreliable, inflexible and overcrowded PT system Walking and cycling problematic in urban areas
	Location-related issues		Problems with parking reserved for events (Antibes) Illogical, chaotic, busy dangerous network (Amersfoort) Congestion increased by new development (Southampton) Parking and access problems on campus (Haifa)
User perception/ requirements for the short-term scenario	General Perception		Positive and negative aspects of low speed Concern about losing the control over the system Trust in technology but not mixed with other traffic Concern about automation leading to unemployment Conflict of Health benefits of walking and CTS
	Operation Issues	System	Suitable for short distances and targeted applications Concern about insufficient space for separate tracks High service frequency or on-demand operation Short waiting times, careful network design Access control systems to prevent overcrowding Conflict of child-proof but social-inclusive system
		Vehicle	Vehicle size to depend on demand characteristics Use of environmentally friendly vehicles (e.g. ZEV) For safety reasons vehicle speeds to be below 80 km/hr Space for wheelchair, pushchair, luggage, bulky items Design like mini-van or existing shuttles Vandalism proof interior for public applications Heating, air-condition, clean interior, powerful engine
		Safety	Higher level of safety then manually driven systems Emergency stop, system override and door opening Passengers to be seated, wearing safety belts Alternative manual system for emergencies
		Security	Concern about personal security, especially at nights CCTV, phone links to staffed centre, transparency
		Access	Access to vehicles (low-floor, ramp, large sliding door) Access to system (integrated with PT, low costs)
		Payment	System for free or hidden cost for private applications Use of credit cards or SmartCard technology Alternative payment modalities for infrequent users
		Features	Multi-media systems for information and entertainment Swivel chairs for group travel, warning for obstacles
	Possible applications		Only using dedicated infrastructure in contained areas
User perception/ requirements for the long-term scenario	General issues		Concern about AUTS congestion and replacing the car Implementation on governmental level, standardisation
	Operation Issues	System	Concern about cost, who is targeted user, very futuristic
		Vehicle	Has to provide clear advantages compared to PT, car
		Safety	Concern about safety in case of elevated structures
		Security	Concern about personal security on elevated structures
		Access	→ See short-term scenario
		Payment	Sharing a vehicle acceptable if it decreases the fare
		Features	→ See short-term scenario
	Possible applications		Inter-urban traffic, high-speed rail-links, feeder to PT Historic city centres, connection to suburbs
Additional Results			AUTS to meet higher standards for car-owners Cyclists need more compelling arguments Image problems of AUTS for young age-group Mixed view on technology/ safety in view of age-groups

Table 4.8:Summary of Focus Group Results

4.3.3 Discussion

Responses on current problems regarding urban transport centred mainly on the conflicts between private cars and public transport. On one hand, the convenience but environmental impacts of using private cars and on the other hand, the environmental benefits but perceived (and too often real) inconveniences of using public transport.

The responses to the presentation of AUTS technology and possible applications were then able to show whether or not group participants representing the user group end-user could envisage AUTS to be an answer to one or more of these problems mentioned. This question was asked for the short-term, as well as for the long-term scenario presented for AUTS technology.

In view of the short-term scenario there was much concern about the possibility of mixing automated transport systems with manually driven vehicles, cyclists or pedestrians. Most participants trusted the technology available for automated operation and obstacle avoidance, but could not envisage efficient operation of AUTS in shared environments, but clearly favoured separated solutions with dedicated infrastructure or lanes.

In view of the long-term scenario the presented system seemed too unrealistic and/ or too futuristic. There was much concern about the funding and political consensus for the implementation of AUTS on a large scale. Even though group participants were very sceptical about the automated transport systems presented, they felt very confident about automated systems in cases of having personal experience, e.g. airport people mover.

This showed that perception can change dramatically with increasing personal experience and normality of AUTS. Furthermore the way in which AUTS and its added value is communicated to the targeted user group is crucial and will be an important factor deciding over success or failure of a AUTS initiative, which at this early stage of the development could be a large drawback.

The structured interview activities were targeted at all user groups and sub-groups not covered through the focus group activities, which focused on the end-user with general needs. Therefore the structured interviews aimed at investigating user requirements and perceptions of AUTS from end-user with special needs, decision-maker, operator, and decision-maker/ operator combined.

The responses on the awareness of AUTS were very mixed with interviewees from the Netherlands having used the Schiphol or Rivium system and interviewees, who are professionally involved with transport, being aware of this technology. Transport problems mentioned, as observed before in the focus group activities, concentrated on private car usage, the condition of the existing road network and the level of service of the public transport network. AUTS technology could be envisaged being a solution to some of these, but only being implemented in addition to existing modes.

All envisaged applications were in contained areas, using dedicated infrastructure or tracks. Operators were worried about the operational risk of implementing a technology, with which only little experience exists and decision makers were concerned about the added value of AUTS, of where AUTS would fit in into overall transport policy and of finding political consensus for a novel system. But generally the technology was still seen as not mature enough to be implemented without any risks yet.

The results from the structured interviews strengthened the impression that, despite a trust in technology, an automated system operating in a shared environment seemed too far from existing systems. This shows that when planning to implement AUTS, especially when trying it on a larger scale, a very strong case has to be built to present clear benefits and added value of the system to everyone involved in the process of decision-making, implementing, operating and using the an AUTS application.

These activities carried out in context with the user needs analysis for AUTS showed a discrepancy between responses on a theoretical subject and on opinions on systems people have personal experience with. Therefore the universally mentioned concern about AUTS in a shared environment has to be seen in context with the fact that a system like that does not exist yet, and therefore no group participant or interviewee having personal experience with it. This main issue could therefore change substantially with growing experience and exploitation of the technology.

Therefore the next step in this analysis has been to carry out an ex-post user needs analysis. In this analysis end-user perceptions and requirements for AUTS were analysed again after having used a small-scale demo application. This user needs analysis had more quantitative elements, using a stated preference questionnaire survey, analysing changes in perception after having used a system.

5 EX-POST USER NEEDS ANALYSIS

5.1 Introduction

5.1.1 Background

The ex-ante user needs analysis (see chapter 4) has shown a generally positive perception of AUTS by all key stakeholders. In that analysis only the general AUTS concept was presented to survey participants representing all potential user groups, who had no or only very little prior knowledge of these systems. Therefore qualitative survey techniques (focus groups/ structured interviews) were chosen.

The results from that analysis have given a first qualitative understanding of user requirements and perceptions. Based on this, as a next step to gain a deeper understanding of these issues, a more detailed quantitative survey (stated preference questionnaire) has been carried out with passengers who have used a small-scale AUTS application at one of the demonstration sites for these systems.

Therefore, based on this, the results from this quantitative ex-post analysis has provided additional results to the qualitative ex-ante user needs analysis (see chapter 4) and has also enabled a comparison between the perception of the vehicle/ system performance by passengers with the analysis of vehicle data and its comparisons with benchmark values from conventional public transport vehicles (see chapter 6).

This has enabled an analysis of differences in user requirements and perceptions of the general AUTS concept once end-users have used the system. Furthermore the level of satisfaction with vehicle performance parameters (e.g. speed, acceleration, deceleration, jerk, etc.) and system performance parameters (e.g. user interface, waiting times, traffic safety, personal security, etc) were analysed in detail.

In the following the objectives and the more detailed methodology used in order to meet the aims and objectives as stated above is described, including the planning of the survey, the questionnaire design and a description of the survey sites and the AUTS applications in operation there. This is then followed by the analysis of the questionnaire survey data and the conclusions to be drawn from it.

5.1.2 Objectives

The key objectives of this analysis were to analyse the user perceptions of a specific AUTS application and how survey participants transfer their experiences to envisaging different uses of similar systems in other areas. The perception of specific vehicle and system operating characteristics (for a full list of parameters to be analysed see the methodology section) was to be investigated. Similar questions as in the ex-ante user needs analysis were to be asked, but in a more specific way by giving ratings for it, which is possible now, as the survey participants had direct experience with the technology. Based on these changes of the attitudes of users toward AUTS (for the demo site and generally) after they have used the system can be analysed.

5.1.3 Methodology

Planning of Survey

At the two end-user survey sites (for a detailed description see below) the AUTS concept was demonstrated to the general public. In both cases the system applications did not provide public transport, but only demonstrated the concept. Both sites were operational for the duration of two weeks. Questionnaires ware handed out to passengers having used the system. This quantitative stated- preference questionnaire survey of ex-post end-user perceptions and requirements was carried out at two sites in Antibes and Coimbra. The main characteristics of both sites was the implementation of a small-scale AUTS application with one or more fully automated vehicles on a simple track open to the general public and operated for a short period of time.

Questionnaire Design

The survey was designed to address perception of technology issues (for the questionnaire see Annex F and G). The questionnaire consisted of three main sections, social background, the AUTS concept, and detailed system performance. Performance parameters included acceleration, deceleration, jerk, speed, travel time, personal security, traffic safety, and human-machine interface. The questionnaire survey has covered issues relating to the perception of the AUTS concept in general and the system performance in more detail. Furthermore in order to be able to analyse possible connection between certain survey participants' characteristics and trends in rating for specific questions, the questionnaire contained a section on social background.

The questionnaire used at the two sites (a small number of questions were different in the two questionnaire versions due to different system characteristics, e.g. at the Antibes site only one vehicle was in operation, whereas at the Coimbra site a small fleet of vehicles has been used, thus allowing questions relating to platooning) included the following issues, grouped under the three main headings as described above:

- Survey Participants Characteristics
  - Gender
  - Age Group
  - Car-Ownership
  - Travel Mode
  - Employment Status
- Vehicle/ System Performance
  - General Vehicle Performance
    - Acceleration and deceleration on straight line
    - Acceleration and deceleration in curves
    - Vehicle coming to a halt at station
    - Appropriateness of overall travel time
    - Appropriateness of vehicle speeds
    - Stopping accuracy vehicle at station
    - Length of waiting time after requesting a vehicle
    - Perception of vehicle noise (only Antibes site)
    - Perception of headway safety (only Coimbra site)
    - Perception of headway speed (only Coimbra site)
    - Usability of in-vehicle human machine interface
  - General System Performance
    - General ease of use of system and technology
    - Perception of personal safety in vehicle
    - Perception of traffic safety of system
    - Overall level of comfort of ride
  - Emergency Stop Performance
    - Emergency stop perceived as necessary
    - Deceleration due to emergency stop
    - Vehicle coming to a halt after emergency stop
  - Obstacle Detection Performance
    - Deceleration due to obstacle detection
    - Vehicle coming to a halt after obstacle detection
    - Traffic safety perception for obstacle detection
- General CTS System/ Application
  - Usefulness of CTS in general
  - Usefulness of CTS for application
  - CTS concept summary statement

Site Description

- Antibes:

The city of Antibes Juan les Pins is located on the French Riviera, in the south of France. The population of Antibes is 73 000, with a density of 2 780 h/km^2, and it doubles in summer months. The specific geographic configuration of Antibes is perceived by the local authorities as a constraint in terms of accessibility and traffic. P&R is being considered but the frequency and connections of public transport are insufficient and the vehicles are considered inadequate, particularly in the historical city centre.

The political desire to revamp the public spaces and improve the quality of life in the city centre is a good opportunity for AUTS. The local authorities include the following in their planning: define historical centre as a pedestrian area connected to the suburbs by urban shuttles, create multimodal platforms, create a better public transport service with dedicated lanes, build new railway lanes to improve the accessibility to the centre and the connection with the main cities, enlarge the public transport offer in terms of frequency, comfort, connections.

This strategy requires finding innovative and complementary solutions to Public Transport and AUTS, including automated people mover or car-pooling or -sharing, are seen as a way to introduce new mobility management. The experiment could be a pretext to suppress roadside parking. The demand is concentrated on the parking management located near the Porte Marine. The Fort Carré carpark with 1 000 parking spaces is not used much since the distance between these two points (1.5km) is considered excessive. The main characteristic expected to be demonstrated is the flexibility for system capacity and operating periods.

The demo site was at the marina and consisted of a single loop of ~800m length, with three stops for passengers to board. The operation was carried out using the FROG second generation vehicle developed for the Rivium II system near Rotterdam to be opened in the summer of 2005. Vehicle control and navigation was based on a combination of electro magnetic markers in the road surface and GPS/ digital map. The demo was operated for a duration of three weeks in June 2004, it was open to the public and was used by ~3000 passengers. See figure 5.1 for photos and map.

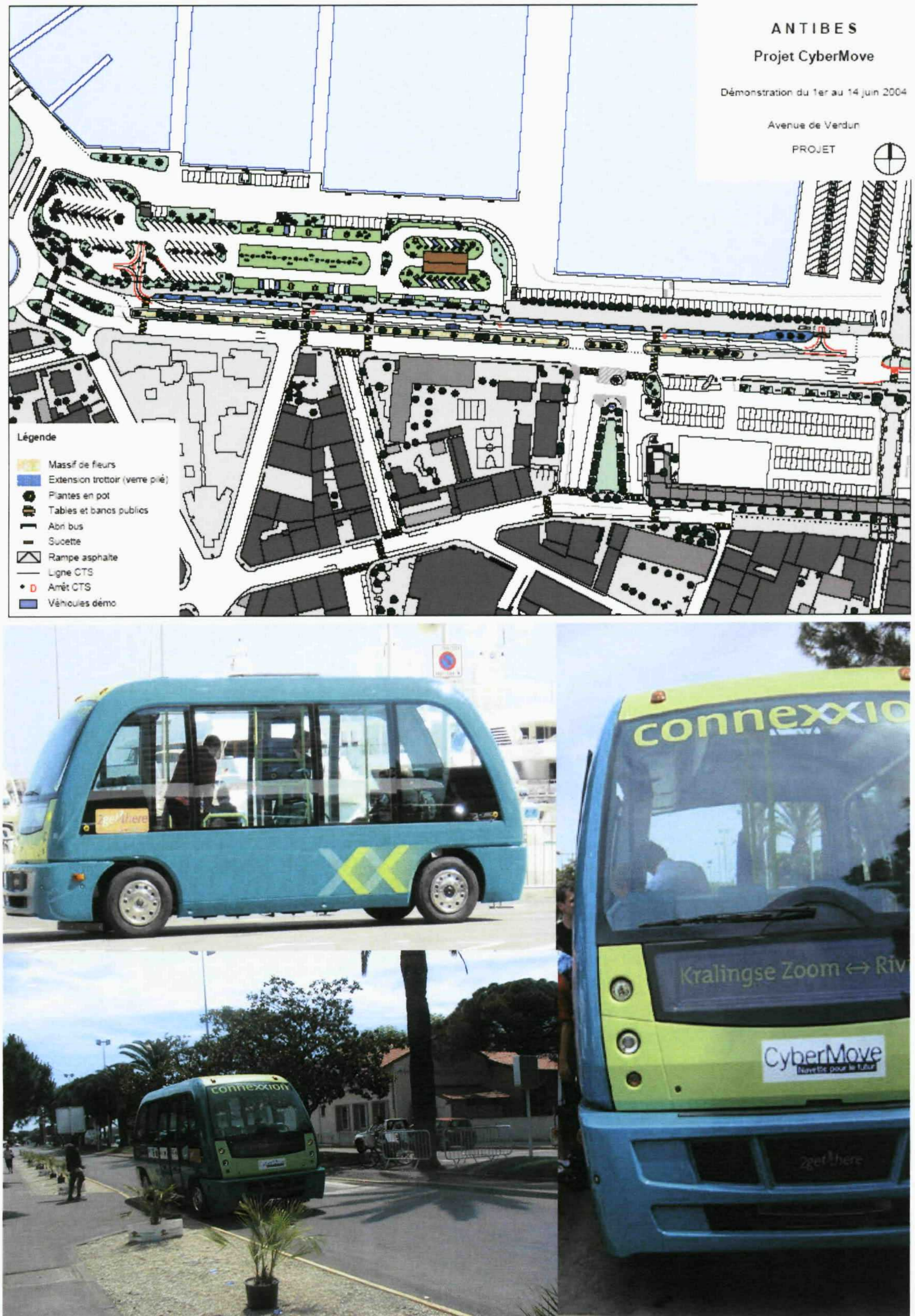


Figure 5.1: Map and Pictures from the Antibes Site

- *Coimbra:*

The selected experimentation site for the demonstration site Coimbra, Portugal is inside a new re-development area financed by the EC POLIS Programme, supported by the Portuguese Government. This site will profit from this program that will intervene in an area of about 80 hectares of both sides of the Mondego River. The area is between an old bridge named Santa Clara Bridge and a new bridge named Europa Bridge, and predicts a green park area with several buildings to support activities in the area. The mobility is mainly based on lanes for pedestrians or special mobility devices. The demo will demonstrate the potential of AUTS for a sustainable solution for the urban mobility.

The main application for AUTS at this site is the connection between carparks, the rail station and the historic city centre of Coimbra. The zone covered by the proposed AUTS System has a car-park with a demand of 770 vehicles/day (peak 8:30-10:00 and 17:00-18:30). In lunch time the demand is lower than 50 vehicles/ hour. The train station is another place where people arrive and depart from. The peak hours of the train station is more spread over the time, but it is similar to the demand of the car-park.

The car-park users are mostly people that have jobs around the area (in Dr. Emídio Navarro Avenue and the city centre) and the other part of users are people that need to access several services in that avenue and mostly in the city centre. The people from the train station come from south peripheral areas of the city of Coimbra and need to get to their jobs, mostly in the city centre, and for people that need to get to the local commerce in the city centre. The green park users it is referred to people that use the park only for their amusement, including elderly and disable people that use cybercars to go from one place to another.

The demonstration site was operated for two days in November 2004 with three vehicle supplied by YME. The application was a single loop of approximately 1800m in length. On this loop 4 stops were located for passenger to board the vehicles. Vehicle speeds were low (3-8km/hr) due to the operation in a mixed environment with pedestrians and cyclists. Vehicle control and navigation was by buried cable. The in-vehicle Human-Machine Interface (HMI) for passengers to choose their desired destination consisted of four buttons corresponding with the four stops as shown on a map. See figure 5.2 for photos and map.

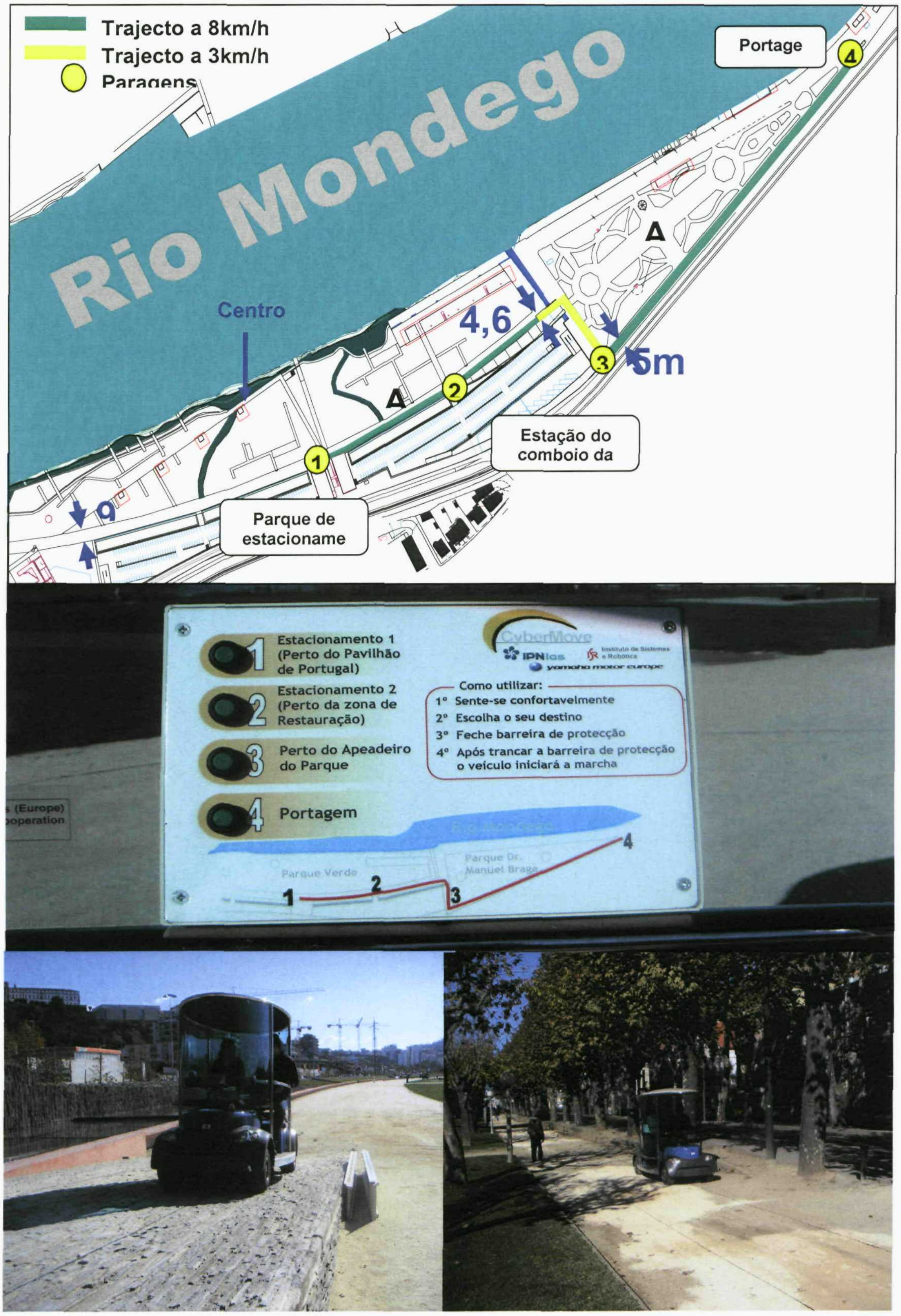


Figure 5.2: Map and Pictures from the Coimbra Site

5.2 Analysis

5.2.1 Quantitative Results (Antibes Site)

Participants Characteristics

Table 5.1 below gives an overview of the characteristics of the participants of the end-user questionnaire survey at the Antibes site.

Participants Characteristics									
Gender	Male	Female							
	67.5%	32.5%							
Age Group	10-20	21-30	31-40	41-50	51-60	61-70	71+		
	7.6%	10.1%	17.7%	24.1%	10.1%	22.8%	7.6%		
Car Owner	0	1	2	3+					
	10.0%	36.3%	45.0%	8.8%					
Travel Mode	Car (Driver)	Car	Car& Bus	Car& Train	Bus	Bus& Train	Motor Bike	Cycle	Walk
	64.1%	4.7%	4.7%	3.1%	6.3%	3.1%	6.3%	3.1%	3.1%
Empl.	Full Time	Part Time	Self Empl.	Student	Training	Retired	Not Empl.	Disabled	Other
	32.2%	2.6%	6.5%	10.4%	2.6%	32.5%	6.5%	1.3%	1.3%

Table 5.1: Participants Characteristics for the Antibes Site

According to table 5.1 above 2/3 of the participants of the end-user questionnaire survey at the Antibes site were male, 2/3 were above 40 years, more than the half owned two or more cars, 2/3 used their private car as drivers as their main mode of transport, and 1/3 were either in full-time employment or in retirement.

In the following the questionnaire ratings for all questions are given both individually and in relation to the specific characteristics as described in the table above. Furthermore the relationship between ratings on system performance and the question whether an emergency stop was experienced is analysed.

Questionnaire Ratings

Table 5.2 below shows the ratings for all questions from the participants of the end-user questionnaire survey at the Antibes site. The questions are split into five categories, detailed vehicle/ system performance, general vehicle/ system performance, vehicle performance in case of having experienced an emergency stop due to an obstacle on the path very close to the vehicle, vehicle performance in case of having experienced deceleration and acceleration due to an obstacle on the path further away from the vehicle, and general perception of the system.

Questionnaire Ratings						
Questionnaire		Ratings				
Question Category	Question	Very Good	Quite Good	Quite Poor	Very Poor	Sum Good
Detailed Performance	Acceleration Straight	***63.4%***	35.4%	1.2%	0.0%	**98.8%**
	Acceleration Curve	***51.9%***	44.4%	3.7%	0.0%	**96.3%**
	Braking at Station	***65.4%***	30.9%	3.7%	0.0%	**96.3%**
	Travel Time	***46.8%***	40.5%	12.7%	0.0%	**87.3%**
	Vehicle Speed	***70.7%***	20.7%	7.3%	1.2%	**91.4%**
	Stopping Accuracy	***75.0%***	22.5%	2.5%	0.0%	**97.5%**
	Waiting Time	***56.8%***	30.9%	12.3%	0.0%	**87.7%**
	Vehicle Noise	***55.6%***	36.1%	6.9%	1.4%	**91.7%**
	User Interface	***64.8%***	24.1%	9.3%	1.9%	**88.9%**
General Performance	Ease of Use	***71.4%***	27.3%	1.3%	0.0%	**98.7%**
	Personal Security	***58.0%***	32.1%	4.9%	4.9%	**90.1%**
	Traffic Safety	***49.2%***	35.4%	13.8%	1.5%	**84.6%**
	Ride Comfort	***47.6%***	43.9%	8.5%	0.0%	**91.5%**
Emergency Stop	Emergency Deceleration	29.4%	***35.3%***	23.5%	11.8%	**64.7%**
	Emergency Stop	26.7%	***40.0%***	26.7%	6.7%	**66.7%**
Obstacle Avoidance	Obstacle Deceleration	***55.9%***	26.5%	14.7%	2.9%	**82.4%**
	Obstacle Stop	35.3%	***41.2%***	17.6%	5.9%	**76.5%**
	Obstacle Traffic Safety	***50.0%***	40.6%	9.4%	0.0%	**90.6%**
	Obstacle Performance	***58.8%***	29.4%	11.8%	0.0%	**88.2%**
General System	Usefulness in General	***70.0%***	28.8%	1.3%	0.0%	**98.8%**
	Usefulness for Purpose	***86.7%***	13.3%	0.0%	0.0%	**100.0%**
	Agree with Statement	46.8%	***49.4%***	2.5%	1.3%	**96.2%**

Table 5.2: Questionnaire Ratings for the Antibes Site

In the following the results for the ratings for the questions from the participants of the end-user questionnaire survey at the Antibes site as shown in table 5.2 above are described. The results are given in percent for the four options ('very good', 'quite good', 'quite poor', 'very poor') and for the sum of 'very good' and quite good'. For each question the highest percentage for the four ratings is shown in bold.

For the questionnaire category 'detailed performance' all nine specific issues were rated as 'very good' by the majority of respondents, with percentages ranging from 46.8% to 75.0%. The percentages for the sum of the 'very good' and 'quite good' ratings ranged from 87.3% to 98.8%. The lowest ratings can be found for the questions relating to 'travel time', 'waiting time', 'vehicle noise', and 'user interface'.

For the questionnaire category 'general performance' all four specific issues were rated as 'very good' by the majority of respondents', with percentages ranging from 47.6% to 71.4%. The percentages for the sum of the 'very good' and 'quite good' ratings ranged from 84.6% to 98.7%. The lowest ratings can be found for the questions relating to 'personal security', 'traffic safety', and 'ride comfort'.

For the questionnaire category 'vehicle performance in case of an emergency stop' both specific issues were rated as 'quite good' by the majority of respondents with percentages being 35.3% and 40.0% respectively. The percentages for the sum of the 'very good' and 'quite good' ratings were 64.7% and 66.7% respectively. Compared to the first two categories these ratings are much lower.

For the questionnaire category 'vehicle performance in case of obstacle avoidance' three of the four specific issues were rated as 'very good' and one specific issue as 'quite good', with percentages ranging from 41.2% to 58.8%. The percentages for the sum of the 'very good' and 'quite good' ratings ranged from 76.5% to 90.6%. The lowest ratings can be found for 'obstacle deceleration' and 'obstacle stop'.

For the questionnaire category 'general system' two of the three specific issues were rated as 'very good' and one specific issue was rated as 'quite good', with the percentages ranging from 49.4% to 86.7%. The percentage for the sum of the 'very good' and 'quite good' ratings ranged from 96.2% to 100.0%. The comparably lowest rating can be found for 'agreeing with the general statement for AUTS'.

Sample Size and Statistical Considerations

Background and General Implications

At this demonstration site approximately 1200 people used the system during the trial period. From this population participants were randomly selected to participate in the survey. A total of 82 were willing to take part in the end-user survey at this site. The small size of the sample, both generally and in relation to the size of the population, has statistical implications on the quality and the transferability of the results of the data analysis carried out for the ex-post user needs analysis.

The sample size generally has implications on the statistical analysis of the data in view of covering all user groups and characteristics (e.g. age groups, social background, public transport user, etc.) and interpreting the results based on this. Although it was possible to cover all these characteristics with the limited sample size of this questionnaire survey, the proportion of responses from some user groups are comparable lower than those from others.

Only an overall analysis of the total responses of all survey participants of the questionnaire survey, as described in the previous section, was possible, not an analysis examining differences in the answers to specific questions in relation to specific survey participants characteristics. This will be discussed in more detail in the following section, where the relationships between individual sections of the questionnaire survey will be examined based on the use of a χ^2-test.

The sample size in relation to the population size has implication on how representative the outcomes are on the whole population. As described in the previous section on questionnaire ratings, for 19 out of 22 issues to be rated the combined 'very good' and 'quite good' ratings where above 80% and 13 over 90%. This shows, that there is very little spread over the answer categories, it can therefore be assumed that the results are robust and can be seen as representative.

Relationships between Questionnaire Sections

Following on from the previous analysis of survey results in absolute terms, in this section a statistical analysis is carried out in order to identify potential relationships between sections of the questionnaire. This analysis is based on using a χ^2-test. According to this test, a relationship between two independent variables is possible if the value for χ^2 is below 0.05 (Field, A., 2000).

Two different types of relationships could be explored for this analysis, the relationship between questionnaire ratings and participants' characteristics, and the relationship between questionnaire ratings and the question whether or not either an obstacle in the vehicle path (gradual slowing down, no full emergency stop), or a full emergency stop has been experienced.

While an analysis of the relationship between questionnaire ratings and participants' characteristics could have delivered valuable information on potential differences in responses, due to the relatively low number of questionnaires returned and the fact that the characteristics are not evenly spread over the population, as discussed in the previous section, a χ^2-test was not possible.

The AUTS test site in Antibes was operated in a shared environment with pedestrians and cyclists. As the ability of the system to operate in a shared way was one of the main characteristics, testing this was very popular with members of the public. Therefore vehicle slowing down due to obstacle detection or emergency stop was experienced by the majority of the survey participants.

Hence for the analysis into a potential relationship between the individual questionnaire ratings and whether or not either an obstacle in the vehicle path, or an emergency stop has been experienced, a sufficient number of respondents have experienced these specific events in order to be able to carry out a statistical analysis of their relationship using the χ^2-test as described above.

Table 5.3 below shows the results of this analysis into potential relationships between individual questionnaire ratings and whether or not either an obstacle in the vehicle path, or an emergency stop has been experienced, for the end-user questionnaire survey at the Antibes site, using a χ^2-test. The χ^2 values are shown in the table, with those of less than 0.05 indicating a relationship in bold.

Relationship between Questionnaire Ratings and Emergencies/ Obstacles			
Questionnaire		Questionnaire Ratings	
Question Category	Question	Emergency Stop	Obstacle Detection
Detailed Performance	Acceleration Straight	**0.043**	**0.018**
	Acceleration Curve	**0.028**	**0.002**
	Braking at Station	0.081	**0.037**
	Travel Time	0.175	0.503
	Vehicle Speed	0.975	0.846
	Stopping Accuracy	0.515	0.308
	Waiting Time	0.131	**0.004**
	Vehicle Noise	0.350	0.149
	User Interface	0.635	0.085
General Performance	Ease of Use	0.604	0.600
	Personal Security	0.275	0.836
	Traffic Safety	0.470	**0.030**
	Ride Comfort	0.123	0.589
General System	Usefulness in General	0.515	0.308
	Usefulness for Purpose	0.131	**0.004**
	Agree with Statement	0.350	0.149

Table 5.3: Ratings and Emergencies/ Obstacles for the Antibes Site

Table 5.3 above shows that some relationships can be identified between a number of individual questionnaire ratings and whether or not either an obstacle in the vehicle path, or an emergency stop has been experienced by the respondents of the end-user questionnaire survey at the Antibes site, according to the χ^2-test (see values in bold in table 5.3) used for this analysis as described above.

Both in the case of experiencing an emergency stop and slowing down of the AUTS vehicle due an obstacle being detected in the path, a relationship can be seen for the ratings for acceleration on straight lines and in curves. This shows that experiencing these braking and/ or slowing down manoeuvres has an impact on the rating of the ride comfort overall for respective survey participants.

In addition it can be seen that a relationship also exists in the case of obstacle detection for 'Braking at Station', 'Waiting Time', 'Traffic Safety', and 'Usefulness for Purpose'. The fact that this is only the case for obstacle detection, but not for emergency stop, shows that it is seen more as a regular occurrence in the operation of AUTS in a shared environment with pedestrians and cyclists.

The relationship with 'Braking at Stations' points at the jerk from the vehicle slowing down and stopping being perceived more negatively if experienced more frequently due to obstacle detection, the relationship with 'Waiting Time' shows the effect on trip times, and the relationship with 'Usefulness for the Purpose' indicate the negative effect of this on the perception of the whole AUTS concept.

Both, in case of experiencing obstacle detection and emergency stop, the calculated χ^2 value indicated that a relationship exists for the perception of vehicle acceleration on straight and on curved sections. This shows that the vehicle performance for unusual events such as emergency stop or obstacle detection are perceived as so uncomfortable that it affects the respondents overall assessment.

Furthermore, in the case of experiencing obstacle detection, relationships can be identified with waiting times, traffic safety, and usefulness for the purpose. This shows that emergency stops are seen as rare events that do not affect any other responses, whereas obstacle detection is perceived more as a regular occurrence, thus affecting their views of waiting times, safety and usefulness.

5.2.2 *Quantitative Results (Coimbra Site)*

Participants Characteristics

Table 5.5 below gives an overview of the characteristics of the participants of the end-user questionnaire survey at the Coimbra site.

Participants Characteristics								
Gender	Male	Female						
	47.4%	52.6%						
Age Group	10-20	21-30	31-40	41-50	51-60	61-70	71+	
	15.4%	29.5%	25.6%	10.3%	5.1%	3.8%	10.3%	
Car Owner	0	1	2	3+				
	15.4%	33.3%	34.6%	16.7%				
Travel Mode	Car (Driver)	Car	Car& Bus	Car& Train	Bus	Train	Motor Bike	Walk
	52.6%	5.1%	3.8%	1.3%	19.2%	6.4%	2.6%	6.4%
Empl.	Full Time	Part Time	Self Empl.	Student	Training	Retired	Not Empl.	House Work
	44.9%	3.8%	5.1%	19.2%	6.4%	15.4%	3.8%	1.3%

Table 5.4: Participants Characteristics for the Coimbra Site

According to table 5.4 above 1/2 of the participants of the end-user questionnaire survey at the Coimbra site were male, 2/3 were below 40 years, more than the half owned two or more cars, 1/2 used their private car as drivers as their main mode of transport, and 1/2 were in full-time employment (including self-employed).

In the following the questionnaire ratings for all questions are given both individually and in relation to the specific characteristics as described in the table above. Furthermore the relationship between ratings on system performance and the question whether an emergency stop was experienced will be analysed.

Questionnaire Ratings

Table 5.5 below shows the ratings for all questions from the participants of the end-user questionnaire survey at the Coimbra Site. The questions are split into 5 categories, detailed vehicle/ system performance, general vehicle/ system performance, vehicle performance in case of having experienced an emergency stop due to an obstacle on the path very close to the vehicle, vehicle performance in case of having experienced deceleration and acceleration due to an obstacle on the path further away from the vehicle, and general perception of the system.

Questionnaire Ratings						
Questionnaire		Ratings				
Question Category	Question	Very Good	Quite Good	Quite Poor	Very Poor	Sum Good
Detailed Performance	Acceleration Straight	29.5%	***56.4%***	14.1%	0.0%	**85.9%**
	Acceleration Curve	26.8%	***56.3%***	15.5%	1.4%	**83.1%**
	Braking at Station	38.2%	***48.5%***	13.2%	0.0%	**86.7%**
	Travel Time	35.6%	***52.5%***	11.9%	0.0%	**88.1%**
	Vehicle Speed	24.4%	***57.7%***	16.7%	1.3%	**82.1%**
	Stopping Accuracy	38.6%	***58.6%***	2.9%	0.0%	**97.2%**
	Headway Safety	25.0%	***56.3%***	18.8%	0.0%	**81.3%**
	Speed Safety	20.0%	***70.0%***	10.0%	0.0%	**90.0%**
	Waiting Time	***51.4%***	34.7%	13.9%	0.0%	**86.1%**
	User Interface	***55.1%***	39.7%	3.8%	1.3%	**94.8%**
General Performance	Ease of Use	***49.4%***	46.8%	2.6%	1.3%	**96.2%**
	Personal Security	19.7%	***68.4%***	11.8%	0.0%	**88.1%**
	Traffic Safety	21.1%	***69.7%***	9.2%	0.0%	**90.8%**
	Ride Comfort	5.2%	***55.8%***	35.1%	3.9%	**61.0%**
	Overall Perception	40.3%	***59.7%***	0.0%	0.0%	**100.0%**
Emergency Stop	Emergency Deceleration	28.6%	***57.1%***	14.3%	0.0%	**85.7%**
	Emergency Stop	28.6%	***66.7%***	4.8%	0.0%	**95.3%**
Obstacle Avoidance	Obstacle Deceleration	10.0%	***70.0%***	20.0%	0.0%	**80.0%**
	Obstacle Stop	11.1%	***55.6%***	33.3%	0.0%	**66.7%**
	Obstacle Traffic Safety	***50.0%***	40.0%	10.0%	0.0%	**90.0%**
	Obstacle Performance	20.0%	***70.0%***	10.0%	0.0%	**90.0%**
General System	Usefulness in General	44.0%	**53.3%**	2.7%	0.0%	**97.3%**
	Usefulness for Purpose	38.7%	**57.3%**	4.0%	0.0%	**96.0%**
	Agree with Statement	38.7%	**56.0%**	5.3%	0.0%	**94.7%**

Table 5.5: Questionnaire Ratings for the Coimbra Site

In the following the results for the ratings for the questions from the participants of the end-user questionnaire survey at the Coimbra site as show in table 5.6 above are described. The results are given in percent for the four options ('very good', 'quite good', 'quite poor', 'very poor') and for the sum of 'very good' and quite good'. Furthermore, for each question the highest percentage for the four ratings is shown in bold.

For the questionnaire category 'detailed performance' eight of the ten specific issues were rated as 'very good' and three specific issues as 'quite good', with percentages ranging from 48.5% to 70.0%. The percentages for the sum of the 'very good' and 'quite good' ratings ranged from 81.3% to 97.2%. The highest ratings can be found for the questions relating to 'vehicle stopping accuracy, and 'user interface'.

For the questionnaire category 'general performance' four of the five specific issues were rated as 'very good' and one specific issue as 'quite good', with percentages ranging from 49.4% to 69.7%. The percentages for the sum of the 'very good' and 'quite good' ratings ranged from 61.0% to 100.0%. The lowest ratings can be found for the questions relating to the specific issues 'ease of use of the system, and 'ride comfort'.

For the questionnaire category 'vehicle performance in case of an emergency stop' both specific issues were rated as 'quite good' by the majority of respondents with percentages being 57.1% and 66.7% respectively. The percentages for the sum of the 'very good' and 'quite good' ratings were 85.7% and 95.3% respectively. Compared to the results of the first two categories these ratings are in a similar range.

For the questionnaire category 'vehicle performance in the case of obstacle avoidance' three of the four specific issues were rated as 'very good' and one specific issue as 'quite good', with percentages ranging from 50.0% to 70.0%. The percentages for the sum of the 'very good' and 'quite good' ratings ranged from 66.7% to 90.0%. The lowest ratings can be found for 'obstacle deceleration' and 'obstacle stop'.

For the questionnaire category 'general system' all three specific issues were rated as 'quite good' by the majority of the respondents, with the percentages ranging from 53.3% to 57.3%. The percentage for the sum of the 'very good' and 'quite good' ratings ranged from 94.7% to 97.3%. The ratings for all three specific issues were found to be very similar, with no clearly identifiable low or high ratings for this.

Sample Size and Statistical Considerations

Background and General Implications

At this demonstration site approximately 800 people used the system during the trial period. From this population participants were randomly selected to participate in the survey. A total of 78 were willing to take part in the end-user survey at this site. The size of the sample, both generally and in relation to the size of the population, has statistical implications on the quality and the transferability of the results of the data analysis carried out for the ex-post user needs analysis.

The sample size generally has implications on the statistical analysis of the data in view of covering all user groups and characteristics (e.g. age groups, social background, public transport user, etc.) and interpreting the results based on this. Although it was possible to cover all these characteristics with the limited sample size of this questionnaire survey, the proportion of responses from some user groups is comparably lower than those from others.

Therefore only an overall analysis of the total responses by all survey participants of the questionnaire survey, as described in the previous section, was possible, not an analysis examining differences in the answers to specific questions in relation to specific survey participants characteristics. This will be discussed in more detail in the following section, where the relationships between individual sections of the questionnaire survey will be examined based on the use of a χ^2-test.

The sample size in relation to the population size has implication on how representative the outcomes are on the whole population. As described in the previous section on questionnaire ratings, for 22 out of 24 issues to be rated the combined 'very good' and 'quite good' ratings where above 80% and 12 over 90%. This shows that there is very little spread over the answer categories; it can therefore be assumed that the results are robust and can be seen as representative.

Relationships between Questionnaire Sections

Following on from the previous analysis of end-user questionnaire survey results in absolute terms, in this section a statistical analysis is carried out in order to identify potential relationships between sections of the questionnaire. This analysis is based on using a χ^2-test. According to this test, a relationship between two independent variables is possible if the value for χ^2 is below 0.05.

Two different types of potential relationships have been identified for this analysis, the relationship between questionnaire ratings and participants' characteristics, and the relationship between questionnaire ratings and the question whether or not either an obstacle in the vehicle path (gradual slowing down, no full emergency stop), or an emergency stop has been experienced.

While an analysis of the relationship between questionnaire ratings and participants' characteristics could have delivered valuable information on potential differences in responses, due to the relatively low number of questionnaires returned and the fact that the characteristics are not evenly spread over the population, as discussed in the previous section, a χ^2-test was not possible.

Similar to the Antibes site, the Coimbra site was operated in a shared environment with pedestrians and cyclists. As the ability of the system to operate in a shared was one of the main characteristics, testing this was very popular with members of the public. Thus the vehicle slowing down due to obstacle detection or emergency stop was experienced by the majority of the survey participants.

Hence for the analysis into a potential relationship between the individual questionnaire ratings and whether or not either an obstacle in the vehicle path, or an emergency stop has been experienced, a sufficient number of respondents have experienced these specific events in order to be able to carry out a statistical analysis of their relationship using the χ^2-test as described above.

Table 5.6 below shows the results of this analysis into potential relationships between individual questionnaire ratings and whether or not either an obstacle in the vehicle path, or an emergency stop has been experienced, for the end-user questionnaire survey at the Coimbra site, using a χ^2-test. The χ^2 values are shown in the table, with those of less than 0.05 indicating a relationship in bold.

Relationship between Questionnaire Ratings and Emergencies/ Obstacles			
Questionnaire		Question Ratings	
Question Category	Question	Emergency Stop	Obstacle Detection
Detailed Performance	Acceleration Straight	0.241	0.666
	Acceleration Curve	0.826	0.106
	Braking at Station	0.210	0.819
	Travel Time	0.638	0.512
	Vehicle Speed	0.927	0.230
	Stopping Accuracy	0.215	0.313
	Headway Safety	0.833	0.557
	Speed Safety	0.824	**0.002**
	Waiting Time	0.290	0.218
	User Interface	0.611	0.904
General Performance	Ease of Use	0.185	0.899
	Personal Security	0.744	0.248
	Traffic Safety	0.582	0.624
	Ride Comfort	0.989	**0.027**
	Overall Perception	0.180	0.140
General System	Usefulness in General	0.215	0.313
	Usefulness for Purpose	0.833	0.557
	Agree with Statement	0.824	**0.002**

Table 5.6: Ratings and Emergencies/ Obstacles for the Coimbra Site

Table 5.6 above shows that some relationships can be identified between a number of individual questionnaire ratings and having experienced obstacle detection. In the cases of experiencing obstacles, the analysis indicates that a relationship exists for the perception of vehicle speeds safety, ride comfort and summary statement.

This shows that the vehicle performance for obstacle detection is perceived as so uncomfortable that it affects the respondents overall assessment. But unlike for the same analysis for the Antibes test site it can be seen that here experiencing an emergency stop has no relationship to any of the questions of the questionnaire.

Clearly with these large differences between the two analyses, vehicle performance characteristics of the two types of vehicles have to be very different for emergency stops in terms of deceleration and jerk. An analysis of the vehicle performance data collected at the Antibes demonstration site has been carried out in chapter 6.

The relationship with 'Speed Safety' indicates that speed is an issue in a shared environment, the relationship with 'Ride Comfort' shows the impact on the perception of vehicle performance, and the relationship with 'Agree with Statement' illustrates that low comfort level has an effect on the perception of the whole concept.

5.2.3 Qualitative Results (Antibes Site)

Advantages/ Potentials

Survey participants generally liked the concept in view of potential environmental benefits (e.g. reduction of pollution and noise), ability to reduce traffic and the large improvements in levels of service (e.g. speed, reliability and on-demand).

Disadvantages/ Barriers

Concerns expressed in this survey included the likely high costs of these systems, the suitability of CTS for particular application areas, security due to the lack of human presence, and the need for a segregated infrastructure.

Potential Application Areas

Generally, survey participants think of localised closed systems such as on airports, theme parks, other tourist attractions, and in particular for use as a small automated bus service in town centres or for use as P&R applications.

Other Comments/ Remarks

In general, comments are favourable, with some suggestions and remarks about system development and facilities. There is a general feeling that the system has good potential for improved public transport in urban areas.

But concerns about a variety of issues, including vehicle comfort, security, accessibility, cost, reliability arise. The trials were conducted in hot weather, leading to a number of comments about the need to provide air conditioning.

There were some comments about the speed of the vehicle, with some saying it is too fast (traffic safety) and some saying it is too slow (journey times), and the need to provide more hand-holds for elderly or infirm passengers.

Whilst the quietness of the vehicle was generally appreciated, there were also some comments about it being too quiet for the safety of the visually impaired. Other comments concerned social and environmental impacts and technology issues.

5.3 Conclusion

5.3.1 Summary

Following on from the qualitative ex-ante user needs analysis as described in the previous chapter, a quantitative ex-post user needs analysis has been carried out based on a questionnaire survey. This survey of end-user perceptions and requirements was carried out at two public demonstration sites in Antibes and in Coimbra. The main characteristics of both these sites was the implementation of a small-scale automated system with one or more fully automated vehicles on a simple track (loop with a number of stops) open to the general public and operated for a limited period of time (2-3 weeks).

The methodology used was to carry out a stated preference questionnaire survey of passengers after they have used the system at the public demonstration sites. The survey was designed to address passengers' perception of technology issues. The questionnaire consisted of three main sections: social background, AUTS generally, and respondent's perception of the system. Perception of system performance included acceleration and deceleration on straight line and in curves, jerk at stop and for obstacle avoidance, speed, travel time, security, safety, stopping accuracy, human machine interface, ease of use, comfort, and general satisfaction with AUTS.

As mentioned above, the questionnaire was split into three main sections, respondent's characteristics, perception of AUTS technology more generally, and respondent's perception of the specific application used. Based on this the analysis was carried out in three steps according to these three main sections. Furthermore the analysis was carried out on two levels, on a general level without taking participant's characteristics into consideration, and on a more detailed level according to participants' characteristics and whether or not they experienced obstacle detection or emergency stops.

Following on from these results, a comparison between the earlier qualitative ex-ante user needs analysis has been carried out, analysing potential changes in the perception of these systems, after survey participants have personally experienced the systems. Furthermore the users' perception of specific vehicle performance parameters (acceleration, deceleration, jerk) were compared to the values recorded, which in turn were compared to the benchmark values for this from the literature, which has been carried out in the following chapter on ex-post analysis of system/ vehicle performance.

5.3.2 Key Findings

The analysis of the data from the questionnaire survey at the Antibes site showed very high acceptance of the system, with the majority of responses above a value of 80% for the combined 'very good' and 'good' answers. The only exceptions were the responses on questions addressing irregular situations such as performance of the vehicle in case of emergency stops and for obstacle avoidance. Questions on the performance of the vehicle in the case of emergency stops were rated below 80%, with 64.7% and 66.7%. In the case of vehicle performance for obstacle avoidance all values were above the 80% benchmark, except the perception of jerk, with 76.5%.

Both, in case of experiencing obstacle detection and emergency stop a relationship existed for the perception of vehicle acceleration on straight and on curved sections. This showed that the vehicle performance for unusual events such as emergency stop or obstacle detection are perceived as so uncomfortable that it affects the respondents overall assessment. In the case of experiencing obstacle detection, relationships existed with waiting times, traffic safety, and usefulness for the purpose. This showed that emergency stops are seen as rare events that do not affect any other responses, whereas obstacle detection is perceived more as a regular occurrence.

The analysis of the data from the questionnaire survey at the Coimbra site also showed very high acceptance of the system, with the majority of responses above a value of 80%. Again, the only exceptions were the responses on the overall level of comfort of the ride, with 61.0%, and the responses to the vehicle performance for obstacle avoidance, where all values were above the 80% benchmark, except jerk, with 66.7%. In case of experiencing obstacles, the analysis indicated that a relationship exists for the perception of vehicle speeds safety, comfort and summary statement.

But unlike for the same analysis for the Antibes test site it could be seen that here experiencing an emergency stop appeared to have no relationship to any of the questions of the questionnaire. Clearly with these large differences between the results of the two analyses, the vehicle performance characteristics of the two types of vehicles used for the demonstration sites were very different for emergency stops in terms of deceleration and jerk. An analysis of the vehicle performance data collected at the Antibes demonstration site has been carried out as part of chapter 6.

5.3.3 Discussion

The analysis of the end-user questionnaire surveys carried out at the two demo sites in Antibes and Coimbra, showed very high acceptance of the AUTS application that has been used. The only issues that were rated below the assessment benchmark value relate to the vehicle performance in specific situations such as obstacle avoidance and emergency stops. Differences in responses to this from the demo sites were due to different technologies being used and thus different vehicle performance.

More generally, the ex-post user needs analysis questionnaire survey has shown a very high level of acceptance for various vehicle performance parameters, with combined ratings for 'very good' and 'good' accounting for more than 95% for each of the specific questions on these issues. There were still high levels of acceptance for other parameters, but values in particular for the 'very good' rating have been comparably lower for noise levels, the HMI and for travel and waiting times.

This confirmed the earlier results from the user needs analysis, which had shown that the relatively low vehicle speeds and thus longer travel times were perceived as inconvenient. For the views on the performance of an AUTS application as a whole the combined rating for 'very good' and 'good' still ranged from 84.6% to 98.7%, thus still indicating satisfying levels of acceptance, but this is rated comparably lower to the results for most of the other questions on vehicle performance.

When analysing the overall results for questions about the general AUTS concept, the acceptance was very high, but when differentiating between the 'very good' and the 'good' rating it became clear that end-users felt much more comfortable with the way AUTS is used in this particular application rather than envisaging it in different application areas. This could be due to the fact that with an innovative system such as AUTS, the personal experience is very important for establishing an opinion on it.

The results for general ease of use of the system were very positive, with 'very good' and 'good' ratings combined of 98.7%, but for the level of comfort, traffic safety and personal security the categories 'very poor' and 'quite poor' combined accounted for 10-15%, also confirming earlier results from the user needs analysis, which had shown that personal security and traffic safety were an issue, due to a lack of trust in the technology and the fact that the presence of a driver has a reassuring effect.

6 ASSESSMENT OF PERFORMANCE

6.1 Introduction

6.1.1 Background

Following on from the earlier ex-post user needs analysis, where end-users rated the performance of AUTS vehicles (in terms of perception of safety, comfort, and general service characteristics) at small-scale public demonstrations of the system, this analysis has examined the actual performance of the vehicles using data collected on operation of the system. The results from this analysis were then compared both to the ex-post user needs analysis and to benchmark values found in the literature for the performance of comparable conventional public transport vehicles.

As described in the last chapter, the analysis of the end-user questionnaire surveys carried out at the two demo sites in Antibes and Coimbra, showed very high acceptance of the respective AUTS applications that have been used. The only issues that were rated below the assessment benchmark value related to the vehicle performance in specific situations such as obstacle avoidance and emergency stops. This would indicate that the performance parameters of AUTS vehicles are comparable to those of more conventional public transport systems (e.g. bus, metro, LRT.).

6.1.2 Objectives

The key objective of this study therefore was to collect vehicle data at AUTS demonstration sites in order to analyse the actual vehicle performance, which enabled a comparison between the more qualitative perception of end-users and a quantitative statistical analysis of this data. Due to restriction within the project it was only possible to carry out the survey at one of the two sites. The more detailed issues to be analysed included if vehicle performance parameters (speed, acceleration, jerk) are similar to those of other public transport systems, if there are any irregular values, when and why do they occur, and what the relationships between those parameters are.

Furthermore the vehicle positioning in relation to the pre-defined path (using a vehicle guidance system with electro-magnetic markers underneath the road surface on the loop in combination with digital mapping) were analysed in order to examine general accuracy, how it varies over the course of one loop, and how it is affected by specific vehicle performance parameters. In the following the methodology used to meet the objectives as mentioned above is described in detail.

6.1.3 Methodology

The methodology used to meet the objectives describe above, was to collect vehicle data on operation at one of the small-scale AUTS demonstration sites already used for the earlier ex-post user needs analysis. The Antibes site was chosen for this (for a detailed description of the site see chapter 5). The on-board control unit of the vehicle used on this site was able to keep a log of vehicle performance parameters for the duration of 5min, which covers one loop on the track (for plan see figure 6.1).

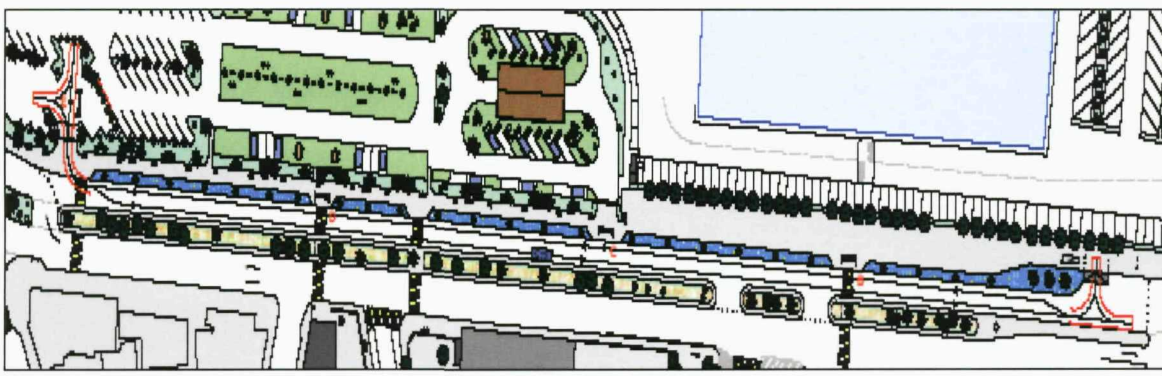


Figure 6.1: Plan of Vehicle Track at the Antibes Site

Measurement and recording of vehicle performance parameters have been carried out every tenth of a second for the 5min period. In order to improve reliability of the data and to identify potential variations of values or trends within data sets, data has been collected for 28 individual 5min periods, resulting in a total sample size of approximately 81,000 for each of the main vehicle performance parameters for this analysis. The vehicle performance parameters collected at the Antibes site included:

- Speed (Actuator/ Measured)
- Acceleration/ Deceleration
- Jerk (Calculated from Data)
- Lateral Position Error
- Longitudinal Position Error
- Orientation Error

In the following section the results of the data analysis of the vehicle performance parameters is described. The results are split into three section, overall results, detailed analysis of vehicle performance (speed, acceleration and deceleration, jerk, vehicle positioning errors), and detailed analysis of vehicle positioning errors (lateral, longitudinal, orientation). This is then followed by a conclusion.

6.2 Analysis

6.2.1 Overall Results

In this section of the assessment of performance the general and overall results of the analysis is described, followed by more detailed specific sections on vehicle performance and positioning errors. As mentioned before, data was recorded in 28 log files for the duration of 5min (300sec) each, covering one full loop.

The data collection has been carried out in such a way that two different scenarios have been covered by 14 data sets each. These two scenarios relate to the service operation at the site, where the vehicle stops at three stops along the loop to enable passengers to board the vehicle, and then carries out a second loop without stops.

Due to the layout of the loop and because of space constraints at the site, the vehicle had to reverse at one point in order to turn around, thus recording negative values for speed. Figure 6.2 below illustrates the two different scenarios for the data collection of vehicle performance parameters showing the vehicle profiles over time:

- Scenario 1: The vehicle reverses and then carries out three stops along the loop
- Scenario 2: After reversing the vehicle completes one full loop without stopping

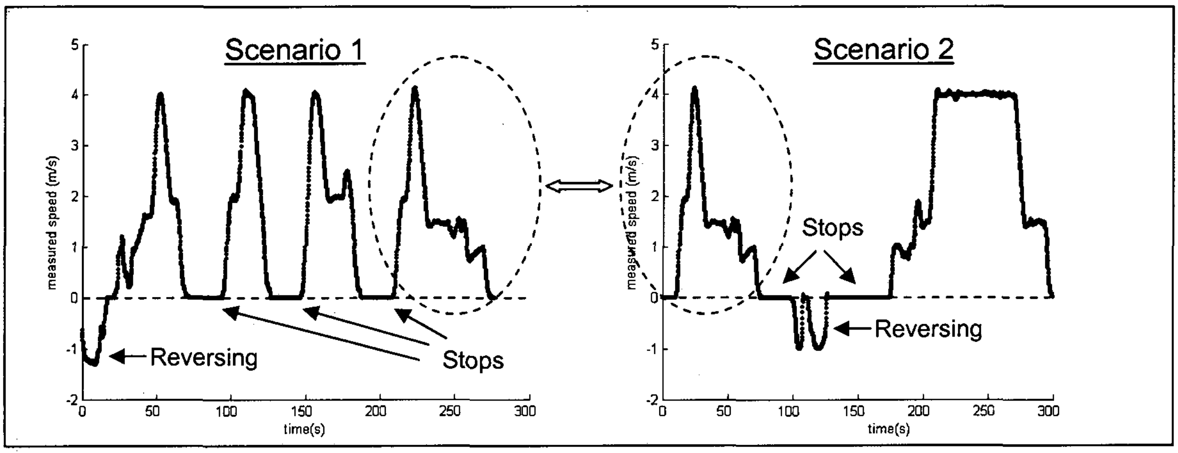


Figure 6.2: Comparison of Speed Profiles over Time for Scenarios 1 and 2

In the following the results of a statistical analysis of the whole 28 data sets, thus resulting in a sample size of 81,000, carried out for the vehicle performance parameters (speed, acceleration, jerk) and positioning error in relation to the pre-defined vehicle path (lateral, longitudinal, orientation error), is shown.

Table 6.1 below shows the mean, standard deviation, maximum values, 25 percentile, and 75 percentile for speed, acceleration, jerk, lateral error, longitudinal error, and orientation error, as result of the statistical analysis of the vehicle performance data. These results can then be compared to the perception of passengers and to benchmark values from other conventional public transport vehicles.

Overall Results of Vehicle Performance Parameter Analysis at the Antibes Site						
Vehicle Performance		Quantitative Statistical Data Analysis				
		Mean	St. Dev.	Max.	25%	75%
Speed	[km/hr]	5.04	4.97	14.94	0.00	7.20
Acceleration	[m/s^2]	0.10	0.16	1.65	0.00	0.18
Jerk	[m/s^3]	0.06	0.09	1.70	0.00	0.11
Lateral Error	[cm]	0.11	0.54	5.64	0.00	0.01
Longitudinal Error	[cm]	3.30	4.70	28.00	0.62	3.66
Orientation Error	[degree]	0.27	0.51	4.80	0.02	0.26

Table 6.1: Results of the Statistical Analysis of Vehicle Performance Data

It can be seen from the table above, that speeds were always below 15 km/hr and on average just above 5 km/hr. These values were due to the operating environment, where pedestrians and cyclists where able to use the same road as the AUTS vehicle, therefore speeds had to be low enough for the vehicle to stop with a safe acceleration if an obstacle has been identified by the obstacle detection system.

Values for acceleration were on average 0.10 m/s^2 with a maximum value of 1.65 m/s^2. In the literature various benchmark values can be found for comfortable acceleration levels for seated passengers facing the direction of travel (Abernethy et al, 1977 and 1980), ranging from 2.9 to 5.4 m/s^2, with maximum values measured on public transport vehicles ranging from 2.1 to 4.0 m/s^2 (De Graaf et al, 1997).

Jerk was calculated from the acceleration. It was on average 0.06 m/s^3, with a maximum value of 1.70 m/s^3. In the literature various benchmark values were found for safe jerk levels for seated passengers facing the direction of travel (Abernethy et al, 1977 and 1980), ranging from 2.5 to 4.9 m/s^3, with maximum values measured on public transport vehicles ranging from 1.5 to 3.5 m/s^3 (De Graaf et al, 1997).

Generally levels of acceleration and deceleration affect the comfort of passengers, whereas levels of jerk relate to safety (Abernethy et al, 1977). When comparing the measured and calculated values to the benchmark and observed values from the literature, it could seen that for acceleration the AUTS performance is better in terms of passenger comfort that conventional public transport systems.

For jerk the AUTS performance was at the lower end of values of other public transport systems and beneath the benchmark value for a safe system operation. This showed that AUTS could provide comparable or even better performance than other conventional public transport systems, which is also reflected by the high ratings for vehicle performance parameters from the end-user in the ex-post user needs analysis.

Error values were recorded for lateral, longitudinal and orientation error. For lateral errors the average value was 0.11 cm and the maximum value was 5.64 cm. For longitudinal errors the average value was 3.30 cm and the maximum value was 28.00 cm. For orientation errors the average value was 0.27° and maximum value was 4.80°.

Compared to vehicle performance parameters such as speed, acceleration and jerk as described above, error values are less crucial for the safe and comfortable operation of an AUTS application, as it has a less direct effect on passengers. Nevertheless specific space constraints on a site might limit the maximum acceptable error. Furthermore when the vehicle comes to a stop to allow passenger to board, all errors should be kept to an absolute minimum for a safe and convenient operation.

6.2.2 *Vehicle Performance*

Actuator Speed and Measured Speed

When analysing the data recorded in the 28 individual data sets in more detail, a first step was to compare the speeds set by the actuator and the actual speeds as recorded on operation. This analysis shows the accuracy of the on-board vehicle control unit and the drive-by-wire technology. Furthermore, as the actuator speed will set an even speed profile, any deviations from this will result in a less smooth ride.

Figure 6.3 below shows a comparison between the speed profiles for actuator speed and measured speed for one data set for scenario 1 (including stops). For the detailed analysis of these and all other vehicle performance parameters scenario 1 has been chosen, as due to the three stops along the loop more vehicle manoeuvres are carried out and thus more varied data can be collected for the analysis.

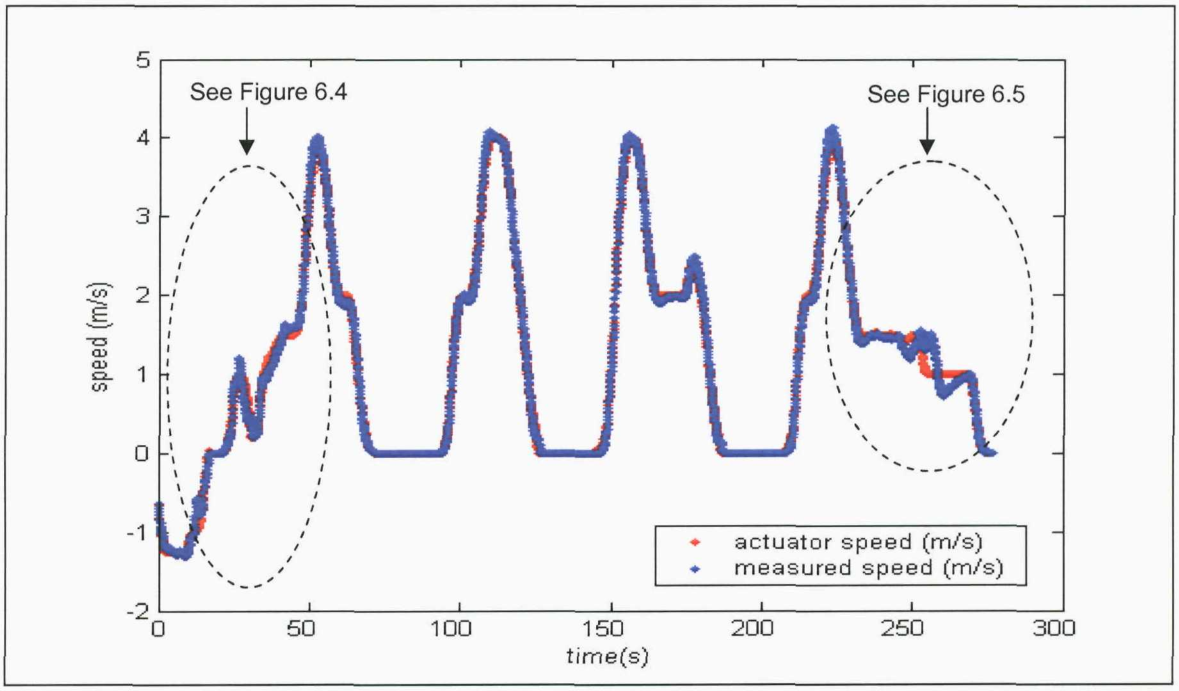


Figure 6.3: Comparison of Actuator Speed and Measured Speed (Overall)

Overall the measured speed profiles followed the actuator speed profiles closely, indicating generally a high accuracy of the control unit. But on closer inspection some areas could be identified, where larger errors can be seen. A more detailed comparison of these is shown in figures 6.4 and 6.5; figure 6.4 shows a very good fit of the two speed profiles, whereas figure 6.5 shows an area with larger differences in speed.

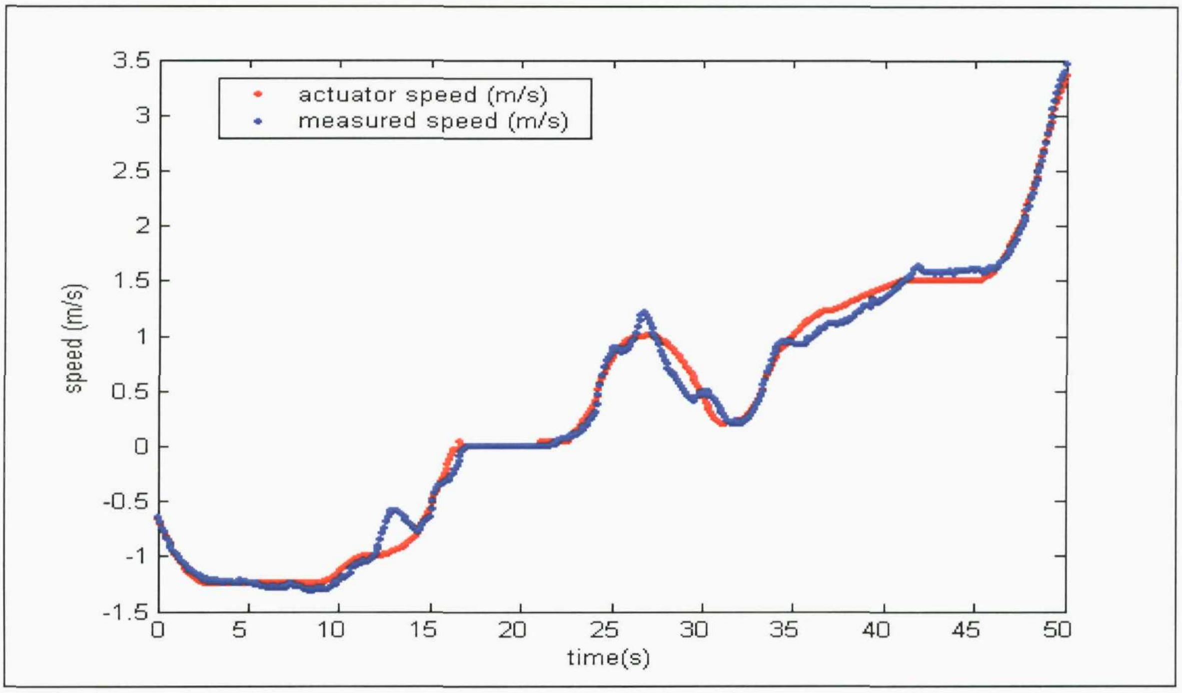


Figure 6.4: Comparison of Actuator Speed and Measured Speed (Good Fit)

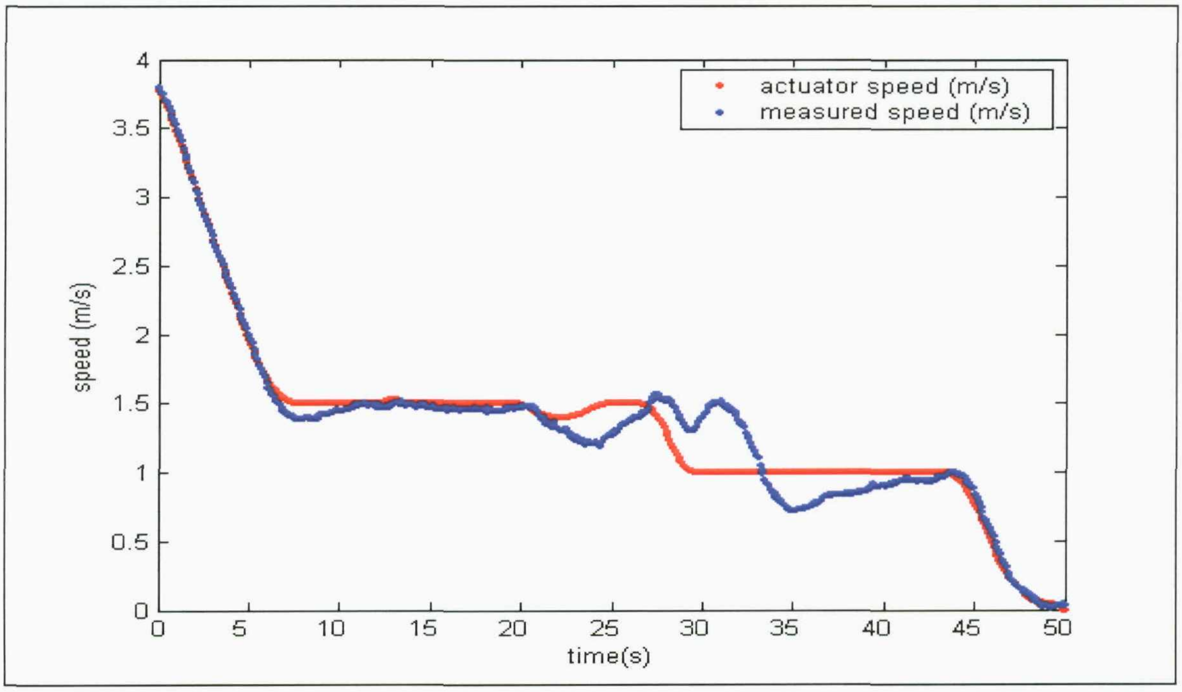


Figure 6.5: Comparison of Actuator Speed and Measured Speed (Differences)

Figures 6.4 and 6.5 show that in some cases the measured speeds very closely followed those set by the actuator, but that in some cases larger differences did occur. But the larger differences only occurred in one area and related to a specific vehicle manoeuvre when turning. But when implementing AUTS as a more permanent applications these effects have to be minimised in order to improve ride comfort for passengers.

Calculated Jerk

Values for jerk were not directly measured as part of the log files. But an understanding of the jerk experienced by passengers was crucial as this a very important parameter to characterise the performance of the system in terms of safety and comfort. Therefore the values for jerk were calculated from the measured speeds. As a direct calculation from the tenth of a second intervals recorded in the logs would result in large unrealistic outliers, the values have been smoothed using the following equation:

$$jerk(i) = \frac{\sum_{i=1}^{10} acc(i+1) - \sum_{i=1}^{10} acc(i)}{1\sec}$$

Where acc(i) presents acceleration measured at 10 times per second

Figure 6.6 below shows a profile of the jerk values over the 5min log period for one data set for scenario 1. As described in the overall results section, values for jerk generally were below set benchmark values as well as observed values from other public transport vehicles. The figure shows that larger values for jerk occured only as peaks for very short periods of time. In the ex-post user needs analysis the perception of jerk has been positive, except for specific vehicle manoeuvres such as slowing down in case of obstacle detection and emergency stops. These specific situations have not been covered by the data collection, therefore no data is available for this.

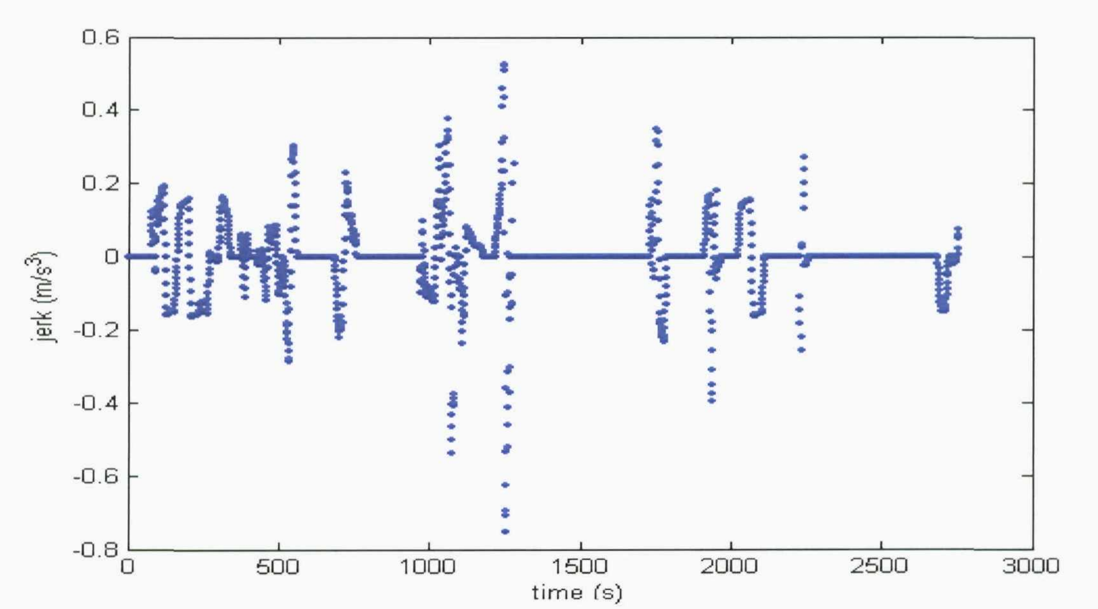


Figure 6.6: Profile of Jerk over Time

6.2.3 Positioning Errors

Measurement Procedure and Accuracy

At this test site vehicle navigation was carried out by the vehicle detecting electro-magnetic markers located within the road surface. These markers are located in distances of 2-3m along the vehicle path. The vehicle data logs include data on actual vehicle location in relation to this pre-defined path.

The location of the magnets are measure using a 'magnet ruler' (technology patented by FROG Navigation Systems) underneath the vehicle. The magnet provides a pulse and based on the position of the magnet relative to the location where the vehicle is expected, the deviation from the pre-defined path can be determined.

The place where the magnet is expected is coded into the system, measured by land meters using GPS giving the 'exact' co-ordinates of each magnet. Exact is in between parentheses as there is potential for measurement inaccuracies (e.g. the hole drilled for the magnet is wider than the magnet itself).

The maximum measurement error is 1cm. A magnet does not have to pass exactly in the centre underneath the vehicle, but for test sites such as at Antibes placement near-centre is typical. The magnet-ruler technology is very accurate near the centre, but the accuracy decreases at the far ends.

The maximum deviation at the far ends can be as large a 1cm. This means that the maximum deviation of a single measurement output could be 2cm, however, as multiple readings are combined to achieve a best fit, the values are corrected. Hence any measurement output will have deviations of less than 0.5cm.

In the following section an overview of the results in view of the recorded data for positioning errors is given. These errors have been recorded through the vehicle logs for lateral and longitudinal direction, and as orientation errors. Analyses are carried out on these data sets, examining values over speed and over time.

Results Overview

Vehicle positioning errors have been recorded in lateral and longitudinal direction and as orientation error. The general results have been described before in the overall results section. In order to get a better understanding of when and why these errors occur, the three different error parameters were analysed in relation to time and speed. This analysis is shown on the next six figures:

- Figure 6.7 shows the lateral error over time
- Figure 6.8 shows the lateral error over speed
- Figure 6.9 shows the longitudinal error over time
- Figure 6.10 shows the longitudinal error over speed
- Figure 6.11 shows the orientation error over time
- Figure 6.12 shows the orientation error over speed

The two figures for the lateral error show that over time error values are generally very low and that larger values only occur at very specific times when particular vehicle manoeuvres are carried out, including turning/ reversing at the start and end of the loop and when accelerating/ decelerating at the three stops. Error values over speed confirm that larger errors only occur at speeds close to zero.

The two figures for the longitudinal error show that over time error values are still low, but of a larger magnitude and over longer time intervals compared to the lateral errors. It can again be seen that larger errors occur when turning/ reversing at the start/ end of the loop and when accelerating/ decelerating at the three stops. Error values over speed show larger errors occur at low speeds and when reversing.

The two figures for the orientation error show that over time error values are also low, but like the longitudinal error of a larger magnitude and over longer time intervals. It can also be seen that larger errors occur when turning/ reversing at the start and the end of the loop and when accelerating/ decelerating at the three stops. Error values over speed show larger error occur at low speeds and when reversing.

As described above, the values from the vehicle data log for positioning errors in relation to the pre-defined (through detection of electro-magnetic markers in the road surface) vehicle path does have a deviation of less than 0.5cm due to measurement inaccuracies. Therefore the detailed results as described in this section have to be judged in view of the inaccuracies and limitations of the measurement procedure.

Lateral Error

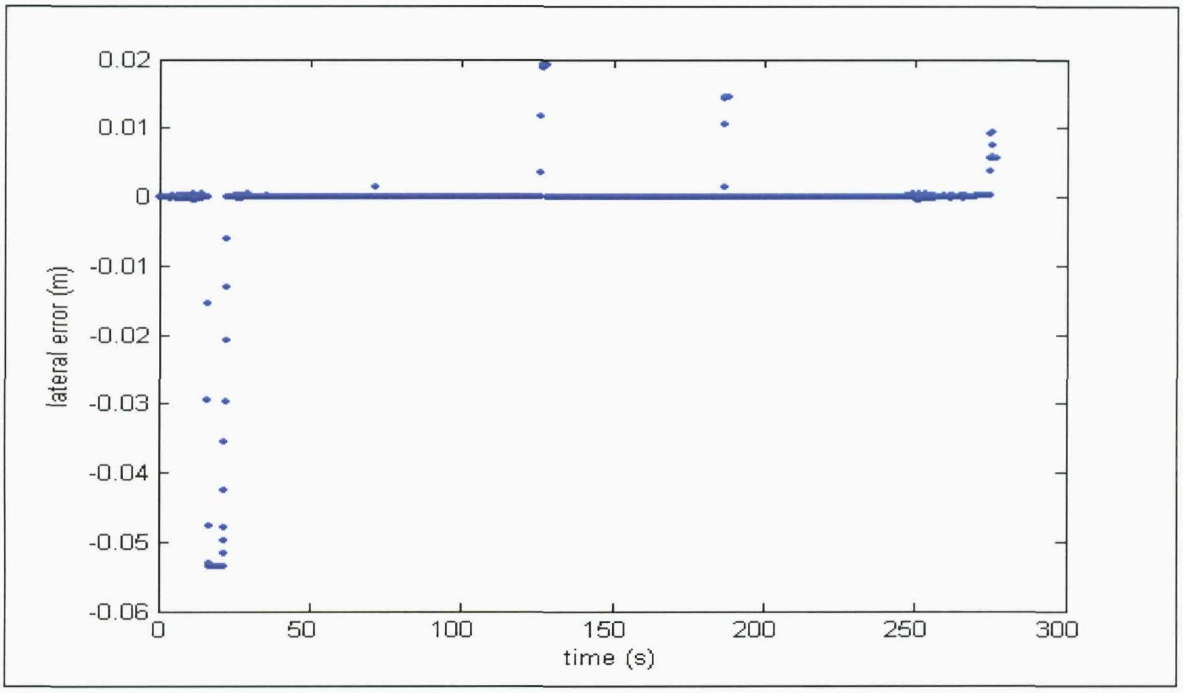


Figure 6.7: *Profile of Lateral Error over Time*

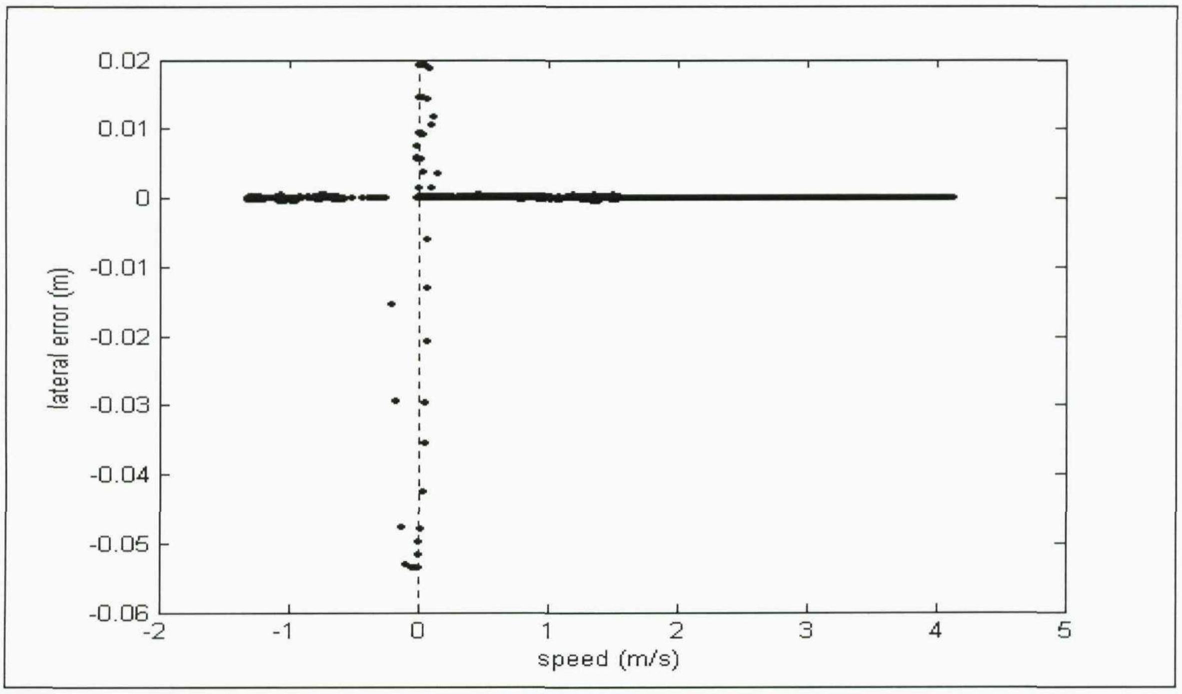


Figure 6.8: *Profile of Lateral Error over Speed*

Longitudinal Error

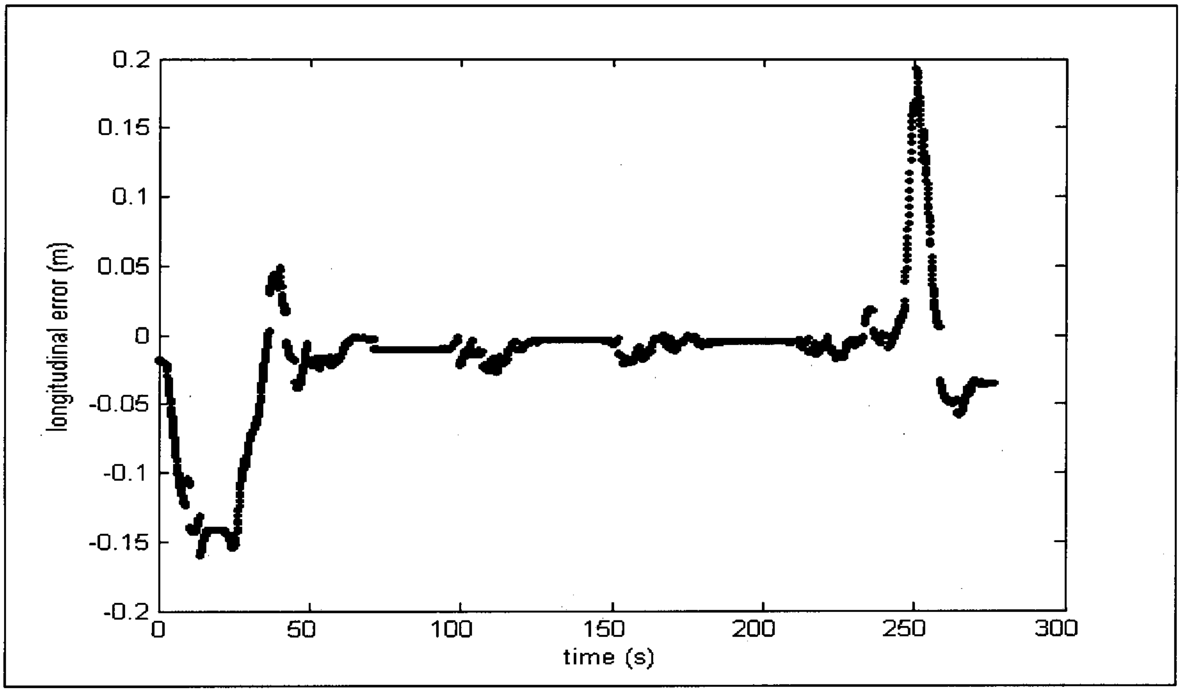


Figure 6.9: *Profile of Longitudinal Error over Time*

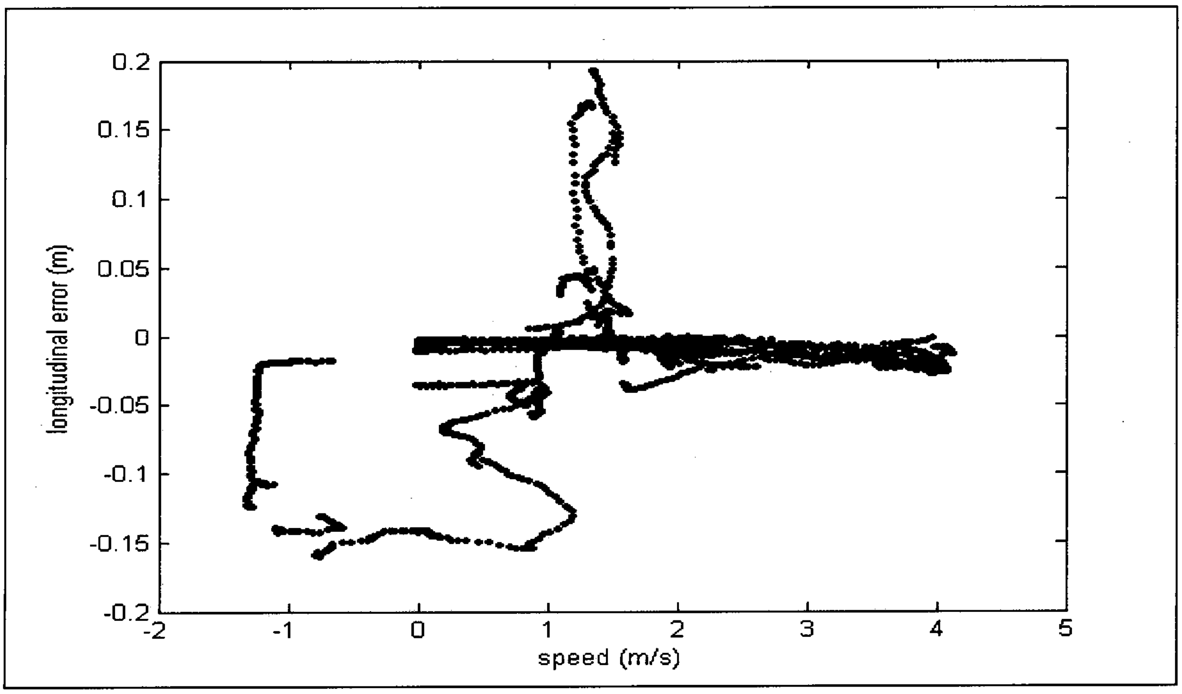


Figure 6.10: *Profile of Longitudinal Error over Speed*

Orientation Error

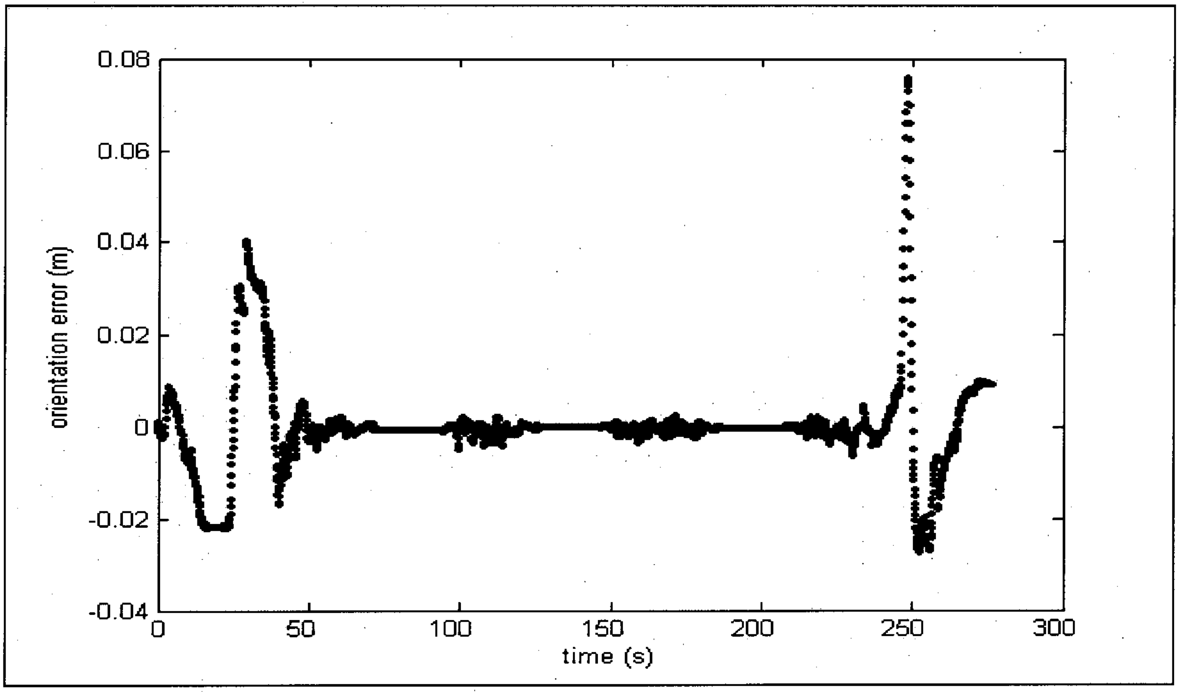


Figure 6.11: Profile of Orientation Error over Time

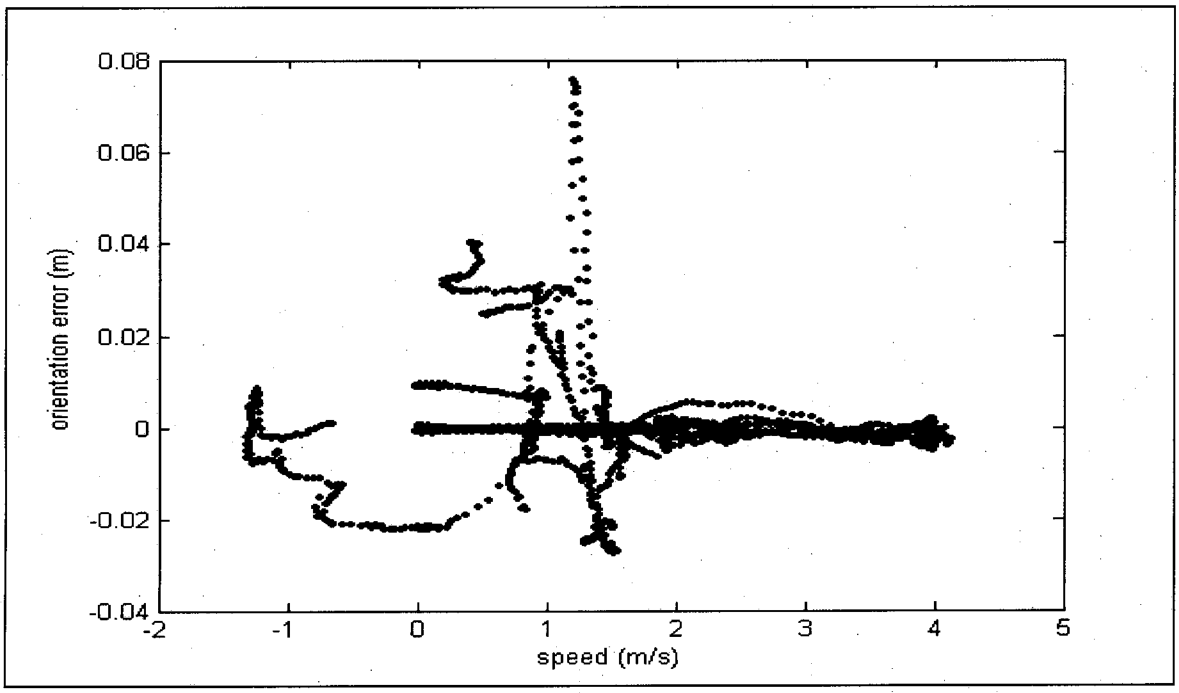


Figure 6.12: Profile of Orientation Error over Speed

6.3 Conclusion

6.3.1 Summary

In the earlier ex-post user needs analysis end-users rated the performance of AUTS, based on having used the system at one of the two public demonstration sites in Antibes and Coimbra. Their perception was generally very positive with high ratings of all parameters. The only less positive perceptions were of the vehicle performance in the case of specific situations such as obstacle avoidance or emergency stops. A next step in this study was then to analyse the actual vehicle performance.

The main objective of this performance assessment was to collect vehicle performance data on operation of the system. The analysis of this data then enabled a comparison between actual quantitative performance and perceived qualitative perception of the performance. Furthermore the actual performance could be compared to benchmark values and performance parameters of other transport systems.

More detailed objectives were to analyse if vehicle performance parameters are similar to those of other public transport vehicles, if there are any irregular values for any of the parameters (including speed, acceleration/ deceleration, jerk, lateral error, longitudinal error, and orientation error), when and why they occur, and what general relationships exist between these individual vehicle performance parameters.

The methodology used to meet these objectives was to collect data at the Antibes demonstration site. The on-board control unit was able to keep logs of all parameters described on a tenth of a second basis for the duration of 5min. This period of time covered one whole loop. 28 log files were recorded for two scenarios, one with three stops for passengers to board, and one with a continuous loop.

The 28 log files for the seven performance parameters over 5min periods recorded for tenth of second intervals resulted in a large data set with a sample size of approximately 81,000. This allowed a statistical analysis of the data. The analysis was carried out for the data overall and for specific vehicle performance parameters in more detail. In the following section the key results of this analysis are described.

6.3.2 Key Findings

Speeds were low with an average value of 5 km/hr and a maximum of 15 km/hr. This was due to the operating environment where the AUTS vehicle shared the infrastructure with a small number of pedestrians and cyclists. Therefore speed had to be low to enable the vehicle to stop in order to avoid any obstacles on the track. This had to be safe and comfortable for passengers in terms of acceleration and jerk.

The recorded values for acceleration and deceleration were all below benchmark values as well as below measured values from conventional public transport systems. From the acceleration data the jerk associated with this was calculated. These calculated jerk values were below benchmark values and were in the lower end of the range of values recorded for comparable conventional public transport systems.

Therefore generally the performance of the AUTS vehicle was comparable to existing public transport modes and offered improvements in ride quality and safety for passengers according to the analysis of acceleration and jerk. Acceleration mainly relates to comfort, whereas jerk relates to safety. Vehicle positioning errors were small, but mainly relate to site specific constraints and system operating characteristics.

When comparing the actuator speeds set by the on-board control unit and the actual measured speeds, it was found that overall the speed profiles were closely matched, but that in some areas larger differences existed. This will lead to a less smooth ride, resulting potentially in a lower perceived level of comfort for passengers. But this mainly occurred when specific vehicle manoeuvres (e.g. turning) were carried out.

When analysing the calculated jerk in more detail looking at the profile of jerks over time, it was found that larger values only occur at specific times and only as peaks over short periods of time. As the ex-post user needs analysis has shown good acceptance of the levels of jerk, these peaks were either not noticed because of their short time interval or were still at a sufficiently low level not to be an issue for comfort levels.

The vehicle positioning errors differed in magnitude for the values of lateral error, longitudinal error, and orientation error. But when analysing the error profiles over time, the same general trend could be identified. This was that the larger errors only occur when specific vehicle manoeuvres (i.e. turning, reversing, and stops) were carried out. This was also confirmed by an analysis of the error profiles over speed.

6.3.3 Discussion

The key results of this analysis as described above have a number of implications for further implementation of AUTS technology. As already discussed, the vehicle speeds are set and are generally a function of the operating environment and the system operation characteristics. The main factor determining the vehicle speeds is the level of interaction of the AUTS vehicle with other traffic.

The ex-ante and ex-post user needs analyses both revealed some concern of users over low vehicle speeds and thus long travel times. As this was due to limitations of the obstacle avoidance system in mixed traffic, the only option to address this issue is to fully segregate the AUTS infrastructure and to operate it on a dedicated track. But this can lead to other problems, including severance effects.

The measured values for vehicle performance parameters such as acceleration, deceleration, and jerk as described above were all within the boundaries for the safe and comfortable operation of public transport systems, but the quality of the performance was lower when carrying out specific manoeuvres. Therefore improvements have to be made to the performance for stops and turning movements

According to the ex-post user needs analysis (no measured vehicle data is available for this), the vehicle performance parameters were much less acceptable for slowing down for stops due to obstacle detection and for full emergency stops. This again was due to the limitations of the obstacle avoidance system and could therefore be addressed by a higher level of segregation of the AUTS infrastructure.

The vehicle positioning errors have to be assessed in relation to the system operating environment. Generally two scenarios could be identified, positioning errors on the track between stops, and positioning errors at the stop. In the first case errors did not affect the passenger experience and were only limited by space constraints. In the second case precision docking would be important for perception of comfort.

Overall the analysis of measured vehicle performance parameters reflected the generally high ratings by users in the ex-post user needs analysis. Generally the performance of the AUTS vehicle could match or even exceed the performance of other public transport system the public currently experiences. Small areas to be improved have been identified and potential solutions to these have been suggested.

7 MODELLING OF NETWORK-WIDE IMPACTS

7.1 Introduction

7.1.1 Background

Work in the previous chapters focused on attitudes to new advanced urban transport systems (ex-ante), experiences with AUTS-related systems and technologies, and results from first small-scale applications (ex-post user needs and vehicle performance assessment). As at this stage in the development process for these systems no large-scale applications have been possible to implement, no results were available. Therefore in order to obtain some first indications of potential impacts of a large-scale application, as the final stage of this research modelling and simulation tools had to be used.

An analysis of the network-wide system impacts of such a large-scale system was necessary to give further results in addition to those from the previous research activities, which all focused on small-scale application which were already in operation or could be implemented in the short-term future. Results of these previous research activities were encouraging in view of the potential of AUTS to provide more sustainable mobility in urban areas. But this is only based on small-scale applications, and therefore large-scale applications could only be considered after an analysis of their impacts.

7.1.2 Objectives

The overall aim of this network simulation was to investigate the use of a large-scale AUTS application as part of an improved overall public transport system in an urban area. The potential future operating scenario used here involved the creation of a car free city centre. There is some evidence, that traffic restrictions in city centres (mostly implemented for limited times) together with a variety of accompanying measures and provision of improved public transport can lead to a more attractive urban environment without adverse effects on businesses and mobility (Crawford, 2002).

But it will be more likely to be implemented as an evolutionary process, starting with road user or congestion charging schemes (Beevers, 2004). The more detailed objectives were to define a potential future operating scenario for AUTS, to test this scenario using modelling/ simulation tools, and to identify potential impacts and to interpret for future applications. The study focused on modal changes of commuter trips into the city centre in the morning peak from the private car for the whole journey to a multimodal trip involving a combination of conventional public transport and AUTS.

7.1.3 Methodology

General Approach

In order to meet the objectives of this study as described above, a network wide simulation of the impacts of a large scale AUTS implication was carried out using a modelling software package. As the implementation process of this technology is still at an early stage, no plans for an implementation of this size exist. Therefore any generic city network can be used for this simulation.

The existing situation in Southampton was used as the baseline scenario against which the results of the modified network (AUTS scenario), that takes account of the newly introduced transport strategy, were compared and evaluated. Effects being investigated included journey times, distances and speeds for the whole network, for the P&R shuttle bus corridors and for specific targeted commuter trips into the city centre.

The model contains the geographical data for all roads and junctions (links and nodes) and data on the respective traffic flows for the AM peak. Thus the main input files which are required are the origin to destination matrix and the network file of the simulated road network. This can then be edited to reflect the scenario to be simulated, and the differences in impacts can be compared.

Modelling Requirements

Due to the nature of the general approach to the modelling as described above, and the fact that this last step in the analysis process for AUTS in this study is to examine a large scale AUTS application, a network wide macro simulation software was chosen as the appropriate tool. There are a number of widely used macro-simulation packages, including CONTRAM, SATURN, and CUBE.

For this network wide simulation of the impacts of a large scale AUTS application the CONTRAM modelling package has been chosen. The initial reasons for this were that it is a well-established dynamic assignment model based on traffic flow interaction, that it was available in TRG, and that it already contained the complete network and O-D matrix data for the city of Southampton through earlier research.

The CONTRAM modelling software that has been chosen for this study uses 'packets' of vehicles (thus choosing a packet size of one represents modelling individual vehicles) and allows for the variation of traffic conditions over time. This enables the simulation of growth or decay of congestion through time.

To take account of congestion delay generated, CONTRAM uses an iterative procedure for assigning packets, which is repeated until a satisfactory convergence is reached. Multi-routing is possible as routes taken for different packets travelling from the same origin to the same destination may be different.

Output includes traffic flows, delays, queues, journey times and average speeds for each time slice and network link. Additionally the routes used by each vehicle are recorded. Further advantages include modelling of various junction types and the ability to assign fixed routes to specific vehicles (e.g. buses).

A comparative review of the models described above revealed that CONTRAM satisfied the requirements specification for this modelling, given that the scenario being examined was a car-free city centre. This scenario, although extreme, meant that modal split for trips to the city centre had to be fixed.

Other sensitivity tests were also conducted using fixed proportions of public transport use/ modal change. If these scenarios proved to be promising, further research which is beyond the scope of this thesis could then be envisaged, involving full multi-modal modelling including modal choice estimation.

Southampton Model

The network simulation was carried out, using an existing model for the city of Southampton, based on the CONTRAM software package. For the Southampton model used for this study, the O-D matrix was developed by a consultancy using an extensive range of interview surveys that have been conducted in 1992-93. These interviews enabled O-D data to be estimated for most of the Southampton area. The network file was developed by TRG in 1993-94 for research purposes, and later updated in 1996 to include road network modifications.

The model was calibrated by comparing modelled flows and turning movements with observations. The modelled flows were shown to be generally in the region of 95% of the observed flows. Observed and modelled journey times were also used as a basis for calibration of the model. Two models were subsequently developed, one for the AM and one for the PM peak period. This study is based on the AM peak, thus focusing on commuter trips to the city centre.

In the following some information about the city of Southampton and the Southampton CONTRAM network will be given. Southampton is a major regional centre in Hampshire in the south of the United Kingdom (see Fig. 7.1). It covers an area of 5,200 hectares with a population of some 215,000 residents and serving a hinterland of 0.5 million. As a port city, access to the centre is constrained by the Rivers Itchen and Test, which converge on Southampton Water.

The road network is mainly radial in nature, with a motorway (M27) skirting the northern edge of the city. A short stretch of motorway (M271) links the M27 with the western area of the city, including access to the western docks of the port. The main roads connecting central Southampton with surrounding areas include the A33 (connecting M3), the A35, the A335 (connecting junction 5 of the M27), the A3024 (connecting junction 7 and junction 8 of the M27), the A3025, and the A3057.

The Southampton CONTRAM network (see Fig. 7.2) consists of 2484 links (525 signalised, 545 give-away, 1414 uncontrolled), 780 nodes (114 signal controlled junction, 48 round about, and other junctions). Total link length is 793 km for the network.

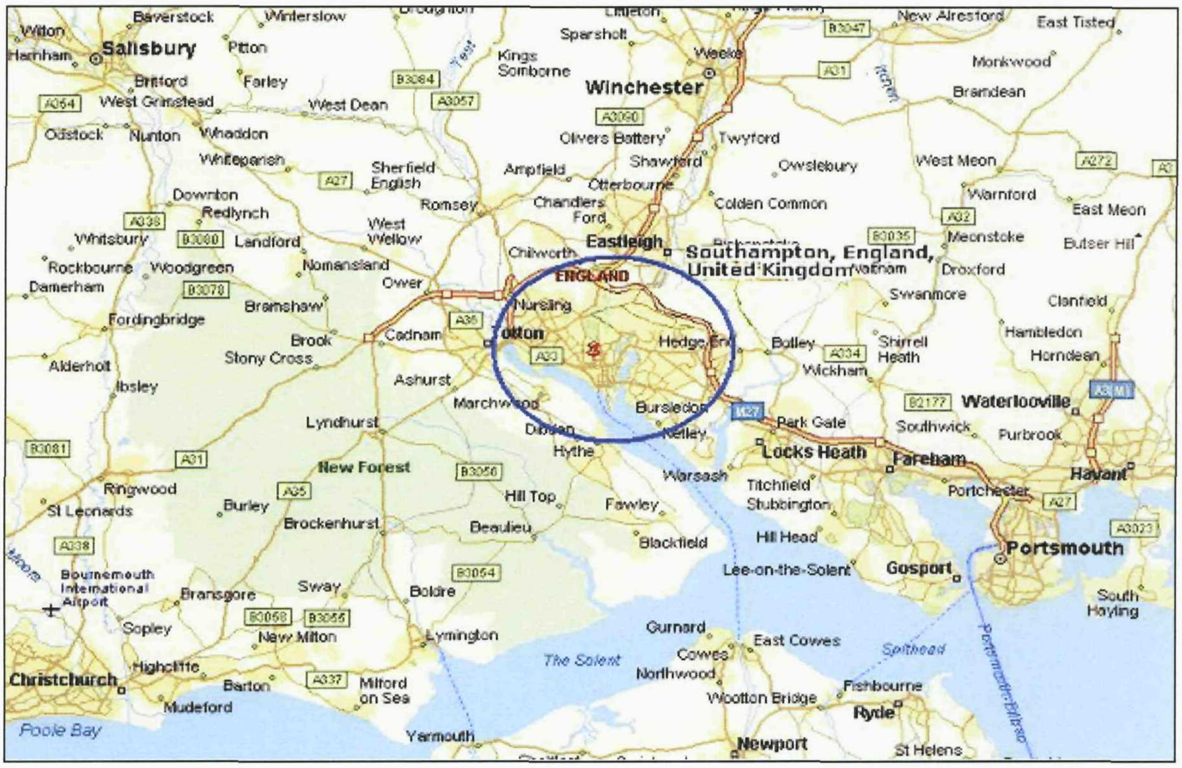


Figure 7.1: *Map of Southampton/ Hampshire*

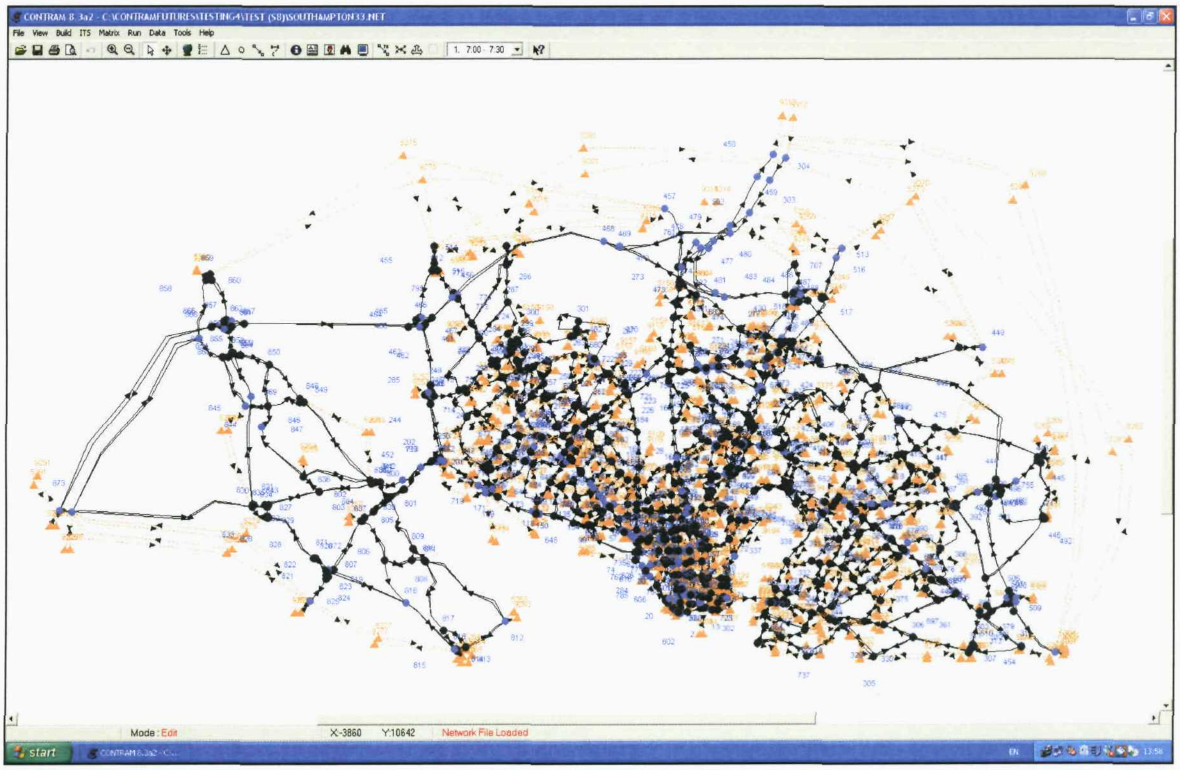


Figure 7.2: *Southampton CONTRAM Network*

7.2 Analysis

7.2.1 AUTS Scenario

Application Description

The AUTS application scenario investigated in this study will operate in the assumed car free city centre to cover the last part of the multimodal commuter journey to places of work within the city centre and for local city centre movements.

The improved public transport system, which will cater for the increased demand due to restrictions to the private car in the city centre, consists of high-frequency P&R buses, which connect the P&R sites and the central interchange.

Therefore the typical commuter trip from origin (residential areas in suburbs outside the M27 boundary) to destination (place of work in the city centre), which will be analysed as part of this study, consists of the following steps (see Fig. 7.3):

- Trip origin to P&R site by private car
- Interchange to P&R shuttle bus service
- P&R site to city centre interchange by bus
- Interchange to AUTS vehicle
- Interchange to destination by AUTS

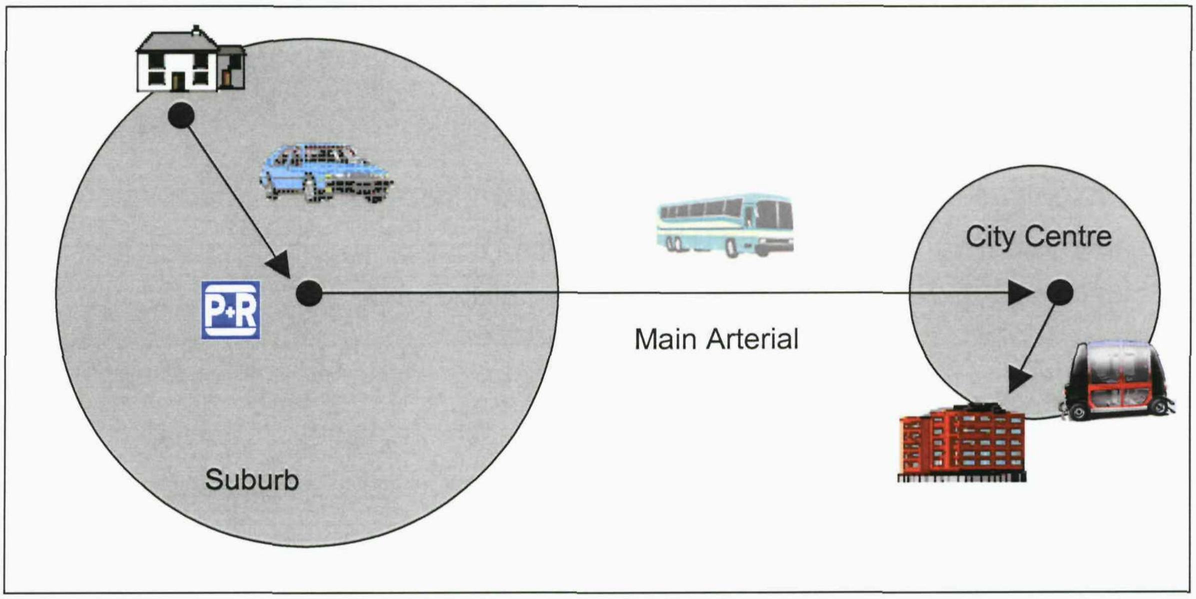


Figure 7.3: AUTS Application Scenario

These P&R shuttle buses are assumed to go directly from the P&R site to the city centre interchange without stops (journey times could be further improved through implementation of bus priority schemes). Additional buses (similar to services currently in operation) on the same corridor will provide stopping services for passenger not using the P&R system, e.g. those living in the area between the P&R sites and the city centre.

According to the existing road infrastructure network in Southampton six main arterial leading from junctions of the M27/ M271 motorways towards the city centre can be identified. Therefore six P&R sites where assumed to be located near the motorway junctions with a P&R shuttle bus services to be operated on the six main arterials/ corridors (see Fig. 7.4).

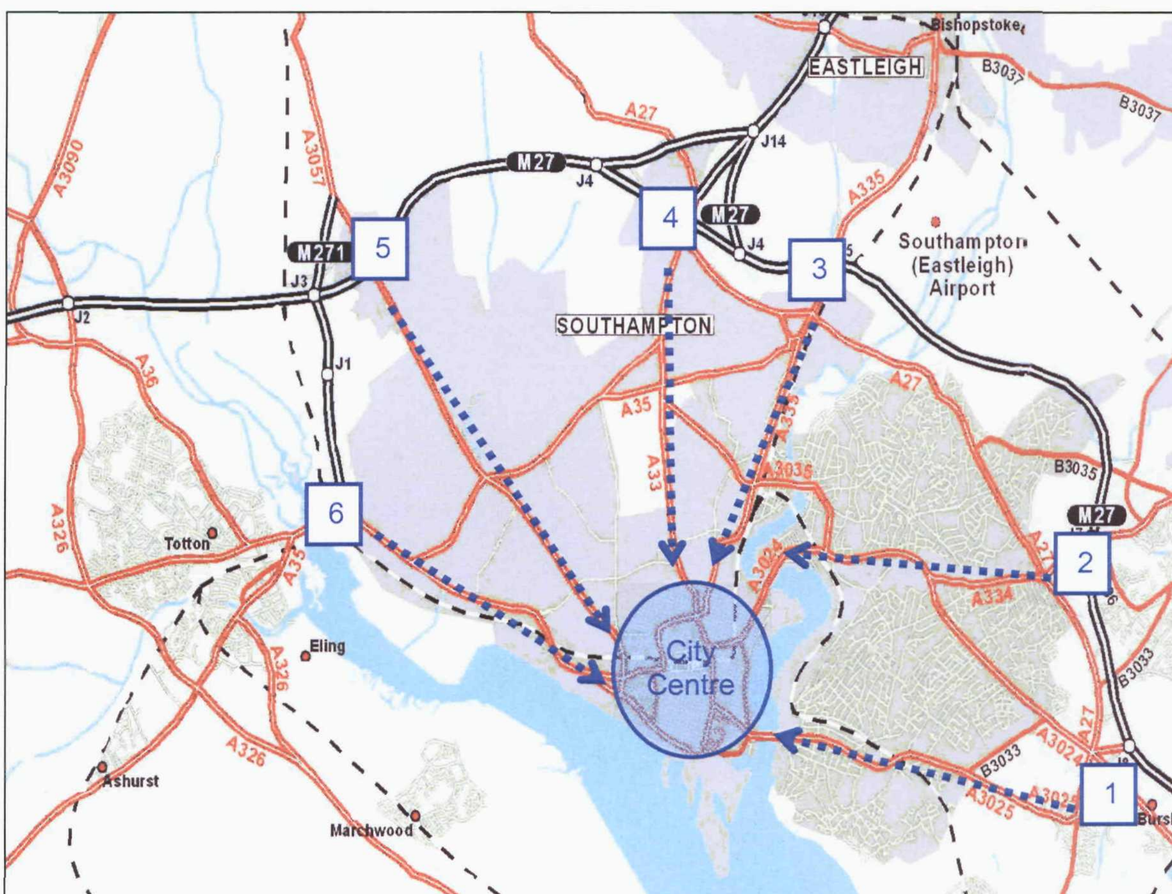


Figure 7.4: Location of P&R Sites/ Bus Corridors

Modelling Assumptions

Table 7.1 shows a summary of the approach used for the Southampton AUTS network modelling activity, including objectives, indicators and the general background.

Summary of Simulation Approach		
Objectives/ Indicators	**Network/ Demand/ Trips**	**Transport Strategy**
Objectives To assess AUTS impacts on traffic efficiency at network level, in view of bus corridors and for specific commuter trips Indicators *Network-wide (total)* - Journey time [veh-hr] - Distance [veh-km] - Network speed [km/hr] *Bus-Corridors (in/ outbound)* - Travel time [min] - Vehicle speed [km/hr] *Commuter Trip* - Journey time [min]	Network - Car trips to/ from city centre - Additional bus corridors Demand - AM and PM Peak periods - Trips to/ from city centre Trips *Short Trip* - Car - Walk + Bus + AUTS *Medium/ Long Trip* - Car - Car + P&R + Bus + AUTS - Car + P&R + Train + AUTS	Car-free City Centre Car-free city centre, therefore all journeys between the city centre and all other areas have to taken by public transport (e.g. train, bus and AUTS). AUTS in this situation work as a supplement to major public transport in the city centre area being responsible for feeding or collection to/from major stations (bus, coach, train etc), high streets and other attraction points in the city centre.

Table 7.1: Summary of Simulation Approach

A crucial assumption for this modelling activity is the modal shift from private car to the suggested multimodal P&R strategy for commuting trips. Commuting trips can be grouped into two main categories, short journey and medium/ long journeys.

Short journeys are those which originate from the area between the motorways M27/ M271 and the city centre. Commuters from this area are assumed not to use the P&R scheme as this is further from their destination, but it is assumed they will use local buses or the buses from the P&R site en-route to get to the city centre.

Medium/ long journeys are those which originate from outside the area surrounded by the motorways M27/ M271. Commuters from this area will therefore use private cars to get to the P&R site and then continue the multimodal journey described before.

To maintain capacity on the six main bus corridors, it was assumed that a sufficient proportion of the overall travel demand will switch from private car to the multimodal P&R system for their daily commuting trips. It was also assumed that all private car trips to the city centre from outside the M27 would be replaced by the new P&R system.

The main objectives of the network modelling of the Southampton AUTS application are to assess AUTS impacts on traffic efficiency at the network level, in view of the bus corridors and for specific commuter trips. This is based on the transport strategy of creating a car free city centre with an AUTS application in the city centre.

Therefore all journeys between the city centre and all other areas have to be taken by public transport. The AUTS application in this situation works as a supplement to existing public transport in the city centre area, responsible for feeding or collection to/ from major stations, high streets and other attraction points in the city centre

The AUTS scenario assumes a 100% modal change from private car to the multimodal journey for both, short and medium/ long journeys. In case of the short journeys, private car will be directly replaced by buses. In the case of the medium/ long journeys, private car will be replaced by Car+P&R+Bus+AUTS (see Table 7.2).

Summary of Simulation Assumptions		
Scenario	Short journey	Medium/ Long journey
Baseline Scenario	Car: 100%	Car: 100%
AUTS Scenario	Car: 0%	Car: 100% to/ from P&R
	Bus: 100%	Car+P&R+Bus+AUTS:

Table 7.2: Summary of Simulation Assumptions

The indicators, which will be used to compare and evaluate the baseline scenario and the AUTS scenario as described above, can be grouped under three main categories: network-wide, bus corridors and specific commuter trip. The specific indicators include journey times, network distances and vehicle speeds.

Demand Data

According to the modelling assumptions as described above, the demand data has been changed reflecting these assumptions, in order to study the impacts of the AUTS scenario. The results from this analysis can then be compared to the impacts of the original demand data (=baseline scenario). Parts of the demand data that have been altered for this are trips originating from outside the city centre that have the city centre as the final destination for the am peak and vice versa for the pm peak.

The trip destination/ origin 'city centre' has been defined here based on the area shown in figure 7.4 above. In the Southampton CONTRAM model this area consists of a number of zones that have been combined for this analysis. For all trips that have been affected by alterations according to this, two different cases can be distinguished, i.e. short journeys and medium/ long journeys. These two cases relate to the location of the trip destination/ origin in relation to the area enclosed by the M27/ M271 motorways.

Short journey are defined as trips from/ to within this area and medium/ long journeys are defined as trips from/ to outside this area. For the medium/ long journey all the affected demand data has been altered to a combination of private car trips to the nearest P&R site and then bus trips on newly defined bus corridors. For the short journeys all the affected demand data has been altered to walking to the nearest bus stop and then bus trips, using the same bus services on the newly defined bus corridors.

When replacing private car trips by bus trips on the newly defined bus corridors as part of altering the demand data to reflect the AUTS scenario, a maximum occupancy rate of 50 passengers per bus has been assumed. All other demand data, which has not been affected by the AUTS scenario has remained unaltered. Initially a modal change of 100% has been assumed, but in the following sensitivity analysis the impacts of different lower modal change rates (25%, 50%, and 75%) have also been analysed.

Practical Issues

As described above, a key assumption for the AUTS scenario was the high (up to 100%) modal change from private car to the multi-modal public transport journey for all commuter trips into the city centre in the AM peak. Due to the real or perceived higher comfort and convenience of the private car (as seen in the ex-ante user needs analysis) it would be very difficult to achieve such a high modal change.

The proposed AUTS application will offer a much improved public transport experience, closer to the private car, than conventional public transport. But market education might be needed (as seen in the ex-post user needs analysis) to raise the public awareness for this. Furthermore a number of accompanying measures can be introduced in parallel to implementing AUTS in order to achieve a high modal change

Potential accompanying measures for the AUTS scenario are:

- Road User Charging
- Congestion Charging
- Bus Priority Schemes
- Car Parking Restriction
- City Centre Access Control
- Increased Parking Fees
- Public Transport Subsidies

In practice a very high modal change can only occur with a complete restriction of private vehicles in the city centre together with accompanying measures. Although the assumed car-free city centre and accompanying measures specifically designed to discourage commuters to use private cars will have a strong influence on the modal choice for commuter trips, the assumed modal change is clearly an extreme case.

Therefore the magnitude of the positive traffic impacts of this scheme, as described in the results section of the AUTS network simulation study, might also be unrealistic, depending on the effectiveness of the measures introduced and other individual behavioural impacts. In order to assess the effects of lower modal changes on the potential impacts of the scheme a sensitivity analysis has been carried out.

7.2.2 System Impacts

Network-wide Results

In the following section the general network-wide traffic impacts of the cybercars scenario as compared to the baseline scenario is described

	Network-wide Results		
	Total Time [10^3 veh-hr]	Distance [10^3 veh-km]	Network Speed [km/hr]
Baseline Scenario	21.24	915.39	43.55
AUTS Scenario	13.45	747.01	56.13
Improvements	37%	18%	29%

Table 7.3: Network-wide Results of the AUTS Application

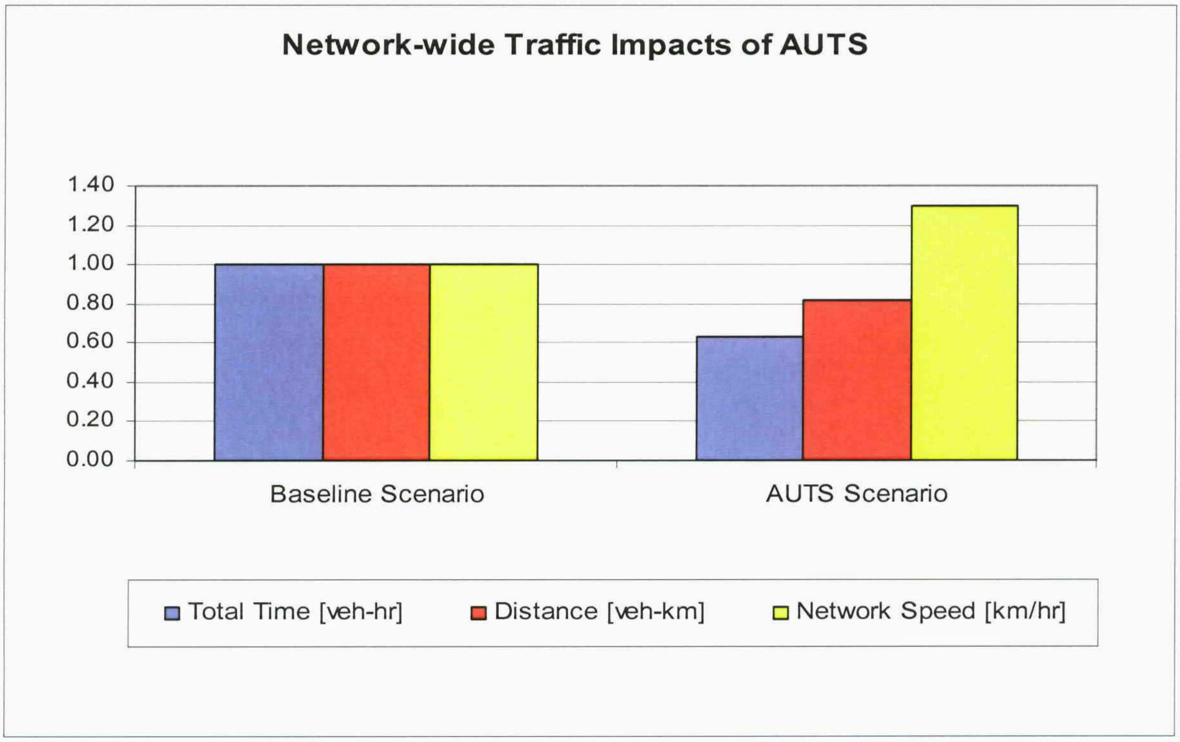


Figure 7.5: Network-wide Traffic Impacts of AUTS

The above table/ figure shows that the introduction of a P&R service on six main corridors leads on a network-wide level to a reduction of 37% in total travel time, an 18% reduction in distance and an increase of 29% in network speed.

These benefits are due to a combination of 2 factors:

(i) There are now considerably fewer vehicles travelling in the network, as many car journeys have been substituted by bus. This also automatically reduces the journey time and distance travelled figures.

(ii) Higher average speeds in the network because of the reduced amount of traffic.

The extent of these benefits is based on to the assumed 100% modal shift from private car to the combination of private car, P&R, shuttle bus, and AUTS in the city centre. As this is an extreme scenario, this extent might not be realistic.

In order to address this issue, a sensitivity analysis has been carried out following the main analysis of the modelling results in order to examine the changes in extent of the benefits based on a series of lower assumed modal change values.

Results for Bus Corridors

In the following section the traffic impacts on the bus corridors of the cybercars scenario as compared to the baseline scenario is described.

		Results on Bus-Corridors	
		Travel Time [min]	Vehicle Speed [km/hr]
Baseline Scenario	Inbound	16.97	22.87
	Outbound	11.30	34.20
AUTS Scenario	Inbound	13.76	30.77
	Outbound	11.22	33.39
Improvements	Inbound	19%	35%
	Outbound	1%	2%

Table 7.4: Results on Bus Corridors for the AUTS Application

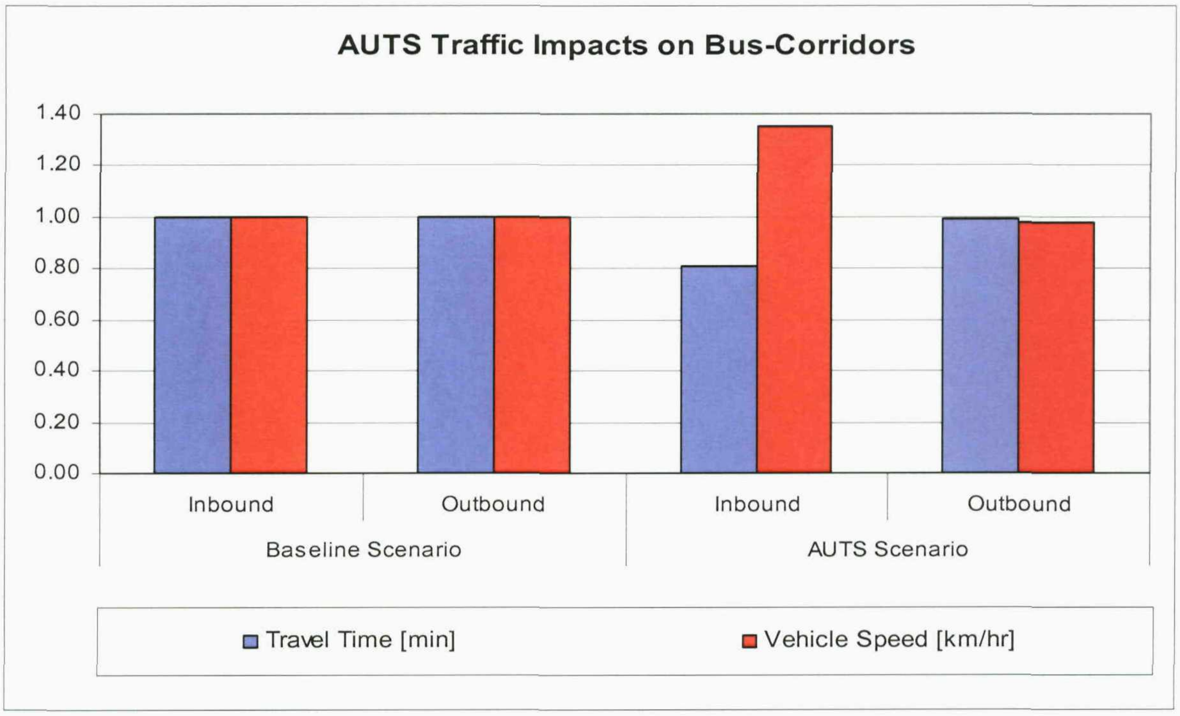


Figure 7.6: AUTS Traffic Impacts on Bus Corridors

The above figures show that the introduction of a P&R service on the six main corridors leads on the corridor level to reductions in travel time of 19% and to an increase in vehicle speeds of 35% for the inbound trips. But for the outbound trips only small changes can be observed, with a reduction in travel time of 1% and even a slight decrease in vehicle speeds of 2%.

As described before, the extent of these benefits (in case of the inbound trips) is mainly due to the considerably reduced number of vehicles in the network. Also these benefits are based on to the assumed 100% modal shift from private car to the combination of private car, P&R, shuttle bus, and AUTS in the city centre. But as this is an extreme scenario, this extent might not be realistic.

The only marginal differences for the outbound results are due to the fact that as part of the AUTS scenario only commuter trips originating from outside the city centre with the city centre as the trip destination in the AM peak were affected. Therefore large impacts can be observed for trips towards the city centre, but all outbound trips are not affected by changes to the demand data.

Results for Commuter Trips

In addition to the network-wide and bus corridor data, complete commuting trips from homes to places of work will be compared. With the baseline scenario being a direct trip using private car, and the cybercars scenario being a multimodal journey using private car + P&R + bus/ train + AUTS.

When calculating the time for the multi-modal trip, transfer time, waiting time (for the bus/ train at the P&R site and for the cybercars in the city centre) and the travel time using the cybercars in the city centre have to be considered. Figure 7.7 shows a comparison of the individual trip steps for baseline and AUTS scenario.

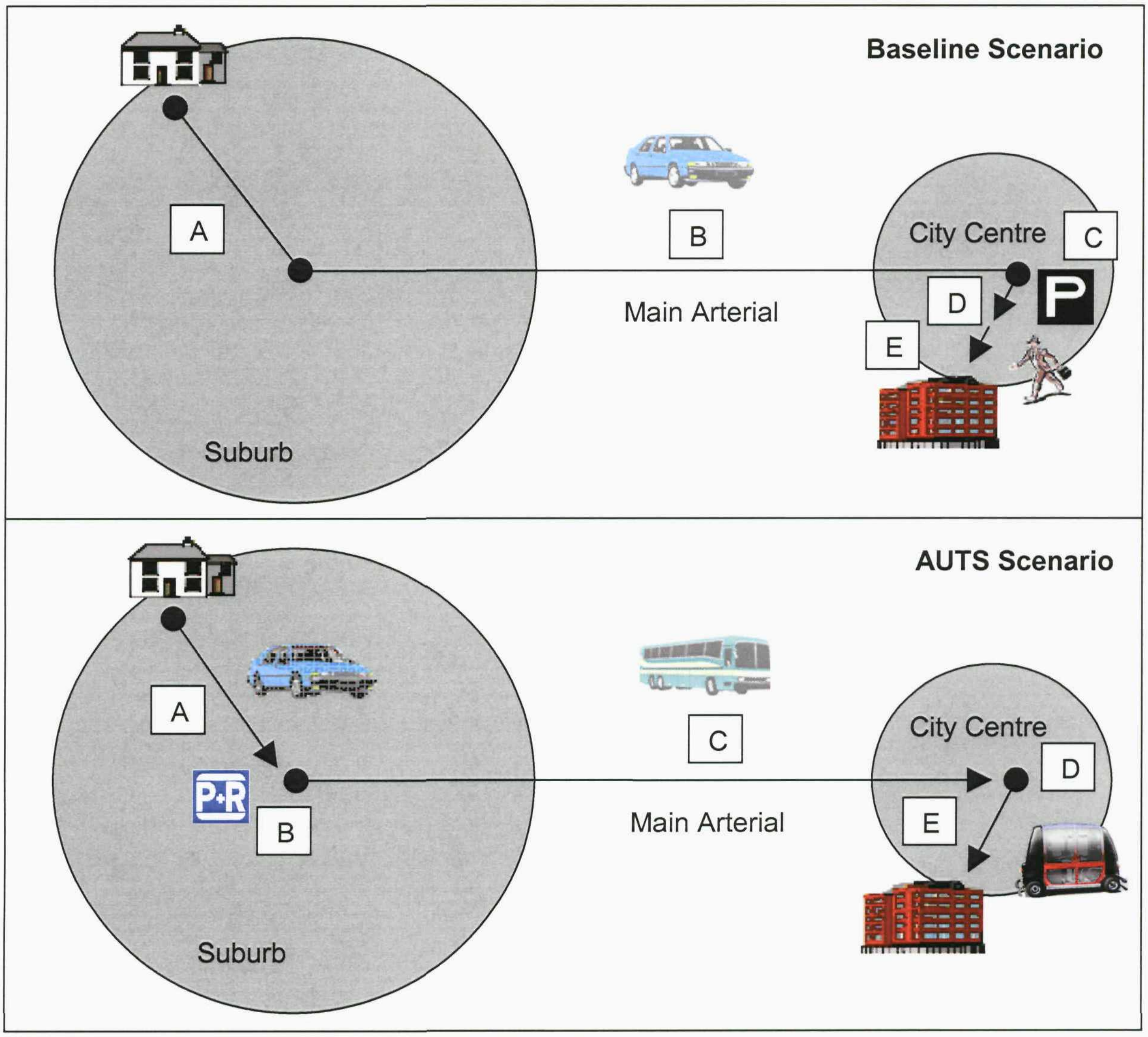


Figure 7.7: *Comparison of Baseline and AUTS Scenario*

Table 7.5 below shows the calculation of overall travel times for commuter trips for baseline and AUTS scenario for all trip steps as illustrated in Figure 7.11.

		Trip Stages					Sum
		A	B	C	D	E	
Baseline Scenario	Description	Suburb to Arterial	Arterial	Arterial to City Centre	Parking	Car park to Office	
	Mode	Private Car	Private Car	Private Car	n/a	Walking	
	Travel Time	2.7	16.8	1.5	2.0	2.0	25.0
	Data Source	Model	Model	Model	Assumption	Assumption	
AUTS Scenario	Description	Suburb to Arterial	Interchange	Arterial	Interchange	Interchange to Office	
	Mode	Private Car	n/a	Bus	n/a	AUTS	
	Travel Time	2.1	5.0	11.2	1.0	3.0	22.3
	Data Source	Model	Assumption	Model	Assumption	Assumption	

Table 7.5: Commuter Trip Travel Times

The data source for each of the journey steps is indicated in the above figure. The 3min travel time for the AUTS journey is based on an average distance of 1km and an average speed of 20km/hr. This assumed speed relates to a car-free and uncongested environment and limited interaction with pedestrians/ cyclists.

In the baseline scenario the private car is used from the trip origin directly to a car park near the trip destination. This is followed by finding a parking space and then walking the last section of the trip to the final destination. In the AUTS scenario this is replaced by the multi-modal journey as described in the figure above.

The calculation shows that the multimodal journey in the AUTS scenario can offer comparable, or even slightly lower, travel times to the journey using private car. But as mentioned above, this is based on the assumption of high (or even 100%) modal change from private car to the P&R scheme for commuter journeys.

Compared to the results presented before this is only a relatively small improvement, but this is due to the fact that a multi-modal public transport journey is being compared to a direct trip by private car. Trip times have to be at least similar, but overall network effects and sustainability impacts are the main objective.

Future large-scale applications of AUTS, based on the small-scale application used for this study, replacing the multi-modal journey by a direct door-to-door cybercars service has the potential of providing much improved travel times compared to the private car, whilst still maintaining the environmental benefits.

In the case of the direct door-to-door AUTS service e.g. lengthy interchange times can be avoided. Furthermore this application would also have the potential to offer similar levels of convenience and comfort as the private car, whilst at the same time offering most of the advantages of a public transport system.

As described before, all benefits are based on to the assumed 100% modal shift from private car to the multi-modal AUTS scenario. But as this is an extreme scenario, this might not be realistic. Therefore a sensitivity analysis has been carried out. The results from this analysis are described in the following.

7.2.3 Sensitivity Analysis

As described before, the main assumption for this network modelling study was a 100% modal change from private car for morning peak trips into the city centre to a combination or private car, park&ride, shuttle bus and AUTS. Although the assumed car-free city centre and a variety of accompanying measures specifically designed to discourage commuters to use private cars will have a strong influence on the modal choice for commuter trips, a 100% modal change might not be realistic.

Therefore the magnitude of the positive traffic impacts of this scheme might also be unrealistic, depending on the effectiveness of the measures introduced and individual behavioural impacts. In order to assess the effects of lower modal changes on the potential impacts of the scheme a sensitivity analysis has been carried out. For this the same simulation as before has been carried out with the demand data changed to reflect a range (25%, 50%, 75%, and 100%) of modal change values.

Table 7.6 below shows the results of this sensitivity analysis, describing the network-wide impacts for a variety of assumed modal change values. The modal change values shown are 25%, 50%, 75%, and 100% (original analysis) respectively. For each the total time, total distance and network speed are given in addition to the values for the baseline scenario. The values in brackets show the percentage of improvements of each of the modal change values compared to the baseline scenario.

Network-wide Results for Different Values of Modal Change				
		Total Time [10^3 veh-hr]	Total Distance [10^3 veh-km]	Network Speed [km/hr]
Baseline		21.24	915.39	43.55
Modal Change	25%	15.22 (28%)	797.16 (13%)	52.91 (21%)
	50%	14.59 (31%)	781.35 (15%)	54.08 (24%)
	75%	14.01 (34%)	765.77 (16%)	55.10 (27%)
	100%	13.45 (37%)	747.01 (18%)	56.13 (29%)

Table 7.6: Network-wide Results for Different Values of Modal Change

Figure 7.8 below shows the percentages of network-wide improvements in total time, total distance and network speed for the four modal change values (25%, 50%, and 75%) that have been examined as part of the sensitivity analysis for CONTRAM modelling of the Southampton AUTS scenario.

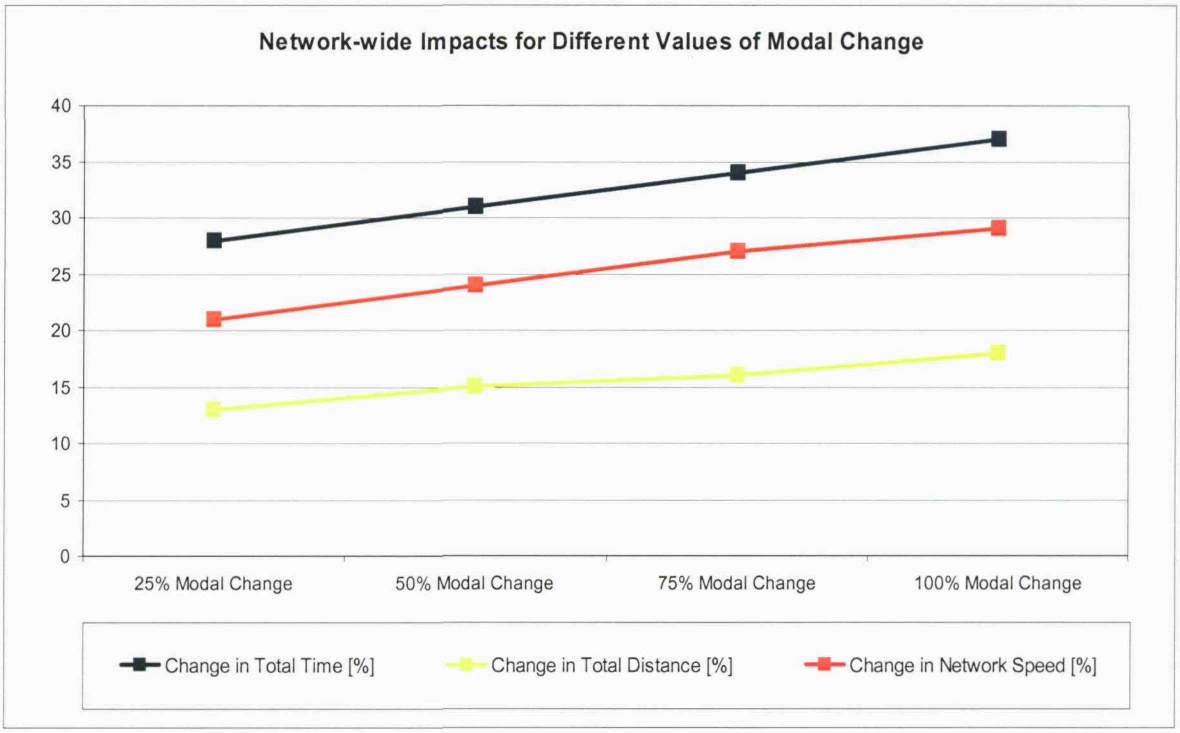


Figure 7.8: Improvements for Different Values of Modal Change

As was expected, it can be seen from the figure above, that the improvements are the lowest at 25% modal change and that each of the values gradually increase for the higher modal changes with maximum values at the previously assumed 100% modal change from private car to the AUTS scenario. For the total time the improvements range from 28% to 37%, for the network speed the improvements range from 21% to 29%, and for the total distance the improvements ranged from 13% to 18%.

Whilst maximum values for improvements of network-wide impacts can only be achieved at a modal change value of 100%, this sensitivity analysis has shown than even at the lower end of the modal change values analysed considerable improvements can be expected. For the lowest modal change value of 25% the improvements are 13% for total distance, 21% for network speed, and 28% for total time.

7.2.4 Feasibility Study

General Approach

The previous sections of this network simulation study have dealt with implications of a large scale AUTS application. For this the suggested application and its context within the larger multi-modal system have been described. A number of assumptions have been made for this, and the realism and implications of these assumptions have been discussed. In this section the practical details and implications will be analysed in order to study the feasibility of the proposed scheme.

The feasibility study for the AUTS scenario includes the following main sub-sections, which will be described in more detail:

- User Needs
- Demand Data
- System Requirements
- Infrastructure Requirements
- AUTS Operation
- Business Case
- Traffic Management
- Policy Implications
- Future Work

User Needs

User needs and requirements for this AUTS scenario, based on the findings of the earlier ex-ante as well as ex-post user needs analyses relate to traffic safety and security, operating environment, travel time and vehicle speeds, and vehicle performance. Vehicle operation in a mixed environment with limited interaction with pedestrians and cyclists would be acceptable to end users, but the absence of a driver would have implications for personal safety of travellers.

This could be addressed through security systems (e.g. CCTV, intercom to staffed operations centre, etc.) but staff presence might be necessary especially at times of low demand (evening/ nights). Furthermore, although the system is capable of operation in mixed traffic, disruptions to the vehicle trip are perceived as very uncomfortable and should therefore be avoided through discouraging or disabling other traffic to use the AUTS infrastructure.

Demand Data

One of the main design parameters for the city-centre AUTS application is the peak hour demand. This is the maximum demand the system is required to cater for. Passengers will arrive at the main city centre bus stop on the shuttle buses from the park&ride sites. As part of the modelling a maximum occupancy rate of 50 passengers was assumed for these buses. Depending on the magnitude of the modal change these buses will have a maximum frequency of 2min for each of the 6 main routes.

According to the CONTRAM model output for the AUTS scenario, when assuming a 100% modal shift from private car to public transport, a maximum value of 74 buses per 150min peak period can be observed, i.e. 1 bus every 2 minutes. This is a large frequency, but with a dedicated bus lane and bus priority measures (bus rapid transit concept) this could be operated achieved. But as discussed before the 100% modal shift might not be realistic, therefore the frequency would be lower.

A number of studies have been carried out to analyse required number of vehicles for serving peak demands with AUTS, particularly for the PRT concept (see for example Lowson, 2003 or Rydell, 2000). The anticipated maximum peak demand for the system in the AUTS scenario can be served by an application like this according to the literature. The number of vehicles required could be estimated through micro-simulation techniques, which lies outside the scope of this research.

As this scenario assumes that all buses from the 6 bus corridors will arrive at one central bus stop in the city centre, that enables an interchange to the AUTS vehicles, there will be a very high demand in peak times. This will result in a large number of AUTS vehicles in order to guarantee short waiting times, which would be crucial for the public acceptance of the system. More details on system operation will be described in the following sections of this feasibility study.

System Requirements

A system capable of meeting the requirements described for the AUTS scenario would have to include automatic route guidance and obstacle detection functionalities, similar to the technology used for the two test sites in Antibes and Coimbra as described before. Route guidance would be based on either a buried cable or electromagnetic markers in the road surface, combined with GPS and digital mapping. Obstacle detection would be based on laser scanner technology.

Due to the larger scale of this application compared to the test sites, and the fact that it would consist large fleet of AUTS vehicles, additional functionalities are required. These relate mainly to fleet management/ operation and vehicle routing. At the test sites vehicle were only operated on a loop, here they would operate in a network of routes, so that a central control system would have to provide vehicles on demand and determine the shortest path to the desired trip destination.

Vehicle speeds are mainly related to the characteristics of the operating environment. In this scenario a key assumptions is a car free city centre. The only vehicles coming into the city centre would be buses going to the central bus stop. Therefore there would be no interaction of AUTS vehicles with other vehicles. If the AUTS infrastructure is segregated speed of up to 50 km/hr would be possible, if there is interaction with pedestrians speeds would have to be restricted to 20 km/hr.

In order to improve in vehicle travel times the main interchange and all city centre stops have to be off-line, so that all vehicles can go from their respective origins to their destinations without stopping, except at junctions (the interchange and stops will be described in more detail in the next section). Empty vehicles will either be at the central bus stop or distributed in the network. Operation is on demand and each journey will be direct using the shortest path.

Infrastructure Requirements

One of the main advantages of AUTS applications over more conventional public transport systems is, that it requires comparably little infrastructure, i.e. no rail infrastructure is needed as the existing road infrastructure can be used. The only infrastructure required for the system operation relates to the vehicle guidance. A buried cable or electromagnetic markers under the road surface are required for all roads to be used by the vehicles.

At the test sites it could be observed that the installation of this minimal infrastructure is very quick (about 24hrs for the small sites), which means that installations costs will be low and it also allows high flexibility for changing or altering the network or specific links. But, as discussed before, additional infrastructure might be required in order to restrict vehicle interaction with other vehicles, pedestrians, and cyclists, e.g. through physical barriers to create segregated AUTS lanes.

The vehicle speeds (and with that the in-vehicle travel times) are a function of the level of interaction with other traffic, due the obstacle avoidance system. As there are no manually operated vehicles (except buses) in the city centre, the only interaction would be with pedestrians and cyclists. But the demonstration sites have shown that a small number of pedestrians can result in a number of stops and slowing down of the vehicle, therefore segregated lanes might be necessary.

As mentioned before, a key part of the infrastructure necessary for the AUTS scenario is the central bus stop interchange. This interchange would need to have bays for up to 1 bus every 2 minutes from each of the 6 bus corridors. In order to minimise interchange time and walking distances, the AUTS stop would have to be located very close to the bus bays. A large number of AUTS vehicles will have to be parked nearby at peak times in order to guarantee on-demand operation with only short waiting times.

AUTS Operation

Based on the previous sections on demand data, system requirements, and infrastructure requirements as part of this feasibility study for the Southampton AUTS scenario, in this section the operation of the AUTS application will be described in more detail. This application has been devised to reflect the results from earlier work in this research, particularly the user needs analysis.

As this multi-modal P&R system is a very specific niche application of the AUTS concept, there is no experience either from studies, tests/ demonstrations, or implemented systems available. Therefore this description of the system operation will be based on a different application that has some commonalities with the AUTS scenario, but a number of additional assumptions have to be made.

Since 1998 an AUTS related application has been in operation in Rivium near Rotterdam in the Netherlands. There a fully automated system connects a public transport interchange (metro and buses) to a number of stops on a loop within a business park. The system is operated on demand and provides individual direct transport from origin to desired destination (see figure 7.9).

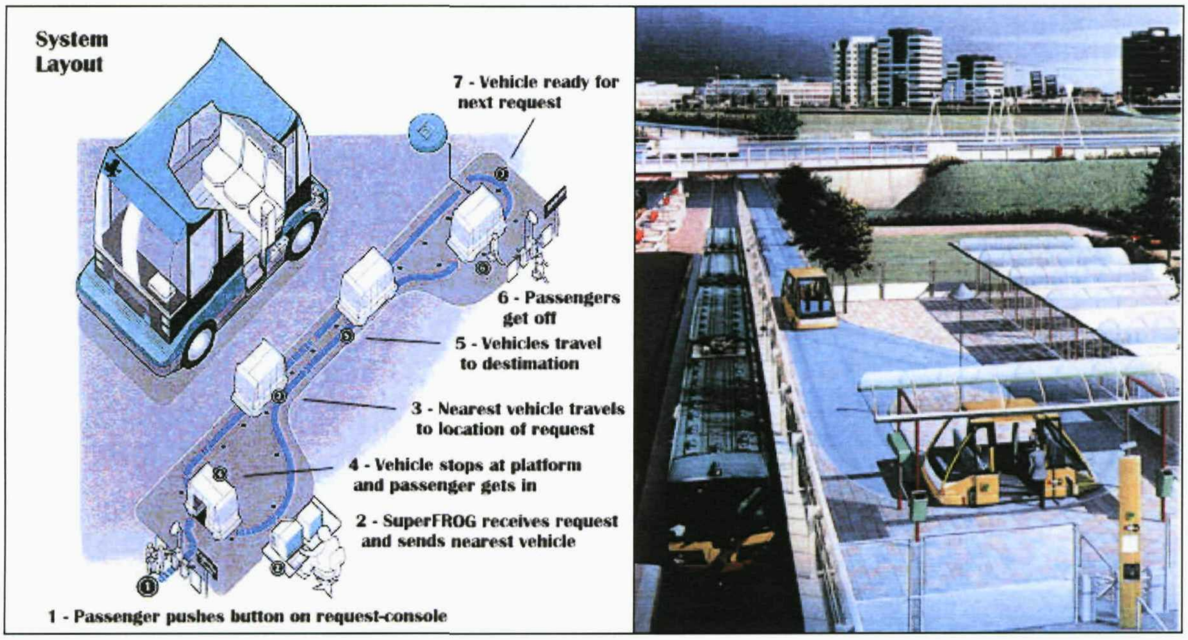


Figure 7.9: Operational Diagram and Illustration of the Rivium AUTS Application (FROG Navigation Systems Website www.frog.nl accessed 26.02.08)

The Rivium application is similar to the Southampton AUTS scenario in so far as it also provides fully automated, individual, on-demand transport from a public transport interchange to a series of stops. But the main difference is the scale of the operation, i.e. the demand is much lower, the number of stops is smaller, and the stops are on a simple loop, not a network as in the AUTS scenario.

Furthermore it is a stand-alone system within a business park, unlike the AUTS scenario, where AUTS is only one component of a larger multi-modal public transport system. But despite these differences the basic operating concept is similar. For the AUTS scenario the central interchange will have to be much larger with a large number of stops for the shuttle buses and bays for the AUTS vehicles.

This is due to the much higher demand, i.e. the number of passengers arriving by shuttle bus and then having to change to the AUTS vehicles. According to the demand data as described in the previous sections the maximum number of buses arriving from one of the 6 main arterials is 1 bus every 2 minutes. The assumed occupancy rate per bus is 50 passengers. Bus frequency varies over the 6 arterials.

The maximum number of passengers arriving at the central bus stop in the morning peak from the 6 main arterials can then be estimated as approximately 100 passengers per minute according to the maximum bus frequency, the bus occupancy rate, the number of main arterials, and the assumption that the average bus frequency is 2/3 of the maximum occupancy, all values are as described above.

The car-free city centre consists of a circular area with a diameter of approximately 2km, the bus station is assumed to be in the middle of this area. Trips from the bus station to the final trip destination within the car-free city centre and back to the bus station to be available to the next passenger will therefore be 2km maximum. With an assumed vehicle speed of 30km/hr, the trip time would be 4min.

In order to minimise waiting times at the interchange at peak times, 500 vehicles would be necessary at an assumed return travel time including time for boarding and alighting of 5min. This number could be reduced by allowing longer waiting times or by operating a collective service covering key locations within the city centre. The latter solution has been implemented successfully at the Rivium site.

Business Case

A number of systems with functionalities and technologies similar to AUTS have been developed, tested and implemented - although often only on a small scale - in the past. When carrying out studies to prove the feasibility of these systems for a particular application, results of the economic analysis are an important indicator. A number of different methodologies have been used in order to carry out an economic assessment of the various systems and technologies.

In addition to reviewing documents on economic analyses of transport schemes, literature relating to business cases for AUTS-related systems and technologies were also reviewed. The AUTS scenario used for the Southampton CONTRAM modelling as described before uses a very specific application of AUTS for a very specific purpose (feeder service to/ from a public transport interchange in a car-free city centre), based on earlier work in this study, particularly the user needs analysis.

Therefore most systems and technologies reviewed, though related to the general AUTS concept, differ from the exact application as studied in this scenario. Furthermore most feasibility studies that have been reviewed used this technology as a stand-alone system either as the sole mode of transport in a newly developed area or a system that replaces existing conventional public/ private transport systems. In the following the key results from this review will be described in more detail.

Yoder et al (2000) used regression analyses to compare costs of 25 Automated Guideway Transit (AGT) systems. This was used as a basis for estimating costs for the planned PRT application in Rosemont, Illinois. Based on the regression analysis, a cost range was determined for different system components. Cost components analysed in the study included guideway, stations, maintenance and control, power systems, vehicles, communication, and engineering.

In a study on introducing a city wide dual mode system in Boston (Benjamin, 1990), the costs of implementing three different systems (pallet, automated highway, PRT) were compared to the projected 1990 baseline that did not consider the use of any advanced transport systems. The vehicles used for the three technologies included private cars, buses and specialised vehicles. Here the analysis of costs and benefits considered did not only cover capital and operating costs, but also pollution and noise.

A recent review of the state-of-the-art of PRT and other emerging technologies (Buchanan, 2005) includes a compilation of results from economic analyses carried out for a variety of systems. It was found that these systems can offer relatively low capital and operating costs, due to the use of small and light weight vehicles and guideways, and the fully automated system operation. Furthermore, potential improvements in safety, convenience and less environmental impacts also have to be considered.

In a study on Cooperative Vehicle Highway Systems (CVHS) business cases for a number of clusters of different ADAS technologies were developed for different future scenarios (DfT, 2004). A cost benefit analysis was carried out comparing the costs of implementing in-vehicle and/ or road-side systems with the potential benefits. The costs varied widely with estimated market penetration. Benefits included safety, decreased fuel consumption and emissions, and journey time savings.

As part of the EDICT project comparative analyses were carried out between PRT systems and more conventional systems like Light Rail Transit (LRT) and bus systems. This study found that investment costs for a PRT (based on the ULTRa system to be built and demonstrated at Heathrow in CityMobil) are only 35% of the costs for the more conventional systems and that, for example, a 10km track implementation of a PRT system could achieve savings of up to 111 M€.

Savings in investments costs were mainly due to the lighter vehicles/ guideway. But In terms of system operating costs large savings can also be achieved due to the automated operation. Vehicles used are much smaller than those in bus/ rail systems, but through high frequencies similar capacities can be reached. Due to higher convenience, a higher modal shift to public transport can be anticipated. Furthermore, travel time savings, reduced congestion, reduced pollution, and increased traffic safety can be achieved.

A number of different guideline documents for economic evaluation and assessment and for scheme selection for transport projects in general have been reviewed. These documents relate mainly to Cost Benefit Analysis (CBA) and affordability. They include: 'Affordable Mass Transit - Guidance, Helping you choose the best system for your area' (CIT, 2005), 'Guidance on Value for Money' (DfT, 2006), and 'Guidance on Multi Modal Studies MMS' (DfT, 2003).

A full cost benefit analysis as part of the feasibility study for the AUTS scenario described for the network simulation would be very difficult, as costs vary largely with the size of the application and only little information exists for small-scale applications so far. Furthermore the benefits would be very difficult to monetise, as e.g. environmental impacts, accident savings, or improved image of this public transport system would be very difficult to quantify at this stage.

A full quantitative cost benefit analysis therefore lies out outside the scope of this research. In order to be able to address the business case in a simplified and more qualitative way the technology options and appraisal summary table (TOAST) will be used (CIT, 2005). Use of this technique enables a qualitative assessment of impacts of the options considered to be taken into account, based on ratings.

Instead of quantifying individual costs and benefits, a rating on a 7-point scale will be applied. The key for the scale used is the following:

- 1: LB (Large Beneficial)
- 2: MB (Moderate Beneficial)
- 3: SB (Slight Beneficial)
- 4: N (Neutral)
- 5: SA (Slight Adverse)
- 6: MA (Moderate Adverse)
- 7: LA (Large Adverse)

In the following the TOAST approach will be used in order to give a qualitative indication of the costs and benefits of the AUTS scenario.

Table 7.7 below shows a qualitative indication of the costs and benefits of the AUTS scenario compared to conventional public (in this case buses) and private transport using the TOAST approach described above.

Qualitative Analysis of Cost and Benefits of the AUTS Scenario (TOAST)			
Cost/ Benefit Category	Assessment on 7-Point-Scale		
Guideway Costs	5[a]	SA	Slight Adverse
Costs of Facilities	5[a]	SA	Slight Adverse
Vehicle Costs	6[b]	MA	Moderate Adverse
Costs of Stops/ Stations	6[b]	MA	Moderate Adverse
Communications Costs	7[c]	LA	Large Adverse
User Time Savings	4[d]	N	Neutral
Operating Costs	2[e]	MB	Moderate Beneficial
Saved Pollutants	2[e]	MB	Moderate Beneficial
System Reliability	2[e]	MB	Moderate Beneficial
System Punctuality	2[e]	MB	Moderate Beneficial
Image/ Attractiveness	1[f]	LB	Large Beneficial
Sustainability Impacts	1[f]	LB	Large Beneficial
Accident Savings	1[f]	LB	Large Beneficial

a) Similar infrastructure and facilities, but some additional costs for guidance system and recharging facilities
b) Due to automation and on-demand operation considerably higher costs for vehicles and stops/ stations
c) Much larger cost for communications due to the on-demand real-time scheduling and fleet management
d) Time savings for the whole multi-modal trip but no change for the last section of the trip in the city centre
e) Considerable benefits for operation, pollutant, reliability, punctuality through automation/ central control
f) Large benefits on image/ attractiveness, sustainability, accident savings though very advanced technology

Table 7.7: Qualitative Analysis of Cost and Benefits of the AUTS Scenario

It can be seen from the table above that even though costs are likely to be higher for an advanced systems such as AUTS, a qualitative assessment of benefits, which are difficult to monetise, can help improve the assessment. Furthermore a weighting can be applied to the individual cost/ benefit categories, in order to give more/ less importance to them, which could further improve the overall assessment.

Traffic Management

Traffic management measures required for the AUTS scenario relate mainly to the fleet management and real-time on-demand vehicle scheduling systems as described before. In addition a number of specific traffic management functionalities are required for a safe and efficient system operation. These include signal controlled junctions, vehicle priority and access control. These functions are necessary in order to enable the car-free city centre and to limit vehicle interaction with other traffic.

At the entrance into the car-free city centre access control measures (vehicle detection to open barriers) have to implemented so that only public transport (and emergency) vehicles are able to enter the area. Furthermore as in most areas the AUTS lane will be segregated from other traffic, crossings have to be provided. These crossing have to be signalised and priority has to be given either to vehicles or pedestrians/ cyclists, depending on the circumstances.

Policy Implications

The policy implications for the AUTS scenario relate mainly to the accompanying measures required in order to achieve a sufficiently high modal shift away from the private car to the multi-modal public transport trip for commuting into the city centre in the morning peak as described before. These policies and strategies contain both measures to reward ("carrots") modal change to public transport as well measures to penalise ("sticks") non-compliance with the scheme.

Measures to reward modal change include e.g. public transport subsidies, or bus priority schemes and other measures that improve the public transport journey. Measures to penalise non-compliance include e.g. road user/ congestion charging, car parking restrictions or increased parking fees in areas close to the car-free city centre. Furthermore the car-free city centre has to be seen as part of a wider policy on transport, the environment, and sustainability.

Future Work

The aim of this feasibility study was to describe the practical and operational issues for the Southampton AUTS scenario and to analyse the viability of this application. As part of this process a series of assumptions had to be made, as no experience with similar systems exist, and as more detailed work on the practicalities of the scenario lie out of the scope of this research. Future work in this area relates mainly to quantitative research methods including multi-modal and micro-simulation modelling and stated preference questionnaire surveys in relation to the AUTS scenario

Micro-simulation work on the Southampton AUTS scenario could give valuable information on the operation of the system. In contrast to the network-wide macro-simulation used for this research, micro-simulation models the movements of individual vehicles. This would allow an analysis of waiting times at the interchange, travel times, number of vehicles, etc. based on more detailed demand data and user preferences. Furthermore full multi-modal modelling could be carried out in order to be able to estimate modal share of the AUTS application and the impact of this share on network operations.

Some of the data necessary for this modelling and simulation work could also be obtained by carrying out an additional large scale stated preference survey (including information on willingness to pay) of potential end-users of the system. This survey could then give further insight into end-user preferences, behaviour and the expected modal shift from the private car to the multi-modal AUTS scenario. Based on this and the other research activities that were described above a more detailed and fully quantitative cost-benefit analysis could then be carried out.

7.3 Conclusion

7.3.1 Summary

This modelling of network-wide impacts of a large scale multi-modal AUTS application formed the fourth and final stage of the analysis process of this study. As the previous analysis activities in this study have focused on existing systems and technology that can be implemented in the short term, this simulation was necessary to gain insights into the potentials of a larger scale application, which at present cannot be implemented. The results of the previous analysis activities were encouraging in view of the potentials of AUTS for providing more sustainable mobility in urban areas; therefore the simulation results enabled an assessment of its suitability for wider implementation.

The objectives of this simulation were to investigate the use of a large-scale AUTS application as part of an improved overall public transport system in an urban area. The potential future operating scenario used here involves the creation of a car free city centre. There is some evidence that traffic restrictions in city centres (mostly implemented for limited times) together with a variety of accompanying measures and provision of improved public transport can lead to a more attractive urban environment without adverse effects on businesses and mobility. But it will be more likely to be implemented as an evolutionary process, starting with road user charging schemes.

The more detailed objectives were to define a potential future operating scenario for AUTS, to test this scenario using modelling tools, and to identify potential impacts and interpret them for future applications. The study assumed a large modal change of commuter trips into the city centre in the morning peak from private car for the whole journey to a multimodal trip involving a combination of conventional public transport and AUTS. In order to meet the objectives of this study, a network simulation was carried out, using an existing model for the city of Southampton, based on the CONTRAM software.

The existing situation has been used as the baseline scenario against which the results of the modified network (AUTS scenario), that takes account of the newly introduced transport strategy, were compared and evaluated. Effects being investigated included journey times, distances and speeds for the whole network, for the P&R shuttle bus corridors and for specific targeted commuter trips into the city centre. The potential AUTS operating scenario used here was a convenient, user-friendly and non-polluting transport system to cover the 'last mile' of commuting trips to workplaces in the city centre.

7.3.2 Key Findings

The AUTS application investigated in this study will operate in the car free city centre to cover the last part of the multimodal commuter journey to places of work within the city centre and for local city centre movements. The improved public transport system, which will cater for the increased demand due to restrictions to the private car in the city centre, consists of high-frequency shuttle buses, which connect the P&R sites and a central interchange. Therefore the typical commuter trip consists of trip origin to P&R site by private car, interchange for P&R shuttle bus service, P&R site to city by shuttle bus, interchange for AUTS, and to the final trip destination by AUTS.

Results of this analysis can be grouped under network-wide results, results for bus corridors, and results for commuter trips. The network-wide results were a reduction of 37% in total travel time, an 18% reduction in distance and an increase of 29% in network speed. The results for bus corridors were a reduction in travel time of 19% and an increase in vehicle speeds of 35% for inbound trips. For outbound trips only small changes could be observed, with a reduction in travel time of 1% and even a slight decrease in vehicle speeds of 2%. The results for the commuter trips showed that the multimodal journey can offer comparable, or even slightly lower door-to-door travel times (reduction from 25.0min to22.3min) to the journey using private car for the whole trip.

The main assumption for this network modelling study was a 100% modal change from private car for morning peak trips into the city centre to a combination or private car, P&R, shuttle bus and AUTS. Although the assumed car-free city centre and accompanying measures specifically designed to discourage commuters to use private cars would have a strong influence on the modal choice for commuter trips, a 100% modal change might not be realistic. Therefore the magnitude of the positive traffic impacts of this scheme might also be unrealistic, depending on the effectiveness of the accompanying measures introduced and individual behavioural impacts.

In order to assess the effects of lower modal changes on the potential impacts of the scheme a sensitivity analysis has been carried out. For this the same simulation as before has been carried out with the demand data changed to reflect a range of modal change values (25%, 50%, 75%, and 100%). Whilst maximum values for improvements of network-wide impacts can only be achieved at a modal change value of 100%, the sensitivity analysis has shown than even at the lower end of the modal change values analysed (i.e. already at 25%) considerable improvements can be expected.

7.3.3 Discussion

In addition to earlier encouraging results from the previous research activities in view of the potentials of AUTS to provide more sustainable mobility in urban areas, the network simulation study has shown further potentials of a larger scale implementation. With the success of such an application patronage and thus modal change would be expected to rise. As the sensitivity analysis has shown, this increase in modal change will consequently lead to even further benefits.

In this simulation no environmental impacts were considered, but the large modal shift from private cars towards buses connecting the P&R sites with the city centre suggests substantial reduction in emissions. This positive trend can be even further enhanced with the provision of buses using alternatives to internal combustion engines, e.g. use of compressed natural gas, fuel cell technology, etc.

The AUTS feeder application covering the 'last mile' from the main city centre bus stop to the respective final trip destinations has not been further analysed in this study, as only little impacts on a network-wide level can be expected from this, and because the capacity of the road network within the car-free city centre can be assumed to be sufficient to cater for the demands of this application.

The use of AUTS within the city centre suggested further environmental benefits, as the vehicles were highly likely to be electric vehicles in order to keep emissions and noise in the city centre to an absolute minimum. And although the production of the necessary energy is likely to generate emissions at the point of production, at the point of operation (i.e. in the city centre) no emissions would be generated.

As the AUTS application in the city centre was not simulated in this study, the results and impacts relate mainly to the introduction of P&R sites on the outskirts of the city. From these P&R sites buses run on six main corridors into the city centre. This consequently resulted in a large modal shift from the private car to public transport. This was based on earlier results that AUTS should be implemented as a complementary mode to the existing urban multi-modal public transport system.

8 CONCLUSION

8.1 Summary

This study had as a general aim to analyse if and to what extent AUTS can provide more sustainable mobility in urban areas. A first preliminary step was to define AUTS for the purpose of this study. It was defined as a transport system with the following properties. AUTS consists of fleet of road vehicles with fully automated driving capabilities for passengers transport on a network of roads with on-demand and door-to-door capability. The vehicle fleet was under control of a central management system in order to meet a particular demand in a particular environment.

After describing the more detailed aims and objectives of this study, and the methodology used to meet these objectives, the structure of this study including all main analysis activities was specified. This structure followed a four step process. The first step in this process was the general research background, the second step was the development of a generic AUTS concept, the third step was the testing of a small-scale system, and the fourth and final step was the simulation of a large-scale system. As part of this process each step provided input into the next stage.

For the general research background a literature review of related systems and a survey of the state-of-the-art of AUTS have been carried out. Based on this a generic concept was developed, used as background for the ex-ante user needs analysis. As part of the testing of a small-scale system an ex-post user needs analysis was carried out to analyse changes in perception. An assessment of performance was carried out to compare the qualitative ex-post user needs results with actual vehicle performance. This was followed by the modelling of network-wide impacts.

In the following the key results for these six main analysis activities described above, that have been carried out as part of this study are described. This is then followed by a discussion of these key results. This discussion examines how these key results relate to the starting point of this study, the question if and to what extent AUTS can provide more sustainable mobility in urban areas. Furthermore future research work necessary to gain further knowledge of this area as well as strategies to overcome current implementation barriers are suggested.

8.2 Key Findings

Experience with Related Systems and Technologies

Various related systems and technologies which provide one or more of the functionalities of AUTS have proven to be feasible and to provide some of the benefits anticipated for AUTS.

A number of car sharing schemes are in operation in various countries, customers are satisfied with the system, but many systems failed, because they were not economically viable. Except the automated operation, taxis are the form of public transport most similar to AUTS, but high costs and environmental issues prevent them from being a sustainable mode. Demand responsive transport systems are mainly niche applications for elderly and disabled at the present, but through ITS technologies the performance could be improved. Various innovative systems have been developed, including personal rapid transit, dual mode, automated highway, technology increasingly mature, but no large implementation yet. A number of key service parameters can be identified for all systems that have implications for AUTS.

Experience with First Small AUTS Applications and Tests

A number of early AUTS applications have already been used or tested over the last years; these systems have proven to be safe and reliable, but perceived risks so far delayed wider implementation.

A number of different systems (on road, guideway, dual mode), vehicle sizes (from 2 to 20 passengers), and maturity of the technology (test site, public demo site, fully implemented). All systems so far are small scale niche applications, including connections from car parks or public transport interchanges to exhibition centre, business park, or airport terminal. Studies for specific AUTS applications have shown potential for increased network and link capacity, higher convenience for end user and lower costs (implementation and operation). Market research carried out for the existing systems has shown that the end-users of these systems perceive them to be very user friendly, convenient and safe modes of transport. Further widespread implementation has so far been hindered by decision makers perceiving the introduction of an innovative technology such as AUTS to be too high a risk.

Public Acceptance of the General AUTS Concept

Users and stakeholders were able to envisage the potential of AUTS to improve urban mobility, but some concerns remained at this stage over technology being mature enough for systems in mixed traffic.

Environmental benefits of using public transport were recognised, but the private car was the preferred mode, because it is more convenient and it is seen as a status symbol. End users can envisage small AUTS sites as a short term scenario, but prefer segregated systems, as there is concern about AUTS in mixed traffic with other modes of transport. End users are less confident about the large AUTS applications described for the long term scenario, as they are perceived as being rather futuristic and unrealistic systems. Stakeholders saw the potential of AUTS, but the technology has to be proven to be safe and reliable, has to comply with certification guidelines, it has to be economically viable and meet policy objectives for the site.

Public Acceptance after having used an AUTS application

After having used the system, public acceptance increased, as due to the innovative characteristics of AUTS, users who had no direct experience with the system before, had a different attitude.

The performance of the system in terms of comfort and convenience has been rated very highly by passengers who took part in this survey. There was some concern over personal security if no driver is present, but no concerns over traffic safety of an automated system. On both test sites the systems operated on a segregated track (segregated from motorised traffic, but some interaction with cyclists and pedestrians), therefore passengers had no experience with and therefore could not comment on perception of system operation in mixed traffic, with was the main concern in the user needs analysis. But it could be seen that the attitude towards the general AUTS concept and its suitability of a number of potential urban applications has changed compared to the user needs analysis. The majority of those who participated in the survey were able to identify potential application areas, rated the suitability of the technology highly, and stated that they would use these systems.

Performance of the System (Safety, Reliability, Comfort)

AUTS vehicle performance parameters including acceleration, deceleration, and jerk were below the benchmark values for comparable systems in terms of comfort and safety levels for passengers.

The analysis of various vehicle performance parameters collected at a small-scale public demonstration site has shown that AUTS vehicle have comparable and for some parameters superior performance characteristics compared to other conventional public transport systems. And all parameters a far below benchmark values for a safe and comfortable system operation. The only area where the quality of the performance parameters, though still comparable to other systems, is lower, is when specific vehicle manoeuvres (including turning, reversing, and stops) are carried out. Vehicle performance in these situations therefore has to be further improved in order to make AUTS a superior system compared to the systems it is aimed at replacing or complementing. Vehicle positioning errors have also been analysed, but these relate more to site specific characteristics and constraints.

Network Benefits of a City Centre wide AUTS Application

AUTS as part of the multi-modal public transport system and with accompanying measures (e.g. park&ride, bus priority, car free city centre, etc.) can improve network efficiency and reduce travel times.

The simulation has shown large potentials for improvements in network speeds and reductions in levels of congestion on a network-wide level. Due to the modal shift towards the use of buses large improvements were also possible for inbound trips in the morning peak on the six main bus corridors considered in this study. Furthermore overall travel times for the whole commuting trip were also reduced. In this simulation no environmental impacts were considered, but the large modal shift from private cars towards buses connecting the P&R sites with the city centre suggests substantial reduction in emissions. This positive trend can be even further enhanced with the provision of buses using alternatives to internal combustion engines. The use of AUTS within the city centre suggest further environmental benefits, as the vehicles are likely to be electric to keep emissions and noise in the city centre to a minimum.

8.2 Discussion

So far the development process of AUTS has shown parallels with earlier work on related systems such as PRT, where first results from test have been encouraging, planners and decision makers have shown interest, but there is only little progress from the initial small scale applications. There are a variety of AUTS technologies that have been tested and demonstrated as part of individual company's R&D work and as part of research projects, but since the first two applications in the Netherlands in 1997 no new systems have been implemented. Therefore it is crucial to assess whether or not AUTS has the potential to move beyond these initial stages and to identify research gaps.

The user needs analysis has shown interest in these technologies by end-users and key stakeholders. The only concerns were over operation in mixed traffic and large-scale implementations for future scenarios. It could be observed that attitudes were even more favourable when those surveyed used the system. Increased implementation so far has been hindered by decision makers perceiving this technology as too much of a risk and therefore favouring more conventional transport systems. There also is a lack of clear certification guidelines for road-based automated transport systems.

In depth evaluations and assessments of various related systems have shown the potential for improvements in terms of system efficiency, und-user convenience, social inclusion, energy usage, pollution, etc. Experience from the first AUTS applications and results from the ex-ante as well as ex-post user needs analysis have confirmed that small-scale AUTS applications have the potential to provide more sustainable urban mobility. Furthermore the analysis of vehicle data has proven that the system is safe, reliable and meets passenger comfort parameters from other systems.

In addition, the network simulation has also shown positive impacts of a large-scale application which at this stage cannot be implemented. Based on this the implementation of AUTS can be recommended to offer more sustainable mobility in urban areas, but further research is needed to overcome the current implementation barriers identified as part of this study. Furthermore the maturity of the technology, particularly in view of sensor and information processing technologies, means that AUTS can have a higher success rate than e.g. the PRT concepts that were developed in the 1960s.

This research has shown that there a large potentials for AUTS to provide more sustainable mobility in urban areas. But a number of implementation barriers have been identified, which so far have hindered a more wide-spread and large-scale implementation of AUTS. Future work in this field therefore has to address these issues and develop means to overcome these barriers in order to realise the potentials of AUTS as described above. Furthermore sensor technologies and robotics algorithms have to be further improved, and new vehicle, infrastructure and operational concepts have to be developed for larger and more advanced systems.

The barriers to the deployment of AUTS as identified in this research relate to the current lack of end-user familiarity with an innovative technology like AUTS, the lack of consistent AUTS-specific system certification guidelines, and the lack of data and evidence for traffic safety performance, system reliability, and economic feasibility. Future work in this field therefore has to address these issues in order to ensure market acceptance of these systems and to enable planners and decision makers to consider the implementation of AUTS instead of more conventional transport systems, without concerns over the high risk of introducing a very innovative and unproven technology.

The current lack of end-user familiarity can be addressed by market education and more system demonstration involving the general public. As AUTS is a very advanced technology existing certification guidelines for conventional transport modes are difficult to apply, therefore new guidelines, ideally on an EU-wide level, should be developed in order to facilitate the implementation process. The current lack of reliable data on system safety and security and economic feasibility can be addressed through more vehicle and system testing at private and public sites and further more in-depth studies, particularly simulation and modelling work on macro and micro level.

One of the results from the state of the art survey and the ex-ante user needs analysis was that some of the implementation barriers identified do not apply on private sites. Therefore systems on private sites can be implemented more easily and then provide the experience required for a more wide-spread implementation in more public sites. An important example for this is the AUTS system currently being constructed at London's Heathrow airport. It will initially connect the long-stay car park to the new terminal 5, but there are plans in the long term to extend it to cover all terminals, public transport interchanges and hotels and businesses in the surrounding area.

In order to summarise the implications of the key findings of this study for the potential future implementation of AUTS technologies and the suggested strategies to enable a more wide-spread implementation of these systems, the potentials of AUTS, the main deployment barriers and the deployment path will be described below.

- Potentials of AUTS
  - Public transport where conventional transport is restricted (historic city centre)
  - Public transport for low-demand areas (rural) or at low-demand times (night)
  - 'Feeder applications' to public transport interchanges and/ or park&ride
  - System to cover 'last-mile', not served by conventional public transport
  - Sole mode of transport on various private sites (theme park, exhibition, campus)
  - Small to medium-scale in contained environments for targeted demands

- Deployment Barriers
  - End-User familiarity with conventional public transport systems and modes
  - General perception of public transport/ implications of the 'private car society'
  - Organisational issues for coordinating AUTS and existing multi-modal systems
  - Little experience with leading to a high risk for operators and decision-makers
  - Scepticism towards AUTS operating in shared environments with other traffic
  - Legal/ certification issues and securing funding for implementation and operation

- Deployment Path
  - Staged introduction of AUTS to prepare the market and to prove the technology:
    - Technology-related:
      - Driver-Assistance
      - Semi-Automation
      - Full Automation
    - Application-related:
      - Test-track/ demonstration
      - Small-scale pilot project
      - Small-scale permanent system
      - Gradual increase of scale
    - Environment-related:
      - Private grounds
      - Public system
  - Education of the market to address unfamiliarity with AUTS
  - Securing funding for AUTS implementation (e.g. user charging, mobility tax)

ACRONYMS

ACC	Automatic Cruise Control
ADAS	Advanced Driver Assistance System
AHS	Automated Highway System
APM	Automated People Mover
AUTS	Automated Urban Transport System
AVL	Automatic Vehicle Locating
CCTV	Close Circuit Tele-Vision
CIAM	Congres Internationaux d'Architecture Moderne
CSO	Car Sharing Organisation
DETR	Department of the Environment, Transport and the Regions
DFT	Department for Transport
DRT	Demand Responsive Transport
EC	European Commission
ECMT	European Conference of Ministers of Transport
EEA	European Environment Agency
EU	European Union
FP	Framework Programme
FOE	Friends of the Earth
FROG	Free Ranging on Grid
GIS	Geographical Information System
GPS	Global Positioning System
HMI	Human Machine Interface
ICE	Internal Combustion Engine
ITS	Intelligent Transport System
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Cooperation and Development
P&R	Park and Ride
PRT	Personal rapid Transit
PT	Public Transport
R&D	Research and Development
RUF	Rapid Urban Flexible
SEU	Social Exclusion Unit
TDC	Travel Dispatch Centre
UK	United Kingdom
UN	United Nations
UTF	Urban Task Force
WBCSD	World Business Council for Sustainable Development
WWF	Worldwide Fund for Nature
ZEV	Zero Emission Vehicle

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ANNEXES

Annex A:	*State-of-the-Art Survey Form (Sites)*
Annex B:	*State-of-the-Art Survey Form (Systems)*
Annex C:	*Focus Group/ Interview Presentation*
Annex D:	*Focus Group Discussion Topic Guide*
Annex E:	*Structured Interview Topic Guide*
Annex F:	*End-User Questionnaire (Antibes Site)*
Annex G :	*End-User Questionnaire (Coimbra Site)*

Annex A: State-of-the-Art Survey Form (Sites)

0 General Information

Partner: ....

Country: ....

Location of Site/ Study: ....

1 Site Description

1.1 Application Area

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1.2 Existing Transport Systems

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1.3 Demand Characteristics

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1.4 Planning Details

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Additional Points???

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2 System Description

2.1 Infrastructure Technology

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2.2 Vehicle Technology

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2.3 Proposed Route/ Facilities

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2.4 Advantages over Conventional/ Existing Systems

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Additional Points???

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3 Planning Process

3.1 Availability of Funding/ how acquired

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3.2 Stakeholder Involvement

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3.3 Land Use Planning (Regulations, Effects, etc.)

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3.4 Local Authority Interest

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Additional Points???

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4 Conclusions

Summary and analysis in view of potentials and limitation of the system

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Additional Points???

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Annex B: State-of-the-Art Survey Form (Systems)

0 General Information

Partner: ....

Country: ....

System: ....

1 General System Description

1.1 Infrastructure Technology

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1.2 Vehicle Technology

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1.3 Advantages over Conventional Systems

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1.4 Possible Application Areas

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Additional Points???

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2 Studies Carried Out

2.1 Number of Studies and Short Overview

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2.2 Application Areas

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2.3 Detailed System Description

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2.4 Experiences with Planning Process

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Additional Points???

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3 Operating Systems

3.1 Number of Operating Systems and Short Overview

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3.2 Application Areas

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3.3 Detailed System Description

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3.4 Experiences with Planning and Operation

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Additional Points???

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4 Conclusions

Summary and analysis in view of potentials and limitation of the system

Additional Points???

Annex C: Focus Group/ Interview Presentation

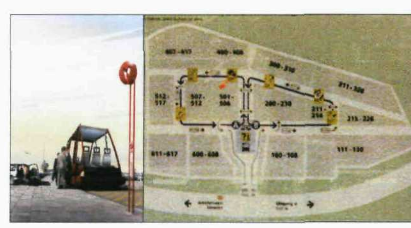
AUTS Definition

AUTS is a transport system that consists of individual vehicles, which...

- are designed for particular environments,
- are designed to meet particular demands,
- have fully automated driving capabilities,
- provide individual on-demand transport,
- are under supervision of a central system,
- initially are for short trips at low speeds,
- in the longer term can run at high speeds,
- are part of the people mover technology,
- are close to personal rapid transit (PRT),
- are able to use existing road infrastructure.

Existing Systems: Schiphol-Airport

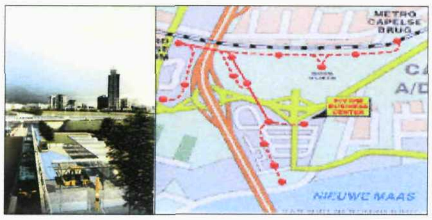
Existing Systems: Schiphol-Airport



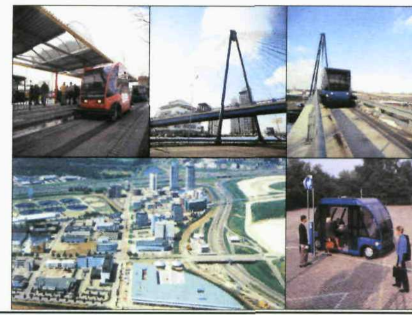
Existing Systems: Schiphol-Airport

- Operates since December 1997
- Connects the terminal and the long-stay car-park
- Operates fully automated
- Has Space for group of passenger and luggage
- Runs without rails on a separate track
- Crosses junctions with car traffic

Existing Systems: Rivium



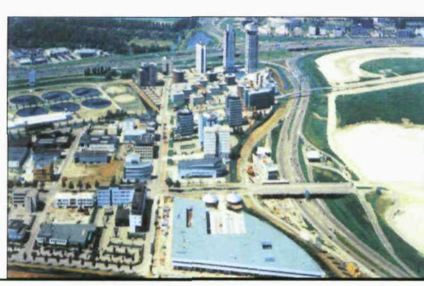
Existing Systems: Rivium



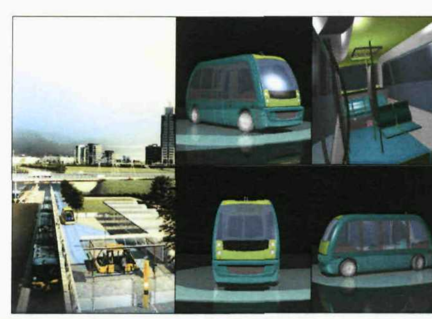
Existing Systems: Rivium

- Operates since February 1999
- Connects the bus /metro to the business park
- Operates fully automated
- Complementary to existing shuttle bus
- ParkShuttle provides less stops
- ParkShuttle needs less travel time

Short-Term Scenario: Rivium II



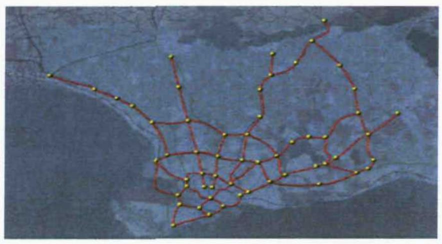
Short-Term Scenario: Rivium II



Short-Term Scenario: Rivium II

- Connection from subway station via housing area to existing and extended business park
- 2.5km double-track, 1 bridge, 5 stations and one roundabout crossing with other traffic
- Operates fully automated
- maximum speeds 30-40 km/hr
- Capacity of 20 persons per vehicle
- 2000 persons per day

Medium-Term Scenario: Copenhagen



Medium-Term Scenario: Copenhagen

Medium-Term Scenario: Copenhagen

- Network covering greater Copenhagen (population ~1.4 million)
- Network length ~5 km
- Dual-mode operation (uses roads and monorail)
- CyberTram vehicles (flexible mass transport)
- Planned network mainly for commuters
- Relieve overloaded ring-road and crowded old city

AUTS Long-Term Scenario

The AUTS long-term scenario takes the same principles and technologies but applies them on a much wider scale. The system will provide demand-responsive door-to-door, individual transport and can be used in a privately or publicly owned vehicle. One example is commuting between a suburb and the city centre. The vehicle will run on normal roads with other traffic in the suburb and will then transfer on to a dedicated, high speed rail link, to take the passenger to the city centre. The vehicle can be called via mobile phones and the control system then moves the vehicle via the shortest route to the chosen destination.

Annex D: Focus Group Discussion Topic Guide

Topic Guide

Introduction/ Warm-up

- Issues relating to urban mobility (e.g. how do you get to work everyday?)

About travelling

- Establish different kinds of journeys carried out in the city
- What criteria for mode choice (time, cost, preferred mode, etc.)
- Likes/ dislikes about existing methods of transport
- e.g. Bike/ walking (exercise, outdoors, environment, not relying on others, etc.)
- e.g. Bus (accessibility, can read book, watch world go by, not underground, etc.)

Presentation of Stimulus Material

The AUTS Concept

- Show slide, explain aims, objectives and general concept of AUTS

Related Existing Systems

- Short description of Schiphol ParkShuttle and Rivium I, show the six slides and video, explain the applications
- Stress system fits in with existing roads (stops at junctions), runs on normal road, passenger control, luggage capacity, safety features
- What questions about the system? What reactions? What perceived benefits? Advantages? Drawbacks and how to overcome these?
- Explain different forms of this kind of vehicle/ system being investigated (can be different shapes or sizes, operate in different places, etc.)
- What would they contribute in this context? What user appeal? What exact features in these contexts?
- Could they apply it to city centres? What implications? What questions about this? Why do they think someone is looking at this?

Short/ Medium-Term Scenario

- Show the six slides for applications of AUTS (Rivium II and Copenhagen)
- Show 'map', based on fictional town (show key features of town: e.g. shopping/ pedestrian area, historical monuments, cinemas, bars, etc.)
- Let participants draw AUTS network and facilities (e.g. parking, depot, etc.)
- Let participants draw AUTS vehicle on a blank sheet of paper (what features?)
- Imagine your system has been implemented. Make up the following:

  - What year is it?
  - Who was responsible for choosing AUTS, why did they do it?
  - What did they say about AUTS in the launch speech?
  - Who objected to the system (if anyone?) what did they say?
  - What are initial reactions of users? Who uses it first? Likes/ dislike?
  - A few months in, who uses the system most? What do they think?
  - Any modifications introduced?
  - What decision is made after two years?

Long-term Scenario

- Show slide with written statement about the AUTS long-term scenario and the part of the RUF info-video
- Reactions, responses - accept the principle(s)? Views on longer term urban transport requirements, from a user's perspective.
- Discuss longer term, other possible applications of AUTS e.g. 'dual mode' private car/ AUTS, monorail application of AUTS for high-speed transport into the centre of town.
- Reactions to longer term scenarios – role of these more 'futuristic' applications of AUTS

Any questions from or for observers?

Summarise, thank and close.

Annex E: Structured Interview Topic Guide

User Groups 'Local Authorities', 'Interest Groups', 'Operator'

Presentation of CyberCars Info Material
- show slides and video
- explain technology and possible applications

Are they aware of this technology/ development?
- what do they know about it?
- what are their sources?

User Group 'Local Authorities'

What are their comments/ views on CyberCars?
- would they support it?
- would it be supported by decision-makers?

What are their main transport problems?
- description of problems (main topics)
- could CyberCars be a solution (why? /why not?)

What transport systems currently in use?
- description of the system (main characteristics)
- why have they chosen this system?
- what initial/ current problems?
- what land use implications?

What plans for future transport systems?
- their plans (what? when? why?)
- would they implement CyberCars?
- what land use implications?
- which criteria for decision?

User Group 'Interest Groups'

What are their comments/ views on CyberCars?
- can they meet their special needs?
- more suitable then current systems?

What are their problems with current systems?
- relating to system characteristics?
- relating to vehicle characteristics?
- relating to infrastructure characteristics?
- relating to system operation?
- relating to information system?
- could CyberCars be a solution (why?/ why not?)

What requirements on CyberCars system?
- for safety and security?
- for accessibility and availability?
- for comfort and convenience?
- for booking and information systems?
- other topics?

User Group 'Operator'

what are their comments/ views on CyberCars?
- would they generally consider implementation?
- what application could they think of?

What current freight/ passenger movements?
- description (main characteristics)
- could CyberCars be a solution (why? /why not?)

What transport systems currently in use?
- description of the system (main characteristics)
- what alternatives did they have?
- why have they chosen this system?
- what initial/ current problems?

What plans for future transport systems?
- their plans (what? when? why?)
- would they implement CyberCars?
- for which application?
- which criteria for decision?

User Groups 'Local Authorities', 'Operator'

Use the 'Criteria for Decision on CyberCars System'
- what relevance has each criteria?
- any additional criteria?

Annex F: End-User Questionnaire (Antibes Site)

Section A – About you

To ensure that the results of the questionnaire are representative we need to know some information about you. This information is strictly confidential and no information from this questionnaire will be published which will allow an individual to be identified.

A1) Are you...?
(Please tick one box only)

Male ☐ Female ☐

A2) Please indicate your age.
(Please tick one box only)

10 - 20 ☐ 21 - 30 ☐
31 - 40 ☐ 41 - 50 ☐
51 - 60 ☐ 61 - 70 ☐
71+ ☐

A3) How many cars does your household own or have continuously available for private use?
(Please tick one box only)

None ☐ One car ☐ Two cars ☐ Three or more cars ☐

A4) Please indicate your usual daily means of travel, e.g. to work or place of study.
(Please tick one box only)

Car (as driver) ☐
Car (as passenger) ☐
Bus ☐
Bicycle ☐
Bus and Train ☐
Motorbike ☐
Combination of car and bus ☐
Combination of car and train ☐
Walking ☐
Other (please specify) ☐

....

A5) Are you...?
(Please tick one box only)

Employed full time (>30 hours a week) ☐
Employed part time (< 30 hours a week) ☐
Self employed ☐
On training scheme ☐
Full time student ☐
Retired from paid work ☐
Unemployed ☐
Sick/disabled ☐
Other (please specify) ☐

....

Section B – Using the system

B1) Please indicate the level of satisfaction you experienced for the following detailed points.
(Please tick one box only)

	Very good	Quite good	Quite poor	Very poor
Acceleration and deceleration on straight line (smoothness)	☐	☐	☐	☐
Acceleration and deceleration in curves (smoothness)	☐	☐	☐	☐
Vehicle coming to a halt at a station (jerk and jolt)	☐	☐	☐	☐
Appropriateness of the overall travel time (comfort)	☐	☐	☐	☐
Appropriateness of the vehicle speeds (safety)	☐	☐	☐	☐
Accuracy of the vehicle when stopping at a station (distance)	☐	☐	☐	☐
Length of waiting time after a vehicle has been requested	☐	☐	☐	☐
Perception of the level of noise emitted by the vehicle	☐	☐	☐	☐
Usability of in-vehicle HMI to request a stop	☐	☐	☐	☐

B2) Please indicate the level of satisfaction you experienced for the following general points.
(Please tick one box only)

	Very good	Quite good	Quite poor	Very poor
General ease of use of the system/ technology	☐	☐	☐	☐
Perception of personal safety in the vehicle	☐	☐	☐	☐
Perception of traffic safety of the system	☐	☐	☐	☐
Overall level of comfort of the ride	☐	☐	☐	☐

B3) Did you experience an emergency stop during the ride?
(Please tick one box only)

Yes ☐ **(Go to B4)** No ☐ **(Go to B6)**

B4) Please indicate the level of satisfaction you experienced during the ride for the following points.
(Please tick one box only)

	Very good	Quite good	Neither good nor poor	Quite poor	Very poor
Deceleration during emergency stop (smoothness)	☐	☐	☐	☐	☐
Vehicle coming to an halt during emergency stop (jerk and jolt)	☐	☐	☐	☐	☐

B5) Did you think the emergency stop was necessary?
(Please tick one box only)

Yes ☐ No ☐

B6) Did you experience an obstacle on the track during the ride?
(Please tick one box only)

Yes ☐ **(Go to B7)** No ☐ **(Go to Section C)**

B7) Please indicate the level of satisfaction you experienced during the ride for the following points.
(Please tick one box only)

	Very good	Quite good	Neither good nor poor	Quite poor	Very poor
Acceleration and deceleration to avoid obstacle (smoothness)	☐	☐	☐	☐	☐
Vehicle coming to a halt to avoid obstacle (jerk and jolt)	☐	☐	☐	☐	☐
Perception of traffic safety while obstacle on track	☐	☐	☐	☐	☐
Performance of the vehicle while obstacle on track	☐	☐	☐	☐	☐

Section C – The system in general

C1) Please indicate your general view on the following points.
(Please tick one box only)

	Very good	Quite good	Quite poor	Very poor
Usefulness of automated transport systems in general	☐	☐	☐	☐
Usefulness of the technology for this specific application	☐	☐	☐	☐

C2) Please read the statement below:

Automated transport systems offer the capability to alleviate various current problems in urban mobility and have the potential to provide a real alternative to the private car, bringing together the advantages of conventional public transport (e.g. less emissions, lower costs, higher capacity) and the private car (e.g. individual, on-demand, door-to-door transport).

To what extent do you agree with this statement?
(Please tick one box only)

Strongly agree	Tend to agree	Neither agree nor disagree	Tend to disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐	☐

C3) Advantages/ disadvantages compared to conventional public transport?
(Please write in below)

____

____

____

C4) Further potential application areas for automated transport systems?
(Please write in below)

____

____

____

C5) Additional comments and/ or suggestions?
(Please write in below)

____

____

____

____

Annex G : End-User Questionnaire (Coimbra Site)

Section A – About you

To ensure that the results of the questionnaire are representative we need to know some information about you. This information is strictly confidential and no information from this questionnaire will be published which will allow an individual to be identified.

A1) Are you...?
(Please tick one box only)

Male ☐ Female ☐

A2) Please indicate your age.
(Please tick one box only)

10 - 20 ☐ 21 - 30 ☐
31 - 40 ☐ 41 - 50 ☐
51 - 60 ☐ 61 - 70 ☐
71+ ☐

A3) How many cars does your household own or have continuously available for private use?
(Please tick one box only)

None ☐ One car ☐ Two cars ☐ Three or more cars ☐

A4) Please indicate your usual daily means of travel, e.g. to work or place of study.
(Please tick one box only)

Car (as driver) ☐
Car (as passenger) ☐
Bus ☐
Train ☐
☐

Motorbike ☐
Combination of car and bus ☐
Combination of car and train ☐
Walking ☐
Other (please specify) ☐

....

A5) Are you...?
(Please tick one box only)

Employed full time (>30 hours a week) ☐
Employed part time (< 30 hours a week) ☐
Self employed ☐
On training scheme ☐

Full time student ☐
Retired from paid work ☐
Unemployed ☐
Housework ☐
Other (please specify) ☐

....

Section B – Using the system

B1) Please indicate the level of satisfaction you experienced for the following detailed points.
(Please tick one box only)

	Very good	Quite good	Quite poor	Very poor
Acceleration and deceleration on straight line (smoothness)	☐	☐	☐	☐
Acceleration and deceleration in curves (smoothness)	☐	☐	☐	☐
Vehicle coming to a halt at a station (jerk and jolt)	☐	☐	☐	☐
Appropriateness of the overall travel time (comfort)	☐	☐	☐	☐
Appropriateness of the vehicle speeds (safety)	☐	☐	☐	☐
Accuracy of the vehicle when stopping at a station (distance)	☐	☐	☐	☐
Perception of traffic safety when following a vehicle (headway)	☐	☐	☐	☐
Perception of traffic safety when following a vehicle (speed)	☐	☐	☐	☐
Length of waiting time after a vehicle has been requested	☐	☐	☐	☐
Usability of in-vehicle HMI to request a stop	☐	☐	☐	☐

B2) Please indicate the level of satisfaction you experienced for the following general points.
(Please tick one box only)

	Very good	Quite good	Quite poor	Very poor
General ease of use of the system/ technology	☐	☐	☐	☐
Perception of personal safety in the vehicle	☐	☐	☐	☐
Perception of traffic safety of the system	☐	☐	☐	☐
Overall level of comfort of the ride	☐	☐	☐	☐
Overall satisfaction with the system/ technology	☐	☐	☐	☐

B3) Did you experience an emergency stop during the ride?
(Please tick one box only)

Yes ☐ **(Go to B4)** No ☐ **(Go to B6)**

B4) Please indicate the level of satisfaction you experienced during the ride for the following points.
(Please tick one box only)

	Very good	Quite good	Neither good nor poor	Quite poor	Very poor
Deceleration during emergency stop (smoothness)	☐	☐	☐	☐	☐
Vehicle coming to an halt during emergency stop (jerk and jolt)	☐	☐	☐	☐	☐

B5) Did you think the emergency stop was necessary?
(Please tick one box only)

Yes ☐ No ☐

B6) Did you experience an obstacle on the track during the ride?
(Please tick one box only)

Yes ☐ **(Go to B7)** No ☐ **(Go to Section C)**

B7) Please indicate the level of satisfaction you experienced during the ride for the following points.
(Please tick one box only)

	Very good	Quite good	Neither good nor poor	Quite poor	Very poor
Acceleration and deceleration to avoid obstacle (smoothness)	☐	☐	☐	☐	☐
Vehicle coming to a halt to avoid obstacle (jerk and jolt)	☐	☐	☐	☐	☐
Perception of traffic safety while obstacle on track	☐	☐	☐	☐	☐
Performance of the vehicle while obstacle on track	☐	☐	☐	☐	☐

Section C – The system in general

C1) Please indicate your general view on the following points.
(Please tick one box only)

	Very good	Quite good	Neither good nor poor	Quite poor	Very poor
Usefulness of automated transport systems in general	☐	☐	☐	☐	☐
Usefulness of the technology for this specific application	☐	☐	☐	☐	☐

C2) Please read the statement below:

Automated transport systems offer the capability to alleviate various current problems in urban mobility and have the potential to provide a real alternative to the private car, bringing together the advantages of conventional public transport (e.g. less emissions, lower costs, higher capacity) and the private car (e.g. individual, on-demand, door-to-door transport).

To what extent do you agree with this statement?
(Please tick one box only)

Strongly agree	Tend to agree	Neither agree nor disagree	Tend to disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐	☐