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Abstract:

The CyberCars Project was focused on the development and dissemination of a new form of urban transport based on cybercars, which are road vehicles with fully automated driving capabilities. Such innovative transport system can provide on-demand and door-to-door capabilities for passengers or goods. The project has focussed on the improvement of the technologies, on the certification procedures and on the dissemination. For the technologies, several new techniques have been developed such as the guidance with magnets which leads to improved performances at a lower cost, or various obstacle avoidance techniques which lead to safer operation at higher speeds. Guidelines have been established concerning the development of cybercars and their installation and should lead to new certification procedures. The dissemination took the form of numerous presentations at various important conferences worldwide, an active web site and several technical demonstrations in cities such as the final one in Antibes where a fully automatic vehicle circulated safely during ten days in the city, to the delight of the citizens.

Keyword List:

Cybercars, automated vehicles, automated transport, urban transport, demand responsive transport, electric vehicles, car-sharing

Project Website:

<http://www.cybercars.org/>

CONTENT

INTRODUCTION	3
1.1 Background	3
1.2 Project highlights.....	4
2. PROJECT RESULTS AND MAJOR ACHIEVEMENTS.....	6
2.1 Status Review (WP1).....	6
2.1.1 User needs analysis for CTS systems	6
2.1.2 User needs analysis for CTS applications	7
2.1.3 Key technologies analysis	8
2.2 Development of the Vehicles (WP2).....	9
2.2.1 Objectives	9
2.2.2 Problems and solutions.....	9
2.2.3 Activities.....	11
2.2.4 Results and innovations	14
2.3 Development of Infrastructures (WP3).....	17
2.3.1 Objectives	17
2.3.2 Problems and solutions.....	17
2.3.3 Results and innovations	19
2.4 Performance analyses (WP5).....	22
2.5 Development of Certification Procedures (WP6)	23
2.5.1 Introduction	23
2.5.2 Certification standards	23
2.5.3 Certification method	24
3. DISSEMINATION AND IMPLEMENTATION PLAN	26
3.1 Project Website	26
3.2 Participation to Events	28
3.3 Papers Presented.....	32
3.4 Media Coverage	34
4. CONCLUSION, OUTLOOK AND VISION	35
APPENDIX. GLOSSARY	37

INTRODUCTION

1.1 Background

In many urban environments, private automobile use has led to severe problems with respect to congestion, energy (our dependency on oil resources), pollution, noise, safety and general degradation of the quality of life. Therefore, historical cities centres are facing severe problems, traditional commerce in them declines, moving to the periphery, and they become less attractive to tourists. Although public transport systems have seen many recent improvements (mostly due to information technologies), in many cases the car still offers a much better service at the individual level. This leads to a constant increase in its use, hence to non sustainable development of urban transportation. A new approach for mobility, emerging now as an alternative solution to the private passenger car, offers the same flexibility and much less nuisances: small automated vehicles form part of the public transportation system and complements mass transit and non-motorised transport, providing passenger service for any location at any time. Such systems can also evolve to provide door to door freight delivery or garbage collection. Experiments are under way in several places in Europe and in Japan and the first operational system (the ParkShuttles) have been in use in the Netherlands since the end of 1997 and is now being expanded.

This concept started with car-sharing: a fleet of individual vehicles shared among a relatively large number of users, offers the possibility of using a car for some time or having a car available at both ends of a train trip. These systems are increasingly popular in Switzerland and Germany. They work well in specific areas where the demand is properly structured, but have yet to offer a door to door service : currently, the vehicles are only available at a few locations and have to be returned. Modern fleet management technologies have recently improved the service, e.g. also allowing short trips without the need to return the car to its point of origin (Praxitèle and Liselec Projects in France, City-Car in Switzerland, IntelliShare in the USA, Crayon in Japan,...). Specific vehicles, well-adapted to city driving, have generally been used for these systems: small size, convenient, energy efficient, quiet, often based on electric power. They even compete with public transportation in terms of energy consumption on per passenger-km basis. To date, these systems have not generally proven that they can compete economically, one reason being limited vehicles availability in too few locations, thus limiting the number of potential customers (see European Project Utopia).

A novel form of vehicle-sharing is now appearing, mostly in Europe, based on automated vehicles, avoids this problem of availability (anywhere and anytime). The car has automated driving capabilities on an existing road infrastructure, with a right of way similar to dedicated bus-lanes. With existing technologies, the speed of these vehicles is limited to about 30 km/h, which is quite sufficient in many urban areas but the technology, as well as the infrastructures (with dedicated high speed sections) will certainly evolve. Some vehicles also allow traditional manual driving for running in normal traffic. In such cases, they are called dual-mode and their automated capabilities allow them to be collected and distributed by platooning or remote control. Eventually, this concept of dual-mode vehicles deployment could be applied to private cars, which would be allowed (with some possible restrictions and an access fee), to run in restricted

urban areas. These vehicles would certainly run on “clean” energy in these areas, be controlled in speed and in parking, would pay for the access right and would automatically park themselves (underground or in remote locations) when not in use.

The advantages of autonomous driving capabilities and the new transportation systems, based on environmental friendly vehicles, are numerous. First, they provide reduction of congestion, and better traffic flow, air quality and energy conservation. Second, the system (in its automatic mode) is much safer than manual driving, and there is no need for a drivers’ license so anybody can use it, including also people with handicaps and in particular elderly persons. Third, the cars can be moved easily from one location to another, using fully autonomous driving platoon formations with a single driver. Fourth, the cars can drive autonomously to a remote parking area when not needed, hence leaving valuable urban space free for pedestrians and cyclists. Fifth, the concept and technologies are also appropriate for delivery of goods in city centers and even for garbage collection : the same infrastructure could be used by specifically adapted vehicles with delivery (or collection) “boxes”. Finally, flexible design will make it possible to optimize the overall system performance, taking into account the needs and requirements of the private consumer, the system operator and the public (e.g. municipality), permitting the system to operate in different modes at different times of the day, week and year.

1.2 Project highlights

Several companies and research organizations have been involved, before the start of the project, in the development of these new vehicles, which we now call cybercars. The first system has been in operation in the Netherlands since the end of 1997, running successfully 24 hours a day with four vehicles. Several other systems were under development at this time in Europe, which seems to be leading the world into this technology, although similar techniques are also being experimented on a more limited basis in Japan and in the USA. However, they all had some limits in their performances or in their cost. In particular, all the existing vehicles at that time ran at very low speed, in crowded or clustered environments because of poor (and expensive) collision avoidance systems.

The Project’s **main objective** was to accelerate the development and the diffusion of this novel transportation system by improving the performances and lowering the cost. This was achieved by bringing together all European actors of this field, in order to test and exchange best practices, share some of the development work and make faster progress in the experiments. Several cities throughout Europe have collaborated with the partners in the Project, studying the potentiality to run such systems, providing their specific constraints and accepting to do some preliminary tests of technologies and demonstrations. A major part of the work involved the improvement and testing of key technologies for better guidance, collision avoidance, energy utilisation and fleet management and the development of simple, standard user interfaces.

Another **important objective** was to suggest European level certification guidelines, concerning all relevant issues – safety in particular – for systems which were developed and tested in a very imprecise regulatory framework.

The project was able to improve significantly the performances of these technical systems or to lower their cost. A good example is the development of a guidance technology based on navigation and recalibration on magnets in the ground. All these improvements will now help the companies providing these transportation systems by lowering their costs while improving the performances and in particular the safety. The initial targets of 30% have been exceeded in several cases.

Another significant outcome of the project is the detailed implementation guidelines which can help the manufacturers and the operator to achieve the highest safety for their system. These guidelines have been put to test successfully in the installation of several systems.

Finally, the project has performed a thorough dissemination activity during the entire length of its life with a very active web site (www.cybercars.org), numerous scientific papers and conferences, excellent media coverage and several technical demonstrations in cities such as the final one in Antibes, now available on a DVD.

At the end of the CyberCars project, it can be said that the concept has gained worldwide acceptance as can be testified in the document "Mobility 2030" [reference: Mobility 2030: meeting the challenges to sustainability; World Business Council for Sustainable Mobility, July, 2004] and several high profile projects are now on the way.

2. Project Results and Major Achievements

2.1 Status Review (WP1)

The main objectives within Work Package 1 was to investigate user requirements for Cybernetic Transport Systems (CTS) and its applications, and to analyse the key technologies for CTS.

The activities carried out included a literature review on CTS related transport systems, moderated formal group discussion (focus group technique) and structured interviews with interviewees representing various user groups and sub-groups.

The results from both user needs analyses, for CTS technology in general and for specific CTS applications in urban environments, and the analysis of key technologies have fed in as input into other work packages, including the system design for the demonstration sites and the city test sites and the system evaluation, with the technical assessment and the user acceptance as main assessment categories.

2.1.1 User needs analysis for CTS systems

The user needs analysis for CTS systems focused on user requirements and perceptions for CTS systems in general. The objectives were to establish all user groups involved and to obtain information on requirements and perception of CTS technology, covering all user groups involved in the use, operation and decision making processes in context with CTS. The analysis is carried out on a general system level.

The methodology used for the user needs analysis for CTS, was to review literature on system characteristics and user needs in context of CTS related existing systems, to develop a common analysis frame work for user groups involved and application classifications and to use group discussions and interviews to obtain information on user requirements and perceptions, covering all user groups.

In this Project, an analysis framework was developed to establish which user groups and sub-groups are involved in the process of implementing, decision-making, planning, operating, using and being effected by CTS. Based on this framework a resulting matrix of site and application characteristics was developed.

According to the analysis framework, the user needs analysis, on the highest level, investigated requirements for end-user, who could be potential system user, or non-user, who are effected by the system, decision-maker and operators, both in case of a public application and decision-maker/ operator combined for the special case of a private application. According to different user group and/or site characteristics, different activities were carried out in order to obtain responses on the concept of CTS from all user groups involved.

The literature review covered the system operating characteristics and the user requirements for various systems related to CTS technology. These related systems

included automated transport systems, demand-responsive transport systems and car-sharing/ -pooling schemes. The review was carried out on related examples, as there were no user needs analyses for CTS at the beginning of the project.

2.1.2 User needs analysis for CTS applications

The user needs analysis for CTS applications focused on user requirements for the application of CTS technology in urban environments. The objectives were, to gather information on user requirements for the use of CTS technology for specific concepts in spatial settings. The analysis investigated how CTS can be a solution to specific problems.

The methodology used for the user needs analysis for CTS applications, was to relate specific potential user groups to specific concepts in their spatial settings, to learn more about the design of CTS, that people can imagine and to investigate the conditions under which people would use them. This information can differ for short and long-term scenario. The analysis has been carried out using an interactive questionnaire in combination with a virtual site.

The focus groups were carried out to obtain responses from end-users with general needs on present urban transport issues, user requirements and perceptions of CTS technology for different technology levels, including the short-term (e.g. 2005, relating to the CyberMove city test sites) and the long-term scenario (e.g. 2030, relating to the long-term definition of CyberCars) and whether they can potentially be a solution to problems in urban transport. Structured interviews were carried out to cover all other user groups involved and their views on the use of CTS in urban environments.

The literature review on CTS related systems unveiled gaps in the literature on user requirements. Most references only contained lists with envisaged user requirements, instead of results of market research with actual users involved, reinforcing the decision to carry out group discussions (focus groups) and interviews for the analysis of user requirements and perception for CTS.

The focus groups activities revealed a common inability of group participants to envisage the use of CTS technology in a shared environment with other traffic, including manually driven vehicles, bicycles or pedestrians, despite a general trust in the technology involved. Potential applications of CTS technology imagined by group participants were therefore mainly in contained environments.

The structured interviews again showed concern about the use of CTS in environment mixed with other traffic. But a high potential for CTS technology to solve some of the present transport problems was acknowledged, however concern about operational, political and institutional issues in view of the actual implementation of CTS technology, especially in urban environments was expressed.

The variety of activities carried out in context of the user needs analysis for CTS revealed a conflict between perception of a theoretical subject presented and an actual existing system, which can be used and experienced. This has to be considered in context with the concern about CTS in a shared environment. The results of this analysis may change with growing experience and exploitation of CTS technology.

2.1.3 Key technologies analysis

The analysis of key technologies focused on current technologies for CTS and the needs for improvements. An automated guided vehicle is a complex combination of many technical systems. Some of these are relatively standard, others need to be adapted to the specific needs of CTS and a third group is the unique CTS technologies. The analysis concentrated on the latter two groups.

The methodology used for the analysis of key technologies for CTS was to review vehicle technologies (control, guidance, obstacle avoidance, platooning) and infrastructure technologies (HMI, fleet management, remote operation, energy management). Data was collected on technical performance, cost and current availability. For each technology realistic improvements have been derived in terms of operational capabilities and/ or cost.

2.2 Development of the Vehicles (WP2)

2.2.1 Objectives

The main objective within Work Package 2 was to improve existing technologies for automatic navigation, obstacle detection and platooning, identifying new solutions which are more performing and cheaper than the existing techniques.

A second important goal was to improve the control architectures for vehicles, in term of both hardware (HW) and software (SW): to this respect, a major issue was to insure the necessary safety and reliability for all the basic functions, starting from engine management, braking and steering.

The general frame was to extend the application domain of cybercars, according to the roadmap defined at the beginning of the project. In fact, driving automation was expected to enlarge its operation from private grounds, where most of the applications were exploited, to local tracks, pedestrian zones or specific city areas, aiming progressively to more complex environments and road networks, with a greater interaction with other road users and traffic.

2.2.2 Problems and solutions

The analysis performed in the first phase of the project (Workpackage WP1) has shown that state-of-the-art technologies, mostly derived from robotics, still had a number of limitations or inefficiencies regarding the requirements of AGV's. On one hand, some existing technologies had to be improved in term of performance. On the other hand, there was an opportunity to identify new concepts, allowing the simplification of the operation of cybercars and reducing the cost of equipment.

The problems were identified as follow :

1) Vehicle controls

Cybercars were derived from existing robotic solutions, which were not well fitted to outdoor and less controlled environments, often offering limited performances and especially poor reliability. Although the control of road vehicles became a bit easier due to advances in drive-by-wire technologies from the automotive sector (see ADASE Project), the design, development and validation of such computer controlled systems was still far from easy and, for a low volume production, the cost was high and the reliability not certain.

The focus of the work was therefore to develop new hardware products as well as software production and validation technologies, to simplify the development phase. This approach was characterised by the following aspects:

- Improved integration for different functions under full computer control;
- Reliability, especially for safety critical controls;
- Use of new drive-by-wire products from the automotive industry;

- Monitoring the projects in the automotive sector for new sensors;
- Distributed system approach, allowing flexible implementation for different applications;
- Methods for easy design and validation.

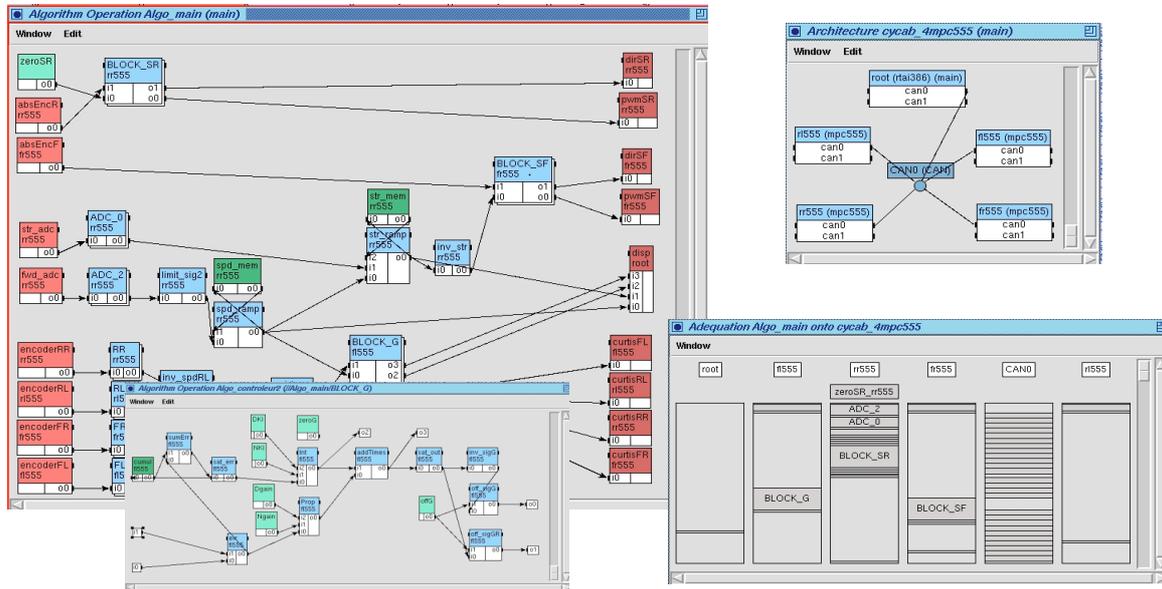


Figure 1 SynDEx Tool used for cybercars software development

2) Navigation and guidance

In the cybercars applications at the beginning of the Project, few techniques for localisation and navigation were employed, like wire guidance, transponders and magnetic sensors. All of these had some advantages but also some drawbacks, as described in deliverable D1 and summarised in the deliverable D2. In particular, wire guidance and transponders presented problems especially with installation procedures, maintenance and cost. The other approaches using vision, inertial navigation or GPS were at the preliminary research stage.

The situation suggested concentrating efforts on the following points:

- Improvement of the magnetic localisation, in term of cost, accuracy and easy installation;
- Study of solutions allowing a limited investment in the infrastructure;
- Effort to implement a modular architecture, allowing the flexible adaptation of different techniques on vehicle platforms, depending on application requirements;
- Development of new techniques based on vision, GPS and inertial navigation .

3) Obstacle detection and avoidance

The existing technologies for safety relied on expensive laser systems, typically with a scanned beam, detecting objects in the front area and on tactile bumpers, switching off the traction in case of a contact. Regarding vision systems, a certain experience on road vehicles already existed, with most systems based on stereo cameras and an inverse perspective mapping, with the assumption of a flat road. These solutions were not robust

enough for an implementation in a cybercar with no human intervention. Also the laser sensors had several limitations in terms of performances and cost.

Based on the above considerations, the following approaches have been addressed:

- Techniques to improve safety for both road users and cybercars users, in several operational conditions, mostly based on improved processing of laser signals;
- Improvement of image processing for stereo vision, focusing the modelling of the environment, the calibration methods and the path tracking;
- The evaluation of automotive radar systems (devices, processing), which could provide a low cost and reliable solution due to the high volume productions;
- The testing of well-known ultrasound sensors, offering an economic device with however some environmental limitations.

4) Vehicle platooning

Only a limited experience was available on this topic. A certain similarity existed with commercial techniques, used in Adaptive Cruise Control (ACC) for automobiles, which are based on ranging systems, such as lasers or radars, but which concerned only the longitudinal guidance. New improvements were under way at research level, which consider longitudinal and lateral guidance using vision and targets or radar and markers on the road. Such developments took place in the parallel European Program Chauffeur but in a different context (highways).

Based on the above situation, the activities have been focused on the sensor issues, taking into account the coupling of longitudinal and lateral guidance, and aiming to avoid the use of equipment in the infrastructure. A technique using the laser obstacle sensor was developed by the project.

2.2.3 *Activities*

Four types of vehicles were considered for the implementation of activities:

- a People Mover assuring a comparatively larger capacity of 20 passengers (Frog in Figure 2),
- a smaller four seats AGV applied to transport visitors in show areas (Yamaha-AGV in Figure 3),
- an even smaller two passenger vehicle developed by INRIA and now sold by Robosoft (CyCab in Figure 4),
- two general purpose platforms, which can be used for different applications depending on the specific equipment mounted on-board (Robosoft).



Figure 2 ParShuttle II (Frog)



Figure 3 Yamaha AGV at Floriades



Figure 4 CyCab (INRIA/Robosoft)

2.2.4 Results and innovations

1) Vehicle controls

Consistent improvements in distributed and safe architectures, as well as the HW subsystems have been obtained and implemented on various vehicles. The main results are as follows:

- Development and application of the software tool SynDEx, for optimising distributed real-time embedded systems; the SW has been used by project partners for several applications; to create, implement and certify the control systems; rapid prototyping has also been demonstrated using the same tool.
- Advanced architecture and components for ParkShuttle II, with double CAN network for improved reliability: in particular the system provides redundancy for safety critical applications and three different levels of braking (normal, fast and emergency);
- A CAN based architecture implemented in RobuCab, CyCab, Yamaha vehicles, and in the test platform prototype;
- A new braking system offering improved comfort (low jerk) and enhanced vehicle range by energy regeneration; the system has been tested at the Floriade show on 25 vehicles running for 5000 Km each;
- The definition of a vehicle solution for dual mode driving (manual + automatic) on a city car; the vehicle is based on a small and clean thermal engine plus an electric traction, and uses standard automotive components for steering and braking.

2) Navigation and guidance

The results are a significant improvement of two vehicle platforms (ParkShuttle and RobuCab) and the availability of several research prototypes ready for extended testing. The following major results can be highlighted:

- The magnetic ruler technique on the ParkShuttle has been improved with new signal processing schemes: this resulted in halving the density of sensors in the vehicle and beacons on the infrastructure, increasing the distance from the antenna to the magnets (20 cm), and obtained better accuracy of 0.1 m at 20 Km/h;
- A magnetic probe based on induction has been studied and realised in RUF vehicle : the very compact device is able to control the path of a cybercars when choosing among different tracks on the level ground (normal operation in automated mode is on an elevated rail);
- A vision system allows to reconstruct the left and right borders of the road, being well adapted to capture the dynamic features of the scene; it has been tested in urban areas (city centre and harbour of Antibes) at 36 km/h and 25 frames per second;
- A modular architecture has been implemented in different platform; a particular example is the RobuCab, where different composition of modules allows implementing various applications such as vehicles for public or for individual urban transport, teleoperated vehicles, and outdoor platforms for research;
- A new approach for path tracking based on fuzzy logic has been studied and shows promising results.

Other additional results concern the setting-up and evaluation of some more traditional techniques, like the wire guidance and the scan laser with reflecting beacons. Regarding autonomous techniques, other prototype systems have been realised and tested, like a vision system able to track the side of the road, which for the moment operates at low speed, and a RTK-GPS receiver coupled with inertial navigation.

At this time, the improved magnetic rulers are considered as a fundamental option for short-term applications on local tracks. In a longer time perspective, computer vision could offer interesting possibilities with a lower impact on the infrastructure. Inertial sensors are a relevant technology to follow for future developments, even if they do not provide today the necessary performance; however improved characteristics and lower costs are anticipated, due to the on-going trends of microsystems technologies for automotive products.

3) Obstacle detection and avoidance

- Automotive radar sensors and systems have been evaluated in two configurations; suitable performances have been demonstrated in a platooning scenario and when braking behind a stopped vehicle; however, the angular field of view now offered in existing products has been found insufficient;
- Some advanced solutions for stereo vision have been implemented, including a technique with simplified calibration and applicability on non-flat roads and a technique based on 3D models with an 'evolutionary' approach allowing pattern recognition;
- New data processing has been developed for a dual laser scanner on the ParkShuttle, with measurements performed at two heights for increased safety; the system provides a recognition of on-path and near-path obstacles, an easy and automatic configuration of the area of interest from the route plan, and enhanced comfort due to the strategies for a gradual stopping;
- More standard solutions have been tested for the purpose of understanding the domain of operation, particularly a certified laser scanner and a device with low cost ultrasonic sensors;

From the experience gained in the work, it can be concluded that the scan laser remains at the moment the preferred option, with significant improvements now obtained in the data processing. For this technology, it is now known that suppliers are developing 2nd generation devices for application on vehicles, with smaller dimensions and a reduced cost (see European Project Carsense). The automotive radar has shown an interesting potential for cybercars, when systems with a larger field of view will be available, as expected from the present trends (European Project RadarNet). Finally, vision systems maintain a great interest for the variety of functionalities they provide, also considering the integration of obstacle detection and navigation. In this area, significant progress has been obtained, but further experimentation and setting-up appears necessary for cybercars.

4) Vehicle platooning.

Three techniques have been demonstrated in simple scenarios in a test area but in an urban setting.

- The 1st approach uses a camera based technique extracting features from the image of the preceding vehicle: the method proved to be a basic building block for a fleet

of homogeneous vehicles, which is adaptable to different vehicles by simple SW modifications;

- The 2nd approach applies a laser scanner with reflective beacons; this simple method could provide distance and orientation of the preceding vehicle between 2 and 15 m; it has the advantage of adding practically no cost if the same laser sensor is used for collision avoidance.
- The 3rd approach is a camera-based technique with IR lights. Progress has been made in the use of low cost vision sensors and the coupling between image processing and control.

In addition, general aspects of platooning have been considered, to provide guidelines for the implementation of techniques.

From the above developments, a preliminary feasibility of platooning schemes at low speeds has been demonstrated and the approaches for possible applications have been identified. Additional work remains to be done to consolidate these techniques and to define details of the solutions for a demonstration site. A specific challenge to be addressed in future work concerns the issue of string stability and the robust control for such a train of vehicles.

2.3 Development of Infrastructures (WP3)

2.3.1 Objectives

The objectives were to improve the technologies needed to run efficiently and easily a CTS (Cybernetic transportation System) at the global level. In particular, we wanted to improve noticeably the performances of the following subsystems:

- Fleet management
- Human-machine interfaces
- Remote operation
- Energy management

2.3.2 Problems and solutions

Compared to traditional transportation systems which often rely on heavy material infrastructure such as rails or heavy road infrastructures, the CTS need only a very light one, often no more than the equivalent of a bicycle path, or even just two small tracks for the wheels. Even with such light infrastructures, high transportation needs can be satisfied just by increasing the number of vehicles when needed. On the other hand, the road infrastructure is replaced by a non-material infrastructure based on information and in particular on telecommunications. These telecommunication networks are now readily available, even if the bandwidth needed is high. The CTS use these capabilities to their full extent and there is no need to incorporate new developments for them.

Therefore, the main efforts have been concentrated on the use of these communication networks in order to perform essentially tasks in the following subsystems:

1) Fleet management

Cybercars by definition are under control of a management system in order to adapt the resources to the demand. Since it is expected that a large number of users will have access to a large number of vehicles, it was necessary to develop sophisticated management tools in order to optimize the use of the mobile resources which are not only the vehicles but also the human resources for running smoothly the system (for maintenance, assistance, cleaning, etc.) and the physical resources such as parking places, recharging stations, etc. Such systems had already been developed for car-sharing systems and for industrial AGVs. However, such systems had to be adapted to the particular problems of public transportation with automated vehicles. For example, the redistribution problem of empty vehicles among the different parking lots with car sharing systems, human transport problem for industrial AGVs, whose infrastructures and technologies in the previous years were mainly focused on material handling systems (MHS) rather than human transport. Furthermore, the fact that the vehicles could be moved autonomously changed the problem by allowing many more “stations” for pick-up or destinations.

For Cybernetics Transportation Systems (CTS), the fleet problems concerned essentially the following elements:

- Vehicle allocation to a particular demand,
- Vehicle relocation after a trip,
- Demand management and fare collection,
- Distributed versus central management,
- Communication architecture.

2) Human-machine interfaces

In simple systems such as the ones already in place at the beginning of the Project, and which have a very limited number of stop points for the vehicles, a system of buttons such as the ones found for elevators was quite easy to understand and simple to put in place. If the system becomes, as expected, much larger, it will not be feasible to install these call buttons everywhere in the city.

The most convenient interface will therefore be based on mobile terminals such as mobile phones or PDA and by specific programming on these devices. New digital high-speed connections such as GPRS or UMTS will allow for browser-type interfaces on these terminals but one had to be careful to use existing guidelines for developing these interfaces. In particular, some form of European propositions for standards were developed. The interfaces were also developed inside the vehicles and on fixed terminals with possibly more functions given the comfort of the larger screens. These interfaces had also to take into account the need for ticketing which had to be developed in a multi-modal environment.

All of these interfaces on mobile or fixed units or in the vehicle had to be compatible and easily connected to other information systems concerning the city and the purposes of the trip. We thought about interfaces with commercial destinations (shops, restaurants, hotels, theatres, etc.) and also with tourist and cultural information.

3) Remote operation

The remote control of the vehicles from the central management system was found necessary not only for the monitoring of the state of the vehicles (location, mode of usage, energy, etc.), but also for the possibility to remotely drive the vehicles. This was considered as an important back-up function for the automatic driving when a vehicle is stopped for an unknown reason: emergency switch activated by someone, obstacle, hardware or software malfunction, etc. In these cases, it would be convenient for the operator in the control room to take control of the vehicle and see if he/she can eventually operate it. If the remote driving is possible, then the conflict could potentially be resolved and the vehicle returned to its automatic mode or removed from the operation. Remote driving of road vehicles had already been demonstrated several times, for example for army vehicles and for maintenance vehicles because of the potentially dangerous situations. In a city environment, the difficulty lied with the environment, which might be unpredictable (moving vehicles and/or pedestrians).

4) Energy management

In order to let vehicles go to recharging stations autonomously when needed, it was found necessary to take full advantage of the automated driving of the vehicles. Automatic docking stations were therefore considered a necessity.

2.3.3 Results and innovations

Here are the key results obtained during the Project :

1) Fleet management

To have control over the vehicles a fleet management system is necessary. The basic of the system is to know the position of the vehicles and the position of the requester. The system makes a route planning to get a vehicle as soon as possible to the requested place. Information will be given about the arrival time. Also this information is given if the passenger has given the destination. Real-time updating can be given and is important for the acceptance of the system. Optimisation is done for systems which requires a continuous flow of vehicles during particular time of the day in combination with driving on demand during the rest of the day. Main results and innovations include:

- A new efficient Centralized Fleet Management Software (CFMS) for fleet management of CTS from a central computer using a digital radio network, including: design tools of system architecture, management rules for optimisation of user reservation queue, route planning and travel time computation, real time updating of traffic matrix and redistribution of cybercars after service, performance evaluation.
- New traffic management system embedded in a fleet management system for the Rivium application, including traffic management rules for optimisation of the CTS transport capacity and for different levels of transport demand.
- Two versions of PC based simulators of control system required to make sure that vehicles do not collide when they are guided through the junction. One for a junction and one for the line between junctions. These simulators are able to adjust relevant parameters such as flow distribution (straight, right, left and off) to evaluate the impact on capacity of the junction, and to test various configurations

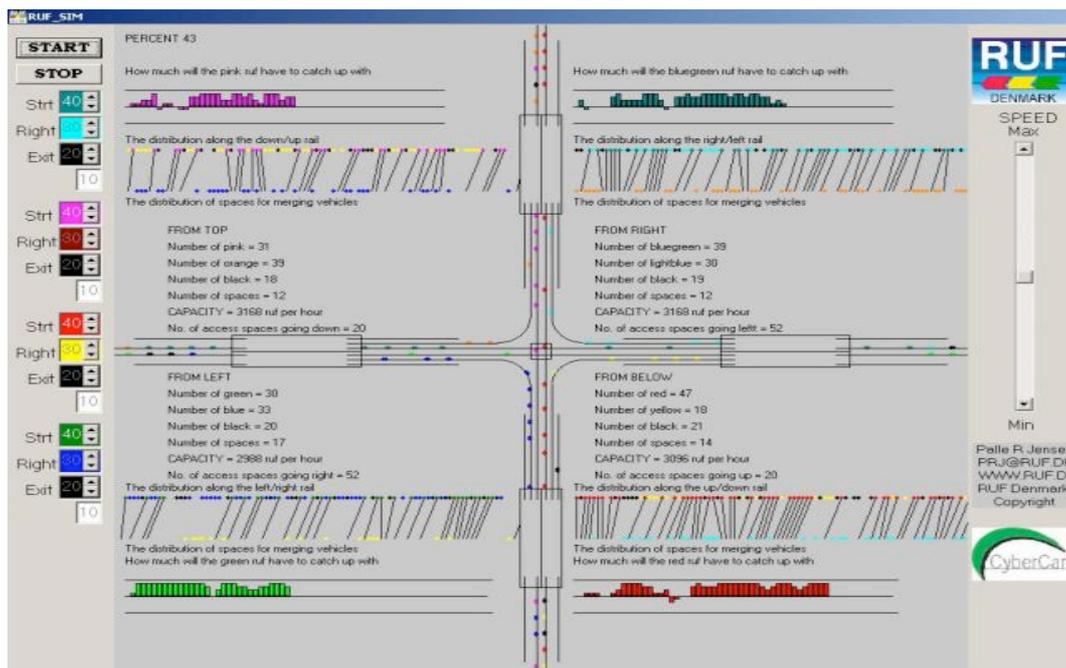


Figure 7 RUF Simulation tool for fleet management

of junctions in order to optimise its function.

- A fleet management software, Traffic Manager HB® for the pilot of Ouchy.
- Design tool to evaluate the operation of a particular system with the different available energy-systems, and management software for the optimisation of the operation.

2) Human-machine interfaces

The passengers have to be supported with tools, which make it easy for them to have access of cybercars. Effort is made to provide the passenger with an easy to use and clear interface. For accessing cybercars special attention is given to door-systems. Specially, elderly people should access the vehicle in an easier way. Using of Internet and the availability of the mobile phone has led to new techniques. Passengers can request for a vehicle, see an overview route with the position of the vehicle. Passengers can be informed about the waiting time. In this way the acceptance of cybercars can be improved. With this kind of communication, payment for the cybercars can also be done.

Main results and innovations include:

- A HMI software and concepts for CTS specificity, user tests, wireless communications evaluation, technology selection regarding on-board and off-board hardware and software;
- An HMI prototype consisting of a physical mock-up of the cybercars (dashboard, anterior seats, auxiliary controls) and an on-board information system;
- On-board interfaces system for the Rivium2 site, which are touch screen based interface and can be used to order a car, choose a destination, provide transport information, provide in vehicle entertainment and area information. It is also menu based, self-explanatory, and suited for different languages;
- Visualisations of electronic interfaces for public transportation; a solution to the physical access (a special door system);
- A simplified Human Machine Interface for the RobuCab, including a batteries level indicator, an emergency stop, a touch screen with a GUI and a simple push button;
- An on-board interface for Serpentine Capsule, including three payment methods: small change and tokens, SMS (Short Message Service), and magnetic card; two information terminals for the users: roadside and on-board interactive terminal.



Figure 8 Image of INRIA circuit on P800 phone

3) Remote operation

Internet and mobile phone can be used for remote operation and servicing. An operator has not to be available continuously. He will be informed if something happens, can get

an overview of the situation and can take appropriated measurements. Main results and innovations include:

- Description of a concept for remote operation of a cybercars system;
- A telephony (GSM/GPRS) compliant HMI for interacting with the transport application. The response time of calling is 3s minimum depending on the network charge. In the future, an i-mode sites and web pages for smart phone or PocketPC will be developed. The video acquired from the WebCam installed in the RobuCab will be lively export on Web sites and be able to display it on a mobile phone.

4) Energy management

Batteries are at this moment mostly used. Charging batteries is an item that has been taken in account. Batteries have to be charged in time and in the right way to obtain maximum life cycle of the batteries and maximum availability of the vehicles. Algorithms are made available and can be used in the traffic management system to redirect a vehicle to a charging-station. A simulation model is developed and tested for several implementations. Continuous charging through the ground by high frequency magnetic fields has been developed and tested. Main results and innovations include:

- A simulation model for evaluating the optimal recharge level for cybercars; management rules for the optimal recharging of cybercars at the recharging stations; a software for optimum recharging strategies; performances test and evaluations;
- An automatic energy transfer system, which can recharge automatically the on-board batteries of the cybercars, without human intervention, being compatible with the environment, substructures, types of vehicle;
- The Magnetoslider® for Serpentine's Capsule, by which the on-board batteries is charged by infrastructure without contact;
- A model and simulation of charging procedures;
- A theoretical model for evaluation of the performance of cybercars, which is intended for optimisation of the battery module and of power train parameters. It includes the relations between the electrical motor efficiency and load factor, and between the batteries efficiencies and depths of discharge for driving and regenerative braking operation.



Figure 9 Automatic recharging station

2.4 Performance analyses (WP5)

For most of the technical developments presented above, performances were evaluated and compared to the objectives set in WP 1. The performances and/or the cost objectives have been confirmed in most cases with improvements in navigation technologies and obstacle detection of better than 30%.

The evaluation of the service provided to the final user was done during several demonstration and in particular during the two week test of the ParkShuttle II of Antibes in June 2004. The users responses were extremely positive as can be testified by the following graphs :

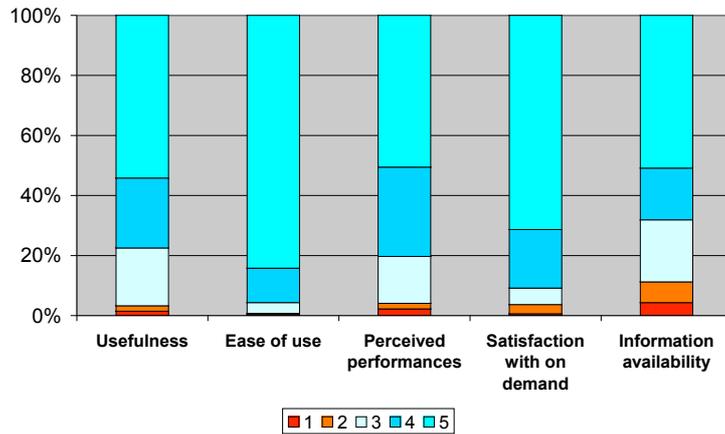


Figure 10 : Acceptance and quality of service indicators (1)

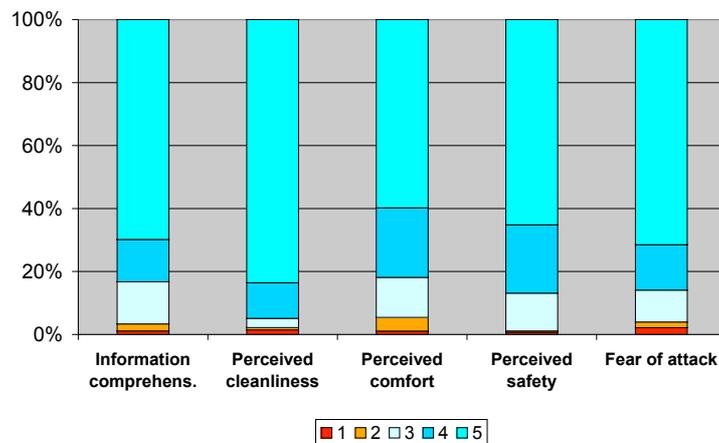


Figure 11 : Acceptance and quality of service indicators (2)

The industrial partners have also established detailed implementation plans and are already involved in several large scale proposals for the sale and operation of CTS.

2.5 Development of Certification Procedures (WP6)

2.5.1 Introduction

The CyberCars project is focused on the testing, analysis and improvement of existing techniques, but also pays attention to existing legal constraints that could hamper the diffusion of CTS in the cities. Traditional vehicles that use the public roads have to meet a large number of requirements, laid down in standards and regulations. Most of these standards and regulations are related to safety. When manufacturers develop new vehicles, they know the limits within which they have to stay in order to have their vehicle certified for use on public roads. However, generally accepted certification procedures for Cybernetic Transport Systems (cybercars) do not exist at present. This makes the introduction of such systems difficult, because neither manufacturers nor operators nor authorities have guidance as to what is acceptable from a safety point of view. Workpackage 6 of the CyberCars project therefore addressed the certification guidelines that are needed to certify that systems are safe.

This work has started with a report on existing guidelines. It describes the results of a survey of existing standards and guidelines that could be relevant for the future certification of CyberCars. The report focuses on the certification requirements for the vehicles as such. Requirements for the environment in which the vehicles will have to operate are subject of the alternative project CyberMove.

The work has then been continued to set out the requirements for certification procedures, to propose a method to establish acceptable safety levels, and to analyse a cybercars system in order to find out whether or not it meets the requirements. The basic idea for this method was developed by TNO for the analysis of automatic guided vehicles and was first evaluated on drive-by-wire systems. Within the framework of the CyberCars project the development was continued and adapted to the specific cybercars requirements. The result was evaluated by analysing the safety of two cybercars systems: The 2nd Generation ParkShuttle II in Rivium and the CyberCab in Floriade. The method proved to provide very useful information that can be used to improve products in the concept and design phases. The method has also shown a potential to develop into a certification instrument, but additional research and additional test cases are necessary to improve the process of establishing safety criteria and to prove the reproducibility of the method.

2.5.2 Certification standards

Based on the results of the survey presented in deliverable 6.1, and the present developments in the field of regulations for traditional road vehicles, a number of requirements for certification standards for cybercars can be defined. Certification standards for cybercars should:

- Be based on the system safety approach and the safety life cycle.
- Contain performance criteria instead of design criteria.
- Include ranking systems so that a quantitative assessment is possible.

- Define acceptance levels for different kinds of vehicles.
- Use relevant existing standards and follow developments in standards for road vehicles carefully.

In addition, a number of practical requirements can be defined that ensure that the analysis method is fit for use. The method has to fulfil the needs of several parties who are involved in the decisions concerning the safety of cybernetic transport systems.

- *User friendliness*: The tool must be easy to use, so that people from different backgrounds can use it with a minimum of training.
- *Uniformity*: The tool must be suitable for analysis of almost every vehicle system, vehicle or vehicle component without the need for special adaptations.
- *Reproducibility*: The results should be the same, independent of the people that carry out the analysis.
- *Acceptability*: In order for a tool to be acceptable, it should have a firm basis in existing standards.

Since there was no direct reference for a certification standard for cybercars, it was decided to develop one. The basic idea was to develop a simple and user-friendly method for the safety analysis of cybercars systems that can be used during the complete design process of the system. The method can be applied to assess the first concept for a new system. After that the same method should be suited for the different phases of the design process and finally for the certification test of the completed system. As the basis for the analysis method the Failure Modes, Effects and Criticality Analysis (FMECA) was chosen, which has the advantage that it is extensively used in the vehicle industry and that most developers have either heard of it or have contributed to one.

The limitations mainly exist in three aspects:

- *Human Factors*: Human factors are not part of the guidelines. This is not so much a problem if we consider that cybercars are not controlled by human drivers, but nevertheless humans play a role in controlling central systems, maintenance, repairs etc.
- *Software*: Software is a difficult subject in any safety analysis. How can a judgement be made as to whether or not software is safe? Certainly in complicated control software like that in cybercars the number of possibilities for failure is very large.
- *Present laws*: In order to be approved for use on public roads, present laws require the presence of a driver in a motor vehicle. Since cybercars do not have a human driver, they cannot be approved under the present laws.

2.5.3 Certification method

A complete certification program for a cybercars system will consist of a combination of functional tests and evaluations and a series of FMECA analyses. The functional tests should prove that the system does what it is supposed to do according to its specifications. The FMECA analyses should prove that the risks involved in system failures are within the range of acceptance.

Such a certification process can be carried out when the development phase is concluded and the system is ready for introduction, or it can start when the first concept is available

and end with the final functional tests and analyses (recommended). The certification process should result in a certificate that shows that the system meets the requirements.

A basic structure for the certification process was designed, which consists of a number of process steps, each in its turn divided in sub-steps.

1. Preparation of the safety evaluation
 - Collect information about the system
 - Form a group of experts
 - Agree on goals, safety criteria, planning and process
 - Set up a program for functional tests
2. System definition and function analysis
 - Define system boundaries
 - Divide into subsystems
 - Make Passport diagrams
 - Define all functions
3. FMECA
 - Establish failure modes
 - Establish causes
 - Establish effects
 - Identify possible safeguards
 - Establish severity and likelihood
 - Add recommendations
 - Add comments
4. Conclusions and reporting
 - Draw conclusions
 - Lay results down in a report

3. DISSEMINATION AND IMPLEMENTATION PLAN

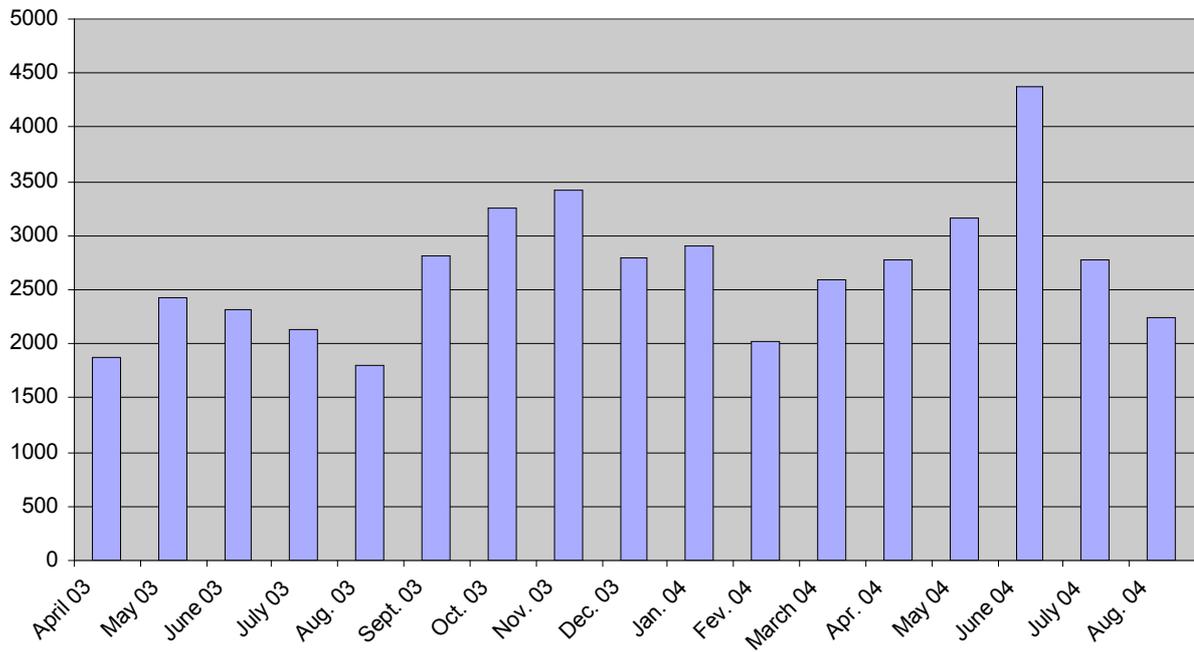
The CyberCars Project has been particularly active in the dissemination of its activities and results. Dissemination took many forms : participation to conferences and events, publication of scientific articles, publication of brochures, demonstrations of cybercars, presentations to the medias, realization of an extensive web site. A final video is now released.

However, the best dissemination is through the commercial activities of the industrial partners. The three major actors in the field of CTS are very active proposing solutions to numerous transport problems in cities and private sites. These actors have also defined their own commercial outlooks through documents.

3.1 Project Website

The Project website (www.cybercars.org) has been an excellent tool for the presentation of the project. Because of its extended documentation (deliverables, conferences, articles, pictures, videos, links to other projects,...) and clear explanations about the objectives and technologies developed, it attracts a large number of visitors from all over the world. It is also referenced by many other sites dealing with modern transportation technologies. Several thousands of hits are recorded each month and this number has been steadily increasing.

Cybernetic Technologies for the Car in the City



Number of visitors of the CyberCars web site

3.2 Participation to Events

2001 Event Participation by Consortium

Date	Event (Organiser)	Location	Type	Action by consortium
Sept. 8-10	European Control Conference ECC (IEEE)	Porto, Portugal	Conference	Paper presented (refereed)
Oct. 22-24	Electric Vehicle Symposium EVS15 (AVERE)	Berlin, Germany	Conference + Expo	Paper presented (refereed)

2002 Event Participation by Consortium

Date	Event (Organiser)	Location	Type	Action by consortium
Jan. 22-23	Congrès International francophone (ATEC)	Paris, France	Conference	Conference by Georges Gallais
March 13	ASPAN meeting	Geneva, Switzerland	Meeting	Conference by T.Chanard (CGA)
April-October	Floriades	Amsterdam, NL	Demonstration	Demonstration of 25 cybercars (Yamaha AGV) for moving visitors (300,000 in 6 months) by Frog
April 8-9	Colloque transport (AQTR)	Quebec, Canada	Conference + Expo	Paper + Keynote speech by Michel Parent (invited)
April 17	Intertraffic TWA congress	Amsterdam, NL	Conference	Papers by TNO
June 4-6	Surface Transport Technologies for Sustainable Development (European Commission)	Valencia, Spain	Conference	Paper presented by CRF
June 17-20	Intelligent Vehicle Symposium (IEEE)	Versailles, France	Conference + Demos	Symposium organisation by INRIA Several paper presentations (refereed) Several demonstrations by partners
Aug. 8-9	Intelligent Transportation System Conference (ITS Australia)	Perth, Australia	Conference + Expo	Keynote speech by Michel Parent (invited)
Sept.3-5	Intelligent Transportation System Conference (IEEE)	Singapore	Conference	Paper by Michel Parent (refereed)
October 3	Connekt, the Center for Expertise in Traffic and Transport, ITS Netherlands	Amsterdam, Netherlands	Meeting	Kerry Malone presented CyberCars and CyberMove projects.
Oct. 10-	Mobilité Urbaine et	Montreal,	Conference +	Conference by Michel Parent (invited)

12	Transports Avancés (CEVEQ)	Canada	Expo	
Oct. 16	Intelligent Transportation System World Conference (ITS America)	Chicago, USA	Conference + Expo	Several paper presentation (refereed) Posters and Leaflets in Exhibit
Oct. 30	Autumn Conference (UPIAV)		Conference	
Nov. 28-29	Territoire, Transport et Nouvelles Technologies (INRIA)	Sophia-Antipolis, F	Seminar	Organisation by INRIA Several paper presentations Demonstration of vehicles
Nov. 28-29	Transport planning research colloquium	Delft, NL	Seminar	
Nov.	Israel Annual Conference on Automotive Engineering	Herzliya, Israel	Conference	
Dec. 2-5	International Conference on Control, Automation, Robotics and Vision (IEEE)	Singapore	Conference	Keynote speech by Christian Laugier, INRIA (invited) Several paper presentations by partners (refereed)
December 17	Royal Dutch Institute for Engineers	Delft, Netherlands	Meeting	Kerry Malone presented the results of the User Needs Analysis of the CyberCars and CyberMove projects

2003 Event Participation by Consortium

Date	Event (Organiser)	Location	Type	Action by consortium
Jan. 12-16	82 nd Annual Meeting of the Transportation Research Board (TRB)	Washington, USA	Conference	Several papers presented (refereed)
Jan. 16	Journées INRIA-Industrie	Versailles, France	Conference + demos	Conference by Michel Parent (invited) Demonstration of cybercars (Robosoft+INRIA)
Feb. 3-5	“Beyond the Border” Seminar (DaimlerChrysler)	Frankfurt, Germany	Private seminar	Conference and participation by Michel Parent (invited)
March 14	Meeting Minatec	Grenoble, France	Private seminar	Presentation of CTS by Cybercars industrial partners to Minatec (science park)
April 1	ILIATECH Meeting (INRIA)	Versailles, France	Seminar + expo	Conferences by Michel Parent and Vincent Dupourqué Exhibits of cybercars
April 3-6	International Electric and Hybrid Vehicle Show (Monaco)	Monaco	Exhibit	Presentations of vehicles by Yamaha and A&E. First demonstration of ParkShuttle II (Frog)
April 11	International Seminar on	Seoul, Korea	Seminar	Keynote presentation by Michel Parent

Date	Event (Organiser)	Location	Type	Action by consortium
	Wireless Internet Society (Ajou Uni.)			(invited)
May 23	BAB local authorities	Bidart, France	Demonstrations	Vehicle demonstrations by ROBOSOFT
July 1-3	International Conference on Advanced Robotics (IEEE)	Coimbra, Portugal	Conference + Demos	Conference organised by ISR Keynote presentation by Michel Parent (invited) Paper presentations by partners (refereed) Demonstrations by partners Demonstration of 4 cybercars (Yamaha AGV) for moving visitors (up to 1000 in a week) in the “Industrial and Commercial Fair – CIC 2003”
July 6-10	EURO/ INFORMS Conference	Istanbul, Turkey	Conference	Kerry Malone presented the paper, “Cybernetic Transport system Deployment” (refereed)
July 25	Meeting Futuroscope	Poitiers, France	Private seminar	Presentations by Michel Parent (INRIA) and Vincent Dupourqué (ROBOSOFT)
August 1-15	Public demonstration	Anglet, France	Public demonstration	Cybercars as a support of communication (ROBOSOFT)
August 24-25	Advanced Bus Rapid Transit Workshop (TRB)	San Diego, USA	Seminar	Keynote presentation by Michel Parent (invited)
Sept. 2-5	International Conference on Automated People Movers (ASCE)	Singapore	Conference + Expo	Paper presentations by Michel Parent and by Martin Lowson (refereed)
September 11	NETMOBIL (5 th FW accompanying measure project)	Brussels, Belgium	Technical Workshop	Kerry Malone presented the CyberCars and CyberMove projects for the Advisory Group of NETMOBIL
Sept. 16-19	International Conference on Emerging Technologies and Factory Automation (IEEE)	Lisbon, Portugal	Conference	Paper presentation by ISR (refereed)
Sept. 24-26	Urban Mobility & Advanced Transportation (CEREVEH)	Poitiers, France	Conference + Expo + Demos	Papers by partners (invited) Demonstrations by partners
October	Public demonstrations	Bayonne, France	Demonstration	Demonstration of CTS (ROBOSOFT)
Oct. 15-16	Fêtes de la Science	Paris, France	Demonstration	Demonstration of CyberCars and CTS (ROBOSOFT)
Nov. 16-20	<u>ITS World Congress and Exhibition</u>	Madrid, Spain	Conference + Expo	Papers by partners (refereed and invited))
Dec. 17-19	Computational Intelligence, Robotics and Autonomous Systems	Singapore	Conference	Paper by Michel Parent (refereed)

2004 Event Participation by Consortium

Date	Event (Organiser)	Location	Type	Action by consortium
Jan. 11-15	83 rd Annual Meeting of the Transportation Research Board (TRB)	Washington, USA	Conference	Several papers presented (refereed)
Jan. 19-20	ADASE Concertation Meeting (IST)	Brussels, Belgium	Seminar	Presentation of the CyberCars Project
March 23-26	International Symposium on Robotics (ISR)	Paris, France	Coonference+Exhibit	Demonstration of cybercars
March 24-26	Euro-India Meeting (IST)	New-Delhi, India	Conference+Exhibition	Cybercars booth
Apr. 1-4	Salon international des vehicules electricques et hybrides	Monaco	Exhibition	Presentation of ParkShuttle
Apr. 6-8	Salon de la nouvelle ville	Paris, France	Exhibition	Presentation of ParkShuttle
April 22-24	CODATU	Bucharest, Roumania	Conference+Exhibition	Paper presentation (refereed)
May 17-19	VTC Conference (IEEE)	Milan, Italy	Conference	Invited paper (IST session)
May 22-27	FISITA Conference	Barcelona, Spain	Conference	Paper presentation (refereed)
May 24-26	ITS-Europe (ERTICO)	Budapest, Hungary	Conference+Exhibition	Paper presentation (refereed)
Oct.	ITS-World Congress	Nagoya, Japan	Conference	Several papers presented (refereed)

Note : List and Web sites of these events are available at www.cybercars.org

3.3 Papers Presented

Background papers (before start of project)

Parent Michel, Texier Pierre-Yves. "A Public Transport System Based on Light Electric Cars". Fourth International Conference on Automated People Movers. Irving, USA. March 1993.

Parent Michel and Daviet Pascal. "Automatic Driving for Small Public Urban Vehicles". Intelligent Vehicles '93. Tokyo. July 1993.

Parent Michel, Dumontet François, Texier Pierre-Yves and Leurent Fabien. "Design and Implementation of a Public Transportation System Based on Self-Service Electric Cars". IFAC/IFORS Congress. Tianjin, China. Aug. 1994.

Parent Michel, Daviet Pascal, Abdou Sofiane. "Vision Technique for Platoon Driving". Fourth International Conference on Applications of Advanced Technologies in Transportation Engineering. Capri, Italy. June 1995.

Jensen, Palle R. "The RUF Concept, a Dual-Mode electric/hybrid vehicle riding on top of a very slender guideway". 1997 SAE Future Transportation Technology Conference. San Diego, August 6-8, 1997

Parent Michel. "Automated Public Vehicles : A First Step Towards the Automated Highway". 4th World Congress on Intelligent Transport Systems. Berlin, 21-24 Octobre 1997.

Jensen, Palle R. "The RUF System New Visions in Transportation". NVT2000, Aspen, Colorado, Oct. 18-20, 2000

Project papers (since Aug. 2001)

Kaïs Mikaël, Hafez Névine, Parent Michel. "An Intelligent Vehicle Architecture for Automated Transportation in Cities". ECC'01. Porto. Sept.2001.

Michel Parent, Cyriacus Bleijs . "The CyCab : an electric vehicle specifically designed for car-free cities". EVS 15 Symposium. Berlin. Oct. 2001

G. Gallais. « Les Cybercars, un Nouveau Système de Transport en Ville ». Revue Trans Flash du Centre d'Etude. Supplément N°21 au Trans Flash N° 267. Janv. 2002

K. Malone (TNO), B. Saugy (Serpentine), JW van der Wiel (Frog). "Cybernetic Transport System: Lessons to be learned from User needs Analysis and field experience". IEEE Intelligent Vehicle Symposium. IV'2002. Versailles. France. June 2002.

P. Pomiers (ROBOSOFT). CEL-based Integration Policy for Critical Multi-layered Applications. Dans Proceedings of the IEEE Intelligent Vehicle Symposium (IV 2002) - Versailles, France, June 2002.

P. Pomiers (ROBOSOFT). Safe Interfacing of Multi-Layered Asynchronous Processes with Embedded Real-Time Synchronous Distributed Applications. In Proceedings of the CLAWAR (CLAWAR 2002) - Versailles, France, June 2002.

Tirmant Hélène, Baloh Michael, Vermeiren Laurent, Guerra Thierry-Marie, Parent Michel. « B2, An Alternative Two Wheeled Vehicle for an Automated Urban Transportation System ». IEEE Intelligent Vehicle Symposium. IV'2002. Versailles. France. June 2002.

P. Pomiers (ROBOSOFT). Integration Policy for Critical Multi-layered Distributed Robotics Applications. Dans Proceedings of the 14th CISM-IFTOMM Symposium on Robotics RoManSy 2002 - Udine, Italy, Juillet 2002.

Pradalier Cédric, Sekhavat Sepanta. “Concurrent Matching, Localization and Map Building Using Invariant Features”. IEEE/RSJ International Conference on Intelligent Robots and Systems. September 30 – October 4. Lausanne. 2002.

Parent Michel, Gallais Georges. “Intelligent Transportation in Cities with CTS”. ITS World Congress. Chicago. Oct.2002.

Ollivier Edern, Parent Michel. “Odometric Navigation with Matching of Landscape Features“. ICARCV. Singapore. Dec.2002.

G. Alessandretti, G.Irato, P.Motetti, E.Nodari, A.Rambaldini, A.Toffetti - “Rendere familiare un'interfaccia cognitiva” - Proceedings of the workshop on Ergonomics at Polytechnic of Milan. January 2003

S. Bekhor, Y Zvirin & L. Tartakovsky (TRI). “Investigating the Potential Application of Cybernetic Cars for a University Campus”. 82nd Annual Meeting of the Transportation Research Board (TRB). Washington. Jan. 2003.

Michel Parent. “Intelligent Transportation Services and Wireless Internet” . International Seminar on Wireless Internet Society. Seoul, Korea. April 03.

L. Conde Bento, Urbano Nunes, Abel Mendes, and Michel Parent. "Path-Tracking Controller of a bi-steerable Cybernetic Car using Fuzzy Logic”, in: *Proc. of the 11th Int. Conference on Advanced Robotics 2003* (ICAR 2003), vol. 3, 1556-1561, Coimbra, Portugal, June/July 2003.

Qian Yu, Helder Araújo, and Hong Wang. "Stereo-Vision Based Real time Obstacle Detection for Urban Environments”, in: *Proc. of the 11th Int. Conference on Advanced Robotics 2003* (ICAR 2003), vol. 3, 1671-1676, Coimbra, Portugal, June/July 2003.

G. Artus and P. Morin and C. Samson "Tracking of an omnidirectionnal target with a nonholonomic mobile robot", IEEE Conf. on Advanced Robotics (ICAR),Coimbra, Portugal, June/July 2003

João Alves, Jorge Lobo, and Jorge Dias. "Camera-Inertial Sensor Modelling and Alignment for Visual Navigation”, in: *Proc. of the 11th Int. Conference on Advanced Robotics 2003* (ICAR 2003), vol. 3, 1693-1698, Coimbra, Portugal, June/July 2003.

Martin Lowson. “Service Effectiveness of PRT vs Collective-Corridor Transport”. Journal of Advanced Transportation. Vol. 37, No.3. 2003-09-29

Martin Lowson. “A New Approach to Effective and Sustainable Urban Transport”. Transportation Research Record 03-2140. 2003

Michel Parent, Georges Gallais. “CyberCars : review of first projects” . International Conference on People Movers APM 03. Singapore. Sept.2003.

Abel Mendes, L. Conde Bento, and Urbano Nunes. "Path-Tracking Controller with an Anti-Collision Behaviour of a bi-steerable Cybernetic Car", in: Proc. of the 9th IEEE Int. Conference on Emerging Technologies and Factory Automation (ETFFA 2003), Lisbon, Portugal, Sept. 2003.

Nicolas Simond and Patrick Rives, "Homography from a Vanishing Point in Urban Scenes", IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS), Las Vegas, USA, October 2003

Tom Vöge, Mike McDonald. "User Needs Analysis for Automated Urban Transport Systems – A Qualitative Approach". ITS World Congress. Madrid. November 2003.

G. Artus and P. Morin and C. Samson "Tracking of an omnidirectional target with a unicycle-like robot: control design and experimental results", Rapport de Recherche INRIA, RR4849, 2003

Michael Baloh, Michel Parent "Modeling and Model Verification of an Intelligent Self-Balancing Two-Wheeled Vehicle for an Autonomous Urban Transportation System" CIRAS 2003, Dec. 2003. Singapore

Michel Parent. "From Drivers Assistance to Full Automation for Improved Efficiency and Better Safety". IEEE-VTC Conference. Milan, 17-19 May, 2004

A. Rambaldini, G. Alessandretti et. al. "Iterative Design of a New On-Board System for Public Vehicles: From the Idea to the Prototype". World Automotive Congress FISITA 2004. Barcelona, 23-27 May 2004

Michel Parent. "Road Map Towards Fully Automated Driving". ITS-Europe Conference. Budapest, 24-26 May, 2004

Urbano Nunes. "Multi-target detection and tracking with laserscanner", IEEE Int. Vehicle Symposium (IV'04), Parma, June 14-17, 2004.

Shlomo Bekhor & Yoram Zvirin: Estimating the Potential Use of Cybernetic Cars for a University Campus. Proc. 10th World Conference on Transport Research (WCTR), Istanbul, Turkey, July 2004.

Tom Vogue et al. "Analysis of Potentials and Limitations of Automated Urban Transport Systems" 11th ITS World Congress, Nagoya, October 2004

Urbano Nunes. "A stereovision method for obstacle detection and tracking in non-flat urban environment", Autonomous Robots Journal (in press).

3.4 Media Coverage

The CyberCars project has received considerable media coverage throughout the duration of the project but in particular during and after the Antibes demonstrations. More than one hundred articles have been written in the French and International press and several dozens of interviews in the radio and television took place.

The project has published a final brochure and a video to present the cybercars concepts and the results obtained.

4. CONCLUSION, OUTLOOK AND VISION

The major problem which has been encountered in the study of automated highway systems is the deployment of this technology. Recent work show however that there are several realistic paths towards this deployment and that the technologies are arriving at a faster pace than expected ten years ago. We can now identify three paths which can lead to full driving automation in large parts of the road network :

driving assistance techniques on passenger cars,
driving assistance and dedicated infrastructures for commercial vehicles,
new forms of urban transport (car-sharing and cybercars).

We now can see that these three concurrent approaches use the same technologies and can lead to a large interoperable road network in the long term future.

Car manufacturers are very actively introducing drive-by-wire technologies in their vehicles for numerous reasons: simplification of mechanical design, lower cost, better performances, new functionalities. Among the new functionalities, many concern taking control over the driver for various situations: longitudinal and/or lateral control on highway, emergency braking, lateral control in case of skidding, parking assistance, lateral and longitudinal control in Stop&Go situations. The objectives of these new functions are to improve comfort for the driver and also to improve safety. It has been shown (see the European Project Stardust at www.trg.soton.ac.uk/stardust/) that these functions can also improve, in some cases, the throughput.

Commercial vehicles are also being equipped by manufacturers with drive-by-wire technologies and advanced sensors (using the same technologies as for the private automobiles). The objectives are however slightly different. The main objectives for these technologies are the lower operation cost for the user. This means better fuel efficiency, better safety and lower personal cost. These are the major drivers for developments such as platooning where a single driver can drive a train of two or three vehicles (which can be trucks or busses). The infrastructure operators (freeways or city roads) have another objective for these technologies: it is to improve significantly the throughput and to separate different kinds of traffic for better comfort and safety of the cars and vulnerable road users.

In cities, the ownership of a private vehicle is becoming more a constraint than a pleasure. With the arrival of new forms of car rental (in particular with low cost operators) available throughout entire cities, citizens are turning away from car ownership and become truly multi-modal. The most advanced forms of car rental are the station-car systems, first experimented in the French Praxitele project (www-rocq.inria.fr/praxitele/). In these systems, the subscriber can pick up a car at any station and leave it at another station, therefore using the vehicle only a minimal amount of time, often just to reach a mass transport. Such systems rely on advanced real time management and wireless communication. Car manufacturers such as Honda now offer specific city oriented vehicles (small, low noise and ultra low emissions) which integrate communication and management technologies for such car-sharing systems. Cities which have to face the

degradation of the quality of life brought by traffic, might also be tempted to restrict access to all non zero pollution vehicles if an alternative with specific, city oriented vehicles is offered by car-sharing organisations.

The future of such systems lies in the development of cybercars in order to have a real door to door service (cars can be called at any location and can be left anywhere because of their autonomous driving capability). The first cybercars in operation are specific urban vehicles which run at low speed in restricted environments such as private parks, campuses or pedestrian zones. The next generation of cybercars (now under development such as with the AMICA project from Fiat) will be city cars with dual mode capabilities: they run automatically on a restricted environment and manually elsewhere, just like a regular car (but with advanced drivers aids). The operators of such fleets will certainly be very interested to have access to dedicated infrastructures such as the automated bus lanes (see above) to extend the automatic range and increase the speed in automatic mode.

If these public vehicles become very popular, it will be a simple matter to develop a new dedicated (and protected) infrastructure (very light and possibly elevated) which could have a high throughput because of platooning techniques, to link the automated zones together. Such infrastructures which would form a loose network could be very efficient to link suburban zones, and at a later stage for interurban travel.

With the availability of a large network for automated travel, private cars would be interested to use these infrastructure (under control of the overall management of the resource and possibly with a toll) for automated driving, using the capabilities of the driver aids. For the same reason, freight transporters would also be interested to use the network for automated goods delivery, in particular for city environments where large (and perhaps medium size) delivery trucks are or will be prohibited.

We can see that this is the most promising approach since it can serve a large portion of transport needs. If the political will is present to offer an alternative to traditional cars, this approach could lead quickly to a large infrastructure dedicated to driverless cars (with mostly existing roads for low speed driving in limited access areas) and new infrastructures for high speed driving.

APPENDIX. GLOSSARY

A&E

Autos and Energies, a specialist in electric vehicles; partner of the CyberCars Project.

ACC

See Adaptive Cruise Control

Adaptive Cruise Control

A vehicle function that adjusts the throttle and the brake to control vehicle speed in order to keep the vehicle a fixed, user-defined, and sensor-determined gap (in time or distance) from the preceding vehicle; an enhancement of conventional cruise control.

AGV

See Automated Guided Vehicle

Automated Guided Vehicle

A term referring to any one of a large class of vehicles that operate independent of human control; an AGV typically relies on some element(s) of the infrastructure to assist in navigation (e.g., buried wire, radio beacons, optical reflectors, physical guideways, visual cues, etc.). An AGV is usually applied in industrial settings where the environment is relatively controlled and human interaction is minimal.

Autonomous

When used in reference to a mechanical actor (e.g., a vehicle or robot), capable of performing a task (usually path planning and motion) independent of human intervention.

Collision Avoidance System

A broad term referring to any vehicle-based system that uses sensors and a control loop to help prevent a collision; also called Crash Avoidance System

CRF

Fiat Research, the research branch of the Italian car manufacturer, involved in many projects on driving assistance as well as on car-sharing and electric vehicles; Partner of the CyberCars Project.

CTS

See Cybernetic Transportation System.

Cybernetic Transportation System

An innovation transport system for passengers or goods, with on-demand and door-to-door capability, which is composed of a fleet of cybercars under control of a central management system; propose by the CyberCars Project.

Cybercars

Road vehicles with fully automated driving capabilities. Developed in the CyberCars Project.

DITS

Dipartimento Idraulica Trasporti e Strade, University of Roma, "La Sapienza"; partner of the CyberCars Project.

Frog

Frog Navigation Systems (Netherlands), a world leader in automated transportation of goods and people, who has developed and operated the ParkShuttle I & ParkShuttle II; partner of the CyberCars Project.

Fully Autonomous

Term used to describe a vehicle or mobile robot that requires no human intervention in order to carry out a function or mission involving path planning and motion

Global Positioning System

A system consisting of 24 satellites and controlling ground stations, operated by the US Department of Defense, that provides highly synchronized signals to allow receivers (usually but not always ground-based) to pinpoint their location anywhere on the earth to a high degree of accuracy; this, along with map databases and map-matching software, is the key enabling technology for in-vehicle route guidance, automatic collision notification, and other intelligent vehicle applications.

GPS

See Global Positioning System

HMI

See Human-Machine Interface

Human-Machine Interface

The hardware or software through which an operator or mechanic interacts with the controller of a packaging machine or line. An HMI, sometimes referred to as MMI (man-machine interface) or OI (operator interface), can range from a physical control panel with buttons and indicator lights to an industrial PC with a color graphics display running dedicated HMI software.

Image Processing

Application of one or more computers to examine data contained in images (typically pixels in a video signal) that enables higher-order processing (e.g., identifying and tracking objects in successive images and thus over time, establishing road and lane boundaries for use in steering control, etc.)

INRIA

A leading French research institute in computer science and automation; the Coordinator of the CyberCars Project, and home site of the experimentations.

Intelligent Transportation Systems

A broad term (used primarily in the US) to apply to a number of systems that overlay computer, communications, and control systems on the existing ground

transportation infrastructure (including individual vehicles) to improve safety and operational efficiency

Intelligent Vehicle

A vehicle which is capable of sensing its immediate environment to assist the driver in operating the vehicle more safely, more efficiently, and/or with less stress. IV's can operate autonomously (with only on-board sensing) or cooperatively (receiving relevant data from nearby vehicles or the roadside via wireless communications).

ISR

Instituto de Sistemas e Robotica, University of Coimbra; partner of the CyberCars Project.

ITS

see Intelligent Transportation Systems

IV

see Intelligent Vehicle

Obstacle Detection

A function whereby a vehicle system or mobile robot senses an obstacle in the planned path and can classify the obstacle sufficiently to determine if it must be avoided.

Platooning

A situation in which a group of vehicles travel coupled closely together in single file, operating as a single unit, as in an Automated Highway System, to achieve throughput, safety, fuel efficiency, and other benefits. The coupling may be achieved through vehicle-based sensors (e.g., Intelligent Cruise Control) using a coordinated strategy, or through actual inter-vehicle communications among the platoon members

Robosoft

A French high-tech company involved in advanced robotics and imbedded computer systems and manufacturer of the CyCab; partner of the CyberCars Project.

RUF

An engineering company in Denmark which is developing dual-mode vehicles, fully automated on dedicated tracks; partner of the CyberCars Project.

SSA

CN Serpentine S.A., developer of the Serpentine automated transportation system; partner of the CyberCars Project.

TNO

A large research organization in the Netherlands, with many activities in the field of transportation; partner of the CyberCars Project.

TRB

Transportation Research Board (part of US National Academy of Sciences)

TRG

Transportation Research Group, University of Southampton (Great Britain), where the transportation department has a large experience in the evaluation of new transportation technologies; partner of the CyberCars Project.

TRI

Transportation Research Institute, Technion - Israel Institute of Technology, a leading technical university in Israel, with a specialty in environmental impacts of transportation; partner of the CyberCars Project.

UB

University of Bristol (Great Britain), a leading university which is developing the Ultra, an automated transportation system based on electric cars; partner of the CyberCars Project.

YME

Yamaha Motor Europe N.V., manufacturer of automatic electric vehicles; partner of the CyberCars Project.