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Advanced
Robotics
Solutions and
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Automated People Transportation

Applications, Technologies and Perspectives

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This document has been prepared for everyone involved in the field of automated people transportation, namely economic and technical decision-makers at delimited sites with a high density of people needing to move short distances – for example, industrial facilities, academic campuses, shopping centers, amusement and theme parks, cultural sites, hospitals, retirement communities, and city centers with pedestrian or restricted traffic zones.

It presents first the different applications for automated transportation solutions – those existing today as well as in the near future. It shows the economic, environmental and societal advantages these applications offer. It explains the electronic, information, communication, visual and mechanical technologies that enable these solutions. It concludes with a look forward, starting from existing operational applications currently transporting tens of thousands of persons monthly and showing the market opportunities that will have an impact on individual and mass transportation in the coming years.

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Automated people transportation : what for and why?

Work, leisure…

Imagine yourself in one of the following situations :

1. **You're downtown and just finished your meeting**.
   Your next meeting is in 20 minutes several miles from here, with an important client.
   You're running a bit late, and the next meeting is critical – you have to be on time and on top of your game.

However, you're not nervous at all, because you are sure you will arrive on time, relaxed and ready to go. Why ? because before the meeting you have just finished, you had called the transport management system with your cell phone. You had identified yourself , entered the location of your first meeting and the time of your second meeting. The system immediately confirmed that your *robuCAB*™ would be waiting outside your first meeting to drive you to your destination.

And it works! Your *robuCAB*™ is there waiting, just for you. You ease into the comfortable seat; you identify yourself on the embedded terminal, and you relax – you're off ! If you want to see the city, the large windows of the *robuCAB*™ allow you to admire the architecture at your leisure. If you prefer to gather some information to prepare for your next meeting from the web, the integrated touch-screen puts the information literally at your fingertips. In any case, you arrive in front of your client's building, with no worries and on time via a private road in perfect safety.

2. **You are really happy to visit this amusement park with your family.** You've been waiting for such a long time.Today, you really want to take advantage of the day to see and know everything about the park.

   But how? The park is huge and the attractions so numerous ! How will you be able to visit everything, with Johnny just starting to walk and his older sister Susie so curious ?

Fortunately the park has the robuRIDE™ automatic shuttle system. All you have to do is select the tour you want to take. Naturally, you choose the grand tour! Afterwards, you don't have to worry about the schedule – the system recommends the best sequence for you to see and do everything while optimizing in real time your route to minimize the waiting times at the various attractions.

In addition, by using the shuttles recommended by the system, you are surprised to note that each *robuRIDE*™ hallows you to arrive right on time at your programmed multimedia events! You didn't wait for a single shuttle, you were able to satisfy Johnny's huge appetite, and Susie was able to spend an unbelievable amount of time in the stores. How do they do that? Thist doesn't matter – what is important for you is that you were able to enjoy your day with your family.

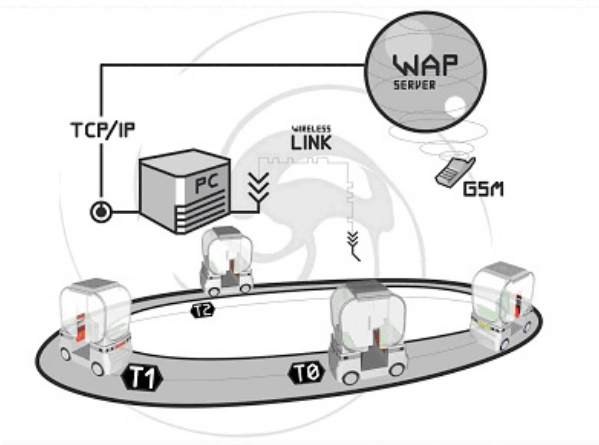
New Taxis and Shuttles

None of this is science fiction. Most of what has been described in these scenarios already exist. These scenarios involve two automated transportation applications – one is the "taxi-type" (individual on-demand and point to point transportation); the other is the "shuttle-type" (pre-programmed multi-person transportation). These new modes of transportation are appropriate for all types of delimited sites receiving a high density of persons needing to travel relatively short distances (i.e., up to several miles):

- **Inner city-centers** pedestrian and semi-pedestrian zones,
- **Industrial or academic sites**, including factories, Business or academic campuses, technology parks, research centers, laboratories, etc…
- **Public parks** such as amusement parks, vacation complexes, theme and cultural parks, historic sites, archeological sites, museums, etc…
- **Airports and train/bus stations** for their internal Terminal connections as well as connections to parking lots, city centers, etc…
- **Health care site**, including hospitals, retirement communities, rest homes, convalescent centers
- **Shopping centers, Trade fairs, Museums…**

All of these sites can find advantages in automated transportation solutions – whether in taxi mode, in shuttle mode, or in some combination of the two. Whatever the selected solution, it applies a package of technological innovations serving both the end-user and the system installer :

- A fleet of automated vehicles, with capabilities for identifying locations and moving autonomously on private roads
- A fleet management system, capable of optimizing in real time the movement of vehicles as a function of information from the surrounding environment provided to the system (number of clients, time of day, programmed events, etc.)



- Man-machine interfaces designed for the specific site owner and the end-users, for their interaction with the vehicles at the site and for the fleet management system (tactile LCD[1] screens with intuitive graphic interfaces, voice interfaces, dialogues in natural language, etc.)
- Mobile communication systems tailed to the vehicles – mobile internet, Wap[2], I-Mode[3] on GPRS[4] or UMTS[5]

Economic, environmental and societal advances

The ROBOSOFT automated transportation solutions offer not only currently available technology, flexibility and comfort but also economic advantages for both the system installer and the end-user. These features make the new taxi and shuttle systems an attractive package compared to traditional solutions and offer clear advantages for the overall quality of transportation.

Automated transportation solutions also offer planners some long-term development solutions that bring advantages that are simultaneously economic, environmental and societal.

From an *economic* point of view, the ROBOSOFT automated transportation solutions provide great flexibility and a reduction in operating costs for a limited initial and ongoing investment :

- **Flexible operations**. The vehicles are available 24/7/365 in whatever quantities the system installer desires; the fleet size fixes the limits of the solution, rather than the number of available drivers as in traditional systems. The fleet management system *robuFLEET Manager*™ optimizes vehicles' use by providing all necessary software tools to the system installer to calculate at any given moment the optimal fleet size to meet profitability, availability and other criteria.

[1] Liquid crystal display
[2] Wireless application protocols
[3] NTT DoCoMo's mobile internet access system.
[4] General Packet Radio Service
[5] Universal Mobile Telecommunications System

- **Reduced operating costs**. In traditional public transportation systems, wages costs represent up to 70% of the total operating budget. The *robuCAB*™ and *robuRIDE*™ automated transportation solutions considerably reduce operating costs compared to traditional solution, due to the absence of any driver. As the system is fully automated, human errors are avoided wich implies a better protection of the equipment, and a reduction of the maintenance costs.

- **Limited up-front costs**. The *robuCAB*™ and *robuRIDE*™ vehicles cost significantly less than traditional vehicles with the same capacity due to the fact they were developed specifically for automated transportation. A 22-seat *robuRIDE*™ shuttle costs 30-40% less than a 15-seat electric bus. The only variable costs are those infrastructure costs (steering and safety) that may differ from one site to another as a function of the specific site characteristics.

- **A potentially profitable service**. Initial studies show that end-users are willing to pay up to 2 Euros per ride. Moreover, sponsors may be interested by the forward-looking originality of these vehicles as part of their marketing communications program.

From an *environmental* point of view, automated transportation systems represent a decisive step towards "clean" or environmentally friendly vehicles :

- **An intermodal development**. By complementing existing modes of transportation, ROBOSOFT's automated transportation systems are a tool for promoting mass transit. Targeted to short trips (less than 3 miles) these systems favor a new way of thinking about transportation compared with the current "100% automobile" approach: "I'll take the bus and then the automated shuttle – it's less expensive, and I'll save time; I have fewer unpleasant surprises and I can read while I'm traveling."

- **An improvement for persons with reduced mobility**. Beyond the improvements in general public services, the *robuCAB*™ and *robuRIDE*™ also make short trips much easier for persons with reduced mobility, such as handicaped or elderly people.

Finally, from a *societal* point of view, automated transportation constitutes a significant advance in the way people can organize their displacements within high population areas, whether in a professional or personal context :

- **No atmospheric or noise pollution**. By using electric propulsion systems, *robuCAB*™ and *robuRIDE*™ are completely silent and do not emit any gases nor pollutants.

Safer transportation systems

The automation of transportation vehicles makes them less sensitive to human error, which is the cause of most motor vehicle accidents. Also, the regulations imposed upon automated systems, which are much more restrictive than safety regulations for vehicles with drivers, oblige suppliers to install several levels of security that do not exist on traditional vehicles – including speed limitations, obstacle detection systems and manual and automatic emergency brakes. The *robuCAB*™ and *robuRIDE*™ systems have been designed to comply with the European Union machine directive (98/37) and its people transportation annex; they also comply with the electromagnetic compatibility regulations of the CE marking system. Installed systems must in addition undergo a safety audit by a government-approved auditing organization before being put into service.

Technological advances

A concentration of new technologies

An automated people transportation system constitutes in itself a real laboratory of leading-edge technologies, in domains as varied as electronics, information technology, telecommunications, optical technology, electromagnetism, electricity, mechanical engineering, etc. Merging technological advances in mobile robotics, automotive information technology and telecommunications allows operational applications in automated transportation that were only thought possible in science fiction a few years ago.

The technologies responsible for this leap in automated transportation can be grouped into three categories: the vehicles, the embedded technologies and those linked to the system management infrastructure.

A new generation of vehicles

The *robuCAB*™ and *robuRIDE*™ are closer to mobile robots than to traditional electric vehicles. They have been designed so that all of their functions (acceleration, braking, steering, etc.) are computer controlled. Sensors on the vehicles control all of these functions by furnishing real-time information to the control system. They use the "drive-by-wire" concept developed in aviation, which eliminates all elements of mechanical transmission such as steering columns, drive shafts, connecting rods, etc. The direct consequence is that vehicles with this design are extremely simple, and that the generated free space can be used to add more passengers in greater comfort, with many possible layouts. These vehicles are quite modular and customizable to take into account not only the varying nature of the passengers but also environmental factors such as climate, safety, etc.

Embedded technology in the vehicles

Hardware and software control technologies

The computer control system for the *robuCAB*™ and *robuRIDE*™ vehicles is built on a network of MPC555 (Motorola) microprocessors specifically designed for the next generations of high-end vehicles. This modular architecture allows the placement of as many microprocessors as required either on the computers or in the vehicles. They are distributed on thevehicle and connected through a CAN[7] network, one of the standards in the automotive world. The software has been developed using the SynDEx[8] environment created by researchers at INRIA[9], which allows the automatic generation of robust distributed real-time applications with severe constraints on an unlimited number of microprocessors.

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[7] Controller Area Network. The CAN website (http://www.can-cia.de/can/) defines CAN as "a serial bus system especially suited to interconnect smart devices to build smart systems or subsystems."

[8] **SynDEx** is a system level CAD software, supporting the "Algorithm Architecture Adequation" (AAA) methodology, for rapid prototyping and optimizing the implementation of real-time embedded applications on multicomponent architectures. It has been designed and developed at INRIA in the Rocquencourt Research Unit France, by the OSTRE team. (as quoted from the INRIA website at http://www-rocq.inria.fr/syndex/.

[9] The [French] "Institut National en Recherche en Informatique et en Automatique" [The French National Institute for Research in Computer Science and Control].

Navigation technologies

The *robuCAB*™ and *robuRIDE*™ systems, thanks to their dedicated control architectures, are adapted to all navigation and guiding methods currently avalaible :

- ”Buried guide wire”, simple and inexpensive, but limited to simple routes
- Magnetic transmitters or pilots, also buried in the ground
- Lasers, with reflectors on vertical surfaces
- GPS[10] / DGPS[11] systems, which identify precisely the location of the vehicle in real time through satellite links without any additional infrastructure.

The modularity of embedded information technology allows the system installer, for each application, to choose the navigation and guiding system suitable to his specific needs.

Technologies for identifying and avoiding obstacles

The *robuCAB*™ and *robuRIDE*™ vehicles have two types of sensors to detect obstacles :

- One or more lasers
- Ultra-sonic sensors

As with the steering system, the choice of obstacle avoidance systems to be implemented on the vehicle depends on the specificities of the operation site. The choice may also be function of administrative or certification constraints, which may vary from site to site.

Technologies for coupling vehicles

The *robuCAB*™ and *robuRIDE*™ vehicles may be equipped with systems to connect one or more vehicles to make “trains” to accommodate passenger volumes. This coupling uses either a laser placed on the front of each vehicle or a linear camera with emitting beacons installed in the following vehicle.

Man-machine interface technologies

As a “computerized” vehicle, the interface between the *robuCAB*™/*robuRIDE*™ system and the end-users uses the most recent information technology advances for the man-machine interface – joysticks to change vehicle position, touch-screens, graphic screens, etc. In the near future, voice control technologies will be integrated into the *robuCAB*™ and *robuRIDE*™ systems.

[10] Global Positioning System
[11] Diferential GPS

Multimedia technologies

robuCAB™ and *robuRIDE*™ vehicles can be equipped with multimedia systems, as for example when they are provided with projection screens either inside or outside the vehicle. These imbedded multimedia systems can also be used to provide passengers with local information, or as advertising tools.

Infrastructure technologies

Fleet management technologies

The fleet of vehicles is under the controlled by a software-based management system that handles all inquiries and information of each vehicle, and optimizes the route and the timing of each vehicle. The fleet management system takes into account delays or operating glitches to re-plan in real time, the entire system. This management system uses the most recent optimization algorithm technologies.

Communication technologies

robuCAB™ and *robuRIDE*™ vehicles can be considered as mobile internet access machines. They are compatible with mobile telephone standards, whether they concern internet access (WAP and iMode) or GMS and GPRS. These communication technologies also allow system installers to provide end-users with simple and precise information about the routes and schedules.

Looking forward

Applications already widely used

Tens of thousands of persons are using automated transportation vehicles every month. At the Fort of Simershof, in Bitche (Moselle, France), ROBOSOFT has installed the first entirely robotized mass transportation system for cultural tourism. This fort, one of the most famous of the Maginot Line, opened to the public in July 2002 to preserve the memory of the soldiers that valiantly defended it. To reconstruct the lives of these soldiers, the park has organized a visit of 30 minutes inside the fort on board a completely automated *robuRIDE*™ synchronized with an exceptional show. Simershof is the first mass automated transportation system ever put into operation for group shows on this scale : the system transported some 150.000 persons since July 2002.

Other sites being currently under investigation include :

- A business site, where a fleet of 25 vehicles is under study to bring visitors to different buildings in this brand-new car-less site;
- A city center, where automated shuttles could be used to link different destinations within the city. the goal here is to eliminate cars from downtown, and set it free to pedestrians and bicycles.
- A technology park, where the "zero cars" concept would involve automated shuttles linking exterior parking lots to the center of the park as well as providing transportation from place to place inside the site;
- A theme-park, where the managers are looking for an original solution to the queueing problems at the attractions, based upon rapid transportation of a large number of visitors from one point to another within the park.

A market with high growth potential

It is difficult to estimate precisely the size of the automated people transportation market. The potential growth of this market is however considerable. In terms of total available market (TAM), some 40,000 sites meet the criteria for a target application: delimited sites receiving a high concentration of persons having to travel distances ranging from several hundred yards to several miles.

Among these sites, some are already willing to put automated transportation solutions in place immediately – especially industrial sites, academic campuses and amusement, cultural and theme parks. Other applications on the horizon include train and bus stations, airports, shopping centers and hospitals, which depend more on the existing local infrastructure. Other applications include city centers, which are experiencing rapid increases in the number of visitors.

The scope and the cost of the automated transportation solutions will vary considerably based upon the type of application required and the maturity of the market; for example, an initial installation might start with 5 vehicles in 2007, growing to 6 in 2008 and 8 in 2009. As the installed base increases, the cost of automated transportation solutions will fall considerably: on a per vehicle basis (thereby amortizing with each vehicle the infrastructure and installation costs), this cost will likely decrease from an average of 100,000 Euros per vehicle in 2007 to close to 20,000 Euros in 2012.

Finally, estimating the current penetration rate for automated transportation solutions at appropriate sites at less than 0,1% and assuming a 0,5% penetration rate in 2008 shows a particularly dynamic market, growing from a potential estimated at 200 vehicles in 2007 to 11700 vehicles in 2011. The value of this market in 2008 is greater than 20 million Euros.

	2007	2008	2009	2010	2011	2012
Total number of sites (in thousands)	40	42	45	48	51	55
Penetration rate	0,1%	0,1%	0,5%	0,5%	1%	1%
Average number of vehicles per site	5	6	8	15	23	30
Target market (in thousands of vehicles)	0.2	0.25	1,8	3,6	11,7	16,5

Conclusion

This document seeks to show the major advantages of automated people transportation: economic advantages, as these solutions are flexible and adaptable, offering low operating costs; environmental advantages, as the solutions offer significant air and noise pollution advantages; and societal advantages, as the solutions are safer and less sensible to human error.

The document also discusses how technological advances in mobile robotics, automotive-related information science and telecommunications allow operational applications for automated people transportation that were thought to be only possible in science fiction a few years ago. In the same way that a portable telephone is a concentration of various advanced technologies, an automated people transportation system uses an impressive number of technologies and applied sciences.

Finally, this document shows to what extent the market for automated people transportation is already open and mature; a number of applications are already operational, and the potential for additional applications is considerable, with a European market that will rapidly exceed more than 1 billion Euros in the next five years.

From today on, all operators of delimited sites receiving large densities of visitors needing to travel short distances within the site should consider automated people transportation systems as an attractive solution due to their reliability, their economic benefits and their environmental and societal advantages.

Acknowledgments

- INRIA, particularly the IMARA[12] and VISA[13] projects
- The European Commission, which financed the CyberCars and CyberMove projects
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About ROBOSOFT

ROBOSOFT owns and is constantly improving its considerable know-how in the automation of service activities. Its more than 18 years of experience allows it to provide operational robotics solutions in areas as varied as transportation, cleaning, surveillance and health.

ROBOSOFT has brought together the necessary expertise for a complete answer to the scientific and technical challenges of robotics: information sciences, mechanical engineering and numeric controls. Wanting to provide a more complete service to its clients, ROBOSOFT has also developed a distribution capability and is currently offering, in addition to its turnkey solutions, a wide range of components and generic sub-assemblies.

ROBOSOFT counts among its clients, in addition to public and private research centers, a number of large buildings and sites open to the public (hospitals, airports, museums, shopping centers, train/bus stations, campuses, amusement and other parks) and service providers (urban transportation entities, cleaning companies, security services, etc.)

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[12] "Informatique, Mathématique et Automatique pour la Route Automatisée" [Information sciences, mathematics and robotics for automated roadways]

[13] Vehicules Intelligents et Systèmes Autonomes [Intelligent vehicles and autonomous systems]