

## Evaluation of Advanced Transport Systems for Sustainable Urban Mobility

Adriano Alessandrini<sup>\*1</sup> Michel Parent<sup>\*2</sup> Yoram Zvirin<sup>\*3</sup>

CTL - Centro di Ricerca per il Trasporto e la Logistica, Università degli Studi "La Sapienza"<sup>\*1</sup>

(via Eudossiana 18, 00184 – Roma, +39-06-44585148, [adriano.alessandrini@uniroma1.it](mailto:adriano.alessandrini@uniroma1.it)

IMARA Programme, INRIA, Institut National de Recherche en Informatique et en Automatique<sup>\*2</sup>

(Rocquencourt, 78153 Le Chesnay, France, +33-1-39 63 54 91, [michel.parent@inria.fr](mailto:michel.parent@inria.fr))

Faculty of Mechanical Engineering, Technion – Israel Institute of Technology<sup>\*3</sup>

(Haifa, Israel, +972-4-829 2070, [zvirin@technion.ac.il](mailto:zvirin@technion.ac.il))

A general evaluation methodology is presented for Advanced Transportation Systems, which can be applied for other ITS applications. It includes three phases: initial, ex-ante and ex-post, and is based on measurements of several sets of indicators. Results are presented for sites studied in the EU CityMobil and for energy management and optimization. Cross comparisons enable recommendations for adoption and implementation of sustainable urban CTS. System optimization can be achieved, leading to reduced energy consumption and emission of pollutants and greenhouse gases.

It is noted that the first ever large scale PRT is under construction now at the Heathrow Airport.

**Keywords:** *Advanced Transportation Systems, Evaluation, PRT, Cybercars*

### 1. Introduction

There is a widespread consensus now that much of our activities on earth are not sustainable, including the current transport systems. There are several definitions of the term sustainable development; in general it means “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [1].

The existing congested urban transport patterns of a combination of private vehicles and public systems are not sustainable, due to their large energy consumption and emission of harmful pollutants and greenhouse gases. Also, they do not support efficient and clean land use, and provide poor service level, despite increasing investments overall. The socio-economic effects are even augmented by the fact that many of these negative impacts affect disadvantaged social groups who are not likely to own cars. As for public systems, their energy consumption per passenger\*km is not as good as it could be [2, 3], mainly because they run, many times, quite empty. This is because in most cases the system schedule is based on fixed timetables, and not on actual demand. These problems are caused by imbalances of fleet and energy management and there are other shortcomings (limited mobility and accessibility, road safety, etc.)

Inter-modal systems offer a viable approach for providing sustainable transportation to the cities: well-designed systems, combining the use of various transportation modes and in particular the individual (usually private) vehicle and the collective (public) systems. When these will be designed and managed to operate efficiently, they would have the advantages (e.g. comfort) of the

former with those of providing overall mobility by the latter. The recent developments in ITS clearly demonstrate that such systems will greatly contribute to meet all these requirements. A prominent ITS application is the Cybernetic Transportation System (CTS) as a complement to mass transport. Several CTS types have started to appear at the end of the 20<sup>th</sup> century. Some have been implemented or are now under construction in various European locations, or have been deployed in demonstrations, during R&D work in the field. A CTS is a system of road vehicles with automated driving capabilities (either fully or partially). Its vehicle fleet is used for passengers or goods on a network of roads, and is under control of a computerized management system. The vehicles are used individually by the customers; in a way similar to car sharing systems, and thus the CTS offers the link between the private car and the public transport modes [4-6].

The novel CTS are environmental friendly and offer far-reaching solutions that will drastically mitigate or solve the problems mentioned above. They will yield much more effective organisation of the urban mobility, with a more rational use of motorised traffic; less congestion, pollution, noise and CO<sub>2</sub> emissions and better accessibility and safety. The result will be a higher quality of living, an enhanced integration with the spatial and also societal development and advancement towards sustainability.

In recent years we have seen many different proposals and developments on innovative transport solutions with proven technical feasibility. However, albeit their obvious benefits, their immense potential has not yet led to a significant change of the current transportation schemes,

organisation and policies. When analysing the failures of the novel approaches to be implemented commercially, it becomes apparent that non-technical reasons are in the foreground. In order to change this unfortunate situation, there is a strong need to disseminate the knowledge about the novel sustainable transportation systems to the decision makers and to the public. This will bring about public awareness and acceptance, and will enable the authorities to take the measures for implementation. Therefore, there is an important role of the *evaluation* parts of projects for the development and implementation of CTS [4-7]. Assessments of the results of such projects that have, indeed, proven the viability of CTS, should be prepared as a tool for municipalities considering the installation of new urban transport systems. This would enable them to study various options, select the most appropriate one for the specific application and then design, construct and operate the systems.

This paper deals with methods and procedures for the assessment of Advanced Transportation Systems and in particular CTS. One important objective is to outline a way for drawing general conclusions valid globally for such innovative systems, based on the evaluation of results and demonstrations and analysis of cross-comparisons and findings.

In general, the methodology presented here is based on the work done in the European Projects MAESTRO [8], CyberMove [6] and CityMobil [7]. Its basic concept and main steps are described in Section 2. These include the development of an indicators matrix, to be measured in the demonstrations (and hopefully leading to implementations) and for comparing various potential systems in order to select the optimal one for the specific application. Section 3 includes descriptions of several examples of systems that have been demonstrated and evaluated within the framework of CityMobil. Section 4 is an examination of cross-comparisons and findings, including user acceptance, transport patterns, financial and economic impacts and energy & environmental effects. Section 5 presents results for energy management evaluations in CyberMove. The summary in Section 6 illuminates the general conclusions and the future prospects of the role of CTS.

## 2. Methodology of Evaluation

### 2.1. General Evaluation Plan

The evaluation methodology and plan presented here, used for the CityMobil Project [7], were prepared based on [8] and adopted in similar former projects. It includes three evaluation phases: initial, ex-ante and ex-post evaluations, which are preceded and followed project design and implementation

phases, respectively. All these are derived from the project objectives; for CityMobil these are: derivation of more effective organization of urban transport, resulting in a more rational use of motorised traffic with less congestion and pollution, safer driving, higher quality of living and enhanced integration with spatial development.

The initial evaluation is directly linked to site selection and pre-design phases, and consists of:

- Derivation of a list of impacts to observe and monitor with the necessary associated indicators;
- Choice of appropriate evaluation methods for the next evaluation phases;
- Establishment of an evaluation plan for the continuation of the project (beyond the specific demonstration dealt with);
- Forecasting impacts on the basis of the local sites functional specifications and user expectations assessed during the pre-design stage.

The derivation of an evaluation plan is done through selection of a set of core indicators, which have to be used in the other phases of the evaluation, to measure the satisfaction with the service provided in the sites and to make a comparison between the different sites in order to reach cross – correlations and global conclusions.

The output produced in the initial evaluation consists of: (1) The core indicators; (2) The way in which these are measured; (3) The definition of sample sizes required to quantify the indicators.

Concerning the ex-ante evaluation, two main tasks are performed:

1. Construction of a “reference case” (‘before – measurement’) for the indicators selected in the initial phase, to quantify the actual situation. Some of the indicators will have a reference value to be individuated, whereas some others may not have reference values at this stage.
2. First quantitative evaluations of the system, on the basis of system dimensioning results and preliminary impact forecasting. Such evaluations allow judging whether the design is working well and is technically sound. Furthermore, they provide quantitative measures concerning the expectations linked with each indicator, thus setting the reference case for the ex-post evaluation. A threshold of success for each indicator is set in order to have a numerical tool to establish whether the system operates in a satisfactory manner.

The output produced in this phase, other than the reference case, has to be linked with parameters as the Origin – Destination (O/D) matrix representative of the case which is studied and the kind of evaluation to be done in the next phase. Therefore, in this phase it is assessed which local

system is feasible (appropriate) and, eventually, the results provide feedback to the site designers.

The ex-post evaluation is done after the system has been in operation and then field-trials, measurements and surveys are performed. More detailed simulations carried out in the previous phases provide new data for the indicators. In addition, some of the outcomes from the field trials can be used beyond the specific application and results can be transferred to other sites and planned systems.

**2.2 Structure of the Evaluation Plans**

Four main tasks are carried out for the evaluation plan of a demonstration:

1. 1. A brief description of the site in which the demonstration (or city study) is planned to be held. This includes the actual current situation at the site, in terms of modes of transport used, people interested in using the public transport, potential users of the service, etc. Furthermore, it is necessary to learn about future plans concerning the public transport, such as measures to reduce private car use, in order to have a brief overview of the different policies which are considered to be adopted.

2. Selection of the indicators to be measured for quantifying the features of the demonstration. Different evaluation indicator sets have to be measured. A first selection of indicators is shown here, divided according to the sets (categories). It is noted that while this is a general approach, for any specific site and proposed system, some changes might be necessary in order to meet local characteristics. Three main data types are conceived: transport and socio-economic; energy and environmental; Safety. The indicators are listed in Table 1, arranged in nine sets.
3. Selection of the most appropriate measurement methods for the indicators chosen.
4. Preparation of the measurement plan for the activities to be done in order to measure the indicators selected. In such a plan, the deadlines of the different phases of the measurement methods chosen have to be determined at the very start of the project planning. This is needed in order to have an overview of the time required for the evaluation program in all its phases. The target is, of course, to provide as much input as possible to the project in real time during the course of its various stages.

**Table 1 Evaluation indicators, arranged by sets (categories)**

<p><u>Acceptance:</u> Usefulness; Ease of use; Reliability; User satisfaction for the on-demand system; Integration with other systems; User willingness to pay; Authority willingness to pay.</p>	<p><u>Quality of Service:</u> Information availability; Information comprehensibility; Ticketing user satisfaction; Perceived cleanliness; Perceived comfort; Perceived level of privacy; Perception of safety; Fear of attack.</p>	<p><u>Transport Patterns:</u> Induced mode changes in the other segments of the journey; System modal share; Total passenger*km travelled; Total number of trips; Vehicle occupancy; Average journey time per O/D pair; Journey time variability; Total delay per trip; Average waiting time; Waiting time variability; Interchange time; Effective system capacity.</p>
<p><u>Social Impacts:</u> Change in range of key activities accessible within time thresholds; Distribution of accessibility changes by social group; Access time for mobility handicapped users; Incidents.</p>	<p><u>Energy and Environment:</u> Daily energy consumption; Energy efficiency; NO<sub>x</sub> emissions; PM<sub>10</sub> and/or PM<sub>2.5</sub> emissions; CO emissions; CO<sub>2</sub> emissions (green house gases, related to climate change); Noise L<sub>DEN</sub> and L<sub>NIGHT</sub>; Loss of green space from construction (as a secondary input).</p>	<p><u>Financial Impacts:</u> Start up costs for Track construction and civil works; Vehicle acquisition/construction, Control systems and apparatus; Operating costs for personnel; Vehicle maintenance; Track and civil infrastructures maintenance; Control system maintenance; Operating revenues; Perceived public subsidies.</p>
<p><u>Economic:</u> Jobs provided at the demonstration site; Jobs increase induced at the manufacturers; Footfall within defined areas; Net Present Value (NPV); Internal Rate of Return (IRR).</p>	<p><u>Legal:</u> Induced regulation procedure changes.</p>	<p><u>Technological Success:</u> Response time; Accuracy; Data updating delay; Failure rate.</p>

The indicators in the demonstrations are measured using the focus groups (FG) evaluation methodology, on-field measurements, simulations and expert opinions. FG's representing different passenger types and other related groups are identified and interviews are conducted. Passengers groups have been selected to represent affected communities, such as heads of household; people working and/or living in the neighbourhood; university community; visitors; elderly and handicapped passengers; children. Experts are also interviewed. The indicators to be analyzed by on-field measurements or simulations depend on the availability of data and algorithms; in some cases overlapping is possible, which can be used, then, for calibration, validation and predictions.

The approach outlined here is quite general. As mentioned above, the choice of the indicators, and also of focus groups, may differ for any specific site and proposed system. This is also true for the other stages of the methodology, like the choice of the measurement methods and the measurement plan. Details are given in the following for several systems described in this paper. More information can be found in Ref. [7], and still more will be available from the CityMobil Project [www.citymobil.org].

### 3. Evaluation Results

The demonstrations and the city studies involved in projects such as CyberMove and CityMobil have to provide data for the evaluation of the feasibility and performance of the new technologies, in terms of advantages for the users, improvement of transport services and sustainability. In this section, main evaluation results of three CityMobil large demonstrations are presented: advanced bus system in Castellón, PRT at Heathrow Airport near London and cybercars in Rome. Ref. [7] is a complete report with all the details. Also, some results of energy management evaluations in the CyberMove Project are presented in Section 5, based on [6,9]. Two smaller demonstrations, denoted as showcases, have also been performed, [7]: Daventry and La Rochelle. The ex-post evaluation for Daventry is briefly described here.

The CityMobil results presented here are for various evaluation stages of demonstration of CTS, as available at the time of preparations of this paper. Thus one can obtain a picture of the scope of evaluation stages and processes in a project like this and various systems under consideration to be adopted and implemented.

Most of the features that have been incorporated and demonstrated in these projects are quite general,

with much wider implications than just for the specific sites and systems. The results for Rome in Section 3.1, are indeed, representative for most of the other sites studied in CityMobil. Section 4 includes cross-comparisons and findings, considering the different phases of the evaluation done.

#### 3.1. Rome

Rome is building a new exhibition centre, located near the Fiumicino international airport, along the airport highway and with a railway link. The CTS that will serve the car-park P1 (the largest and farthest of 8 car-parks) of the centre is intended to improve visitors' accessibility to the building; to eliminate the need of conventional shuttle; and in the longer term – to demonstrate the economic viability of automated systems for providing an effective feeder transport service.

The car-park capacity is 2,500 car-slots; some of them are located 600-700 metres from the building entrance, meaning walking time of over 10 minutes to reach the exhibition and also to return to the car.

The main features of the new system – “Cybercar” network, are:

- A “car corridor” around the car-park for driving into the slots, which the visitors have been addressed to at the car-park entrance gate. Thus the system will provide a fully on-demand service: an automated vehicle is summoned to wait for the car occupants at the right stop.
- A “Cybercar network” of 2.2 km, with a horizontal lane and five vertical corridors for the whole car-park.
- Car-slots for handicapped people near the entrance building.
- In this configuration, the cybercars are segregated. Congestion problems are avoided due to the absence of intersections between cybercars, regular cars and parking-search traffic. The maximum allowed speed is 30 km/h. The vehicle chosen for the CTS system is a Robosoft with capacity of 30 passengers, Figure 1. In the first stage, 2 cybercars like this will run, and the plan is to work with 6 vehicles in the final configuration.

The ex-ante evaluation for the Rome project was performed by a combination of Interviews, Surveys, Measurements, Simulations, Expert Opinion and data provided by the operator of the system (ATAC, the Rome public transport operator).



**Figure 1. Robosoft vehicle for the Rome demonstration**

**Analysis of the acceptance, quality of service and social impacts indicators**

For the Rome Demonstration, indicators of Acceptance, Quality of Service and Social Impacts were measured through interviews of potential users, showing them a presentation of what the system will look like. In general, the indicators were studied in this phase in terms of importance (from which rankings were derived) given by the

potential users. First measurements, of potential user expectations, were possible only for “usefulness” and “illegal parking tendency” indicators because before the system has been implemented it was not possible to ask them further about a system they do not yet know. Table 2 shows the rankings averaged on the whole interviewed population and also the performance ratings (for the only these two indicators), derived by the ex-ante measurements.

**Table 2 Rankings and performance ratings for Rome evaluation indicators**

Ranking of 1: Most important indicator within this Evaluation Category; Highest ranking: least important.

Evaluation Category	Impact	Indicator	Ranking	Ex-ante performance rating
Acceptance	User Acceptance	Usefulness	1	94%
		Ease of use	2	
		Reliability	3	
		User satisfaction for the on-demand service	5	
		Integration with other systems	4	
Quality of Service	Information	Availability	1	
		Comprehensibility	2	
	Cleanliness	Perceived cleanliness	3	
	Comfort	Perceived comfort	4	
	Privacy	Perceived level of privacy	7	
	Perception of Safety & Security	Perception of safety	5	
Fear of attack		6		
Social Impacts	Service Accessibility	Access times for mobility impaired users	1	
	Safety	Incidents	2	
		Illegal parking tendency (Rome specific)		62%

- Within “Acceptance”, the “Usefulness”, “Ease of use” and “Reliability” indicators are the most important, while a lower score was assigned to “User satisfaction for the on-demand service” and “Integration with other systems”. This indicates that users are more concerned about having an efficient and usable system, and less about the aspects related to the most “sophisticated” features. However, being this a relative score, it does not necessarily mean that these last characteristics are given a low weight in absolute terms.
- As for the “Quality of Service” indicators, “Information availability” and “Information comprehensibility” are considered as the most important. “Cleanliness” and “Comfort” follow, while “Safety” and “Security” are of lower concern. “Perceived level of privacy” seems to be of low concern.
- The “Social Impacts” indicators confirm that the concern about incidents or malfunctioning is lower compared to others, specifically to the accessibility for handicapped users.

Regarding the (expected) performance of the two indicators which were measurable before the system implementation:

- 94% of the interviewees responded that they would use the system when built. Thus the ex-ante value of usefulness was set as 94%.
- The tendency to park illegally despite the presence of the new system, surprisingly, remains quite high: 62% of the illegal parkers would not change their behaviour in favour of the automated shuttles.

Ref. [7] includes detailed results for distributions of the sample (325 interviews) according to different characteristics of the interviewed people: age, education, employment and income. It was found that differences between the opinions of various user profiles, compared to each other and to the average, is limited to only some indicators. Therefore, the above considerations for the whole population are valid for any single group, with only few exceptions. Among these, elderly people or people with a lower education are more concerned about comfort. On the other side, younger people rate comfort as of lower importance, while are more concerned about safety.

#### **Reference case, quantitative evaluation and threshold for success**

For each of the indicators in the ex-ante evaluation reference case, a threshold for success and a first quantitative evaluation are sought. Any new transport system has to be compared against an alternative. In most cases, this is just a measurement reflecting the present situation. In

others, as it is on Table 3 for indicators measured by interviews, there is no explicit reference case as any new transport system is judged against the conventional public transport system everybody knows. The threshold for success is a value which will be used in the ex-post evaluation to see whether on the specific indicator the measured performance is up to the expectations. The first quantitative evaluation is a first measurement, where possible, of the indicator either through interviews, expert opinion or simulations. In Table 3, the threshold for success of user acceptance indicators were set according to the ranking that the interviewees gave to the different indicators. Each interviewee ranked the indicators being 1 the most important and 5 the least. Then, for each indicator the threshold for success is obtained by subtracting the average value from 6. When in the ex-post the interviewee will be asked to give a value from 1 to 5 to each indicator, being 5 much better than conventional PT and 1 much worse, the average obtained will need to be above the threshold to consider the indicator positively evaluated. In the case of usefulness, for example, an average of 3.74 over 5 is expected to consider the system as performed up to the user expectations. The first quantitative evaluation that was carried out could not be compared, as the question asked was just whether they would use the system or not; therefore it cannot be compared to the threshold.

Five of the six User Behaviour indicators, which are specific of the Rome demonstration, have reference case values (the only exception is illegal parking duration), obtained through the surveys collected on the field in 6 different days directly. Such days were chosen on the basis of the expected attendance in the Rome Exhibition to have a representative sample of high (more than 10,000 visitors per day), medium (less than 10,000) and low (less than 5,000). The values for the 'reference case' in Table 3 are averages of the values collected in the six days: 2 each with low, medium and high daily attendance.

The survey results show that the number of cars illegally parked is larger than that accessing this car-park, and the average vehicle occupancy is  $2,615/1,190=2.1$  persons per car. The parking time duration is more than 2.5 hours, and 1,200 visitors come to the exhibition by train.

For three of the six User Behaviour indicators, the first quantitative evaluation and the threshold for success were calculated on the basis of the interviews performed. The results show that about 60% of people now illegally parking would shift to the P1 car-park once the CTS will be operating, thus obtaining more than 2,300 cars (and more than 4,800 users) in P1 and less than 720 cars illegally parked.

Some interesting results in [7] that are not included in Table 2 are briefly highlighted in the following. Concerning induced travel mode changes in the other segments of the journey, the first quantitative evaluation predicts a 60% shift of people using car to reach the exhibition to arriving by train once the CTS will be operating. This value, however, might be inaccurate because of over-expectations by the potential CTS users, but nonetheless, it provides a first rough evaluation of users' expectations. Moreover, the novelty of the system and the convenience that it will offer are expected to create an increasing demand for it. In fact, this is an important objective of CityMobil and similar projects.

The total number of trips and the total passenger\*km travelled (defined as Productivity, P), were calculated on the basis of the percentage of

people interviewed declaring that they would use the CTS once it will be operating: about 93% of the interviewed sample. It was found that P=3,272 (considering an average journey of 400 m, which is the distance between the railway station and the exhibition entrance, for people coming by train; and 200 m as the average journey for people coming by car), and the total number of trips is over 14,000. The other transport patterns indicators and also the environment indicators will be measured in the next phase, when the data about them will be available.

For the two indicators of Access times for mobility handicapped users and Incidents, the procedure adopted was the same used for the Quality of Service indicators. Service accessibility was considered more important than Safety.

**Table 3. Rome: Reference case, quantitative evaluation and threshold for success**

Evaluation category	Impact	Indicator	Ex-ante analysis		
			Reference case	Quantitative evaluation	Threshold for success
Acceptance	User Acceptance	Usefulness		94%	> 3.74
		Ease of use			> 3.51
		Reliability			> 3.10
		User satisfaction for the on-demand system			>2.25
		Integration with other systems			> 2.38
	User Behaviour	Car accessing P1	1,190	2,303	>2,300
		People accessing P1	2,615	4,836	>4,830
		P1 parking time duration	158 minutes		
		Cars illegally parked	1,831	718	<720
		Illegal parking duration	NA		
		People coming by train	1,203		

The Financial and Economic indicators were calculated based on data provided by ATAC and by the CTS provider: the start up estimated costs for the system are 3,300,000€, the operating and maintenance costs 455,000€/year and the revenues 25,000 €/year. The consequent Net Present Value of the cost-benefit analysis, with 10 years time horizon, is less than -7,000,000€. The jobs provided at the demonstration site and the jobs increase induced at the manufacturers were calculated based on experts' opinions, and were respectively 2 and 7.

For most of the Technological success indicators, the thresholds were measured directly from the experts' opinion and from data provided by CTS provider. For what concerns failure rate, less than 2 times per year in which the system is not well operating are allowed, while for the vehicles less than 6 times per year are allowed. The service

is allowed to be stopped for less than 4 days/year and the vehicles less than 8 days/year. No accidents with damages for the users are allowed, and the only type of accidents allowed (and foreseen) are due to problems in the interaction users – system (for example users' misunderstandings or mistakes) or to some minor technical problems.

### 3.2 Castellón

The first line of an advanced transport system, TVRCAS guided bus, for the city and its suburbs – northern corridor, already provides service between the University Jaime I and the historical city centre. The layout of the full line will connect the main centres of mobility: university, intermodal station, historical centre, commercial centres, port and beaches. The system provides a lower cost

alternative to light rail while having the advantages of dedicated rights of way and the modern features of ITS.

It is emphasized that the system in Castellón is a real commercial application. For CityMobil it serves as a demonstration, although the system is quite different than the CTS ones explored, developed and studied in the Project. The ex-ante evaluation for the Castellón demonstration has been performed with focus groups and will continue later, during the real operation of the system. Then it would be possible to measure in situ most of the indicators. Furthermore, it is intended to study again the focus groups in the ex-post analysis of the indicators previously measured. This analysis will allow comparison and evolution of the measured indicators before and after the system operation. Detailed results of the Castellón focus groups and its use in the CityMobil evaluation process are reported in [7]. Some results are presented here in Section 4 – cross-comparisons.

### 3.3 Heathrow Airport

The Heathrow Airport Pilot PRT Scheme has been commissioned following an extended period of analysis of alternatives to provide the key landside transport needs of the airport. It was concluded that the only transport solution which can meet future needs is a PRT network, while existing (conventional) systems are unsuitable. Within CityMobil, the system performance will be monitored, and some aspects of PRT beyond the scheme itself will be studied, with the aim of achieving an evaluation of the PRT operation, which can then be applied to other potential installations.

The system will carry passengers arriving at the Business Car Park to the new Terminal 5 Building which opened in March 2008. There are 3.9 km of dedicated one-way guideway, collecting passengers from two two-berth stations in the car park, transporting them along an elevated dual-guideway mainline section which skirts the perimeter of the airport and terminates in a four-berth station on the third floor of the multi-storey short-term car park alongside the Terminal Building. The system will be served by 16 small four-seater battery-electric vehicles, controlled automatically. Except where there are sudden large peaks in arrivals, passengers will find a vehicle already waiting to collect them at the stations, and there will be little or no waiting. It is intended to later expand the network to serve business, public and staff car parks along the entire northern edge of the airport, plus car hire offices and hotels, and link them through a tunnel to Terminals 1, 2 and 3 in the Central Terminal Area.

At the time of writing this paper, the infrastructure is being completed and several test vehicles have started to run on the guideways. The

ULTra PRT scheme (Figure 2) is expected to begin public operation in the fall of year 2009. The initial operation of the car park to Terminal link is run now by buses. This has particular attractions for the CityMobil evaluation programme, since it provides the opportunity of a direct one-to-one comparison of the passenger satisfaction and benefits of the two different modes. The work on the ex-ante evaluation has just started, and the data collection for the ex-post evaluation will commence one year after system launch.

Six different procedures have been adopted to measure all those indicators, [7]: EDICT Trials [10], Interviews, Simulations, Shuttle Bus Surveys, System Measurements and Cost Information that will be provided later by the management of the PRT system.

It is important to note that the Heathrow system will be the first large scale PRT to be deployed in a real application anywhere in the world. This is a significant breakthrough in the advancement of ITS. Therefore, although the evaluation of the systems is only at initial stages, it is worthwhile to mention it here.



**Figure 2. ULTra PRT vehicles for Heathrow**

### 3.4 Daventry

Daventry, located in Northamptonshire, UK, has been interested in implementing CTS in order to solve some problems, such as current very low use of public transport, environmental impact, lack of accessibility of several populations and adverse land-use effects. Through the showcase held in September 2007, Daventry aimed to increase political support for the funding of a pilot, and to inform the local population about such systems. 3 CyCabs, similar to small golf carts with a fully automatic driving system ran for two weeks near the town centre, on a section of a pedestrian road, Figure 3.





**Figure 3. Cycabs during Daventry showcase**

The users’ impressions were collected by following an acceptance questionnaire that is similar to that used for the ex-ante survey of the Rome site. Only seven indicators were considered compared to the other surveys, where more have been measured; however, differently from the other sites, all these indicators were surveyed in terms of both weight and performance rating. Therefore, in spite of the small number of indicators and the relatively small sample, the survey is of high value and allowed a more complete analysis of the system User Acceptance.

Similarly to the Rome evaluation, Ref. [7] includes detailed results of the sample distributions according to different populations and the ratings they gave to the indicators. The main results of the average ratings show that:

- “Usefulness” and “Ease of use” came out as the most important, while “Reliability” received lower rating (as observed for the Rome analysis; however, this result does not provide an actual quantification of the importance given to these different aspects, but only rate of importance). Although the performance ratings

are very close (all within 3.1 and 3.5), it is interesting that the most important indicator is rated as the lowest performing; this can be interpreted as a request for improvements on this aspect.

- Regarding “Quality of Service” indicators, the perception of safety is rated as the most important. Differently from the previous category, it is also considered as best performing, but again all the indicators have performance values very close to each other (2.9 to 3.2 out of 5). The “Fear of attack” indicator is weighted as the less important but is also the one with the lowest performance. Compared to Rome, the distribution of results was less varied among the populations.

#### 4. Cross-Comparisons and Findings

An important objective of the evaluation program is to derive cross-comparisons from results obtained in different sites, and various systems, leading to general conclusions valid globally for such innovative systems. In the following these are presented based on the CityMobil findings [7].

As expected, it has been possible to obtain only limited cross-comparisons, due to the widely different nature of the sites and technologies, and the stages of the evaluations performed. Table 14 in [7] shows a comparison for Rome, Castellón and Daventry, of the User Acceptance, Quality of Service, Transport Patterns, Social Impacts and Environment categories. As an example, Table 4 here presents the results for User Acceptance. As explained above, the method used to obtain the ratings was similar for the three cases. It is described in detail for the Rome case.

**Table 4. Comparisons for the user acceptance indicators**

Evaluation Category	Impact	Indicator	Ratings			Performance ratings		
			Castellón	Rome	Daventry	Castellón (ex-ante)	Rome (ex-ante)	Daventry (ex-post)
Acceptance	User acceptance	Usefulness	High	1 (most important)	2	High	94%	3.5/5
		Ease of use	High	2	1 (most important)			3.1/5
		Reliability	High	3	3			3.5/5
		User satisfaction for the on-demand service		5 (less important)				
		Integration with other systems	High	4		Medium		
		Route/Path ( <i>Castellón specific</i> )	High			Low		

It can be seen from the Table that for “Acceptance”, a comparison between the feedback on system performance (ex-post survey) or expected performance (ex-ante surveys) of the three systems is, indeed, quite impossible for almost all indicators, except for “Usefulness”: although collected and averaged in different ways (for Castellón a quantification was also performed), the three sites received very good response on this aspect. A more relevant comparison can be made of the ratings given to the indicators by the users. For these, the ex-ante versus ex-post distinction can be ignored, since, at least ideally, the importance attributed to the different aspects of the system should not be different in the two stages. For the “Acceptance” evaluation category, “usefulness” and “ease-of-use” were found to be the most important aspects according to users. “Reliability” is rated, on average, as relatively less important in all the three surveys. The cross comparison shows a certain concern about “willingness to pay”: the Castellón survey rates this indicator as very important; the Daventry users, although giving a lower importance compared to the other aspects of the same category, declared the willingness to pay for a single trip a fare of only 1 to 2 euros.

As for the “Quality of Service” category, it is interesting to notice that “Comfort” is never given the highest importance; in the Rome survey it received a particularly low rate, which can be linked to the short travel times characterizing this system. The same can be said for the “Perception of safety”, that for Rome received an even lower rate, while for Daventry and Castellón, where the trips are longer, it was rated as very important. The “Fear of attack”, on the other side, seems not to pose a concern for the travellers of such systems.

An important cross comparison can be made on the “Accessibility for mobility handicapped users”. This was rated as of primary importance in Rome, while in Castellón it received different levels of attention according to the interviewed groups; it should be pointed out, however, that in this same survey this aspect was frequently observed also in the response to other points like “perception of safety”, “information availability”, “Ticketing”, etc.

In general, it can be concluded that, based on the collected opinions, the users attitude towards these automatic systems is positive. Some concerns emerge from the safety point of view of the systems associated with longer travel times; in fact, this indicator is perceived as generally low, at least for some aspects, for the Castellón TVRCAS and just above the satisfactory level for Daventry, although it is rated as of high importance for these systems. Gaining a high perception of safety will likely represent a major challenge for automatic systems, and therefore it will deserve deep attention during the design and implementation stages of CTS.

## 5. Energy Management

The evaluation of transport projects and systems includes aspects of energy and environment. Indeed, the CyberMove and CityMobil evaluations tasks deal with these aspects. Measurements are taken of energy consumption of vehicles and CTS fleets, and simulation algorithms have been developed for comparisons and predictions. These models also enable proper design and operation of the CTS. Results of such evaluations within CyberMove are presented in [9], and here two examples are discussed.

The simulation tool was initially developed for the calculation of the energy consumption of an electric vehicle (EV), [11], and then extended for application to CTS fleets, [9]. The input data consists of vehicle and loading parameters, road profile and traffic characteristics (e.g. speed profile).

Figure 4 shows the effect of battery weight on the productivity (passengers\*km) of the electric cybercar tested at the INRIA (FR) site. As can be seen, the curves attain a maximum, here – at about 320 kg, for the specific vehicle, speed and route data. The location of this maximum is almost independent of the average speed ( $V_{av}$ ) in the range of the experiments. These results mean that it is possible to optimize the system by using the simulation algorithms for predictions of the behaviour under various operating conditions.

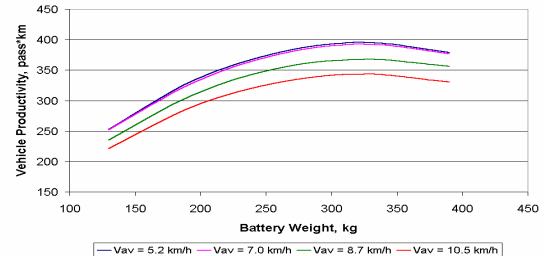


Figure 4. Effects of battery weight on vehicle productivity

Another example where the simulation model was used was a preliminary CTS design for the campus of the Technion – Israel Institute of Technology. The length of the simulated driving route was 1,600m; the averaged value of the road gradients is 7.5%, and the basic average speed 12.0km/h. For estimating the demand for the proposed CTS line, a LOGIT model was used, based on a Stated Preference study, [12]. The simulation was performed separately for the downhill and uphill parts of the road.

The results showed that the total energy consumption of the CTS is inversely proportional to the passenger capacity of the vehicle. Thus, it is possible to optimize the system for minimal energy consumption, by using cars with maximal possible passenger capacity and minimal battery/ies weight that will provide the required driving cycle. Of course, the EV has recharging capability at

breaking and decelerating. The optimized system consists of 18 cars of 5 passengers, with 55kg battery weight. The driving range is 56km (before recharging), vehicle energy consumption 0.221

kWh/km and total CTS daily energy consumption 223kWh.

Table 5 includes additional simulation results for the selected (optimized) vehicle parameters.

**Table 5. Energy consumed and regenerated by a single CTS vehicle (per day)**

Total energy consumption (kWh)	12.4
Total energy consumption per km (kWh/km)	0.221
Downward energy consumption per km (kWh/km)	0.029
Upward energy consumption per km (kWh/km)	0.424
Total regenerated energy (kWh)	3.05
Total regenerated energy per km (kWh/km)	0.54

As can be seen from Table 5, the regenerated energy is very significant and reaches 25% of the total energy consumed by the cybercar. It is, therefore, emphasized that a regenerative braking feature is very important for driving cycles with steep slopes and should be included even if low driving speeds are foreseen, in order to save energy and to increase the driving range and the productivity.

## 6. Conclusions

A CTS is a system of road vehicles with automated driving capabilities (either fully or partially). Its vehicle fleet is used for passengers or goods on a network of roads, and is under control of a computerized management system. The vehicles are used individually by the customers, in a way similar to car sharing systems, and thus the CTS offers the link between the private car and the public transport modes.

Such systems are being studied, in the framework of the EU Project CityMobil, in several sites through city studies, large and small demonstrations with a common evaluation methodology, which can be followed for Advanced Transportation Systems in general. The methodology presented here allows comparing and transferring results.

Several performance indicators, ranging from user acceptance to costs and from transport performances to environmental impacts are used to evaluate the sustainability of these systems.

Although studies and demonstrations are still in progress, as are data collection and evaluation, first results show how these systems are well accepted by users, who value the flexibility that they can provide. Moreover, the findings from the projects CyberCars, CyberMove, CityMobil, etc., clearly indicate that the CTS technologies are already

available. Their commercial implementation depends on non-technical factors and mostly on decisions by authorities. The evaluation results as well as the dissemination activities (including various-scale demonstrations) within CityMobil and projects that follow it, will undoubtedly lead to adoption of CTS as a viable application of ITS.

Furthermore, it is possible to optimize the energy management of CTS. This will result in reducing energy consumption and therefore also emission of pollutants and greenhouse gases. Thus they can be effectively used to solve some specific mobility problems contributing to make urban transport more sustainable.

## 7. References

- [1] G.R. Bruntland, "Our common future", Report of the World Commission on Environment and Development, Annex to General Assembly document A/42/427: Development and International Co-operation: Environment, 1987.
- [2] M. Lowson, "Energy use and sustainability of transport systems", Advanced Transport Group, University of Bristol, BS8 1 England, 2005.
- [3] A. Alessandrini, and L. Persia, "Effects of low environmental impact buses". Proceedings of ISATA 2000 conference, Dublin, Electric/Powertrain volume, pp. 217-228, ISBN 1-902856-09-0, 2000.
- [4] A. Alessandrini, M. Parent and C. Holguin, "Advanced city cars, PRT and cybercars, new forms of urban transportation", Proceedings of the Transport Research Arena (TRA) Europe Conference, Ljubljana, Slovenia, 2008.
- [5] M. Parent, "Cybercars: new technologies for sustainable transport", Proceedings of the Transport

Research Board (TRB) Conference, Washington, DC, 2009.

[6] F. Filippi, A. Alessandrini, D. Stam, T. Chanard and M. Janse, "Final evaluation report", Deliverable D6.3, CyberMove EU Project, 2004.

[7] D. Stam, A. Alessandrini, G. Ruberti, S. Marco, Y. Zvirin and R. Librino, "Field trial A ex-ante evaluation report", Deliverable 5.2.1a, CityMobil EU Project, 2008.

[8] N. James, C. Greensmith, Y. Petropoulos, S. Franzén, F. Filippi and A. Alessandrini, "Guidelines for transport in the 21st century", MAESTRO EU Project, EC Research contract number PL-97-2162, 2000.

[9] Y. Zvirin B. Aronov, A. Alessandrini, K. Malone, H. Raekers, M. Parent, T. Meisner, S. Bekhor and L. Tartakovsky, "A tool to choose the energy system and dimension the vehicle fleet of CTS systems", Deliverable D4.2, CyberMove EU Project, 2004.

[10] EDICT Consortium, "Assessment Framework", Deliverable 2, EDICT EU Project, 2003.

[11] D. Kottick, L. Tartakovsky, M. Gutman and Y. Zvirin, "Results of electric vehicle demonstration program", Proceedings of the 21st IEEE Convention of the Electrical and Electronic Engineers in Israel, pp. 318-321, 2000.

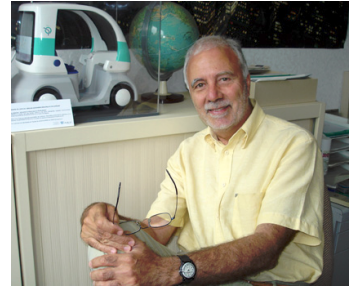
[12] S. Bekhor and Y. Zvirin, "Estimating the potential use of cybernetic cars for a university campus", Proceedings of the 10th World Conference in Transport Research, Istanbul, Turkey, 2004.



**Adriano Alessandrini**  
Mechanical engineer since 1998 (B.Sc. +M.Sc.) and Ph.D. in energy technologies since 2003 Adriano is currently Research Fellow (Assegnista di Ricerca) at CTL (Centre for Transport and Logistics Sapienza Università di

Roma) which he has helped to establish participating to it since its first funding in 2003 by the Italian Ministry of Education, University, and Research as a centre of excellence. He is an expert in transport systems and in environmental impact of transport, his main research field, has been participating and conducting, in 11 years since his graduation, 25 national and EU funded research projects, including CyberCars, CyberMove, CityMobil and CityNetMobil. He has been contracted as expert by the EC to review the contribution EU R&D to the implementation of the Action Plan on Environmental Technology, ETAP.

Adriano lectures as expert in Transport Department, University of Rome Engineering Faculty.



**Michel Parent**  
has an engineering degree from the French Aeronautics School (ENSAE), a Masters degree in Operation Research and a

Ph.D. in Computer Science, both from Case Western Reserve University, USA.

Parent is manager, since 1991, at INRIA of the R&D program on advanced road transport (IMARA). It focuses on fully automated vehicles (cybercars). He has spent half of his time in research and academia at such places as Stanford University and MIT in the USA and INRIA in France, and the other half in the robotics industry. He is the author of several books on robotics, vision and intelligent vehicles, and numerous publications and patents. He was the coordinator of the European Projects CyberCars and CyberMove (2001-2004) and these continue now in CyberCars2 (2006-2009), CityMobil (2006-2011) and CATS (2009-2012).



**Yoram Zvirin**  
received the degrees of B.Sc. (1964), M.Sc. (1966) and Ph.D. (1970) from the Faculty of Mechanical Engineering, Technion – Israel Institute of Technology, Haifa, where he is now Professor, Head of the Internal Combustion

Engines Laboratory and Holder of the Sylvia and Alexander Hassan/Washington Chair in Energy Conversion. He served as Head of the Technion Transportation Research Institute (1997-2000), and as Director (CEO) of MadaTech – Israel National Museum of Science (2002-2008). Zvirin has been involved in many national and international research programs on Environmental Friendly Transport Systems, e.g. the EU programs and projects CANTIQUÉ (1999-2001), COST346 (1999-2006) and ATREMIS (1999-2005) – energy consumption, emissions and air quality; CyberCars / CyberMove (2001-2004), CityMobil (2006-2011) and CATS (2009-2012) – cybernetic transportation systems. He has worked during sabbatical leaves in several leading universities and research institutes. Since 2008 he is a member of the EC Transport Advisory Group (TAG).

*Received date: February 3, 2009*

*Received in revised form: May 2, 2009*

*Accepted date: May 15, 2009*

*Editor: Masao Kuwahara*