CITIES DEMONSTRATING AUTOMATED ROAD PASSANGER TRANSPORT

Guidelines to designing and implementing automated road transport systems

SEVENTH FRAMEWORK PROGRAMME

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Who should use this document (and) how

This document is the fifth and last deliverable of the workpackage 14 of the CityMobil2 project, called "Common study evaluation and selection for phase 2". It represents a guideline for the design and implementation of the Automated Road Transport Systems (ARTS), made on the basis of the work regarding the city studies and the operating demonstrations.

It is divided in three main sections, each of them aimed at different "users".

The first section is an executive summary on how the ARTS can be used and what expect from them and is mainly indicated for those people who want to have a general overview on the ARTS and on the concept on the basis of their insertion in the mobility, before deciding for the implementation.

An explanation of the last mile service to be provided by the ARTS is reported, together with the procedure to insert them on the road. The main transport service technical characteristics are showed, in terms of service better accomplished, commercial speed, waiting times for the users, demand attracted and system capacity. At the end of the section the investment and operating costs requested by an ARTS are explained, together with the expectations about the financial and the social viabilities. All such parts can contribute to guide the readers to the adoption of an ARTS on a specific site to give benefits to the mobility.

The second section is a guideline on how to choose the site to implement an ARTS. It is aimed at those people who have to select a site for an ARTS, once it has been already decided to implement it.

It is made of three parts.

In the first part the overview on the innovative systems of transport is reported. It is the Passenger Application Matrix (PAM), a tool built in the framework of the FP6 European project CityMobil (2006-2011) and including the results of the evaluations of the new technologies tested during the project by demonstrations, showcases and case studies, and updated with the ARTS city studies and demonstrations made at the moment in the framework of the CityMobil2 project. It represents the state of the art and the starting point for the decision makers on which innovative transport systems work better according to the site of application.

In the second part the preliminary site diagnosis operations to be done, in order to have a first idea on the possible sites where an ARTS could be implemented, are reported. Preliminary operations such as the analysis of the local transport problems, the local and regional transport policies and strategies to solve them, the potential impacts of the insertion of an ARTS in the mobility, and a first rough estimation of the demand to be served, the kind of service required to serve it, according to the existing situation, have to be made.

The third part concerns the pre-design method to calculate, on the basis of the data estimated in the site diagnosis phase, the ARTS main transport features (number of vehicles requested, average waiting time at the stops, vehicle commercial speed, vehicle mileage) and the costs required for it. Starting from such outputs, it is possible to choose which is the best site where an ARTS could be implemented in a urban, suburban, or extra-urban context.

The third section is the deeper one, and is focused on how to design and implement an ARTS, once the site was chosen. It is aimed for transport experts, with the aim of giving them all the possible tools for the design and the implementation.

It is made of six parts.

The first part concerns the demand analysis in the ex-ante phase. It is made by Stated Preference (SP) surveys, providing a questionnaire to the potential users of the ARTS in order to assess their preference if the ARTS is compared with a conventional transport mean, as for example a minibus. The rules and the scheme adopted to design the survey are reported, together with the discrete choice model estimation.

The second part is focused on the supply dimensioning in the ex-ante phase. An overview on the different methods to dimension the ARTS is provided. According to network complexity, the dimensioning can be made by transport calculations, by using a Dial-A-Ride-Problem (DARP) solution algorithm, or by using dedicated software. Different software can be used: a simulation tool called DARP, developed by the CTL and based on a Dial-A-Ride-Problem solution with time windows algorithm, or several mico-simulation tools, such as those developed in the CityMobil project. Another part of the supply dimensioning is represented by the urban integration of the ARTS. According to the present CityMobil2 experience, the ARTS have to be integrated by providing dedicated measures, such as road markings signalling the ARTS dedicated lanes, road markings on regular roads (if used) and on pedestrian areas, crossing protections, etc.. Examples from the most recent CityMobil2 demonstrations are available in this part of the document.

The third part regards the recommendations for service operations, mainly focused on adequate training of the operators of the system and on adequate maintenance of the system. Furthermore the infrastructures, road-side sensors, communication networks, management centres have to be set.

The fourth part is about the cost-analysis in the ex-ante phase. An estimation of the costs and the benefits due to the ARTS implementation is required, both in terms of financial viability and socio-economic viability. Considering the costs due to the track, the vehicles, the control systems, the personnel, and the benefits due to the system revenues and linked with the community, the Cost-Benefit Analysis (CBA) is the tool to measure such impact of an ARTS.

The fifth part regards the monitoring of the designed ARTS, requiring a workplan to select the indicators and data to be collected during the system operations in order to allow an ex-post evaluations of the system. Lists of indicators are available both in the CityMobil and CityMobil2 project, to assess user acceptance, quality of the service provided, system performances, technological success, and environmental impacts.

The sixth part regards how to use the design process results: once designed and implemented, the ARTS evaluations have to be inserted in the PAM, to give a feedback allowing to fill its cells, to give to the decision-makers an enhanced and continuously updated tool.

1. How to use ARTS and what to expect from them

1.1 ARTS background: the CityMobil2 project

European cities face four main problems related to mobility: congestion, land use, safety and environmental issues. One of the main causes of such problems is the car-ownership rate. The centres of large cities address this issue combining efficient mass transits with car restriction policies, but peripheral areas and smaller cities remain dominated by private cars.

CityMobil has demonstrated that automation of road vehicles can lead to different transport concepts, from partly automated car-share schemes through CyberCars and PRT, to Advanced BRT, which can make urban mobility more sustainable. However CityMobil has also highlighted three main barriers to the deployment of automated road vehicles: the implementation framework, the legal framework and the unknown wider economic effect.

The goal of CityMobil2 is to address these barriers and finally to remove them. To smooth the implementation process CityMobil2 will remove the uncertainties, which presently hamper procurement and implementation of automated road transport systems.

On one hand CityMobil2 featured 12 cities, which worked to revise their mobility plans and adopt automated road transport systems, wherever they prove effective. CityMobil2 selected the best cases (among the 12 cities) to organise ARTS demonstrations. The project procured two sets of automated transport systems and deliver them to the selected cities, which host large demonstrations for a period of 6 to 8 months with 6 vehicles or small demonstrations for about 4 months with less than 6 vehicles.

To change the legal framework CityMobil2 established a workgroup with scientists, system builders, cities, and the national certification authorities. The workgroup is working to deliver a proposal for a European Directive to set a common legal framework to certify automated road transport systems.

Finally, an industrial and economic study is assessing the industrial potential of automated systems on the European economy and any eventual negative effect and make a balance of them.

The cities selected in the framework of the project are:

- La Rochelle, Lausanne, Trikala: large demonstrations
- Oristano, Vantaa, Sophia-Antipolis, San Sebastian: small demonstrations

Furthermore three showcases are being held in Leon, Bordeaux, and Barcelona, to make people confident with the automation concept provided by the ARTS.

1.2 ARTS application fields

1.2.1 ARTS concept - Last mile service

The ARTS are fully automated systems made of automated vehicles with no driver on board, dedicated infrastructures (not necessarily segregated), and control and communication systems (operational system). The lanes for the ARTS are regulated according to the ARTS rules (speed limits, stops at the stations, etc.), however they can be used by the conventional vehicles, if respecting the ARTS regulations.

Any transport mode is made of three distinct components:

- Vehicles
- Infrastructure: roads, guideways and stations, depot, barriers, gates (vehicle access), etc.
- Operational system: fleet and infrastructure supervision and management system, end-user information system, operator information system and communication systems.

The components of an Automated Road Transport System (ARTS) can be further detailed, because of the automated driving function and the communication capabilities of the system's components. According to the experiences of the demonstrations carried out in the CityMobil and CityMobil2 projects, an ARTS is composed of the following subsystems:

- The fully automated road vehicles
- The physical infrastructure
- The digital (or smart) infrastructure (road-side sensors, communicating traffic lights...)
- The fleet and infrastructure supervision and management system
- The end-user Information System
- The operator information system
- The communication system

In Figure 1 the ARTS system infrastructure is reported. The Fleet and Infrastructure Supervision Management (FISM) is linked with the Communication System, also linked with the vehicles, the end-user information system, the operator information system and a smart infrastructure. The vehicles and the smart infrastrucutre can be linked with a non-smart infrastructure.

ARTSs aim at complementing and integrating the mass transits, providing a public transport service which cover the "last mile" trips and allow the interoperability with the main public transport systems inside and outside the cities. An example of the concept the ARTS are based on is reported in Figure 2.

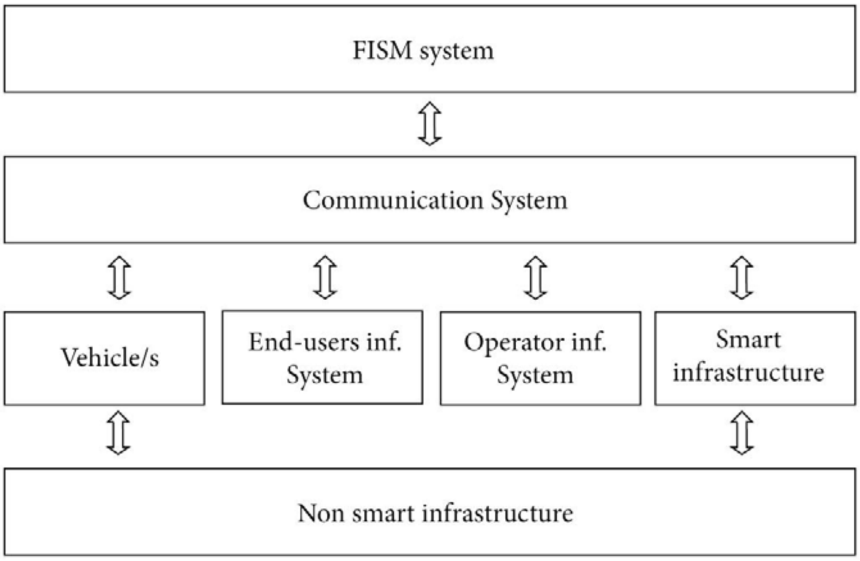

Figure 1 ARTS system infrastructure

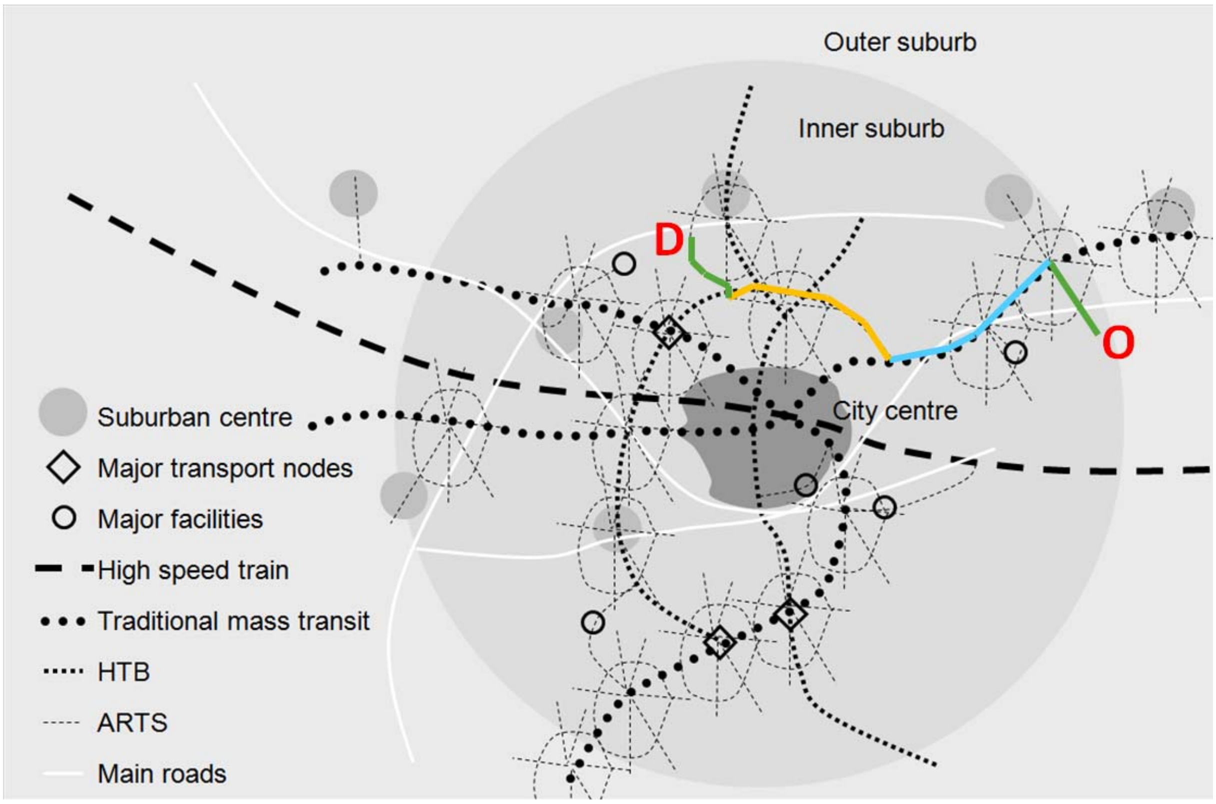

Figure 2 ARTS service concept explanation

To reach the destination D starting from the origin O, both of them in small centres of the inner suburb of a city, the user can use the ARTS from the origin to the traditional mass transit interchange point alon the green route on the right side of Figure 2. The traditional mass transit is used along the light blue route till the intersection with the high tech bus (HTB in Figure 2). After the yellow trip on the HTB, the last part of the route is covered with the ARTS along the second green route until the destination point D.

1.2.2 ARTS insertion on the road

The ARTS are able to provide service in different contexts: **city centre, inner suburbs, outer suburbs, suburban centres, major transport nodes, major parking lots, major educational or service facilities, major shopping facilities, major leisure facilities, and transport corridors**.

In all such contexts they could work in frequency, on-demand or mixed (on-demand/frequency) mode, according to the requests linked with the demand distribution, the existing public transport, and the streets on which the ARTS have to operate.

According to the contexts the ARTS can go through different roads, as reported in Figure 3, where the six categories of roads of the Highway Capacity Manual [1] are reported.

Road class	F	E	D	C	B	A
	Walkway	Collector street	Urban street	Arterial road	Highway	Freeway
Driveway/access density	-	Very high	High	Moderate	Very low	Very low
Parking	-	Significant	Significant	Some	No	No
Separate left-turn lanes	-	No	Some	Usually	Yes	No
Signals/km	-	6-10	4-8	2-6	0.3-1.2	-
Speed limit (km/h)	0	15-40	40-55	55-80	70-100	100-130
Pedestrian activity	Very Important	Important	Usually	Some	Very little	No
Roadside development	Very high density	Very high density	High density	Medium to moderate density	Low density	Very low density

Figure 3 Roads used by ARTS

The roads on which ARTS are able to go are those named from "C" to "F" - arterial road, urban street, collector street, walkway (meaning in pedestrian areas with specific authorizations) - whereas at the moment they are not conceived to go on highways and freeways.

To insert an ARTS on a road, a **risk assessment procedure** has been developed. Such procedure is organized in the following 8 steps:

- Step 1: Project approach
- Step 2: Preliminary hazard risks

- Step 3: FMECA and system design
- Step 4: Verification of system safety/functionality
- Step 5: Operational description
- Step 6: Verification of operational preparation
- Step 7: Approval design/operational safety cases
- Step 8: Operational testing

Each step corresponds to a verification phase. Five actors are involved in the process: the city authorities who manage the infrastructure; the safety (or certification) authorities, normally the national ministry; a safety board from the project; the ARTS manufacturer; and the ARTS operator.

1.3 Transport service technical characteristics

1.3.1 Service better accomplished by an ARTS

ARTS are mainly conceived as feeders for the main public transport inside and outside the cities, providing last mile services, as reported in 1.2.1 and 1.2.2.

Such services can be provided in specific areas with different applications such as those implemented in the CityMobil2 project:

- campuses (e.g. the EPFL university campus in Lausanne, the technology parks in San Sebastian and Sophia-Antipolis)
- short distance facility applications as the seaside promenade service in Oristano
- inside the city centres (with fully dedicated lanes as in La Rochelle or sharing the lanes with conventional vehicles as in Trikala)
- along shared lanes - with higher speed performances - to connect mass transit systems with major facilities, as in Vantaa where the ARTS linked the new railway station with the entrance of annual Housing Fair exhibition.

In all those applications ARTS are able to serve the entire demand and to operate in connection with the main transport systems, providing high quality service both on demand and on frequency, according to the different requests. Thus leading to a higher quality of the service provided in comparison with conventional public transport modes.

It must be stressed that increasing the quality of the public transport service, which is one of the reasons to adopt ARTSs, is not sufficient to increase considerably the PT modal share thus integrated policies are recommended to push more people to use it. Combining ARTS installation with some “push” measures, such as parking or road pricing or rationing, may help to make the push measures better accepted by the users and to decrease the modal share of private vehicles.

1.3.2 Commercial speed ensured by an ARTS

The commercial speed is one of the indicators better measuring, together with the waiting time, the transport performances. It measures the travel time but does not depend on the travelled distance.

The commercial speed for short distance ARTS strongly depends on whether the route is shared or dedicated. In the first case it ranges between 5 and 14 km/h while in the second it ranges between 15 and 20 km/h. The typical speed of surface public transport in big congested cities is around 13 km/h that is the average of slower speeds of the peak hours and faster in the off-peak. As such an average speed of 13 km/h and more can make the system more attractive than surface public transport but not of metro or private vehicles. The attractiveness of an ARTS with that speed range may increase if the ARTS is used on dedicated lanes (not necessarily segregated) with dedicated regulations, where conventional vehicles can circulate but respecting the ARTS regulations.

The same vehicle can have a double average speed if the route is segregated, with respect to a shared route, for two reasons: the vehicles stop only when passengers boarding or alighting require so, and not because of external influences, and the maximum speed can be much higher than that imposed for safety reason when the route is not segregated. Of course segregation as a “community severance” impact which is typical of surface metro, railways and motorways.

However the aim of the ARTS integration in the mobility is to have them circulating on dedicated lanes, with segregation only if strictly required, providing a high quality service without barriers.

1.3.3 Waiting time length

The average waiting time significantly changes with the network extension, the demand and the number of the vehicles employed and ranges between 0.5 and 5 minutes. Given the demand and the network the waiting time is influenced by the number of vehicles, by their capacity and by their commercial speed.

The main success factor to highlight about the waiting time is that, although it can be better or worse than that of a conventional PT system depending on how the two are designed, an ARTS becomes interesting for a site only in case it is designed to have a lower waiting time than a conventional transport system. The main part of the cost per kilometre in running a bus service is the driver cost that grows proportionally with the kilometres the buses make each day (and therefore with the frequency) while in an ARTS the infrastructure cost is more significant and therefore the cost per vehicle·kilometre decreases increasing the kilometres the ARTS vehicles make each day. As a consequence if a transport system is designed to provide long waiting times it is worthwhile to do it by bus while to ensure shorter waiting times ARTS becomes financially competitive against the bus.

Another factor to point out is the correlation between average waiting time and occupancy: lowering the average waiting time the occupancy decreases. As a matter of fact if a service is better responding to the user requests less people travel together in the same vehicle. Lowering occupancy has normally three effects: more vehicles for the same demand; more space used and more energy spent; but an ARTS by using smaller and more energy efficient vehicles is able to provide better use of space and better energy consumption per passenger·kilometre than busses even providing a transport service with lower waiting time and therefore lower occupancy.

1.3.4 Demand attracted

A service with lower and more reliable waiting times and shorter travel times does attract more demand.

Furthermore if ARTSs provide a better transport service in low demand areas which are the “Achilles heel” of any public transport network and, if used there, they can induce more people to shift from private to public transport on the other parts of the journey as well.

Nevertheless a ARTS will not solve the mobility problems alone, other measures to push people to use public transport have to be adopted; the CTS can be the public transport improvement that is always required when adopting such measures.

Last success factor related to demand to point out is the need for a detailed transport study in the ARTS design phase to correctly dimension the system, quantify the demand, evaluate the interactions with the transport networks of the city and identify the “accompanying” measures necessary to make the ARTS a success.

1.3.5 ARTS capacity

ARTS can theoretically reach any capacity by using the platooning technique which allows the vehicles to form a “train” and therefore lowering the average headway distance to keep for safety reasons.

In short distance services such techniques are usually not necessary for two reasons: the speeds are low, consequently the headway distances which grow with the square of the speed are low, and the origin and destinations are not too distant one another therefore one bigger vehicle can host more people travelling at the same time with different O-Ds, the system capacity can therefore be increased by increasing the size of the vehicles rather than by increasing so much their number to cause congestions.

1.4 Costs, profitability and socio-economic viability

1.4.1 Investment to start up an ARTS

Total investments vary according to the network extension, the number of vehicles used and their size; in the CityMobil2 experience for what concerns the ex-ante evaluations provided by the cities involved they ranged between 0.2 and 0.5 M€/km, with the only exception of the Milan ARTS, foreseen to use two fleets of 6 vehicles each during the Expo 2015 [2], resulting in a greater request of personnel to be involved and in an outcoming cost of 1.37 M€/km.

When these costs are compared to the costs of a tramway at street level, which is around 11M€/km, they seems quite reasonable; and excluding the extreme represented by the world event of the city of Milan (where the ARTS vehicles were foreseen to be supported by conventional busses and shuttles to serve the entire demand foreseen), if compared to the investment costs to install a bus line which are around 0.5M€/km, the ARTS result once again to require lower investment costs.

1.4.2 Operation costs

The yearly operation costs for an ARTS vary as well as the installation costs according to the same parameters. Making the same division of costs per network kilometre the costs would vary in a range between 0.3 and 0.04 M€/year per network kilometre. As for the investment costs the more expensive ARTS is the one foreseen to serve the Expo 2015 exhibition in Milan, due to the double request of vehicles and to the "neighbouring" conditions, already reported in section 1.4.1.

Looking at the operational costs per vehilce·kilometre, it is interesting to calculate them on the basis of the operating demonstrations more than on the basis of the ex-ante estimations of the cities. At the present stage such evaluation has been provided for the Oristano small demonstration, operating for 72 days on the seaside promenade of the Sardinian city in summer 2014. On the basis of the data collected during the demonstration the ARTS operational cost is 3 €/veh·km, including in such cost vehicle and battery depreciations, personnel, maintenance, and operative consumptions. The same calculations have been done for a conventional minibus, if replacing the ARTS in the same service, providing a minibus cost of 3.9 €/veh·km.

This result shows how the ARTS can be competitive and cheaper in comparison with conventional means of transport such as a minibus. If compared with a bus service operational cost, which is between 2.8 and 3.5 €/veh·km, the ARTS are however competitive.

1.4.3 Financial profitability

The financial profitability of an ARTS needs further investigation based on real implementations, however as calculated for previous systems using cybercars the financial NPVs are negative, confirming that the public transport services are not profitable in Europe [3].

However ARTS, in order to become financially neutral, can be helped by ad hoc mobility policies pushing people to use them, without being subsidised as most of the public transport services.

1.4.4 Socio-economic viability

ARTS together with the ad hoc mobility policies to use them can guarantee benefits for the community in terms of noxious emission reduction, and incident reduction, thus contributing to the environmental and the safety improvement.

According to how the community values such positive mobility effects generated by the ARTS (and by the reduction in the private car usage), the socio-economic impact of such systems could reach in ten years a magnitude of more than ten times the initial investment.

2. Where to implement ARTS

This section represents a guideline on how to decide where to implement an ARTS. It is made of three sub-sections.

The first one reports the Passenger Application Matrix (PAM), the tool built in the framework of the FP6 European project CityMobil (2006-2011) and including the results of the evaluations of the new technologies tested during the project by demonstrations, showcases and case studies. It represents the state of the art and the starting point for the decision makers on which innovative transport systems work better according to the site of application (city centre, inner suburbs, outer suburbs, etc.). The PAM reported in this document has been updated with the ARTS city studies and demonstrations made at the moment in the framework of the CityMobil2 project, thus enlarging the data available for the different kinds of sites.

The second sub-section reports the preliminary site diagnosis operations to be done, in order to have a first idea on the possible sites where an ARTS could be implemented. This phase includes on one hand preliminary operations such as the analysis of the local transport problems, the local and regional transport policies and strategies to solve them, the potential impacts of the insertion of an ARTS in the mobility, and on the other hand a first rough estimation of the demand to be served, the kind of service required to serve it (in terms of network length, vehicles to cover the network, maximum waiting time at the stops, maximum vehicle speed).

The third sub-section concerns the pre-design method to calculate, on the basis of the data estimated in the site diagnosis phase, the ARTS main transport features (number of vehicles requested, average waiting time at the stops, vehicle commercial speed, vehicle mileage) and the costs required for it. Starting from such outputs, it is possible to choose which is the best site where an ARTS could be implemented in a urban, suburban, or extra-urban context.

2.1 The passenger application matrix as state of the art

In the FP6 European project CityMobil (2006-2011), the final step of the evaluation process, made through the analysis of four demonstrations, five showcases and six city studies in different European cities, was to formalize the generalization of the results coming from the different inputs to the CityMobil technologies (Cybercars, Personal Rapid Transit, Dual-Mode Vehicles, High-Tech Buses) appraisal and finally provide a global assessment of the technologies [4].

In order to set the stage to this process, a dedicated table was built by the evaluation team during the project, named Passenger Application Matrix (PAM). The purpose of this tool is to move the focus from the researcher perspective to the decision maker’s one, typically more practical, trying to think in terms of what system is best to be implemented in order to improve the mobility in a certain specific situation.

In this matrix the city studies, the demonstrations and the showcases are grouped according to the type of areas linked by the single scheme. Being the possible OD pairs the same (rows and columns), the matrix results to be a two-dimension symmetrical one. The information for each OD pair, expressed in terms of the available indicator values, can be considered as the third dimension.

Ten possible origins and ten possible destinations are in the matrix. They are:

1. City centre,
2. Inner suburbs,
3. Outer suburbs,
4. Suburban centre,
5. Major transport nodes (e.g. airport, central station),
6. Major parking lots,
7. Major educational or service facilities (e.g. university campus, hospital),
8. Major shopping facilities,
9. Major leisure facilities (e.g. amusement parks),
10. Corridor.

The cells of the matrix represent all the possible OD pairs.

They are filled with the systems studied in the project, in terms of results of the local evaluation processes.

The use of this general view is ideally focused on each cell of the matrix, and help evaluate pro and cons of the implementation of the different technologies in each particular environment. Nevertheless a strict "single cell based" analysis will not be always feasible, in particular when the city-study modeling are involved; in fact in the modeled scenarios, due to the different dimensions of the cities, the area types may not be consistent with the categorization of the matrix, or the same area type of cities that are very different in dimension may lead to non proper comparisons; on the other hand, the indicator values resulting from the models may refer to single zones of the modeled area and not to the entire city, and this may avoid the cross comparisons as well. Such cases do not however represent a problem to the matrix filling, because in these cases it will be possible to provide valid results to the decision makers by changing the level of the geographical scale and evaluating the information on a more aggregate geographical level, i.e. grouping more cells.

Starting from the technologies and the cities studied in the previous project CityMobil, the PAM will be filled with the data of the CItyMobil2 city studies and demonstrations.

In Table 1 the last release of the CityMobil PAM updated with the CityMobil2 city study and operating demonstration results (in bold) is reported. The acronyms of the technologies reported in each cell are the following:

1. CC: cybercars
2. ICCC: inner city cybercars
3. PTFCC: public transport feeder cybercars

4. PRT: personal rapid transit
5. DMV: dual-mode vehicles
6. HTB: high-tech buses

In the CityMobil2 project ARTS use cybercars as vehicles with 10-passenger capacity, thus the CityMobil2 applications have been included in the CC acronym.

At the present stage the CityMobil2 results included in the PAM are those coming from the ex-ante city studies, plus the results of the demonstrations already finished in Oristano (two months in summer of 2014) and La Rochelle (from the end of 2014 to April 2015) and the showcase of Leon (September 2014).

The next step will be the insertion in the PAM of the ex-post evaluation results of the remaining demonstrations of CityMobil2 - Lausanne (finished in summer 2015 but evaluation results not yet available), Vantaa (finished in summer 2015 but evaluation results not yet available), Trikala, Sophia-Antipolis, San Sebastian.

Table 1 CityMobil PAM updated with CityMobil2 results

Destination → **Origin** ↓	City centre	Inner sub-urbs	Outer suburbs	Subur-ban cen-tres	Major transport node	Major parking lot	Major service facility	Major shop-ping facility	Major lei-sure facility	Corri-dor
City centre	ICCC (Gateshead. Madrid. Trondheim. Vienna) PRT (Gateshead. Madrid. Trondheim. Vienna, Uppsala) DMV (La Rochelle, Orta, Gateshead. Madrid. Trondheim. Vienna) **CC (La Rochelle, Oristano, Reggio Calabria, Trikala)**									
Inner suburbs	ICCC (Gateshead. Trondheim) PRT (Gateshead. Trondheim, Upp-sala) HT-bus (Gates-head. Madrid. Trondheim. Vienna) DMV (Gateshead. Madrid. Trondheim. Vienna)	ICCC (Gates-head. Trond-heim) PTFCC (Gates-head. Madrid. Trondheim. Vi-enna) PRT (Daventry, Gateshead. Trondheim, Uppsala) HT-Bus (Gates-head. Madrid. Trondheim. Vi-enna) DMV (Gates-								

Destination → **Origin ↓**	City centre	Inner suburbs	Outer suburbs	Suburban centres	Major transport node	Major parking lot	Major service facility	Major shopping facility	Major leisure facility	Corridor
		head. Madrid. Trondheim. Vienna) **CC (Oristano)**								
Outer suburbs	PTFCC (Trondheim) PRT (Trondheim) HT-bus (Madrid. Trondheim, Castellon) DMV (Madrid. Trondheim)	PTFCC (Trondheim) PRT (Trondheim) HT-bus (Madrid. Trondheim, Castellon) DMV (Madrid. Trondheim)	PTFCC (Trondheim) PRT (Trondheim) HT-bus (Trondheim) DMV (Sophia-Antipolis)							
Suburban centres	HT-bus (Gateshead)	HT-bus (Gateshead)								
Major transport node	HT-bus (Gateshead) CC (Vantaa)	HT-bus (Gateshead)	DMV (Sophia-Antipolis)							
Major parking lot					CC (Rome) PRT (Heathrow)	CC (Rome)				
Major service facility	PRT (Trondheim) HT-bus (Castellon)	PRT (Trondheim)	PRT (Trondheim)		CC (La Rochelle demonstration CM1,		CC (Trond- (Trondheim showcase,			

Destination → **Origin** ↓	City centre	Inner suburbs	Outer suburbs	Suburban centres	Major transport node	Major parking lot	Major service facility	Major shopping facility	Major leisure facility	Corridor
					Brussles, Leon, MIlan, Vantaa)		**CERN, Saint-Sulpice, San Sebastian, Sophia-Antipolis)**			
Major shopping facility	ICCC (Gateshead) PRT (Gateshead) HT-bus (Gateshead)	ICCC (Gateshead) PRT (Gateshead) HT-bus (Gateshead)		HT-bus (Gateshead)						
Major leisure facility	HT-bus (Castellon)									
Corridor	HT-bus (Gateshead. Madrid. Trondheim. Vienna) DMV (Gateshead. Madrid. Trondheim. Vienna)	HT-bus (Gateshead. Madrid. Trondheim. Vienna) DMV (Gateshead. Madrid. Trondheim. Vienna)	HT-bus (Trondheim) DMV (Gateshead. Madrid. Trondheim. Vienna)	HT-bus (Gateshead) DMV (Gateshead. Madrid. Trondheim. Vienna)						

2.2 Site diagnosis

This is a preliminary step, made of the analysis of the political and planning context of the city providing the study. The local problems that could be solved with the introduction of the innovative system have to be identified and analyzed.

Local and regional transport policies and strategies have to be analyzed to define the objectives for each of the potential implementation sites.

This part represent a kind of step zero of the pre-design phase, reported in the next section 2.3 and adopted to select the most appropriate site where implement the ARTS inside the city.

In this phase several parameters proper of the city where the ARTS is going to be implemented should be analyzed:

- Zone features:
  - Population density
  - Travel generation and attraction
- Road features:
  - Different typology
  - Different use
- Public transport present situation
- Service requested to the ARTS

Starting from such parameters the ARTS requested can be defined and the pre-design can be done in order to accomplish the requests of the city.

2.3 Pre-design of the ARTS

The quantitative pre-design method reported here was developed by the CTL to pre-design advanced transport systems by simulating a number of different demand and supply combinations on different networks and then making statistical regressions from the results [3].

It needs three main inputs, to be established a-priori:

- network (length, number of stops);
- daily demand;
- service levels: vehicle capacity (4, 10, or 20 places), maximum vehicle speed (15 km/h, 20 km/h, 25 km/h, 30 km/h), maximum waiting time at the stops (250 s, 625 s, 1000 s).

Given these inputs, the method provides six outputs through different formulas:

- number of vehicles circulating on the network;
- total vehicle·kilometres run;
- average commercial speed of the vehicles;
- average occupancy rate of the vehicles;
- average waiting time at the stops;
- investment (start-up) and yearly (operating and maintenance) costs of the system.

The flow diagram of the method, with the interdependencies between the inputs and the outputs, is reported in Figure 4.

The formulas to be used to obtain the first four outputs (number of vehicles, vehicle·kms, average commercial speed, average occupancy rate) are the following:

$$\frac{n}{L} = f(D,L) = a_n \cdot \frac{D}{L} + b_n$$

$$\frac{veh \cdot km}{L} = f(D,L) = a_{veh \cdot km} \cdot \frac{D}{L} + b_{veh \cdot km}$$

$$v = (f(D,L) = a_v \cdot \left(\frac{D}{L}\right)^{b_v}$$

$$pax/km = f(D,n) = a_{pax/km} \cdot \frac{D}{n} + b_{pax/km}$$

$$\frac{n}{L} = f(D,L) = a_n \cdot \frac{D}{L} + b_n$$

$$\frac{veh \cdot km}{L} = f(D,L) = a_{veh \cdot km} \cdot \frac{D}{L} + b_{veh \cdot km}$$

$$v = (f(D,L) = a_v \cdot \left(\frac{D}{L}\right)^{b_v}$$

$$pax/km = f(D,n) = a_{pax/km} \cdot \frac{D}{n} + b_{pax/km}$$

where:

- n is the number of vehicles circulating on the network;
- L is the total length of the network;

- D is the total daily demand;
- veh·km is total vehicle·kilometers run;
- v is the average commercial speed;
- pax/km is the occupancy rate (total passengers per kilometre);
- an , bn , aveh·km , bveh·km , av , bv , apax/km , bpax/km are coefficients varying on the basis of the service levels chosen.

The coefficients of such formulas are reported in the Annex A of this document, varying on the basis of the maximum allowed vehicle speed, the vehicle capacity, and the maximum allowed waiting time at the stops.

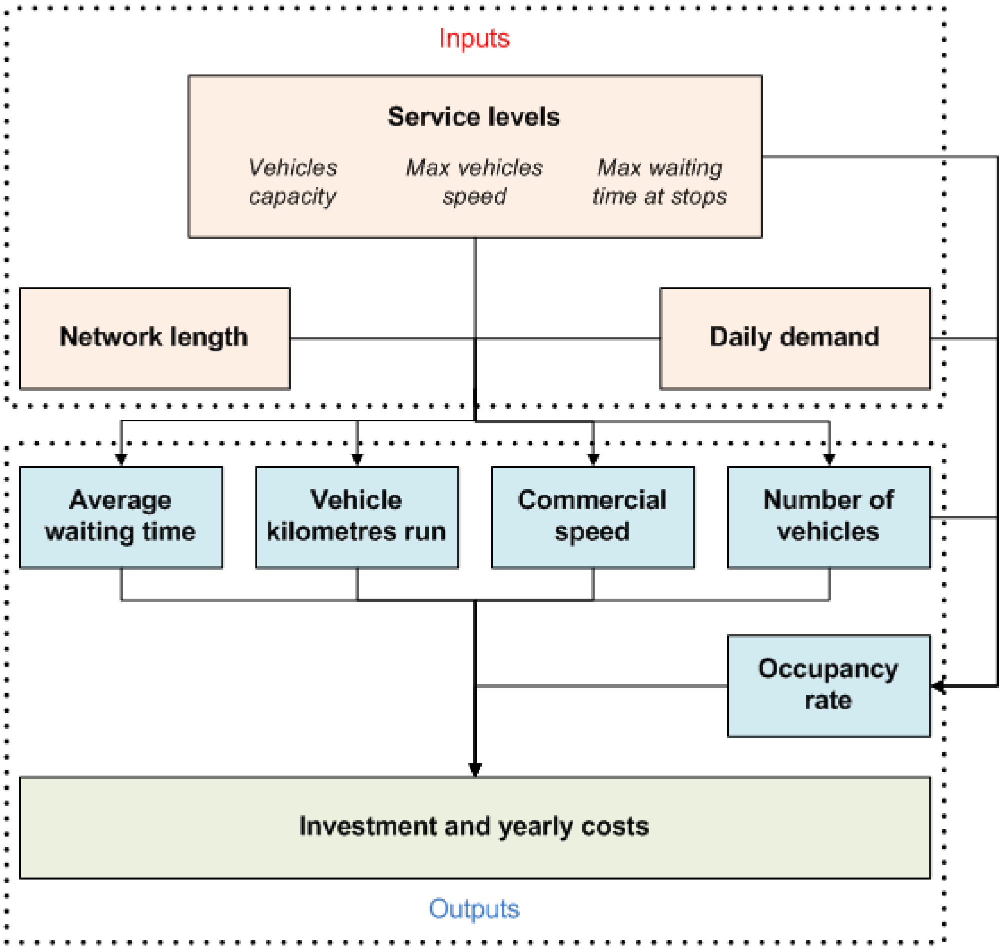

Figure 4 Pre-design method flow diagram

The fifth output, average waiting time at the stops, is provided as ranges minimum-maximum average waiting time, varying on the basis of the service levels chosen. Once the service levels are chosen, the correspondent range of average waiting time can be read in Table 2, Table 3, and Table 4.

Table 2 Average waiting time ranges for 4-place vehicles

4-place vehicles						
	Time windows					
	250 s		625 s		1000 s	
Maximum speed	Minimum Average WT	Maximum Average WT	Minimum Average WT	Maximum Average WT	Minimum Average WT	Maximum Average WT
15 km/h	45s	90s	95s	205s	155s	380s
20 km/h	45s	80s	95s	200s	140s	380s
25 km/h	45s	80s	95s	195s	140s	375s
30 km/h	35s	80s	90s	195s	120s	375s

Table 3 Average waiting time ranges for 10-place vehicles

10-place vehicles						
	Time windows					
	250 s		625 s		1000 s	
Maximum speed	Minimum Average WT	Maximum Average WT	Minimum Average WT	Maximum Average WT	Minimum Average WT	Maximum Average WT
15 km/h	55s	95s	100s	210s	165s	325s
20 km/h	55s	90s	95s	205s	160s	325s
25 km/h	55s	90s	90s	200s	150s	320s
30 km/h	50s	90s	90s	190s	145s	320s

The investment and yearly costs of the system are divided in two parts: infrastructure costs and vehicle costs.

Infrastructure costs are reported in Table 5, and includes start-up (investment) and operating and maintenance (yearly) costs due to stops, control station for the vehicles, personnel, street, and control and wireless communication systems.

Table 4 Average waiting time ranges for 20-place vehicles

20-place vehicles						
	Time windows					
	250 s		625 s		1000 s	
Maximum speed	Minimum Average WT	Maximum Average WT	Minimum Average WT	Maximum Average WT	Minimum Average WT	Maximum Average WT
15 km/h	55s	100s	120s	210s	155s	310s
20 km/h	55s	100s	110s	210s	155s	310s
25 km/h	55s	100s	110s	210s	155s	300s
30 km/h	55s	95s	105s	195s	145s	300s

Table 5 Infrastructure costs

	Start-up	Operating and maintenance
Stops	6 000 €/stop	400–600 €/stop·year
Control station	30 000 € *	6% of start-up/year
Personnel	–	25 000 €/operator·year
Street	60 000 €/km	–
Control and wireless communication systems	52 000 €/km	3 000-5 000 €/km·year

* 30 000 € is the start-up cost corresponding to a number of vehicles between 1 and 20, which requires one operator in the control station. A start-up cost of €10 000 has to be added for each additional operator required (one operator is considered able to control 20 vehicles).

The vehicle costs change according to the vehicle capacity, and include vehicle purchase (start-up and operating and maintenance), vehicle mileage (operating and maintenance), energy consumed by the vehicles (operating and maintenance), and depots and recharging stations (start-up and operating and maintenance). They are reported in Table 6, Table 7, Table 8 for 4-place, 10-place, and 20-place vehicles respectively.

Table 6 4-place vehicle costs

	4-place vehicles	
	Start-up	Operating and maintenance
Vehicles	60 000 €/veh	400 €/veh·year
Vehicle mileage	–	0.15 €/km·year
Vehicle energy	–	0.06 €/kWh·year
Depots and recharging stations	30 000 €/veh	1 700 €/veh·year

Table 7 10-place vehicle costs

	10-place vehicles	
	Start-up	Operating and maintenance
Vehicles	230 000 €/veh	1 200 €/veh·year
Vehicle mileage	–	0.15 €/km·year
Vehicle energy	–	0.06 €/kWh·year
Depots and recharging stations	70 000 €/veh	4 000 €/veh·year

Table 8 20-place vehicle costs

	20-place vehicles	
	Start-up	Operating and maintenance
Vehicles	230 000 €/veh	1 200 €/veh·year
Vehicle mileage	–	0.15 €/km·year
Vehicle energy	–	0.06 €/kWh·year
Depots and recharging stations	80 000 €/veh	4 500 €/veh·year

With the inputs and the first five outputs of the pre-design method it is possible to calculate the investment and yearly costs of the system considered, thus completing the pre-design phase.

3. How to design and implement ARTS

3.1 Ex-ante demand analysis

3.1.1 Stated Preference survey design

Stated preference (SP) surveys represent a technique which is by now well established in transportation demand analysis. Among the extensive literature, a synthetic review of the methodology is in [5], whereas a more comprehensive and focused treatment is in [6] and in [7].

The SP questionnaire used in the CityMobil2 project (for the twelve cities providing a city study for the insertion of an ARTS in their mobility) includes a first part on the stated choices. This considers two transport alternatives as follows:

- minibus: "this is the conventional bus of small size WITH DRIVER, the capacity is about 20 passengers, passengers can sit or stand inside";
- ARTS: "this is a fully automated vehicle WITHOUT DRIVER, the capacity is about 20 passengers, passengers can sit or stand inside".

The attributes and corresponding levels of the SP design are in Table 9.

Table 9 SP design - attribute and levels

Alternative	attribute	number of levels	Levels
minibus/ARTS	waiting time	2	3/8 minutes
	riding time	2	5/10 minutes
	extra-fare	2	as other public transport means/extra-fare of 2 EUR per return journey

In a few cities the level of extra-fare was reduced from 2 EUR to 1 EUR to take into account local conditions.

The number of combinations in the full factorial design (8 combinations) has been reduced to 4 combinations using a within-alternative orthogonal design technique. Therefore, each respondent could express her/his choices between ARTS and minibus in 4 scenarios.

After the SP questions, the questionnaire includes a question on the motivations for choosing ARTS or minibus when the levels of the other attributes (travel time and monetary cost) are the same for the two alternatives. The answer is in free text.

The second part of the SP questionnaire includes questions about socio-economic characteristics of the respondents:

- age
- gender
- income

- education
- occupation
- car availability
- monthly public transport ticket.

The introductory part of the questionnaire is customised for each site because it describes the local characteristics of the layout (area, origins and destinations connected, stops).

3.1.2 Discrete choice model estimation

The SP data collected in the surveys are used to estimate discrete choice models. Discrete choice modelling based on random utility (Random Utility Models, RUM) is an area of growing popularity as many researchers and practitioners seek to find better ways to explain and to forecast the choices made by individuals, households and firms in many application contexts, such as transportation, marketing, environmental science, health services, tourism, employment, education. RUMs lie today at the cornerstone of the transportation demand analysis. It is common practice to represent with RUMs the demand for transport alternatives, typically the mode of transport, but also the route, the destination, the frequency and the time of trip.

The discrete choice models that are estimated are multinomial logit. The following model specifications have been considered:

- basic model, including waiting time, riding time and extra-fare for both the ARTS and the minibus, and ASA (Alternative Specific Attribute) for ARTS;
- basic model with, in addition, one or more variables representing one socio-economic characteristic of the users: gender, age, income, education, occupation, car availability, public transport ticket ownership.

The attributes are included in the utility function of the ARTS and minibus as follows.

For waiting and riding time, variables with cardinal values as in the SP questionnaire are used.

For fare, “effects coding” (-1/1) has been used instead of “dummy coding” (0/1) to eliminate confounding with the Alternative Specific Attribute (ASA):

- the code -1 represents the case where an extra-fare is paid;
- the code +1 represents the case where the same fare as other public transport is paid.

For socio-economic attributes, we make a distinction between two classes.

Class 1: attributes whose levels have ordinal meaning, i.e. whose levels can be ordered: age (integer number), income (category), education (category);

Class 2: attributes whose levels cannot be attributed an ordinal meaning: gender (category), occupation (category), car availability (yes/no), monthly public transport ticket ownership (yes/no).

For the first class, it is assumed that the effect is linear. Therefore, for each attribute, a single variable is created and the following is attributed to each of the different levels:

- the corresponding integer if the variables are integer as in the age case;
- or, if the variables are categorical, the following coding is assigned:
- 1,2,…, as in the case of income and education.

For the second class, for each attribute *L*-1 variables are created where *L* is the number of levels.

The “effects coding” has been used, which has the advantage, with respect to the usual “dummy coding”, of avoiding the confounding with the ASA.

The “effects coding” consists in assigning to each of the levels the codes that are listed in the table below. In short, the difference between the “effects coding” and the “dummy coding” is in that the base level is coded with -1 in the “effects coding”, while it is coded with 0 in the “dummy coding”.

Table 10 and Table 11 show the variables used and the corresponding levels used for specification and estimation.

Table 10 Effects coding

Number of attribute levels		Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variables
2	Level 1	1	-	-	-	-	gender, car availability, public transport monthly ticket
	Level 2	-1	-	-	-	-	
6	Level 1	1	0	0	0	0	occupation
	Level 2	0	1	0	0	0	
	Level 3	0	0	1	0	0	
	Level 4	0	0	0	1	0	
	Level 5	0	0	0	0	1	
	Level 6	-1	-1	-1	-1	-1	

The following model specifications are considered. Common marginal utilities of waiting time, riding time and extra-fare across the two alternatives are used in all specifications.

"1" is the minibus alternative, and "2" the ARTS alternative. The basic model has the following specifications of systematic utilities:

$$V_1 = \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA$$
$$V_2 = \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA + ASA \qquad (1)$$

where *WT* is waiting time, *RT* is riding time, *FA* is the attribute which relates to the payment of the fare for ARTS (as other public transport, or an extra fare), β_1, β_2 and β_3 are the coefficients (marginal utilities), *ASA* is the alternative specific constant of ARTS.

Table 11 Variables and levels used in model specification and estimation

		Levels	Variables	Coding
gender	male	1	GEN	+ 1
	female	2		- 1
household income	less than 10,000 EUR/year	1	INC	1
	between 10,000 and 25,000	2		2
	between 25,000 and 50,000	3		3
	between 50,000 and 75,000	4		4
	more than 75,000	5		5
education	primary school	1	EDU	1
	secondary school	2		2
	university first degree	3		3
	PhD	4		4
occupation	student	1	OCC1, OCC2, OCC3, OCC4, OCC5	see table 2.2
	employee	2		
	self-employed	3		
	retired	4		
	House-wife, house-husband	5		
	unemployed	6		
car available	Yes	1	CAR	1
	No	2		-1
public transport monthly ticket	Yes	1	PTM	1
	No	2		-1

The basic model with gender has the following specifications of systematic utilities:

$$V_1 = \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA$$
$$V_2 = \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA + ASA + \beta_{GEN} \cdot GEN \qquad (2)$$

The basic model with age has the following specifications of systematic utilities:

$$V_1 = \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA$$
$$V_2 = \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA + ASA + \beta_{AGE} \cdot AGE \qquad (3)$$

The basic model with income has the following specifications of systematic utilities:

$$\begin{aligned} V_1 &= \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA \\ V_2 &= \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA + ASA + \beta_{INC} \cdot INC \end{aligned} \tag{4}$$

The basic model with education has the following specifications of systematic utilities:

$$\begin{aligned} V_1 &= \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA \\ V_2 &= \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA + ASA + \beta_{EDU} \cdot EDU \end{aligned} \tag{5}$$

The basic model with occupation has the following specifications of systematic utilities:

$$\begin{aligned} V_1 &= \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA \\ V_2 &= \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA + ASA + \beta_{OCC1} \cdot OCC1 + \beta_{OCC2} \cdot OCC2 + \beta_{OCC3} \cdot OCC3 \\ &\quad + \beta_{OCC4} \cdot OCC4 + \beta_{OCC5} \cdot OCC5 \end{aligned} \tag{6}$$

The basic model with car availability has the following specifications of systematic utilities:

$$\begin{aligned} V_1 &= \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA \\ V_2 &= \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA + ASA + \beta_{CAR} \cdot CAR \end{aligned} \tag{7}$$

The basic model with monthly public transport ticket has the following specifications of systematic utilities:

$$\begin{aligned} V_1 &= \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA \\ V_2 &= \beta_1 \cdot WT + \beta_2 \cdot RT + \beta_3 \cdot FA + ASA + \beta_{PT} \cdot PT \end{aligned} \tag{8}$$

The software NLOGIT by Econometric Software Inc. is used for estimation.

Further details on the SP questionnaires can be found in [2].

3.2 Ex-ante supply dimensioning

3.2.1 Methods to dimension the ARTS

Several methods can be used to dimension an ARTS, according to the network complexity and to the degree of accuracy requested. In this section four different approaches are reported, starting from a line and going to a network: 1) Calculations based on the network features, 2) Use of a Dial-A-Ride-Problem solution algorithm, 3) Use of the DARP simulation tool, 4) Use of a micro-simulation tool.

3.2.1.1 Calculations

The first method is made of calculations on the basis of the network features. It represents the first rough dimensioning step, and has to be mainly considered for those networks that can be summarized as lines and when a frequency service is requested.

The calculations can be based on the division of each line in arcs separated one from another by a node. Constant acceleration driving cycles can be supposed for each link: vehicles accelerate until the maximum speed, keep this speed and then decelerate until a stop. It is assumed that the vehicle stops at any node being it a stop or an intersection.

The main characteristics to be chosen for the system are:

1. Maximum vehicle speed
2. Maximum vehicle acceleration
3. Maximum vehicle deceleration
4. Time spent at each stop
5. Average pedestrian speed

These characteristics directly affect the value of Access Time, Waiting Time, In-Vehicle Travel Time and Delivery Time considered in a possible logit model. Access Time (Delivery Time) can be calculated by considering the distance between the stop and the origin (destination) of the user and dividing it by average pedestrian speed, Waiting Time as half the frequency of a vehicle passage, Travel Time directly from the driving cycle of each link of the line.

The number of vehicles circulating on the line can be calculated starting from the initial O/D matrix. Summing each cell of the matrix total number of daily trips are obtained. Number of hourly trips is the ratio between daily trips and daily hours of service·vehicle places. This value allows to calculate the average time spent in station. The minimum number of vehicles needed to fit the demand is the ratio between time needed to cover the line and time spent in station. The percentage of service time of the vehicles is the ratio between running time and running time plus recharging time.

To obtain the real number of vehicles circulating on the line the following formula is available:

$$NV = (NEV / RT) \cdot 100$$

in which:

NEV = minimum number of vehicles needed to fit the given demand;

RT = percentage of service time of the vehicles.

To avoid problems due to a high request of vehicles during the day, this value has been recalculated in the peak hour (between 4 and 5 p.m.).

The capacity and energy system of the vehicles have to be chosen a-priori.

This procedure represents a possible calculation method allowing to have the requested dimensioning. Other methods can be used, starting from an initial demand and considering the main features of the network studied.

3.2.1.2 Dial-A-Ride-Problem solution algorithm

For networks that cannot be classified as a line, an algorithm for the Dial-A-Ride-Problem solution can represent one of the most reasonable solutions.

Dial-A-Ride is a kind of mass transport, mainly recommended for areas with low and/or sprawled transport demand and where the users have particular requests, such as those for example impaired mobility users.

The Dial-A-Ride aim is to offer a taxi-like service (in terms of quality of the service provided) with lower costs. The success factors of such a service can be summarized in an efficient vehicle use and in a high quality of the service provided.

The consequent problem to be solved in order to provide a service with these features is named Dial-A-Ride-Problem (DARP). Different Dial-A-Ride systems have been suggested [8]-[16]:

- Many-to-many, many-to-one, one-to-many:
    - Many to many: users have different origins and different destinations of their trips
    - Many to one: users have different origins and the same destination of their trips
    - One to many: users have the same origin and different destinations of their trips
- Immediate-request, advance-request:
    - Immediate-request: users call an operation centre to be served as soon as possible
    - Advance-request: users are requested to call the operation centre to reserve their trips not later than an established hour (before the foreseen trip hour)

According to the kind of service requested for the network to be provided by an ARTS, several solutions can be found starting from the above definitions, in accordance with defined DARP solution algorithms.

Some of them refer to an advance-request service with one vehicle providing it [9], [10],[17]-[19], other refer to called "multy-vehilce DARP" [20]-[22], where a fleet of vehicles serves the users, with the aims of minimizing the travel time on-board the vehicles and the total travel costs.

3.2.1.3 DARP simulation tool

Starting from the DARP algorithms reported in section 3.2.1.2, the CTL developed a DARP simulation tool, a software based on different possible Dial-A-Ride systems (many-to-many, many-to-one, one-to-many, immediate-request, advance-request) to simulate the supply of a network where a demand has to be served.

The tool is based on Advanced Dial-A-Ride algorithm with Time Windows, respecting two conditions: 1) the time the user is on-board the vehicle is less than a fixed maximum time, 2) the difference between the hour of pick-up and/or delivery of the user and the desired hour is less than a fixed value.

The input data are:

- Transport network:
  - Nodes (latitude, longitude)
  - Arcs (length, travel time, vehicle energy requested)
  - Vehicle recharging stations (number and position)
- Vehicles:
  - Maximum number of available vehicles
  - Vehicle capacity
  - Vehicle energy capacity
- List of the user requested trips

The output data provided by the DARP simulator are:

- Requested trips served
- Number of vehicles used for the service
- Working time of each vehicle
- Vehicle mileage
- Passenger·km travelled
- Average travel time
- Deviation from the average travel time
- Vehicle occupancy

In such way it is possible to dimension the vehicle fleet required to serve the demand, and the "history" of each vehicle in terms of: service hours, users served, vehicle routes, kilometres travelled, passenger·km travelled, energy spent for each travel, number of recharges, number of stops during the service.

A screenshot of the DARP simulator is reported in Figure 5. The yellow circles with a number inside are the nodes of the network, representing the stops of the system. All the other circles represent the vehicles circulating on the network. Such circles have different areas due to the number of users inside them: the more the area the more the number of users inside. The numbers highlighted in green are the requests (users) being processed; those with a "+" symbol mean they are users boarding the vehicle, whereas users alighting a vehicle are represented with a "-" symbol before the number.

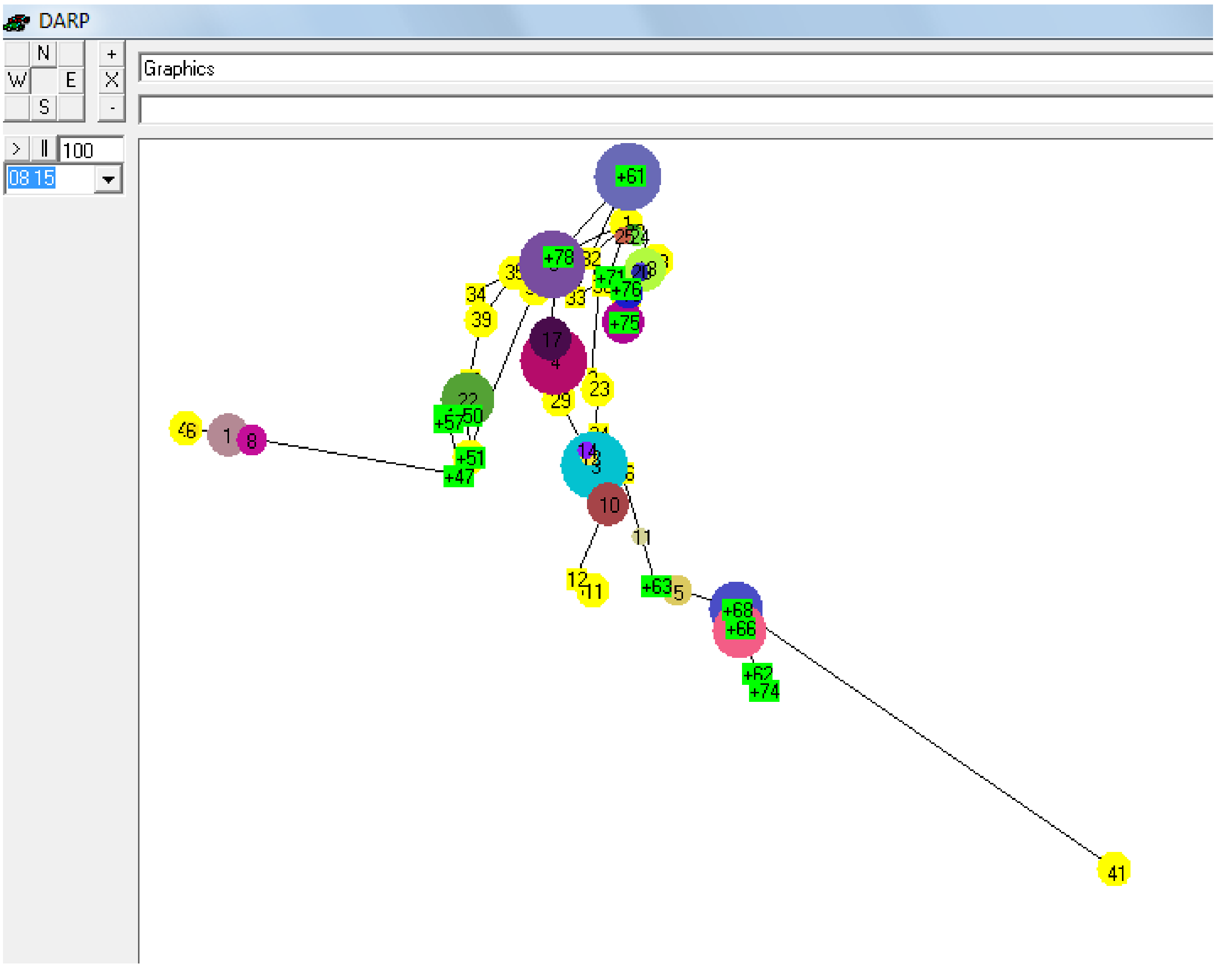

Figure 5 DARP simulation tool screenshot

3.2.1.4 Micro-simulation tool

Another tool to dimension an ARTS is the micro-simulation.

Several micro-simulation tools have been developed and can be used according to the system to be dimensioned.

As example of modelling system the one called MARS (Metropolitan Activity Relocation Simulator) was used in the CityMobil project [29]. It is a strategic land use – transport interaction model capable of analysing policy combinations at the metropolitan level and assessing their impacts over a 30 year planning period in less than one minute. It is aimed at professional transport planners at all levels of responsibility, but also at decision-makers and interest groups. The easy to use model (flight simulator) enables the planner to look at the impacts of strategic policy combinations interactively with decision makers. The outputs are generated automatically making discussion over the changes to policy simple, concise and immediate. [30]

Another example, even if mainly referred to the PRT, is the PRTsim tool, an advanced micro-simulation model especially designed to handle PRT networks and the demand and supply. The first input is a PRT network designed with tracks, stations and merge/diverge point. Another type of input is a demand station-to-station matrix. The model simulates the route choice within the PRT network, the distribution of waiting and in-vehicle travel times, as well as the needed vehicle fleet, in order to fulfil goals of average or maximum waiting times. It also keeps track of vehicle movements and delays, and vehicle queuing at stations, and has algorithms for empty vehicle management. The model has been developed by Professor Ingmar Andréasson at Logistik-Centrum, Sweden [31].

Such tools can be adapted to the ARTS requests, and other examples can be found with a deeper literature review.

3.2.2 Urban integration of the automated transport systems

Part of the work developed in the CityMobil2 Work Package 15, in particular in Deliverable 15.1, consisted in analyzing, ex-ante, the urban integration measures to be implemented in the demonstrations that would be carried out in the framework of the project. This analysis served to create guidelines for the city studies carried out by the CityMobil2 candidate cities. This section builds up on this work, plus the experience gained during the actual execution of the CityMobil2 A.R.T.S. demonstrations.

A proper A.R.T.S. urban integration considers not only vehicles, but also their environment, with the aim of making their integration as safe as possible, both for the A.R.T.S' users and for other road users present in the surrounding environment. These elements can be static or dynamic, and the sum of their potential interactions shall be considered in both states. A final element, which encompasses the whole A.R.T.S integration, is the regulatory layer, that is, the road traffic rules set in place to regulate the interactions and circulation of A.R.T.S.' vehicles and their interaction with other road users.

The physical, static elements that must be considered for a proper A.R.T.S urban integration are the following [24], [25]:

- The frame layer, which represents the shape of the infrastructure (segment, crossing, roundabout);
- The infrastructure's geometry and variables
- The physical elements surrounding the road infrastructure

From a dynamic point of view, the elements that must be considered concern both the A.R.T.S. vehicles and the surrounding road users. Regarding the A.R.T.S. vehicles dynamics, the CityMobil2 project has classified the movements of an automated vehicle in travel stages, equivalent of the phases of a flight of an aircraft (planning, pushback, taxi, take-off…) [23]. With respect to the surrounding road users, it is necessary to identify the type of road users present, not only in the road infrastructure, but also on the surrounding areas (sidewalks, parks, houses…). This leads to consider not only vehicles (motorbikes, bicycles, cars…) but also pedestrians. As a basic principle, the higher it is the expected speed of the vehicles or that of the other road users (motor vehicles), the greater the risk of an accident or of its consequences. In order to minimize these risks, it is necessary, in some cases, to provide a greater level of physical differentiation and protection in the infrastructure.

CityMobil2 identified three levels of infrastructure differentiation [25]: segregated, dedicated and shared. Since most of the CityMobil2 demonstrations would be carried out in urban areas, the use of segregated or dedicated infrastructures was recommended to the CityMobil2 cities and implemented as such in the demonstrations. Of course, there is a trade-off to be made between safety and transport performance, as a greater level of safety implies lower A.R.T.S. vehicles' speeds. However, most cities decided to privilege dedicated infrastructures. The recommendation in this case was to highlight these infrastructure so that the fact of them being dedicated to the A.R.T.S.' vehicles was clear for all the other road users. Not all the cities implemented this, mainly because of the costs, but also for technical reasons, but after carrying out the demonstrations, it was clear that this was a key element.

The urban integration of the La Rochelle demonstration was an excellent example of execution of these guidelines [26]. Figure 6 shows the way in which the ARTS lane was marked to indicate to other road users about the extraordinary character of the vehicles that circulated in this infrastructure.

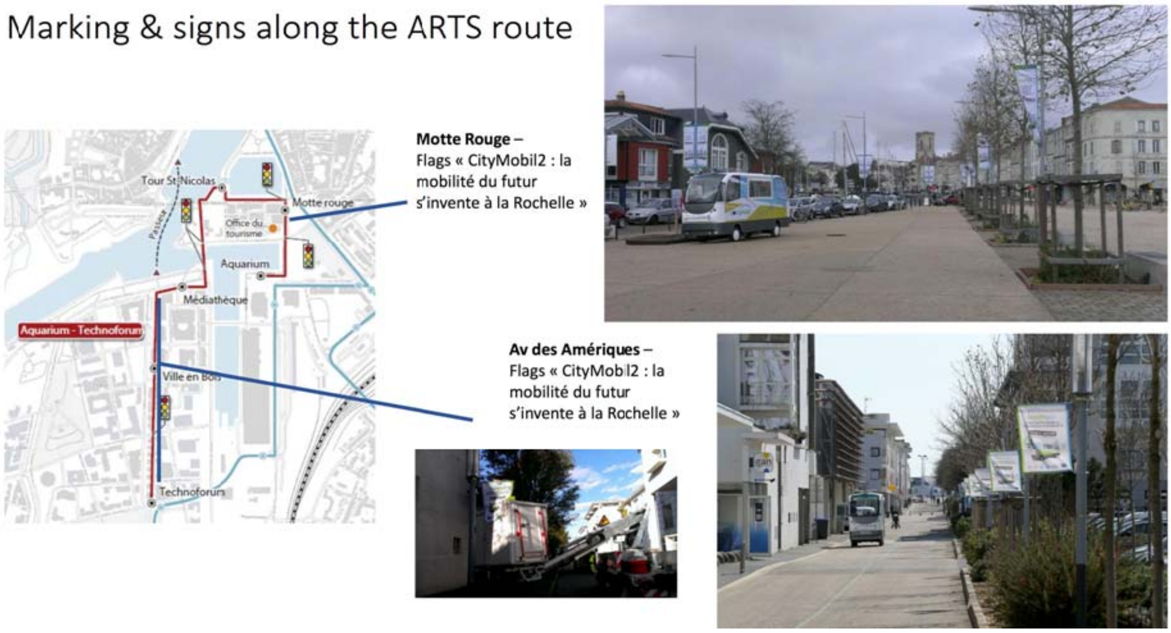

Figure 6 Examples of road markings signalling the dedicated ARTS lane

Marking : Green line along the ARTS route

Figure 7 Road marking on regular roads

Green line : green spot
(on pedestrian areas)

Figure 8 Road markings on pedestrian areas

Figure 7 shows the road markings on regular roads used for the ARTS (in the example of the La Rochelle demonstration).

In Figure 8 the road markings on pedestrian areas are showed, made with green spots.

Trikala also implemented a dedicated lane, signalized using cat eyes as road markings and a specific signage (CityMobil2 only) to indicate the fact that the lane was dedicated [27] , as reported in Figure 9.

Figure 9 Dedicated lane road marking in Trikala

Another important condition for the safe operation of A.R.T.S. is the safeguard of crossings. Since crossings represent a high-risk area due to the presence of motor vehicles, La Rochelle secured all the crossings with roads holding motor vehicle traffic with traffic lights [26].

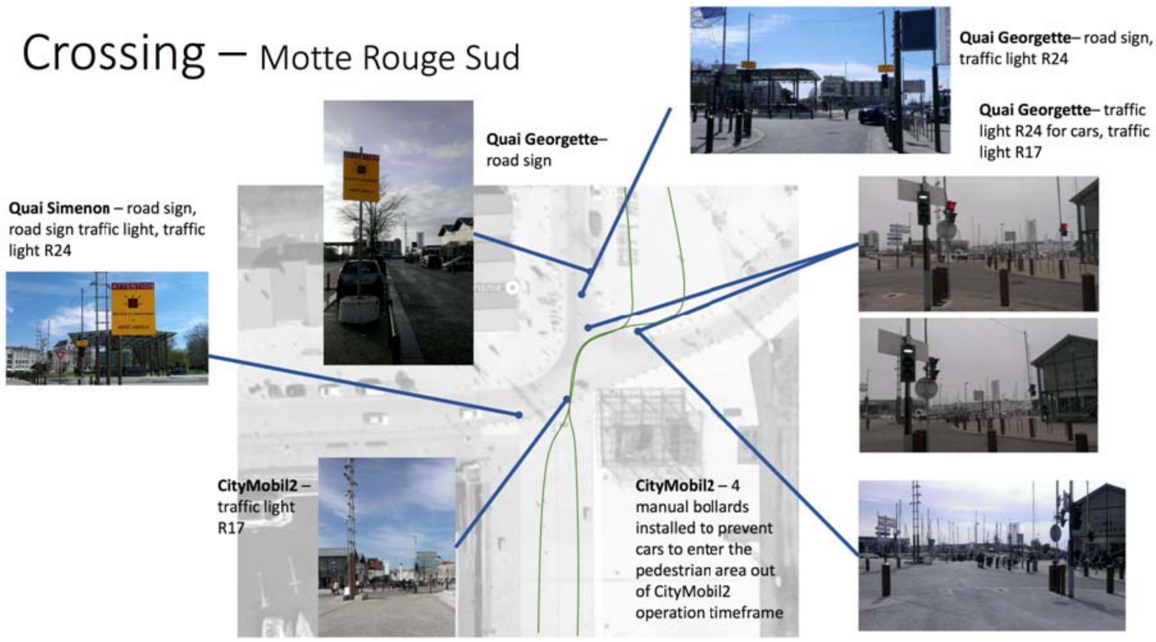

Figure 10 Crossing protection in La Rochelle

The traffic lights communicated with the vehicles via RF to indicate their status and the timing was designed to allow all motor vehicles to clear the crossing area before the A.R.T.S. vehicle was authorized to cross. A similar system was implemented in Trikala.

Figure 10 reports the example of crossing protection of the La Rochelle demonstration.

3.2.3 The final dimensioning of the automated road transport systems

As final result of the ARTS dimensioning, the commercial speed of the system has to be investigated, in order to evaluate the capability of serving the users with a high quality service: the higher is the commercial speed, the better is the service provided. Consequently ARTS could become competitive with conventional transport means - both public or private - increasing the commercial speed, by adopting ad hoc measures to do it.

The business case generated by the Oristano demonstration can be considered as an example of how improving the commercial speed ARTS become highly competitive.

The commercial speed measured during the two months of demo is 6.5 km/h. The occupancy rate was 35% of the vehicle capacity (10-place), with the ARTS operating 5 days a week for 8 hours per day. The consequent yearly estimated mileage is 13 500 km. Considering 100 000€ as investment cost for an ARTS vehicle, 10 years as vehicle duration, 6% of the investment cost as yearly vehicle maintenance cost, 500€/year as vehicle insurance cost, and 0.06 €/km as electric energy consumption cost, the resulting cost per passenger·km is 0.37 €/pax·km.

Such cost is no longer competitive with private cars, whose cost is in the range between 0.28 and 0.34 €/pax·km (considering a 5-place car very used and often changed for the lower cost and a 4-place car little used and little changed for the higher cost), without even considering ARTS management costs and company profit.

In case the ARTS commercial speed is improved to 14.5 km/h, the yearly mileage would go up to 30 000 km/year and the consequent cost per passenger·km would decrease to 0.17 €/pax·km, beating private cars even with a 60% overhead to manage ARTS.

This business case shows how the ARTS implementation is strictly linked with the site where to operate and with the infrastructure regulations and adaptations, in order to allow the ARTS quality of service improvement and the process to push people out of their private cars.

3.3 Recommendations for service operations

Just like the urban integration, the service operation must guarantee the safety of the A.R.T.S. operators, passengers and other road users. In order to guarantee safe operation, two conditions are necessary: adequate training of the operators on the system operation, and an adequate maintenance. For both tasks, the involvement of the A.R.T.S manufacturer is essential, and this should be formalized in binding contract(s), in particular on what attains to the secondary maintenance once the system is operating.

Service operations also concern the physical and digital infrastructures, and therefore include road-side sensors, communication networks, management centres, etc. A city should designate a project master that can in turn provide all these systems or subcontract them to specialized providers. However, the designated project master should be responsible before the city on the system operation and on its performance results.

3.4 Ex-ante cost analysis

The cost analysis of the ex-ante phase has to be based on two different cash flows, one concerning the financial viability of the ARTS and the other concerning the social viability of the ARTS.

The financial analysis cash flow is made of:

- Investment costs:
  - Track construction and civil works
  - Vehicle acquistion/construction
  - Control system and apparatus
- Operating and maintenance costs:
  - Personnel costs
  - Vehicle maintenance
  - Track and civil infrastructure

  - Control system

- Operating revenues

The socio-economic analysis cash flow is made of the same parts of the financial cash flow plus the following:

- Benefits on the users
- Benefits on the community:
  - Safety (accident reduction)
  - Environment (noxious emission reduction)
  - Better use of resources

The tool to measure the financial and socio-economic viability is the Cost-Benefit Analysis (CBA), which final result is the Net Present Value (NPV), financial NPV for the first analysis and social NPV for the second.

As reported in sections 1.4.3 and 1.4.4 the ARTS financial NPVs are often negative, confirming that the public transport services are not profitable in Europe. However ARTS, in order to become financially neutral, can be helped by ad hoc mobility policies pushing people to use them, without being subsidised as most of the public transport services.

Furthermore ARTS together with the ad hoc mobility policies to use them can guarantee benefits for the community in terms of noxious emission reduction, and incident reduction, thus contributing to the environmental and the safety improvement, and the socio-economic impact of such systems could reach in ten years a magnitude of more than ten times the initial investment.

3.5 Monitoring of the designed automated road transport system

Once designed the ARTS, the operations will be monitored in order to collect the data for the ex-post evaluation of the system operations.

Before the starting of the operations, a detailed workplan will have to be prepared, including those indicators to be used for the ex-post evaluation. Such indicators report different ARTS features, as the people acceptance, the perceived quality of the service provided, the transport patterns of the system (performances, use, impacts on the mobility), the environment impacts, the technological success, the social impacts, the economic impacts, and the financial impacts.

A suggested list of such indicators is reported in [28]. The acceptance and quality of service can be collected via questionnaires to the users, the technological success with data logs from the vehicles, the transport patterns with the same data logs together with the performances of the system, the environmental impacts with calculations deriving from the previous collected data, the social, economic and financial impacts by measuring the costs spent for the system, considering the cash flows reported in section 3.4.

3.6 Feedback of the designed ARTS in the Passenger Application Matrix

At the end of the design process, the designed ARTS will be included as feedbacks in the PAM reported in section 2.1 in Table 1. The present PAM situation, in terms of cells filled with data and empty cells to be filled, is represented by the following Figure 11.

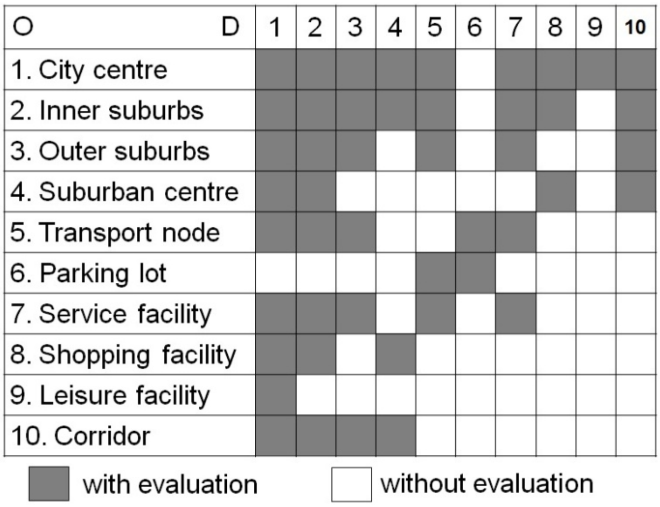

Figure 11 PAM scheme with full and empty cells

The aim is to fill all the cells of the PAM with innovative automated transport systems, and ARTS can provide a large contribution with their development and deployment.

ARTS wide range of application could allow to fill the white cells in Figure 11, in order to reach a complete PAM, representing the tool for the decision-makers to select which transport system would be the best in accordance with the city environment, the user requests, and mobility policies to be adopted.

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Annex A Coefficients of the CTL pre-design method

Table 12 Pre-design coefficients for number of vehicles and vehicle·kilometers run

Max allowed speed (km/h)	Veh capacity (places)	Max waiting time (s)	a_n	b_n	$a_{veh\ km}$ km
15	4	250	$2.7 \cdot 10^{-3}$	1.644	$2.8 \cdot 10^{-1}$
15	4	625	$2.5 \cdot 10^{-3}$	1.040	$2.6 \cdot 10^{-1}$
15	4	1000	$2.2 \cdot 10^{-3}$	0.957	$2.5 \cdot 10^{-1}$
20	4	250	$2.4 \cdot 10^{-3}$	1.187	$2.8 \cdot 10^{-1}$
20	4	625	$2.2 \cdot 10^{-3}$	0.814	$2.7 \cdot 10^{-1}$
20	4	1000	$2.2 \cdot 10^{-3}$	0.557	$2.6 \cdot 10^{-1}$
25	4	250	$2.4 \cdot 10^{-3}$	1.083	$2.9 \cdot 10^{-1}$
25	4	625	$2.3 \cdot 10^{-3}$	0.641	$2.8 \cdot 10^{-1}$
25	4	1000	$1.9 \cdot 10^{-3}$	0.616	$2.6 \cdot 10^{-1}$
30	4	250	$2.3 \cdot 10^{-3}$	1.345	$3.1 \cdot 10^{-1}$
30	4	625	$2.1 \cdot 10^{-3}$	0.855	$2.9 \cdot 10^{-1}$
30	4	1000	$2.0 \cdot 10^{-3}$	0.620	$2.8 \cdot 10^{-1}$
15	10	250	$1.1 \cdot 10^{-3}$	1.732	$1.6 \cdot 10^{-1}$
15	10	625	$1.2 \cdot 10^{-3}$	0.647	$1.6 \cdot 10^{-1}$
15	10	1000	$1.2 \cdot 10^{-3}$	0.466	$1.6 \cdot 10^{-1}$
20	10	250	$1.0 \cdot 10^{-3}$	1.417	$1.7 \cdot 10^{-1}$
20	10	625	$1.2 \cdot 10^{-3}$	0.488	$1.7 \cdot 10^{-1}$
20	10	1000	$1.1 \cdot 10^{-3}$	0.350	$1.6 \cdot 10^{-1}$
25	10	250	$1.1 \cdot 10^{-3}$	1.080	$1.8 \cdot 10^{-1}$
25	10	625	$1.1 \cdot 10^{-3}$	0.563	$1.8 \cdot 10^{-1}$
25	10	1000	$1.0 \cdot 10^{-3}$	0.517	$1.6 \cdot 10^{-1}$
30	10	250	$1.4 \cdot 10^{-3}$	0.996	$2.1 \cdot 10^{-1}$

30	10	625	$1.3\cdot10^{-3}$	0.534	$1.9\cdot10^{-1}$	71.4
30	10	1000	$1.0\cdot10^{-3}$	0.525	$1.7\cdot10^{-1}$	63.1
15	20	250	$0.7\cdot10^{-3}$	2.021	$1.2\cdot10^{-1}$	165.2
15	20	625	$0.9\cdot10^{-3}$	0.662	$1.1\cdot10^{-1}$	78.9
15	20	1000	$0.9\cdot10^{-3}$	0.453	$1.1\cdot10^{-1}$	52.6
20	20	250	$0.8\cdot10^{-3}$	1.476	$1.3\cdot10^{-1}$	158.9
20	20	625	$0.9\cdot10^{-3}$	0.562	$1.2\cdot10^{-1}$	82.0
20	20	1000	$0.9\cdot10^{-3}$	0.311	$1.2\cdot10^{-1}$	50.2
25	20	250	$1.2\cdot10^{-3}$	1.135	$1.6\cdot10^{-1}$	141.6
25	20	625	$1.0\cdot10^{-3}$	0.680	$1.3\cdot10^{-1}$	81.8
25	20	1000	$0.9\cdot10^{-3}$	0.503	$1.2\cdot10^{-1}$	68.1
30	20	250	$0.8\cdot10^{-3}$	1.378	$1.5\cdot10^{-1}$	160.2
30	20	625	$0.7\cdot10^{-3}$	0.733	$1.2\cdot10^{-1}$	95.7
30	20	1000	$0.7\cdot10^{-3}$	0.422	$1.2\cdot10^{-1}$	64.3

Table 13 Pre-design coefficients for commercial speed and occupancy rate

Max allowed speed (km/h)	Veh capacity (places)	Max waiting time (s)	a_v	b_v	$a_{pax/km}$	$b_{pax/km}$
15	4	250	12.682	-0.0173	$9.26\cdot10^{-2}$	
15	4	625	12.148	-0.0128	$6.82\cdot10^{-2}$	
15	4	1000	12.023	-0.0120	$7.05\cdot10^{-2}$	
20	4	250	15.079	-0.0205	$7.55\cdot10^{-2}$	
20	4	625	14.574	-0.0172	$6.61\cdot10^{-2}$	
20	4	1000	14.356	-0.0158	$4.80\cdot10^{-2}$	
25	4	250	17.497	-0.0223	$7.35\cdot10^{-2}$	

25	4	625	16.727	-0.0177	$6.87 \cdot 10^{-2}$	19.74
25	4	1000	16.544	-0.0170	$6.37 \cdot 10^{-2}$	22.19
30	4	250	18.418	-0.0217	$7.07 \cdot 10^{-2}$	14.31
30	4	625	18.155	-0.0211	$6.52 \cdot 10^{-2}$	18.05
30	4	1000	17.950	-0.0203	$6.73 \cdot 10^{-2}$	18.95
15	10	250	15.783	-0.0557	$3.89 \cdot 10^{-2}$	4.76
15	10	625	14.189	-0.0460	$3.94 \cdot 10^{-2}$	5.88
15	10	1000	13.154	-0.0376	$3.40 \cdot 10^{-2}$	11.30
20	10	250	19.000	-0.0611	$3.36 \cdot 10^{-2}$	4.58
20	10	625	16.840	-0.0500	$3.55 \cdot 10^{-2}$	5.26
20	10	1000	15.506	-0.0410	$2.89 \cdot 10^{-2}$	11.87
25	10	250	22.020	-0.0641	$2.94 \cdot 10^{-2}$	5.37
25	10	625	19.323	-0.0518	$2.21 \cdot 10^{-2}$	12.79
25	10	1000	19.158	-0.0536	$2.15 \cdot 10^{-2}$	17.47
30	10	250	22.830	-0.0610	$3.25 \cdot 10^{-2}$	5.13
30	10	625	21.671	-0.0599	$3.44 \cdot 10^{-2}$	7.38
30	10	1000	21.645	-0.0629	$3.13 \cdot 10^{-2}$	9.25
15	20	250	18.968	-0.0855	$2.17 \cdot 10^{-2}$	2.03
15	20	625	18.069	-0.0895	$2.40 \cdot 10^{-2}$	2.25
15	20	1000	16.476	-0.0813	$2.30 \cdot 10^{-2}$	4.50
20	20	250	23.348	-0.0952	$2.08 \cdot 10^{-2}$	1.22
20	20	625	22.219	-0.0987	$2.22 \cdot 10^{-2}$	1.11
20	20	1000	20.072	-0.0904	$2.36 \cdot 10^{-2}$	1.16
25	20	250	25.741	-0.0903	$2.14 \cdot 10^{-2}$	1.63
25	20	625	26.486	-0.1066	$1.87 \cdot 10^{-2}$	4.63
25	20	1000	26.931	-0.1159	$1.90 \cdot 10^{-2}$	6.03
30	20	250	28.160	-0.0948	$1.80 \cdot 10^{-2}$	1.80

30	20	625	30.185	-0.1169	$1.72 \cdot 10^{-2}$	3.18
30	20	1000	29.347	-0.1199	$2.03 \cdot 10^{-2}$	1.90