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## 1. Executive summary:

The CATS (City Alternative Transport System) project initial objective was the final development and experimentation of a new urban transport service based on a new generation vehicle. Its major innovation is the utilization of a single type of vehicle for two different usages: individual use – based on a self-service mode – or collective transport – offered through flexible shuttle services. This new transport service is aimed at filling the gap between public mass transport and private individual vehicles.

The project has investigated through an in depth mobility needs analysis, on-site demonstration and showcases, the impact of the introduction of such a new system in three European cities (Strasbourg FR, Ploiesti RO and Formello IT). The impact on environment as well as the acceptance and the evaluation of market take-up of the system have been studied.

The CATS project was originally built around the CRISTAL system. Four vehicles and two stations were planned to be made available by Lohr Industrie to the project for experiments. However, following their withdrawal of the project regarding the manufacture of the vehicles, a new partner had to be found. Induct Technology and its innovative transport system called NAVIA was chosen due to its similitudes with the Cristal system in terms of capacity and operation principles.

The project began with the analysis and assessment of three European cities. Three city studies were carried out to determine which territory was the most suitable for testing of innovative vehicles. A zone has been defined within each of the three cities for the successful implementation of the Cristal system. The city of Strasbourg, France, was finally chosen to host a demonstration.

The second phase of the project was to organize a six-month demonstration. Following technical tests in Strasbourg during three months, the demonstration has been moved to a more protected environment to be opened to users. Three Navia vehicles have transported about 1'600 people during three weeks despite a really bad weather on EPFL campus in Lausanne, Switzerland.

The last phase of the project consisted of the evaluation of the demonstration during which data was collected to assess the performance of the system and the acceptance of innovative technologies by users. The impacts concerned were those regarding mobility, acceptance, environment, transport patterns accessibility, and attitudes towards innovative transport systems.

As regards the dissemination, a showcase was organized in Ploiesti, Romania, to improve citizen awareness on innovative transport systems.

CATS has started in January 2010, for 60 months, and gathered eleven partners in 5 different countries in Europe and Israël divided among transportation systems manufacturers, research institutes, services providers and end users.

## 2. Description of the project context and the main objectives

The FP7 reference call number SST.2008.3.1.1 “New mobility concepts for passengers ensuring accessibility for all”, addressed by CATS, focuses on the “next generation vehicle” and its market take up, bringing together all elements of a clean, energy efficient, safe and intelligent road transport system.

Cities are the engine of economic and social development. They are also the places where the social challenges of the 21<sup>st</sup> century will be the most pronounced. Parts of these challenges are the growing traffic and accessibility. 80% of European citizens now live in cities where urban transport is responsible for around 40% of total road transport CO<sup>2</sup> emissions.

The cities, facing the impacts of their development – energy supply dependence, pollution, congestion, damages on human health and environment – have to organize differently their mobility. Changes in urban demographics and in automotive technology, design and connectivity have significant implications on urban mobility.

The object of the directive on clean vehicles of the Green Paper on Energy Efficiency, adopted by the European Commission in June 2005, is to accelerate the introduction of clean transport vehicles into the market. The idea is to protect the environment by reducing energy consumption, CO<sub>2</sub> and pollutants emissions by supporting alternative solutions to the use of car.

In parallel, the European Green book “Towards a new urban mobility culture” set the scene for what is necessary, in terms of urban mobility, by means of environmental-friendly and technologically innovative transport modes.

The CATS project is in line with the will to change the way people move in cities. It is built around two clean innovative transport systems (Cristal and Navia) which are anticipating on the implementation of the regulatory measures and political orientations foreseen in the above mentioned documents.

The final aim of these new services is a more efficient mobility in cities through a more balanced use of small clean vehicles and mass transport. These inclusive new transport systems are well adapted to the needs of people with reduced mobility, young passengers and tourists. They are aimed to provide a solution to the last mile, which is the distance between the bus station and the final destination of users. This distance, if not covered, weakens the entire chain of public transport. Shuttles are thus not only new means of transport but a complement to mass public transport.

In addition, systems such as Cristal or Navia fit into the recent trend of sharing goods. The younger generation is no longer eager to own a private vehicle like the old one was. She wants to be able to go where she wants when she wants, regardless of the transport means; as long as the cost appears reasonable.



Figure 1. Navya and Cristal vehicles

CATS main objective was to develop a strategy to test and introduce clean and innovative urban transport systems in cities. The CATS project dealt with:

- innovative transport systems increasing other public transport modes' use by feeding them ;
- a new dimensioning and integration methodology (VOLTair) ;
- electric vehicles, silent and zero emissions well adapted to urban environment and fully accessible ;
- stations design and building integrating all aspects of intermodality (infrastructure, localization, comfort, effectiveness, communication ...) ;
- adaptability of the transport offer to all type of passengers (elderly, disabled, children, tourists needing travel guidance ...).

In the last years, the European Commission has funded several research projects on automated vehicles and transport systems. Alongside with passenger mobility, several projects have been funded to identify solutions for freight distribution in cities. Although it is not CATS aim to investigate such concepts, combining CATS vehicles with some of these technologies and concepts might “sustainabilise” the entire urban mobility system.

### 3. Description of the main S & T results/foregrounds

#### 3.1. WP1 - Mobility Needs Analysis:

The objective of WP1 was to launch a detailed analysis of potential users mobility needs providing a comprehensive basis to the implementation of Cristal system. Specifically, the city studies aimed to identify the possibilities and opportunities to implement the innovative Cristal transport system in the target cities: Strasbourg, Ploiesti and Formello.

##### *3.1.1. User needs analysis*

The aim of WP1 was to determine the best implementation of the Cristal system in the three cities of Strasbourg, Ploiesti and Formello and to evaluate the impacts of this new offer on the behavior of the potential users. The objectives have been achieved through the definition of relevant implementations and the household surveys carried out in the three targeted sectors of the Strasbourg agglomeration.

The city studies for Strasbourg and Ploiesti were carried out using the VOLTair methodology, based on general “top-down” process which combines functional, societal and environmental approaches in order to diagnose the city’s current mobility system with its needs, aims and constraints. This allowed addressing a multimodal concept that can be implemented and dimensioned at a local scale, using the appropriate transportation tools.

In the case of Strasbourg, the bottom-up approach completed the preliminary study of the city, while the top-down approach was refined with the results of the household survey lead by EPFL. Hence, the proposed network for Cristal system was re-defined by integrating the potential users’ requirements and expectations.

Ploiesti’s city study was completed as planned, via the top-down approach using the VOLTair methodology and the bottom-up approach involving the local stakeholders. An overall urban diagnosis enabled the identification of potential locations where Cristal system could be implemented. A network of stations and shuttle lines for selected potential sites was proposed and accepted by the local authorities. A set of recommendations for stations’ integration and the illustrative model example completed the city study.

As for Formello, it was not possible to apply the VOLTair methodology systematically. The city’s territorial characteristics, its territory occupancy and the potential users’ travel patterns lead to the conclusion that Formello does not reach the requirements for the implementation of Cristal system. The city study, completed with an adapted methodology, proposed to local authorities several scenarios addressing the potential complementarity between the regional rail network and the Cristal system, instead of a multimodal local concept.

On both Ploiesti and Formello analysis, the lack of available quantitative data on current transport supply and demand conditioned the system's dimensioning approach, which was pursued through an empiric dimensioning method based on the transport supply.

### *3.1.2. Ex-ante evaluation*

Following the completion of the three territorial studies, CTL has made an ex-ante evaluation of the selected sites. The objective was to set up evaluation criteria and measurement indicators within the different scenarios of use, using MAESTRO methodology. The ex-ante evaluation has provided the first evaluation of the potential implementation of the Cristal system in the three cities. A comparison between the cities has been performed and the first transferability findings have been found out.

Both Strasbourg and Ploiesti showed potentialities for a successful development of the Cristal system, although with some differences. On the contrary Formello was not an ideal candidate for the implementation neither of the system nor of any traditional public transport system due to its territorial and transport characteristics.

Regarding the comparison between the cities the acceptance indicators are usually the same: mean waiting times of about 7-8 minutes, network vehicle speed of 15 km/h (shuttle mode), max distance to the nearest stop of 150-250 meters and an average time to the nearest stop of about 4 minutes by foot. Main differences are due primarily to the different public transport and private car modal shares: respectively 7.5% and 55% for Strasbourg and respectively 40% and 23% for Ploiesti. For this reason a more self-service oriented service has been foreseen for Strasbourg and a more shuttle oriented service has been foreseen for Ploiesti even though in this last case the system is more balanced between the self-service and the shuttle modes than that of Strasbourg.

Costs indicators are quite different among the three cities. Average investment costs are about 20 M€ for Strasbourg, about 10 M€ for Ploiesti and about 4 M€ for each of the three Formello scenarios. Regarding maintenance cost, the more the shuttle mode oriented system the more the maintenance costs, so Ploiesti (1.2 M€) and Formello scenario 3 (1.4 M€) have the higher annual maintenance costs. This major cost is due to the fact that shuttle mode requires more staff to operate rather than self-service mode.

About transferability findings show how small and not so densely populated cities imply little costs rather than bigger and densely populated cities. This fact is due to the less number of stations needed, less vehicles and in general a lower system complexity that allows to keep costs down, in particular the cost per kilometer. Furthermore findings show how small densely populated and low populated cities require longer trips to reach amenities or in general any kind of transport attractive pole. It results in higher fares for passenger per trip in order to fully cover the entire travel cost. On the contrary, high densely populated cities result in deeper meshed urban structures allowing keeping closer to each other any kind of attractive pole so that trips are shorter and as a consequence fares per trip are lower.

As a result, the more the public transport modal share the more the shuttle mode can be successfully developed in order to join the Cristal system to the traditional public transport.



In a complementary manner the more the private car modal share the more the self-service mode can be successfully developed resulting an optimal way to meet the low citizens attitude toward public transport.

### *3.1.3. Site selection*

On the basis of the territorial studies and ex-ante evaluation, a zone has been defined within each of the three cities for the successful implementation of the Cristal system. The objective was to make a comparison between the chosen zones in order to highlight similarities and disparities for an effective development of the innovative transport system.

In Strasbourg the Illkirch-Graffenstaden zone has been selected. In Ploiesti a mixed zone comprising Nord, Centru, Republicii-Traian, Lenachita-Vacarescu and Vest has been selected. In Formello, the whole territory has been selected.

The resulting chosen sectors have extensions of the same order of magnitude but the population densities are quite different (about 2'250 inhabitants per km<sup>2</sup>, 3'750 inhabitants per km<sup>2</sup> and 1'200 inhabitants per km<sup>2</sup> respectively for Strasbourg, Ploiesti and Formello) as well as the territorial features. On the one hand, there is a common urban landscape both for Strasbourg and Ploiesti and, on the other hand, there is a more rural landscape for Formello. So if in the first case there is a more homogeneous dispersion of centralities and amenities in the territory, in the second case there is a more sparse structure lacking of certain amenities and well-defined centralities. Therefore, in the first case there is a more meshed transport demand, while in the second case, there is a typical two way demand to and from the majority of centralities (the city of Rome). Furthermore, the presence of territorial barriers in Formello hampers a direct link between two areas of the city, strengthening the outlined scenario.

### *3.1.4. Multimodality and mobility behavior*

A quantitative household survey was carried out in the city of Strasbourg, for the three target sectors of the agglomeration that had the highest potential for implementing an automated transport system as the one addressed by the Cristal system.

The survey, conducted by telephone, interrogated approximately 200 residents in each of the target sectors, comprising a total of *circa* 600 respondents. To better understand the mobility structure of the three target sectors prior to setting up the questionnaire, several field study trips were undertaken for each of the sectors.

The user acceptability analysis provided household's information on who might be the potential target Cristal users, under which circumstances and for what purposes (work, shopping, leisure, etc.) these users might think of Cristal as an interesting transport option for their trips. Possible complementarities between Cristal and the existing transport modes were identified, both time and space-wise. Recommendations on how to integrate the innovative Cristal system into a global mobility offer were also highlighted.

At a later stage, once Illkirch was defined as the target sector where CATS implementation will take place, a supplement qualitative survey was carried out. This survey aimed to explore the mobility of the Pôle d'Innovation d'Illkirch (PII) from the standpoint of the business companies. It was perceived by all partners to bring useful insight to accomplish the overall objectives of WP1, especially in regard to the decision-making process of locating the stations and setting up the itineraries of Cristal in Strasbourg.

In agreement with CATS consortium, no surveys were carried out by EPFL in Formello or Ploiesti, since the target was to focus on Strasbourg, the city where the case study was planned to be undertaken in real conditions.

### **3.2. WP2 - Operating principles:**

The specific objective of this work package was to define and design the operating principles of the transportation system (and therefore its expected performances) in its 2 running modes: individual self-service and collective urban shuttle. Tools have been developed to assess both the performance and the environmental impact of CATS.

#### *3.2.1. Simulation tool for assessment of energy and environmental impacts*

Assessment of the energy and environmental impacts is one of important factors in the transportation system's evaluation. A simulation tool was developed based on the CyberCar, CyberMove and Conduits findings to make this assessment possible. The tool may be used for calculation of the energy consumption, recoverable energy in the regenerative braking operation, as well as additional pollutant and greenhouse gas (GHG) emissions induced as a result of the transportation system operation. The model was validated by comparing the predicted results of energy consumption with the available experimental data obtained with two different EVs and at different driving conditions.

The evaluation of the environmental impact of the advanced transportation system based on electric vehicles depends on derivation of data on total emissions released in the considered region during the process of electricity production; derivation of data on total electricity supply in the considered region and appropriate calculation of emissions per person · km released due to the vehicles activity. These emission values should be further processed to provide a total emission indicator (*TEI*). The latter is useful as a tool for an integral quantitative assessment of pollutant emissions by CRISTAL or NAVYA system, or any other ITS and a comparison with the baseline emission scenario. *TEI* is defined as a sum of normalized emission values of different pollutants.

The environmental impact of transportation system is a function of not only emissions level, but it is also site dependent and determined by a number of people that are exposed to the polluted air. To account for this fact, we propose to introduce an environmental impact factor (*EIF*) for evaluation of the system's environmental impact and comparison between different transportation modes. The dimensionless *EIF* value is calculated as  $EIF = TEI \cdot D_s$ ,

where  $D_s$  is the receptor density in the site of consideration. Receptor density is calculated as the population per  $\text{km}^2$  of the site area.

In order to assess energy and environmental benefits of the novel transportation system, such as CRISTAL one, an appropriate comparison with conventional motor vehicle transportation should be performed. To estimate energy consumption and pollutant emissions of a conventional vehicles fleet, an assessment of appropriate emission factors is required for various vehicle types and technology generations, as appear in the fleet, at the considered driving, traffic and climate conditions. This evaluation may be performed by using appropriately validated complex Road Emission Models, such as: ARTEMIS, COPERT and others.

The values of emissions produced by a conventional motor vehicle fleet should be further processed, to provide a total emission indicator (*TEI*), as well as an environmental impact factor (*EIF*). A comparison of energy consumption, *TEI* and *EIF* values for CRISTAL system and conventional transportation modes will allow an appropriate analysis of its energy and environmental impacts.

The suggested method of environmental impact assessment based on *TEI* and *EIF* performance indicators is novel and developed for the first time in this project. The developed simulation tool was applied for assessment of energy and environmental impacts of the CRISTAL and NAVYA systems and a comparison with the conventional vehicles fleet in the Ploiesti site.

Table 1 shows the results of *TEI* calculation for a diesel Euro-5 bus at different occupancy values, which are compared with the *TEI* values of the CRISTAL vehicle.

*Table 1: Comparison of TEI values for CRISTAL vehicle and Euro-5 diesel bus*

<b>Service type</b>	<b>TEI</b>
CRISTAL, Shuttle mode, route A	0.033
CRISTAL, Shuttle mode, route B	0.028
CRISTAL, Shuttle mode, route C	0.034
Bus, 20 pass	0.036
Bus, 25 pass	0.029
Bus, 40 pass	0.019
Bus, 60 pass	0.013

The results of *TEI* comparison show that the total emission indicator of the CRISTAL vehicle operated in Ploiesti (Romania) will be lower than the one of a Euro-5 diesel bus until bus occupancy is below 25 passengers.

Because the environmental impact of transportation system is a function of not only emissions level, but it is also site-dependent and determined by a number of people that are exposed to the polluted air, the environmental impact factors calculated for CRISTAL vehicle and a diesel bus were compared. For the fleet of diesel buses,  $D_s$  value was calculated as

Ploiesti population per Ploiesti territory:  $D_{s, bus} = 197,542/58.2 = 3394$ . Calculated values of bus' EIF for different occupancy values and the CRISTAL vehicle are shown in Table 2.

The results presented in Table 2 clearly demonstrate significantly lower environmental impact of electrically driven CRISTAL vehicle over a Euro-5 diesel bus at any bus occupancy values.

*Table 2: Comparison of EIF values of the CRISTAL vehicle and a Euro-5 diesel bus for the case of Ploiesti*

<b>Service type</b>	<b>EIF</b>
CRISTAL, Shuttle mode, route A	2.64
CRISTAL, Shuttle mode, route B	2.24
CRISTAL, Shuttle mode, route C	2.72
Bus, 20 pass	122.2
Bus, 25 pass	98.4
Bus, 40 pass	64.5
Bus, 60 pass	44.1

### *3.2.2. Self-service and shuttle operation*

Since such a system has never been deployed before, CATS needed tools to help the evaluation of the operating principles. There are indeed known operating principles for the two kinds of services, self-service and flexible shuttle service, but it is unclear how to mix them together properly. In particular, attention needs to be given to the transitions between the two modes. Creating a model of CATS operation principles allows assess the completeness in the definition of the service.

The system was defined though several elements:

- *Vehicles*: car (a standalone Cristal for car-sharing), locomotive (a Cristal driven by a professional driver that can redistribute empty vehicles between stations), shuttle (a locomotive pulling several Cristals in convoy)
- *Infrastructure*: car-sharing stations containing parking slots, shuttle stations, locomotive depot, shuttle routes ;
- *Clients*.

The paradigm that has been chosen for the development of the discrete event model is the *event-scheduling scheme* that focuses on the events that instantaneously transform a system's state and/or schedule future events. The system is represented as a chronological sequence of events of the form  $\{..., s(i), e(i), s(i), e(i+1), ...\}$  where  $s(i)$  is the state of the system at the time  $t(i)$  and  $e(i)$  is a system event happening at the time  $t(i+1)$  making changes to the system bringing it to state  $s(i+1)$  and so on.

The system is described using Process Flow Diagrams, based on simulation events that trigger the evolution of the system state. The CATS model is divided into four subsystems

that are loosely coupled and hence will be modeled separately. Events are associated to the four following sub-models:

- Users behavior: events associated with clients;
- Self-service operation mode: events associated with shared cars;
- Flexible shuttle operation mode: events associated with shuttles;
- Vehicle redistribution: events associated with locomotives.

Each of these sub-models is represented by Process Flow Diagram.

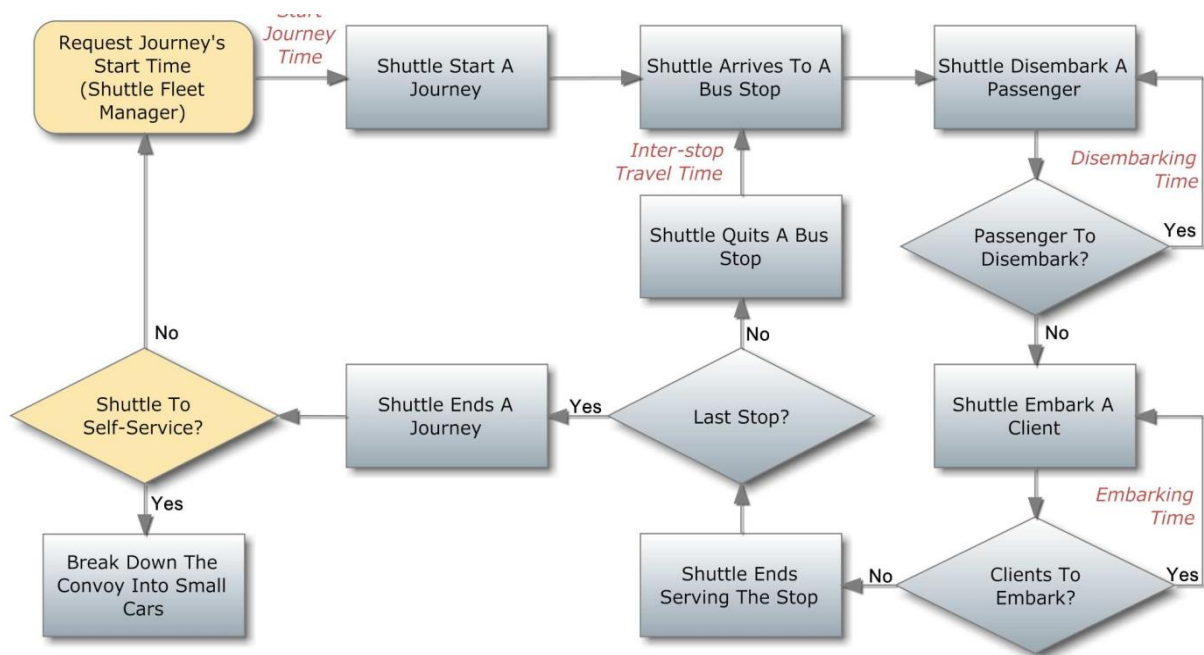


Figure 2. (Shuttle operating principles) A shuttle's journey consists of serving a known number of stops of the shuttle's route at a given time.

This model has several desirable properties. The main one is modularity: not only can the global system be decomposed in subsystems in a rather natural way, but also the model can combine many transportation sub-models. Thus, it can be extended to model a transportation system with more than the current two operating modes. Furthermore, multiple modes can be simulated at the same time and the customer will be free to choose between them.

The reason why this separation is possible lies in the structure of the system. The model's events occur only at stations (e.g. a client arrives or a shuttle embarks a client). The sub-models depend mainly on the station's state (queue of waiting clients, number of available vehicle...) and that is crucial to combine them in a global diagram. A station is considered as a multimodal station, where one can find more than one transportation service. This multimodality helps to mix different sub-models representing various transport modes.

### 3.2.3. Discrete event simulation tool

The CATS simulator strives to be a workbench for two kinds of usages

- *Set-up and evaluation the performance* of a transportation service in a given area: allow, by changing the values of its different parameters, to see what the effect is on various performance measures (waiting time, number of customers served);
- *Research platform* for the creation of a new public transportation service: one can experiment with the operating principles and the “intelligent” algorithms, at the cost of some programming work.

The CATS simulator has been implemented in C++ and great care has been taken to make it portable between MS Windows and Linux. The model of the CATS system in the simulator can be broken into two parts: the model of the transport system, which is based on a simplified version of the city's road network where CATS stations and shuttle routes have been added, and the agent model, which covers the users of the system and the CATS vehicles.

For the simulation, clients and vehicles are supposed to only move between the points where the CATS stations are located. This simplifies the problem and allows the use of small origin-destination matrices to model the trips distribution and the routing information can be precomputed. The model is a graph where the vertices are represented by the Node class and the edges by the Link class.

To create the simplified model, the data about the road network of the target area has been obtained from OpenStreetMap (OSM), a community-driven geographic information database. It has the advantage of being open, so that users of the simulator can correct or enhance the map data as needed, and to be available in a well-documented and usable format (XML).

The simulator models the transport network as a graph of nodes interconnected by links, where each node is connected to every other node. Each node represents a physical location, and can contain several stations of different types. The link between each pair of nodes represents the shortest path between them, and is pre-computed. The users of the system are modeled by the Client class. During the simulation, clients will appear randomly at nodes and ask to travel to a destination node. The vehicle types are each modeled by their own class. They move as a consequence of events, generated by the stations, the users, or even themselves.

The result of a simulation is a SQLite database containing data about all the entities (vehicles, stations, clients) in the simulation and the evolution of their state, as well as a list of all events that happened during the run. This approach allows us to keep all the data needed to reconstruct the state of the system at any moment during the simulation and to extract statistical information using SQL requests.

A sample model has been created in order to test the simulator. It is an adaptation of the the recommendations of Deliverable D1.1, which proposes for the area of Illkirch-Graffenstaden a precise positioning of the stations, as well as that of the shuttle paths. The numbers

concerning the demand for the shuttle and the car-sharing services have been transformed into simple origin/destination matrices for the simulator. Since tuning the model is a very time-consuming process and requires more data, this parameterization is only of demonstration value and no effort has been done to assess its performance.



*Figure 3. A tentative implementation of the CATS system in Illkirch-Graffenstaden, according to the recommendations of deliverable D1.1. Shuttle stations are in blue (as well as shuttle routes) and normal stations are in green.*

The last piece of the simulator is the Results Analyzer, a Graphical User Interface which allows to replay the simulation of the system as a function of time, and to obtain useful statistics about a simulation run. It is written in Python with the Qt library, and uses the SQLAlchemy library to manage the database interfacing part of the code. As can be seen on the screenshot in Figure 2, the main element of the interface is the map of the area under consideration. This map can be panned with the mouse cursor or the scrollbar. Those statistics are computed by SQL queries on the results database and are updated in real-time as the simulation time evolves. It is possible to add new statistics by simply creating queries. Some early support is also present for displaying graphs showing the evolution of selected statistics over time.

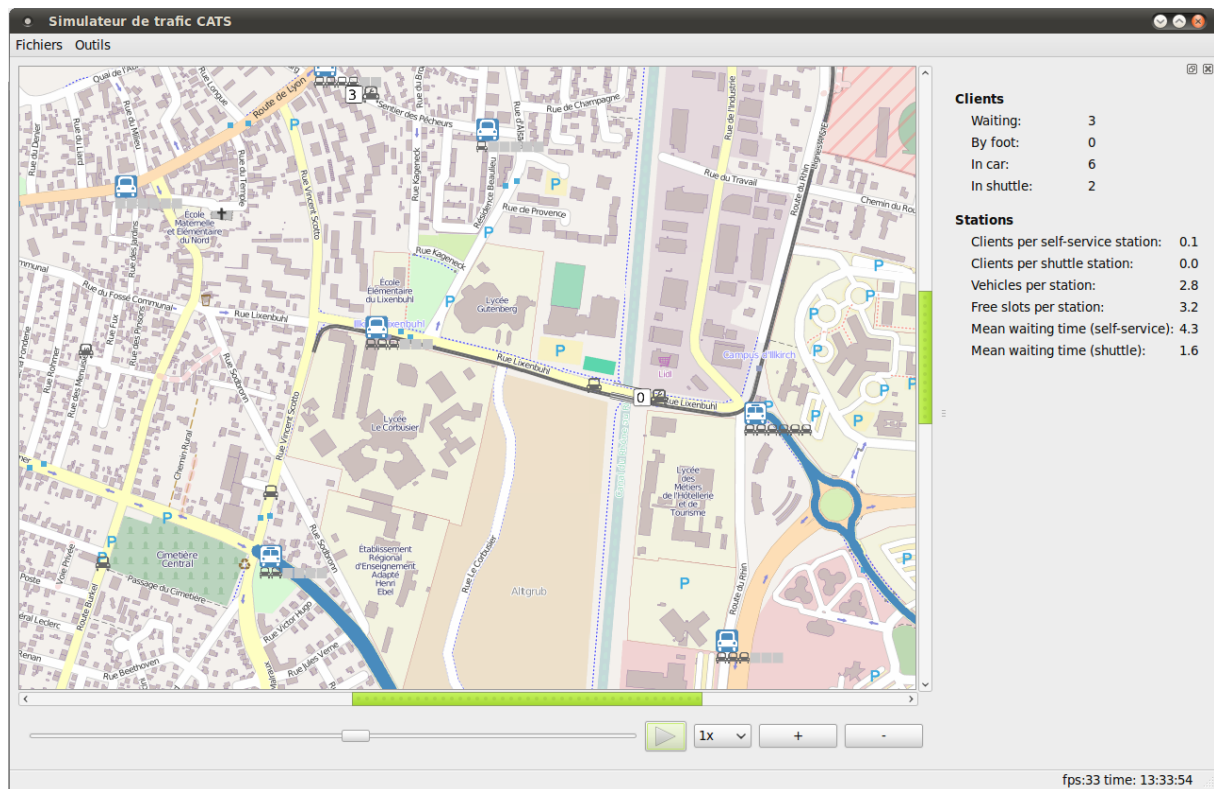


Figure 4. The Graphical User Interface of the Results Analyzer.

### 3.3. WP3 - Development of the station and virtual integration:

#### 3.3.1. Design of the stations

The stations are part of the Cristal system. They represent the interface between the transport mode and its users, providing users a mobility information system that helps them to find the mode of travel that fit their purpose.

The station design includes firstly defining the technical and functional constraints of integrating stations in their environment and also the definition of services available to users (information, reservations, ticketing, etc.)

The services and the use of the stations were thus defined, including technical services, passenger services and integration with the existing transport network. The particularities of Cristal vehicles and system were described through station vocabulary and integration principles. The station typologies and the service modes were discussed and the station area components that should constitute and build a Cristal station were listed. These elements include street furniture and hardscape surfaces but also information systems, lightening and hard infrastructure elements.



### 3.3.2. From Cristal to Navia

Following the withdrawal of Lohr Industrie regarding the manufacture of the vehicles for the demonstrations, WP3 was somewhat messed up. The static and dynamic validation of the system in anticipation of the demonstration has been set aside in order to focus on the reconfiguration of the end of the project.

It was decided, despite the difficulty of the situation, to try to find another innovative system that could be demonstrated in Strasbourg to perform the assessment tasks and the citizen awareness evaluation on innovative vehicles. Induct Technology and its autonomous road transport system called “Navia” has been chosen to replace Cristal for the demonstration. The Navia system was chosen due to its similitudes with the Cristal system in terms of capacity and operation principles.

Although Navia went bankrupt during the project, demonstrations have been completed.

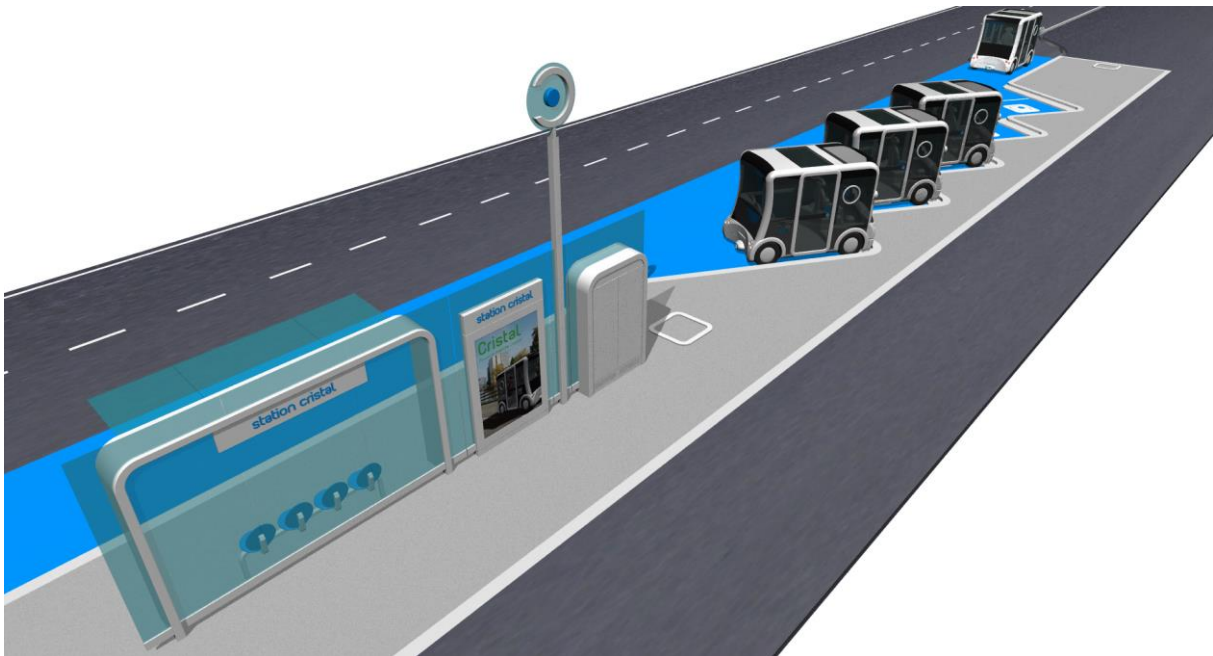


Figure 5. Cristal station

### 3.4. WP4 - On site demonstration:

The key work package of the project was the organisation of the on-site demonstration allowing both the validation of virtual integration and the evaluation activities related to the value of use of the vehicles.

The City of Strasbourg has deliberately set out to turn itself into a testing ground for delivering innovative mobility solutions to meet the requirements of the city's public, individual and freight transport systems. Strasbourg is indeed a pioneer in the introduction of soft modes of public transport, such as tramway (the longest network in France), the tram-train, car sharing and cycling (the city has the largest network of cycle tracks in France).

The city on the Rhine (it is the second-largest French inland port), is setting new standards for experimentation with innovation-led and multimodal mobilities, such as the Toyota hybrid vehicle and the Cristal system for self-service public car rental.

Therefore CRISTAL was presented to the urban area as an innovative solution because of the utilization of a single type of vehicle for two different usages: individual use or collective transport.

When Cristal system was replaced by Navia, Strasbourg reiterated its willingness to be an experimentation city for innovative transportation solutions. Given the fact that the Navia shuttle is a driverless vehicle, new challenges emerged. The interest was to assess whether an autonomous shuttle could satisfy the needs of users in the same way that a guided vehicle.

Two important steps have thus preceded the technical tests:

- elaborating the circuit with the users of the innovation park;
- obtaining an authorization to operate compliantly with the French legal context.

### *3.4.1. First phase in Strasbourg*

The preparation of the first demonstration phase in Strasbourg followed four main stages.

#### **STAGE 1: PRELIMINARY TEST: APRIL 3<sup>RD</sup> 2013**

To prepare the demonstration of Strasbourg, preliminary tests were organized on the site of Strasbourg Innovation Park on April 3<sup>rd</sup> 2013 with the first shuttle arrived on site. The first observations allowed specifying the characteristics of the Navia insertion. On this date one vehicle was tested and the vehicle was driven by an engineer equipped with a joystick.

#### **STAGE 2: NAVIA LINE ELABORATION WITH THE USERS OF STRASBOURG INNOVATION PARK**

In order to define the park users' needs, the CUS organized workshop sessions to identify the best transport line within the innovation park with its users. In fact, 3 workshops were organized between April and September 2013 to define the line and the targeted services level.

#### **STAGE 3: INAUGURAL CEREMONY ON NOVEMBER 19<sup>TH</sup> 2013**

On November 19<sup>th</sup> 2013, the European CATS project was presented to the economic players of Strasbourg Innovation Park in the presence of:

- Mrs Catherine Trautmann European Deputy, CUS economic development VP
- Mr. Jacques Bigit, CUS President
- Mr. Patrick Mercier Handyside, European Commissioner and CATS Project Officer

#### **STAGE 4: INTEGRATION STUDY BY PTB GROUP**

To measure the conditions of insertion of the Navia, the CUS carried out a specific study on the capacities of public road networks and crossroads, in particular, the level of "crossroads service" and the "road activity plan".

The recommendations were the following:

- horizontal and vertical markings along the circuit;
- ban to pass in surrounding areas of crossroads;
- ban to park near the stop station “campus”.

### 3.4.1.1 Legal Acceptance process

Strasbourg demonstration was a European first. In the framework of CityMobil (another project co-financed by the European Commission) automated vehicles were already tested but never on open roads. According to “Vienne agreement”, to imagine a vehicle without a driver on a public road is impossible. In fact, as any vehicle must be driven, it was necessary to commit with state departments a process to make possible the experiment.

This long work ended with an inter-ministerial meeting on December 19<sup>th</sup>, 2013 and the authorization for the CATS demonstration was given jointly by three French national entities:

- “Ministère des transports”
- “Ministère du redressement productif”
- “Ministère de l’intérieur”

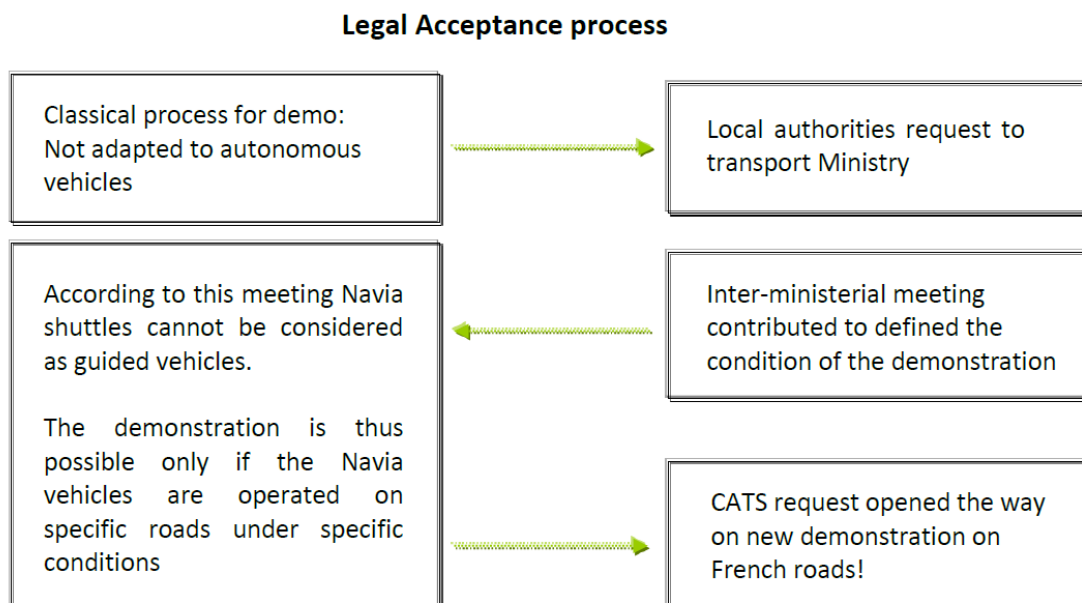


Figure 6. Strasbourg demonstration decision taking process

The conditions laid down by the competent authorities were the following:

- The vehicles must travel at a maximum speed of 15 kilometres per hour;
- Each vehicle need an operator on board;
- Each operator should have a valid driving licence;
- Human validation of the crossroads is needed;
- Other vehicles sharing the same road are obligated to reduce their speed.

Additional information was also needed to inform users on the presence of autonomous vehicles:

- warning speed camera;
- horizontal and vertical road markings.

#### *3.4.1.2 Tests without passenger*

The technical tests were carried out using three Navia shuttles. Only one shuttle was operational at arrival on site. The two others needed some update to be operational. The maximal speed of the shuttles was fixed at 3 meters per second.

"Yield" and "Turn left" crossings were considered as Stops and the operator authorized the departure of the shuttle when the path was clear.

The technical tests led to the identification of the following challenges:

- Challenges due to the vehicle itself
  - *Vehicles hardware*: the vehicles used during the demonstration were prototypes of different versions. These vehicles regularly encountered hardware problems during the demonstration such as problem of alignment, fuse or solder.
  - *Vehicles software*: in addition to technical problems, the vehicles faced sometimes some software problems such as location loss.
  - *Management of crossings*: the operators on board the vehicles couldn't anticipate the crossing; indeed the operators should give a human validation.
- Challenges due to the open road demonstration:
  - The speed of Navia was too low compared to traditional vehicles as the average speed in a protected portion is lower than 10 kilometres per hour,
  - The vehicles seems to be too sensitive to the environment in movement,
  - Speed insertion was too low considering the circulation on the innovation park,
  - The average speed in pedestrian zone or in forced public road network was limited to 5 kilometres per hour.

Because of the conditions of traffic, the fragility of the vehicles and the difficulties of Induct Company, the CUS validated the continuation of the experiment in a closed site: EPFL campus in Switzerland.

#### *3.4.2. Demonstration in Lausanne:*

EPFL agreed in June 2014 to host the second phase of CATS demonstration and to arrange it in a very short time. Indeed, the demonstration had to take place in July 2014 to allow remaining activities to be achieved before the end of the project, this is before December 2014.

The involvement of the EPFL was beneficial for the project and showed its willingness to deploy in the medium term an innovative transportation system on its campus.

Figure 7 shows an example of Navya vehicle running inside the campus on a pedestrian zone together with a bicycle.



Figure 7. CATS demonstration in Lausanne

#### 3.4.2.1 The legal aspects

Following the purchase of a Navya shuttle by EPFL in November 2012 and as part of the CityMobil2 project, the school contacted the Swiss competent authorities to request permission to operate automated vehicles on its campus.

Due to the private status of the EPFL campus, the proposed free access to the shuttles and the demonstration character of the project, the Federal Office of Transport (OFT) and the Federal Office of Roads (OFROU) renounce both to establish a certification procedure and delegate it to the Cantonal Office of Cars (SAN). A common meeting in March 2013 allowed clarifying the certification process, in partnership with the police authority.

The authorization for the CATS demonstration was given jointly by three entities following a site visit beginning of July 2014. These entities are:

- The cantonal Office of Cars (SAN);
- The cantonal Police;
- The cantonal Mobility Service.
- The conditions laid down by the competent authorities are the following:
- The vehicles must travel at a maximum speed of 12 kilometres per hour;
- The maximum number of passengers per vehicle is 9;
- The innovative transport system must be adequately insured.

### 3.4.2.2 The demonstration route

CATS demonstration route was defined on the basis of the territorial study carried in the framework of CityMobil2 European project in 2013. This study intended to identify the needs for mobility not yet answered within the campus and the integration constraints for automated vehicles. The study was conducted in order to prepare a 6-month demonstration of automated vehicles starting in November 2014. It was thus perfectly adapted for the route selection of CATS demonstration and similar to the mobility analysis performed for Strasbourg within WP1.

It was therefore decided to link the Rolex Learning Center (RLC) to the EPFL Innovation Park. The vehicles also stopped at the Starling Hotel and students' home "Les Estudiantines". The route was 950 meters long one-way and served four stops. The location of these stops is shown on the map below. Information panels were printed to show the stations location.

Figure 8 shows a Navya vehicle in operation between the RLC and the Starling Hotel.



Figure 8. CATS demonstration in Lausanne

In some sections, the pathway width did not allow two vehicles to pass simultaneously. To manage these sections, two crossover points were determined. The operation staff inside the vehicles communicated with walkie-talkies to know whether the sections were free or busy to know if they had to wait at the crossing point or if they could move forward. To make the operation more smoothly, students regularly announced their position. This allowed, with a little practice, to minimize the waiting times.

### 3.4.2.3 Daily operation

Once the permission to operate obtained, the demonstration could be organized and take place within the deadlines thanks to the following partners:

- EPFL Vice-Presidency for Planning and Logistics (VPPL)
  - o Demonstration organization
  - o Provision of one vehicle
- Navya
  - o Provision of three vehicles on a rental basis
  - o Intervention in the case of heavy maintenance
- BestMile
  - o Daily exploitation
  - o Daily maintenance
  - o Data collection
  - o Operator team management

The vehicles were operated by BestMile from the 10th to 31st July 2014, on weekdays, from 7:30 to 18:00. This represents a total of 16 operating days and 168 operating hours.

This period of the year was part of the summer break during which students were on vacation. Although July is one of the less crowded months on campus, it does not mean that the demand was non-existent. If the demonstration had taken place during a semester, demand might have greatly exceeded the capacity of the system consisting of three vehicles.

The demonstration was operated daily according to the following scheme:

- a student was present aboard each shuttle to:
  - o explain how the vehicle works,
  - o answer users questions,
  - o distribute and help to complete questionnaires,
  - o note the origin and destination of users,
  - o manage vehicle crossings,
  - o engage the emergency stop if necessary.
- an operator was located midway of the shuttles route to:
  - o manage the students,
  - o supervise the vehicles fleet,
  - o intervene quickly in case of incident or failure,
  - o list the encountered incidents.

### 3.4.3. The main challenges

The main challenges encountered during the demonstration were as follows:

- Vehicles hardware: the vehicles used during the demonstration were prototypes of different versions. These vehicles regularly encountered hardware problems during

the demonstration: loosening of screws, loss of lasers alignment, and problem of fuse or solder ...

- Vehicles software: in addition to technical problems, the vehicles faced sometimes some software problems like location loss. These problems could be handled quickly thanks to the prompt intervention of the operator and the experience gained progressively by the students inside vehicles. The intervention of the manufacturer has been required only once over the lifetime of the demonstration.
- Management of crossings: the demonstration route consisted of several sections whose width does not allow the crossing of two vehicles. Operators on board the vehicles should thus anticipate the crossings so that they did not occur on one-way sections. This involved some “exploitation stops” of the shuttles to wait for the oncoming vehicle to releases the one-way section. With experience, operators managed at the end of the demonstration to anticipate their movements enough to avoid such unexpected stops.
- Rehabilitation: in some places, the repeated passage of the vehicles for four weeks partially damaged the stabilized soil on which the vehicles were traveling.

The identification of these problems made it possible to identify the main challenges for the next generation of vehicles in both mechanical and functional terms.

### **3.5. WP5 - Impact Assessment**

The impacts concerning mobility, acceptance, environment, transport patterns accessibility, certification and legal aspects, and attitudes towards innovative transport systems have been studied after the demonstration.

The evaluation of such impacts started from the evaluation plan prepared in the first phases of the work package, where the indicators to be collected to evaluate the aforementioned impacts (and how to measure them) have been reported. The necessary data were then collected during the demonstration in Lausanne and during the three-day showcase in Ploiesti to allow an ex-post assessment of the indicators.

#### *3.5.1. Evaluation plan*

A common evaluation methodology to evaluate consistently the different sites in all the project’s phases was first defined. This methodology led to the definition of a common evaluation plan for the three cities, including measurement plans for both ex-ante and ex-post evaluation phases.

The evaluation methodology was based on the Maestro Guidelines. The kernel of the evaluation plan is the selection of the indicators to assess, their measurement methods and the measurement planning. The evaluation plan started from the table of the indicators provided by Maestro methodology for urban projects. Some of the indicators suggested from Maestro were discarded because not applicable or not measurable and removed from the list directly from the project evaluation team. The remaining indicators where then



discussed in a plenary meeting to check with all partners (those representing the cities, the evaluation group, the technical partner and those carrying the studies) whether measuring the indicators was feasible, useful, and how and when to measure it in the different cities.

Ten evaluation categories have been considered: Acceptance, Capacity, Transport Patterns, Quality of Service, Resource consumption, Pollution / Nuisance, Safety, Security, Costs and Legal impacts. Each evaluation category featured from one to 10 impacts and each impact was measured by one or more indicators.

Once the assessment preparation phase completed, both Lausanne demonstration (with Navya vehicles) and Ploiesti showcase (with CyCab vehicles) were evaluated. The Lausanne demonstration was evaluated by 181 filled questionnaires for the user acceptance and quality of service assessment and by collection of the transport patterns directly during the three-week vehicle operations. In the Ploiesti showcase 75 questionnaires were filled to assess the perceived quality of service related with the vehicle tested and to verify if an Automated Road Transport System (ARTS) was able to replace an existing bus service linking the city center with the train station.

### *3.5.2. Data collection and analysis*

During the demonstration on EPFL campus, data were collected to allow the assessment tasks of partners CTL, EPFL and Technion to take place. Questionnaires were filled in by end-users while they were inside the vehicles, under the supervision of the operators who also collected transport data.

The questionnaire, designed by GEA to ensure the collection of all the needed data, consisted of four sections: (1) respondent characteristics, (2) the Navya shuttle, (3) the innovative transport service and (4) the user experience aboard Navya. The questionnaire was available in French and English. The results were processed by the operator and sent to the partners responsible for the different assessment tasks.

The students aboard vehicles were responsible for distributing questionnaires to users and help them respond to collect their views on innovative mobility and CATS demonstration. The key figures of the demonstration are as follows:

- 10.5 hours of operation each day during 16 days with 3 vehicles
- 1'600+ people carried out in 16 days of operation
- 181 completed questionnaires in 8 days of survey
- Completely filled out questionnaires: 143
- Questionnaires filled out on one side only: 7
- Questionnaires filled out with some missing responses: 31
- Two weeks of rain, thunderstorms and clouds (a very unusual weather in July in Switzerland)
- 0 accident

The objective of the evaluation was to make an analysis of the data collected during the demonstration in Lausanne as regards to user acceptance and attitudes toward innovative mobility and multimodality.

The characteristics of respondents showed that a wide range of people took part in the test of autonomous vehicles on the campus. A majority of respondents (39%) were visitors. The respondents found the Navya vehicle particularly user-friendly, futuristic, functional and aesthetic. The speed of the vehicle was the notion that divided the most people. The absence of a driver was not experienced as a problem for 78% of respondents.

Questions related to waiting time and willingness to pay showed that people have the same expectations for autonomous transport systems than for standard public transport. The size and the speed of the vehicle were considered well adapted to the EPFL campus environment. For both size and speed, approximately 82% of respondents agreed that the integration was successful and 42% totally agree.

Regarding the quality of the ride, only 14% of respondents found it excellent. Progressively during the demonstration, the ground on which the vehicles were travelling deteriorated due to bad weather and repeated passage of the vehicles on the same trajectory. Holes were formed in some of the stabilized soil, causing jerkiness.

Some 58% of respondents found that Navya is a highly innovative vehicle and 86% that it is innovative; 39% of respondents say they are willing to use autonomous vehicles regularly in the future. Only 5% of respondents were reluctant.

Figure 9 shows these results. The question asked was: On a scale of 1 (disagree) to 5 (agree), do you agree with the following statement.

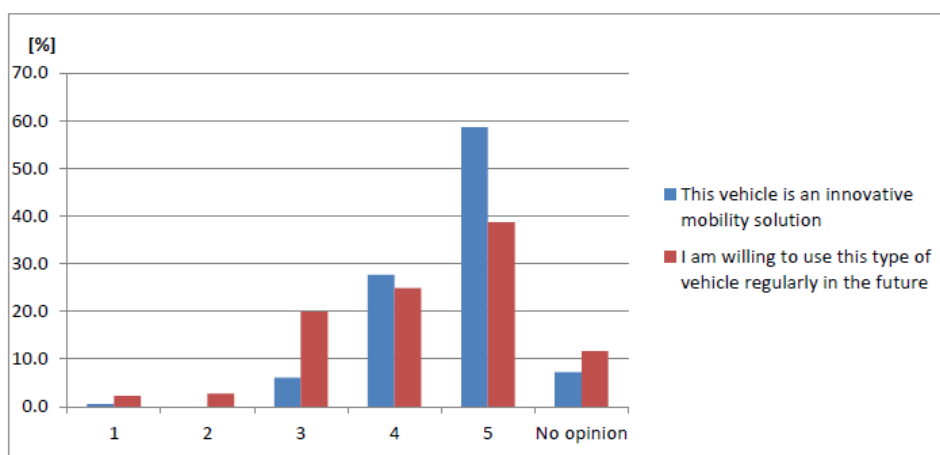


Figure 9. Innovative mobility rating

### *3.5.3. Ex-post evaluation and user acceptance*

People were generally satisfied with the quality of the service provided by the ARTS and vehicles tested both in Lausanne and Ploiesti. The system in Lausanne was able to have 1'600 passengers during the 16 days of demo, with 50% of them making a complete round-trip on board the vehicles to test them. 8.5 km/h as average speed in a pedestrian area where it was required to have 15 km/h as maximum allowed speed. In Ploiesti 75% of the respondents in favor of replacing an existing bus route with an ARTS covering the same route.

The environmental impacts were compared for the ex-ante studied Cristal systems and showed lower environmental impact of the advanced transportation system over a Euro-5 diesel bus at any bus occupancy values.

As general results the ARTS are ready to provide a satisfactory service in terms of quality (as also perceived by the users). They result to be easy to use, clean, comfortable and secure. The comfort can be improved; however extending the service to a larger scale and/or to different context is possible yet with the present quality performances. Further analyses could be useful to assess the safety of the vehicles perceived by the users (however quite positive in Ploiesti).

Concerning the transport patterns, the results of the Lausanne demonstration showed that such systems are ready to be implemented in contexts where vehicles, infrastructures, and regulations are considered together, as in the ARTS definition. The ARTS could be able to solve the last mile problems and to replace existing services (as in the case of bus route in Ploiesti) by providing a satisfactory and performing service to the users. They have to be considered including vehicles, dedicated infrastructures, and control systems, which are the three main parts of them.

### *3.5.4. Transferability*

The transferability of the considered transportation concept to European cities was then investigated. Since cities are of different types and sizes, the analysis considered in which situations the proposed concept can provide a significant added value in terms of transportation benefits.

The analysis is based on the demonstration of the transport system “Navya” performed in Lausanne and on the methodology developed and applied in the European Projects NICHES+ (Jeffery, 2011) and the TIDE (Transport Innovation Deployment for Europe) Transferability Handbook.

It was found that the ARTS can easily be transferred to other ‘protected’ sites, where there is no or only few interaction with other motorized modes. In sites with mixed traffic, the difference of speed between the autonomous vehicles and other driven motorized vehicles must be reduced. In addition, the system has a good potential to solve the ‘last mile’ problem in the public transportation infrastructure, by providing service to local streets in connection to collector and arterial streets.

## 4. Description of potential impact, main dissemination activities and results exploitation

At the beginning of the project, CATS aimed to yield the following impacts:

- Drastic reduction of energy dependency, pollutants and carbon dioxide emission,
- Technological progress,
- Better productivity and competitiveness, social prosperity and business opportunities,
- Societal satisfaction, substantial gain of time and comfort for travel.

After 60 months of research, CATS can review its achievement. The methodology that was elaborated in CATS is stimulating European industries to further develop their competence in the area of safe and efficient driving in the road environment and establish a leading position in the market. The demonstration laid a basis for establishing new business activities for service providers and companies.

In term of cleaner environment both solutions experimented within CATS demonstrated their effectiveness concerning the reduction of CO2 pollutants emissions and the increase of energy efficiency.

The dissemination activities, in regard of the previous impact, were carried around three main activities:

- The production of dissemination tools to ensure a good communication of the project and make stakeholders aware of the project.
- The spreading of the scientific results of the project toward the scientific community by CATS consortium.
- The fostering of interactions with stakeholders.

Therefore, the consortium multiplied concrete effective dissemination measures matching the socio-economic impacts expected through the entire course of the project.

### Project presentation in Strasbourg

The huge upstream work made in Strasbourg to decide where and which trajectory for the system proved the necessity and the benefit to consult the general public. Consultation process helps the acceptance of such system and even creates an expectation toward it.

### Demonstration in Lausanne

It had to be successful in terms of participation, as it was essential for the evaluation process. The EPFL location helped in this matter as it attracted the interest of the press, of people working and studying there. More than 1'500 participated to the demonstration and the number itself is a proof of good dissemination.

### Showcase in Ploiesti

The results of the demonstration were presented in the city of Ploiesti to wider the demonstration audience. The idea was to present new urban transport system and a working automatic vehicle. The habitants could see and test how this system works. One of

the main questions was for instance: “Is it safe?” The testers could verify this assumption by themselves and therefore most of them were reassured after the demonstration: indeed the laser system allowed the cy-car to slow down or completely stop as soon as it detects static or moving obstacle. Most of the children were really interested in the deployment of such system. New urban transport solutions have a good future with young generation.

### **The final conference at the European Parliament**

It aimed at disseminate the project results to decision-maker and industries. The collaboration between the French cluster “Véhicule du futur” and the project allowed us to present the final result in a symbolic place: the European Parliament.

This is particularly interesting as one of the most important feedbacks from the project is the difficulty for regulation to evolve and to adapt to new means of transportation. The consortium identified targeted audience that would profit from the project results:

- Researchers,
- Industries,
- Cities,
- General public.

The final conference of CATS was a success both in term of dissemination and assessment. It allowed the consortium to present the main challenges faced during the entire course of the project along with exploitable results.

### **Dissemination during and after the end of the project**

Disseminate in an interactive way has always been a concern of the project and two movies were made at two crucial point of the project:

- At the beginning to explain the ambition and stakes of CATS,
- At the end of the project to present results.

These two movies are at the disposal of partners to ensure dissemination after the end of the project.

According to EC rules, the project developed an exploitation plan to facilitate exploitation of the results. All the results are expected to be widely used.