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BARCELONA: Demo description and implementation plan

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Coordinator: UITP – International Association of Public Transport

SUMMARY SHEET

Programme	Horizon 2020
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Deliverable Title	Barcelona: Demo Description and Implementation Plan
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Abstract	The EBSF_2 Barcelona demo will pursue the test and validation of innovative technological solutions applied to full electric buses in order to reduce their energy consumption and lower the barriers to accelerate the market uptake of this technology as the primary zero emission solution for urban mobility. The demo team is committed to test 3 technological innovations, extensively described in this report, namely: - An intelligent energy management system able to anticipate energy demands of auxiliaries and optimize energy consumption; - Solutions to optimize the efficiency of the climate system in warm conditions, including an ad hoc HVAC system for full electric buses; - An advanced eco-assistant solution to assist drivers to achieve a more eco-efficient way of driving. Deliverable 7.1 describes the technical innovations to be tested, the test scenarios and the plan for the implementation of the technological solutions, coherently with the EBSF_2 project master plan.
Keywords	Energy Efficiency, Auxiliaries, Electric Propulsion,

INTERNAL DISTRIBUTION

Participant N°	Participant organisation name	Country
1 Coordinator	Union Internationale des Transports Publics - UITP	Belgium
2	Régie Autonome des Transports Parisiens - RATP	France
3	Iveco France SA - IVECO	France
4	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. - FRAUNHOFER	Germany
5	Hübner Gummi- und Kunststoff GMBH - HUEBNER	Germany
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28	Transports de Barcelona SA - TMB	Spain
29	TIS PT, Consultores em Transportes, Inovação e Sistemas, SA - TISPT	Portugal
30	Rupprecht Consult - Forschung & Beratung GmbH - RUPPRECHT	Germany
31	Keolis SA - KEOLIS	France
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33	Transport for London – TFL	UK
34	Università degli Studi di Roma La Sapienza – UNIROMA1	Italy
35	Verband Deutscher Verkehrsunternehmen - VDV	Germany
36	Promotion of Operational Links with Integrated Services, Association Internationale - POLIS	Belgium
37	Tekia Consultores Tecnologicos S.L - TEKIA	Spain
38	Innovative Informatikanwendungen in Transport-, Verkehrs- und Leitsystemen GmbH - INIT	Germany
39	Union des Transports Publics - UTP	France
40	Västtrafik AB - VTAB	Sweden
41	Commissariat à l'Energie Atomique et aux Energies Alternatives - CEA	France
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Entity	Short name	Country	Contact person
European Commission - INEA	EC INEA	-	Mr. Walter Mauritsch

DOCUMENT CHANGE LOG

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0.1	26th October 2015	First draft	IRIZAR	
0.2	15th June 2016	Quality check	UITP	
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ACRONYMS

CAN – Controller Area Network

EBSF – European Bus System of the Future

GPS – Global Positioning System

HVAC – Heating, Ventilation, Air Conditioning

ITXPT – Information Technology for Public Transport

PT – Public Transport

TI – Technological Inovation

VO – Validation Objectives

UMTS – Universal Mobile Telecommunications System

ZeEUS – Zero Emission Urban bus System

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1 Executive Summary

The overall objective of EBSF_2 is to increase the attractiveness and improve the image of bus systems in urban and suburban areas by demonstrating, evaluating and validating the potential impact of technological innovations – almost ready for application – in developing efficient answers to both citizens and bus stakeholders' needs. Mobility challenges, such as the constant increase of passenger flows in densely populated urban areas, call for the need of satisfying a rising mobility demand within a context of efficiency and sustainability concerns.

The EBSF_2 Barcelona demonstration aims at improving the overall efficiency of full electric buses in order to promote their use as the primary zero emission public transport in urban areas. To achieve this goal, this demo will investigate technological solutions to reduce the energy consumption of auxiliary systems on-board the bus, increase the efficiency of climate system and thermal management, including the reduction of maintenance and service costs of the A/C unit, and test a driver assistance system able to reduce the fuel consumption and integrate comfort and safety criteria.

In addition, regarding the IT architecture, it is worth noting that the demo team will follow the standard EN 13149 parts 7/8/9 resulting from previous EBSF project and will apply the recommendations defined by ITxPT (Information Technology for Public Transport) association.

The demonstration will take advantage of 2 fully electric buses (12m, low-floor) implemented in the frame of the European funded project ZeEUS (Zero Emission Urban bus System). The buses will run in real operational conditions in congested urban areas of Barcelona including any kind of daily issue in urban bus transportation (traffic jams, slopes, long straight roads, intricate lines within the town centre, etc.). By building on existing projects, the main advantage is that charging infrastructure, standard vehicles and routes are already defined. The solutions will be adapted and deployed on these elements and thus the demo partners will focus on the reduction of the energy needed for the test vehicles.

Deliverable 7.1 describes the technical innovations to be tested, the test scenarios and the plan for the implementation of the technological solutions, coherently with the EBSF_2 project master plan.

2 Background and Context

2.1 Geographical and urban context

Located on the northeast coast of Spain, Barcelona covers an area of 101kmq in the Mediterranean coast, peppered with small hills, most of them urbanised. Barcelona is currently the Spain's second most populated city with a population of 1.6 million within its administrative limits. Its urban area extends beyond the administrative city limits with a population of around 4.7 million people, being the sixth-most populous urban area in the European Union.

Regarding climate conditions, Barcelona has a Mediterranean climate with mild, humid winters and warm, dry summers. Its average annual temperature is 21 C during the day and 14 C at night. In the coldest month (January) the temperature typically ranges from 4 to 17 C while in the warmest month (August) the typical temperature ranges from 23 to 32 C.

The EBSF_2 project demonstration will be investigating the consumption of full electric buses, vis-a-vis the implementation of specific technological solutions, with regard to the following parameters:

- Slope, the orthogonal topographic configuration of Barcelona implies two main types of bus routes,i.e. flat routes (parallel to the Mediterranean see) and hilly routes (from the mountain to the see);
- Bus demand, which varies greatly among the city bus routes;
- Season period, summer and winter affect the consumption of buses, mainly because of the impact of HVAC system;
- Driver behaviour, it is known that drivers' driving style can affect the energy consumption (around 5%).

2.2 Public transport service background

Bus lines running in the city of Barcelona can be grouped into 3 categories according to topographic criteria, namely:

- <u>Horizontal corridors</u> are parallel to both the Mediterranean Sea and the Collserola mountains, which limit the city respectively along North-West/South-Est axis. These corridors are mainly characterized by flat slope with the exception of some streets and avenues located in the central part of the city with significant slopes due to the presence of hills. Horizontal lines are important from a functional point of view also because they connect the city of Barcelona with adjoining urban municipalities (L'Hospitalet de Llobregat, SantAdrià de Besòs, Badalona, etc..).
- <u>Vertical lines</u> are perpendicular to the previous ones and connect the upper zones of the city to the lower ones (those near to the sea). Vertical corridors are generally shorter than the horizontal ones as the sea and the mountains limit the extension of the city. The main characteristic of these lines is their slope: as they connect the sea and the mountains they have a higher slope than the horizontal corridors. Despite the

slope of vertical streets is almost constant in most of the central part of the city, in some zones the slope is really important and can heavily affect the performance of the bus units. Hence, higher energy consumption in these lines is expected.

- Diagonal lines take advantage of specific avenues of the city (Diagonal, Meridiana and Sants-Paral·lel) to connect important poles of the city as well as different horizontal and vertical corridors.

The nomenclature adopted for vertical, horizontal and diagonal lines is show in Figure 1. This scheme applies to the complete new bus network whose definition started in 2009 and it is still ongoing. In addition to these orthogonal lines, classic bus lines, which will be also used during EBSF_2 tests, are still I operation.

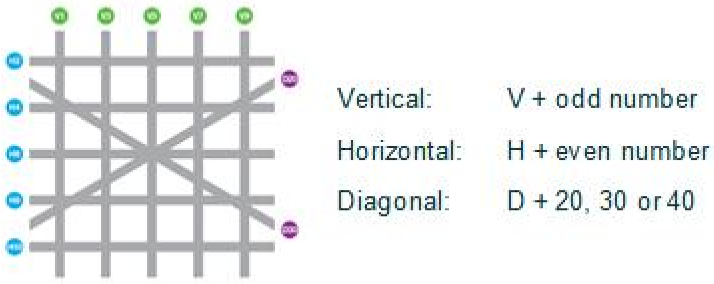

Figure 1 – Nomenclature scheme of Barcelona bus network.

Among the city bus routes the demonstration team has selected two lines to carry out the EBSF_2 tests. The opportunity to use for the tests additional lines will be studied during the development of the demonstration.

a) Flat bus line:
   Line 20 (Estació Marítima – Plaça del Congrés) is a classical bus line with high user demand. Its itinerary is mainly parallel to the see and therefore characterised by a flat slope, except for the first section.

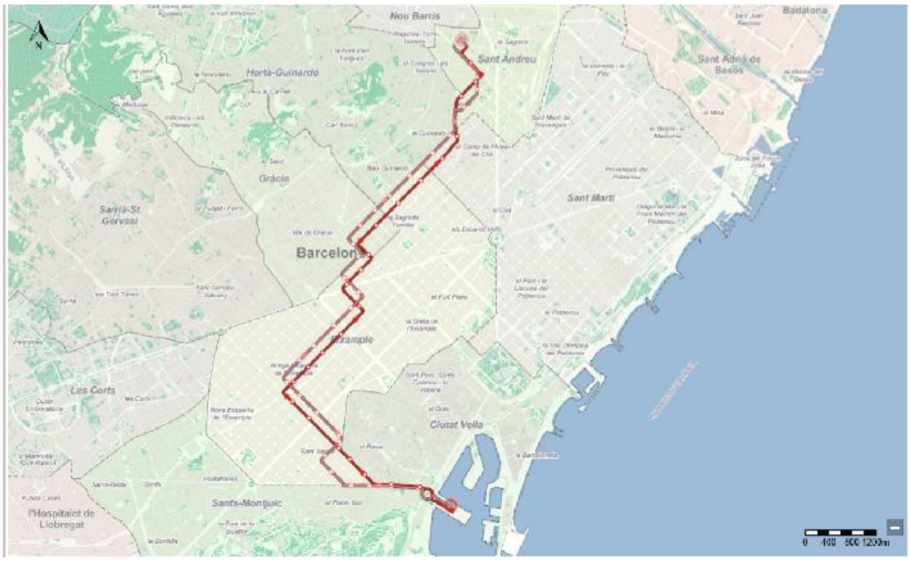

Figure 2 – Line 20 itinerary

b) Diaognal bus line:
   Line 34 (Passegi Manuel Girona . Virrey Amat) is a long bus line which runs along de Diagonal for more than half of the trip. The trajectory of the Diagonal axel follows the Diagonal avenue which constitutes one of the main urban axis of the city also crossing the Cerda's central district and passing through many social and touristic nodes. It is also one of the most congested corridor in Barcelona and it is served by several bus lines. Lline 34 presents a constant slope in its trajectory.

Figure 3 – Line 34 itinerary

Main characteristics of the selected bus lines are summarized inTable 1:

Corridor	Origin-Destination	Main streets	Length (km)	Speed (km/h)	Round trip* (min)	Headway (min) interval	Fleet
20	Estació Marítima – Plança del Congrés.	- Urgell - Industria	18.3	10.38	119	8.89	13
34	Passegi Manuel Girona . Virrey Amat	- Diagonal - Mallorca	21.1	11.279	126	6.85	21

Table 1 – Main characteristics of the test bus lines

During the development of the demonstration, the Barcelona Demo partners will evaluate the possibility to modify the bus lines to run the tests, if necessary.

3 Demo Objectives

The Barcelona demo team is committed to test and assess during the project's life time 3 technological innovations dealing with the EBSF_2 Priority Topics: Energy Management Strategy and Auxiliaries, Green Driver Assistance Systems and IT standard introduction in existing fleets.

The Technological Innovations (TI) are labeled according to the definition and coding agreed within the Task 2.2 "Definition of Validation Objectives and Test Scenario", namely

- Intelligent energy management (TI-1)
- Thermal management (TI-2)
- Advanced driver assistant system (TI-3)

The TIs are extensively described in section 5. For each of them, coherently with the EBSF_2 evaluation methodology which applies to all the project demonstrations, a set of Validation Objectives has been identified, namely:

- **VO1 - Improving the overall energy efficiency of fleets.**
  This will be addressed through an intelligent energy management strategy, an HVAC (Heating, Ventilation and Air Conditioning) system tailored for electric vehicles and an advanced eco-driving assistance tool.
- **VO2 - Improving the overall energy efficiency of specific components (HVAC).**
  The HVAC system will be updated by investigating specific characteristics and needs of fully electric buses to improve efficiency and reduce energy consumption.
- **VO4 - Increasing the uptake of fully electric and hybrid options.**
  Through the innovations proposed in the Barcelona Demo the electric vehicle consumption will be reduced and thus autonomy enhanced, especially thanks to the intelligent energy management system. This will have an important impact in the uptake of full electric buses as a clean option for urban mobility.
- **V06 - Making driving safer.**
  The eco-driving assistant will focus not only on energy efficiency but also on safety and comfort. In fact, reducing harsh manoeuvres by proper assistance will have an impact on both (comfort and safety).
- **VO7 - Making driving practice more environmentally conscious.**
  The eco-driving assistant will make the driver conscious of the environmental effects of its driving decisions.
- **VO14 - Improving interoperability for IT systems.**
  The technological solutions dealing with energy and thermal management will be compliant with EN13149 standard parts 7/8/9 and will use ITxPT specifications. Therefore, the Barcelona demo will support this new IT standard aimed to improve interoperability for IT systems for public transport.
- **VO15 - Speeding up data management.**
  The new eco-driving assistant will provide advance features thanks to the collection and exploitation of additional relevant data. Thus, improved processes to data

management and exploitation will be tested thanks to the appliance of the above-mentioned IT standards.

- **VO17 - Minimizing operating and maintenance costs.**
  Full electric ad hoc HVAC system also pursues minimizing the associated maintenance costs.
- **VO18 - Improving on board travel comfort,**
  The eco-driving assistant will focus also on on-board travel comfort by e.g. reducing harsh manoeuvres.
- **VO27 - Increasing passengers' safety.**
  Also related to the advanced driver assistant system.

4 Demo Description

The Barcelona Demo team is committed to test and assess in real-life operations 3 technological innovations to boost the full electric buses efficiency and promote their use as the primary zero emission public transport solution in urban areas.

- **TI-1 Intelligent energy management**.
  The goal is to demonstrate the reduction of auxiliary energy consumption by 20%. An intelligent Energy Management System able to anticipate energy demands of auxiliaries in order to optimize energy consumption will be adapted and deployed in the electric buses. Since driving cycles of urban buses on specific routes are always similar, they are likely to incorporate an intelligent and adaptive system, capable of learning and predict energy demands to optimize the management of energy flows between the auxiliary systems and the energy storage unit. Frequent loading and discharge of electrical energy to and from the storage system increases the consumption and the energy demand for cooling.
- **TI-2 Thermal management**.
  This TI intends to increase the efficiency of climate system and thermal management for electrified vehicles by 15-20%. Innovative solutions will be tested to minimize energy consumption for thermal management in warm and cold conditions. Saving will be achieved by introducing several technological innovations related to operation mode and specific management of HVAC components.
- **TI-3 Advanced driver assistant system**.
  An eco-drive assistant to reduce vehicle energy consumption by 8% will be tested. The system will produce recommendations for the driver based on the driving style making use of an advanced algorithm. This algorithm will almost constantly produce an assessment of the driving style of the last section of the route and will always informed the driver about his performance (via a 6-led bar). Aspects such as comfort and safety will be also taken into account by the driver assistant.

4.1 Test scenarios

The 3 TIs will be tested within the same scenario. Two electric busses (i2e by Irizar) are already running in the city of Barcelona as part of the ZeEUS Project (November 2013 - April 2017). These two busses will be modified to deploy the proposed TIs and test the energy efficiency enhancement of each of them.

Therefore, demonstration will be carried out under real operational conditions in congested urban areas of Barcelona, including any kind of daily issue in urban bus transportation such as traffic jams, slopes, etc.

The transit operation for both buses will be the same (same route and similar schedule) in order to allow an easy compassion of the results achieved before and after the deployment of the solutions, and also compare results from each vehicle in both scenario. To be able to determinate which improvement is related to any TI, the two busses will not be set up the same way. Bus 1 will be equipped with TI1 and TI2. Bus 2 will be equipped with TI3. The TIs will be installed at different times, so it will be always possible during the tests phase comparing the improvements related to each TIs.

It is worth noticing that thanks to this approach, the results of the thermal management tests will be compared on a same day, same bus line and same climate condition basis. In addition, tests in controlled environment will be carried out thanks to a heat-chamber (paint booth) facility in order to be able to control the ambient temperature during the tests.

Regarding the driver assistance system (TI-3), the opportunity to run the bus on two different routes will help comparing several parameters affecting the energy consumption, such as:

- Slopes: The orthogonal geographical configuration of the Barcelona city gets two types of bus routes.
    - o Flat routes: parallel to the Mediterranean sea
    - o Hilly routes: from mountain to sea
- Bus Demand: the different bus routes have different demands

In addition, the same drivers will be involved (when possible) to analyse energy consumption before and after deployment of the driver assistant system.

4.1.1 Vehicles involved

The demonstration will take advantage of 2 fully electric buses (12m, low-floor) implemented in the frame of European funded project ZeEUS. These vehicles are currently operated in Barcelona within the TMB fleet. .

Figure 4- Full Electric buses involved in the demo

4.1.2 No "EBSF_2 scenario" versus "EBSF_2 scenario".

As already mentioned; the tests will be carried out on 2 different bus lines:

Bus lines	Origin-Destination
20	Estació Maritima-Planca del Congres
34	Passegi Manuel Girona Vierrey Amat

Table 2 – Test bus lines

Currently, auxiliary components are powered in a conventional way. In diesel-powered buses, the auxiliaries are powered via belt-drive and they are powered as long as the engine is running. Their efficiency is dependent on the diesel-engine's rotational speed. In the "no EBSF_2-situation", the power strategy of the auxiliaries on-board an electric bus is based on the power strategy of a conventional diesel-bus. Auxiliaries are powered as soon as the electric drive is activated. Their strategy is set up to take care of basic functionalities and they run independently of the driving situation. In the "EBSF_2 situation", TI-1 will test auxiliary components powered more efficiently thanks to a system able to anticipate energy demands of auxiliaries. The optimization-program is running on a TC3-module, a Linux Based Telematics Module with integrated antennas which will implement all the energy optimization logics. On this module the online-vehicle-parameters are collected and sent to the self-learning algorithm. Improved parameters from the learning algorithm are forwarded to the vehicle and AUX-control.

Figure 5 – TC3 module

The steering pump and air compressor will be also running according to a more energy efficient strategy, which relies on the position and driving situation of the bus which will be known.

Regarding thermal management, HVAC operation is currently based mostly on external temperature. However, in order to optimize the operation there are other inputs to take into consideration, related to HVAC internal systems and components, which need to be monitored to boost its operation efficiency. New operation modes and strategies specifically designed to reduce power consuming (actuators controlled by additional external parameters different from temperature and additional internal information collected from HVAC components currently not monitored) will be test in the EBSF_2 situation.

Regarding TI-3, a selected group of drivers will drive the two demo buses in the “no EBSF_2 situation” and in the “EBSF_2 situation”. In the former case, the drivers will not receive any kind of assessment of their driving style. Even if they want to improve their efficiency, they will not have the necessary feedback to find out if they are actually saving any energy and in that case, how much their saving represents.

To move to “EBSF_2 situation”, both buses will be equipped with an advanced eco-driving assistant, able to provide continuously to drivers driving style assessment and information about efficiency level of their driving.

4.1.3 Risks which may affect the tests quality and mitigations actions

TI-1 is based on an optimization-algorithm which acts as a comfort-application. This application provides enhanced auxiliary control to run the steering pump and air compressor in a more effective way. The vehicle and AUX-control of the bus is always running to realize a minimum functionality of the auxiliary control. So the safe functionality of the vehicle is always ensured. It is the bus-manufacturers’ responsibility to decide whether to take its own management strategy or the improved proposals from the TC3-module.

Regarding TI-1 the main risk is the interruption of the communication between TC3 and the back-office. If this happens, the TC3 will not get any updates and the measured data will not be sent to the back-office. To mitigate this risk, the communication between TC3 and back-office will be ensured by UMTS (Universal Mobile Telecommunications System). UMTS availability in Barcelona is very good, so a failure will be very uncommon.
Another risk for TI-1 is a reduced energy saving if bus-manufacturers decide to not apply or apply partially the proposed management strategy for specific driving situations. To avoid this situation, the improved strategies will be carefully set up by the demo team to make them suitable for most driving situations.

The risks which might affect the test of the TI-2 is mainly related to failure of the proposed innovations such as communication failures, lack of reference data, operation modes/range not well defined or the solutions not feasible to be implement or not as efficient as estimated. To mitigate these risks, the tests will be continuously monitored and intermediate inspections as well as daily data collection will be performed. In addition, theoretical models will be studied to investigate the feasibility of the implementation and the effectiveness of the solutions.

Finally, risks associated to the implementation of TI-3 that may affect the test quality are:

- Traffic conditions: traffic conditions in Barcelona, as in most cities, can suffer significant variations. Indeed variation in traffic flows and congestion can have a negative impact on the energy efficiency of the buses during the test phase.
- Overwhelmed drivers: if the driving assistant is too demanding, the driver might feel overwhelmed due to high number of negative assessments and alerts and eventually unmotivated to improve his/her driving style.

To minimize these risks, bus lines which are not heavily affected by traffic variations throughout the year have been identified for the tests and the demo team has already agreed on arranging regular meetings with driver representatives to receive their feedback and organize training sessions to ensure a smooth and correct approach to the new system.

4.2 Preliminary data collection plan

TI-1 demonstration will rely on CAN-signals and GPS-position of the vehicle. Data will be collected online while driving through the TC3 module, a Linux Based Telematics Module with integrated antennas, and will be sent to the server automatically after each round on the line. Communication will be compliant with ITxPT and EN13149 parts 7/8/9.

TI-2 will also collect data from CAN-bus, including a new set of parameters indirectly related to cabin temperature to add additional information to the HVAC control unit in order to optimize operation mode. The additional information will be gathered via DataLoggers. Operational conditions such as door status, ambient temperature will be also collected. Data collected for TI-2 validation will be stored on a CompactFlash memory and periodically downloaded. TI-2 test will also gather monthly information directly from the drivers through inquiries/surveys.

For TI-3, on-board equipment compliant with ITxPT and EN13149 standard parts 7/8/9 will be deployed. This equipment will collect data such as consumption and position from the vehicle, process instantly the parameters thanks to a central unit and transmit relevant results to a back-office through a standard communication method. KPIs based on this data will be calculated automatically after each service is completed and later aggregated per day, driver, vehicle and route. Data collection for TI-3 test will include schedule details, CAN Bus data (odometer, consumption, speed), location provided by the GPS and driver information loaded on the back-office. In addition, direct inquiries such as questionnaires to drivers and passengers will be performed on a regular basis.

5 Demo Implementation Plan

The demonstration will be carried out in 3 main phases, namely:

1. **Preparation**. Covering all the tasks needed to thoroughly define data collection, technical requirements and develop the subsystems to deploy in the vehicles.
2. **Implementation**. Proper implementation and deployment of the solutions associated to each TI and data collection equipment.
3. **Test, data collection and analysis**.
    - o Data collection during the “no EBSF_2 situation”.
    - o Data collection after the solutions deployment (“EBSF_2 situation”)
    - o Data analysis and comparison to enhance solutions and extract conclusions.

Figure 6 shows the preliminary Gantt Chart.

	2015								2016												2017									
	M	J	J	A	S	O	N	D	E	F	M	A	M	J	J	A	S	O	N	D	E	F	M	A	M	J	J	A	S	O
BCN Demo	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30
1. Preparation																														
2. Implementation																														
TI1												Bus1																		
TI2										Bus1										Bus1										
TI3															Bus2															
3. Test, data collection and analysis																														
TI1				DC									DC											DR						
TI2				DC			DC								DC				DC			DC				DC	DR			
TI3				DC												DC								DR						

DC - Data Collection

DR - Demo Results

Figure 6 – Demo Implementation Gantt Chart

6 Demo Team

Irizar lighting the road	IRIZAR, Leader of Barcelona Demonstration. As a company specialised in bus manufacturing, IRIZAR is responsible for solutions integration in the vehicles. In addition, IRIZAR takes a relevant role in the TI-1 demonstration.
TMB Transports Metropolitans de Barcelona	TMB, as PT operator, is responsible for scenario setting and vehicle operations during the tests.
Fraunhofer	FRAUNHOFFER, as Research Center, has a relevant role in the TI-1 demonstration regarding self-learning algorithms for intelligent energy management.
digimobee	DIGIMOBEE acts as expert in the IT standards taken into account in the IT solutions deployment.
HISPACOLD	HISPACOLD, as IRIZAR's 3rd party and as a company specialized in HVAC systems, is responsible for the TI2 demonstration.
datik IRIZAR GROUP	DATIK, a 3rd party of IRIZAR and a company specialised in Intelligent Transport Solutions, is the main actor in the TI-3 demonstration. In addition, DATIK is responsible for data collection equipment definition and deployment in close collaboration with DIGIMOBEE.

Table 3 – Demo team

7 Partners' Contribution

The following partners have contributed to completion of the deliverable as specified below.

Company	Sections	Description of the partner contribution
IRIZAR	4-6	Descriptions related to TI1 and support in definition of TI2, TI3 and Data Collection Plans
FRAUNHOFER	4-6	Descriptions related to TI1
DIGIMOBEE	4-6	Support with ITxPT and EN13149 related decisions and descriptions
TMB	3-6	Description of scenarios and bus lines involved
HISPACOLD	4-6	Descriptions related to TI2
DATIK	4-6	Descriptions related to TI3
IRIZAR	1-2	Merging, summary and review
UITP	All	Review of document

End of the Document