STARTING EUROPEAN FIELD TESTS FOR CAR-2-X COMMUNICATION: THE DRIVE C2X FRAMEWORK

R. Stahlmann[1], A. Festag[2], A. Tomatis[3], I. Radusch[4], F. Fischer[5]

1. AUDI AG, Germany, *rainer.stahlmann@audi.de*

2. NEC Laboratories Europe, Germany, *andreas.festag@neclab.eu*

3. Hitachi Europe, ICTL, France, *andrea.tomatis@hitachi-eu.com*

4. Fraunhofer Institute for Open Communication Systems, Germany, *ilja.radusch@fokus.fraunhofer.de*

5. ERTICO – ITS Europe, Belgium, *f.fischer@mail.ertico.com*

ABSTRACT

In the last decade, various research and development activities in communication systems for car-to-car and car-to-infrastructure communication have reached a mature technological level and are being standardized. From such communication systems, in particular operating in the 5GHz frequency band with WLAN technology, a great benefit in safety and road traffic efficiency is expected. DRIVE C2X is a European project that plans, organizes and evaluates field operational tests (FOT) for cooperative systems using CAR-2-X communication. This paper presents the testing framework of the project. It covers test methodology, system specification and implementation, tools for test execution and control, as well as operational and technical guidelines. The framework will be used at various test sites across Europe. It enables test sites to execute field tests and assesses the impact of the system on safety as well as socio-economic aspects.

INTRODUCTION

DRIVE C2X [1] is a European project for the assessment of cooperative systems – utilizing car-to-car and car-to-infrastructure (CAR-2-X) communication – by large-scale field operational tests. The field tests attempt to validate the assumptions that cooperative systems can indeed enhance road safety, traffic efficiency and travel comfort. The project creates a test methodology for cooperative systems and coordinates the execution of tests across involved European test sites. Based on the test results, the project assesses the impact of the system on safety and traffic efficiency taking into account socio-economic aspects. This paper focuses on the test framework that is implemented and customized for the tests sites that are associated with the DRIVE C2X project.

DRIVE C2X can be regarded as a next logical step in a series of R&D projects on cooperative systems in the last decade. These projects have consolidated a mature technical basis using WLAN (in particular IEEE 802.11p), GPS and ad hoc networking technologies, as well as cellular communication systems, and studied various applications in different environments and scenarios. The DRIVE C2X project directly builds on the technology components and testing tools developed in the project PRE-DRIVE C2X [2]. It is aligned with the Car-to-Car Communication Consortium (C2C-CC) and the COMeSafety European ITS communications architecture [3,4]. It utilizes the FESTA general methodology for planning and execution of field operational tests [5]. DRIVE C2X follows the communication standards developed by ETSI Technical Committee ITS [6] within the mandate of the European commission to develop a minimum set of standards for the deployment of cooperative systems.

The design of the FOT framework harmonizes the requirements from different stakeholders and takes various technical aspects into account. This approach ensures a wide acceptance of the framework by

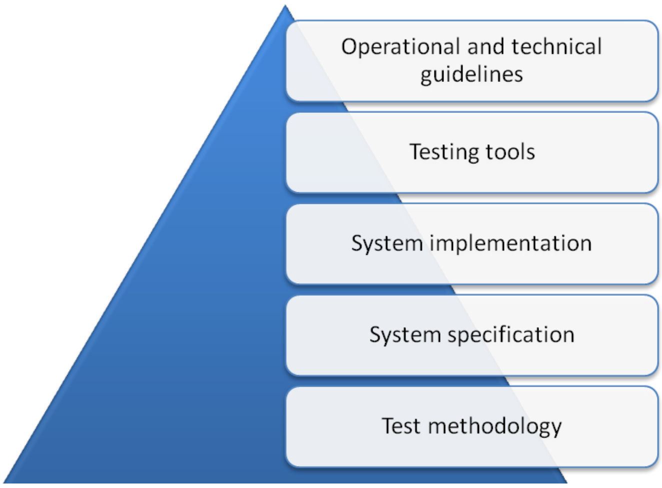

Figure 1: Components of the DRIVE C2X FOT framework

the test sites associated with the DRIVE C2X project. The FOT framework comprises five major components as shown in Figure 1. Eventually, the FOT framework will provide specifications, prototypes, tools as well as guidelines and instructions for field tests with cooperative systems. The framework will be used in later phases of the DRIVE C2X project when the field tests are executed and the impact assessment is performed. The framework is also linked and offered to national FOTs for cooperative systems that are currently being initiated in several European countries and associated with DRIVE C2X.

The remaining sections of this paper detail the core elements of the FOT framework as shown in Figure 1. Finally, we give an outlook for the DRIVE C2X project.

TEST METHODOLOGY

The test methodology applies the well-known FESTA FOT chain V-model [5]. It suggests an a-priori definition of hypotheses and consequently structures the FOT in three main phases: preparation, data collection, and analysis. The individual steps of this methodology are followed in all steps of the project and adapted for the specific requirements of a cooperative systems field trial. In the DRIVE C2X project 18 functions applying both car-to-car and car-to-infrastructure communication technologies are selected for the implementation. Then, use cases, research questions and hypothesizes are created, related performance indicators derived and the necessary measures defined. Having prepared the FOT accordingly, data can be acquired, preprocessed and stored for further analysis in order to conduct the impact assessment related to driver behavior, road safety, traffic efficiency and mobility. In addition to the impact assessment, user acceptance of the system will be investigated and a technical evaluation of the DRIVE C2X system performed. Finally, the FOT results are scaled up to a European-wide level in order to create a reasonable background for future decisions on

The selection procedure of the functions is based on a weighted score model taking into account experiences from the predecessor project PRE-DRIVE C2X [9], expectations for the evaluation quality of the functions, their importance in related projects and standardization, as well as the commitment of involved test sites to realize these functions. As a result, 18 functions from the areas of safety, traffic efficiency and infotainment/ business are selected (see Table 1). For nine of them, a full impact assessment will be applied.

Safety	Traffic Efficiency	Infotainment and Business
Traffic jam ahead warning *	In vehicle signage/ Speed limit *	Insurance and financial services
Roadworks warning *	Green light optimized speed advisory *	Dealer management
Car breakdown warning *		Point of interest notification
Approaching emergency vehicle *		Fleet management
Weather warning *		Transparent leasing
Emergency electronic brake lights *		
Slow vehicle warning		
Post-crash warning *		
Obstacle warning		
Wrong way driving in gas stations		
Motorcycle warning		

Table 1: Result of DRIVE C2X function selection
For functions marked with (*), a full impact assessment will be carried out.

Before implementing the functions in the DRIVE C2X system, a simulation-based pre-validation was applied to the function Green light optimized speed advisory and to one safety-related warning function in order to evaluate both functions. As a result, recommendations for test cases, parameterization of the functions, and technical assessment were presented.

During the preparation phase of the DRIVE C2X FOT the necessary tools and a reference system are developed. The DRIVE C2X project has seven associated test sites that are categorized into system test site (STS) and functional test site (FTS). After system integration and testing of the system and tools in a lab environment, functional testing of the system is conducted at the STS in Helmond, Netherlands. After the DRIVE C2X system has successfully passed the functional testing, the system and the test tools are distributed and adapted to the six FTS: Brennero (Italy), Frankfurt/M. (Germany), Gothenburg (Sweden), Tampere (Finland), Vigo (Spain), and Yveline (France). The FTSs will conduct a piloting phase of data acquisition before starting the test execution of the FOT. All DRIVE C2X test sites are shown in **Error! Reference source not found.**.

Figure 2: Test sites associated with the DRIVE C2X project

SYSTEM SPECIFICATION

The *system specification* represents the technical specification of the DRIVE C2X system. It covers the communication system with radio and protocol stack as well as facilities, HMI, applications, security and management support. The system is specified at three main levels: architecture, entity and component specification.

The *architecture specification* depicts the system at a high abstraction level omitting specification details. Core element of the architecture is the ITS station [3] realized as vehicle, roadside and central ITS station. The architecture defines the communication scenarios, as well as the information flow among the elements by the ITS message types (i.e. CAM, DENM and SPAT). The architecture-level specification also covers external, test-specific systems (test management centre, test site control centre, test driver communication unit) and its connection to the system.

The *subsystem specification* refines the subsystems in greater detail. It clarifies the components of each ITS station and the interfaces towards test site specific subsystems, e.g. vehicle and road side sensors. Figure shows an exemplary entity specification of the roadside ITS station with the ITS station and its external interfaces towards specific test-specific subsystems and other ITS stations. The necessary components are shown in Figure .

The *component specification* is the last level of specification and represents the basis for component implementation. In general, a component represents a modular functionality at a certain layer of the ITS station protocol stack (Figure). Each component specification has a general description of its functionalities and interfaces. Additionally, a UML representation of the component provides details about the structural relationships with other components consisting of a formal specification of the exposed and required interfaces. Finally, sequence diagrams describe the interaction of a component with respect to the exposed interface.

Finally, the system specification includes specification of protocols and message formats used by the DRIVE C2X system. If mature standards are available, the standards are referenced and, if appropriate or needed, enhanced.

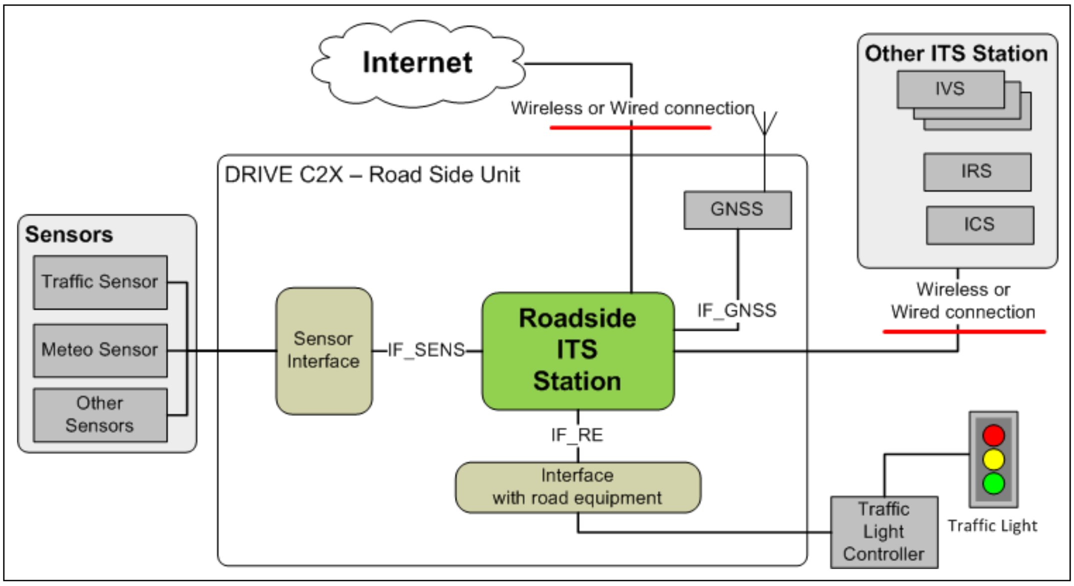

Figure 3: Subsystem specification of the roadside ITS station

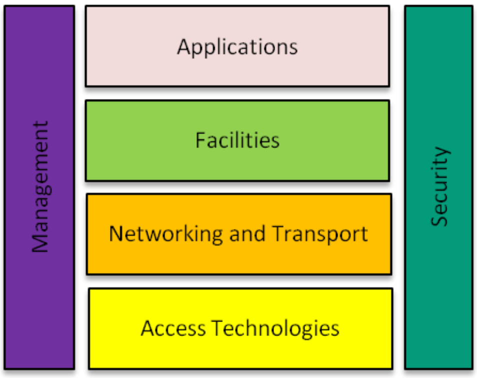

Figure 4: ITS station protocol stack

SYSTEM IMPLEMENTATION

The DRIVE C2X framework provides a *reference implementation* of the system. It comprises a set of software components for the vehicle, roadside and central ITS station [7],[8],[10] as well as external components for testing. The reference implementation comes with corresponding hardware platforms.

The software platform comprises the components shown in Figure : Access technologies comprise communication and positioning devices for IEEE 802.11p, 3G and GPS with software drivers. Specifically, the ITS G5 (IEEE 802.11p) device has dual transceivers that operate on the control and service channels. The interface to the upper layer allows for per-packet-control of radio parameters, such as channel, data rate and transmits power. For network and transport, two main protocol sets are realized: GeoNetworking with the Basic Transport Protocol (BTP) enables ad hoc communication among vehicles and between vehicles and roadside units based on ITS G5. It supports single-hop (for transmission of periodic messages and multi-hop communication. For the latter it offers geographical addressing, i.e., packet routing to a node or number of nodes within geographical area based on their geographical position. BTP implements a UDP-like transport protocol for multiplexing/de-multiplexing of facility-layer messages based on ports. In addition, IPv4/IPv6 forwarding over 3G cellular networks provides connectivity to the vehicles, roadside and control center for applications, management, testing and logging purposes. Facilities components include the relevant message types: Cooperative Awareness Message (CAM), Distributed Environmental Notification Message (DENM), Signal Phase and Time (SPAT) and the intersection topology message (TOPOM). Further facilities include the Vehicle Data Provider (VDP), Position and Time (POTI), as well as digital maps and location referencing (LOCREF) for navigation support. The backend integration manager (BIM) provides connectivity to backend infrastructure via web services.

The software reference system is ported to different hardware platforms: These platforms are embedded systems designed for automotive and roadside infrastructure environments. Being evaluation platforms and pre-products, the platforms meet various hardware requirements for the respective environments. An ITS station is typically realized in two physical units, the communication control unit (CCU) implements access technologies and networking protocols, the application units (AU) execute facilities and applications, whereas security and management functionalities are distributed between the two boxes. CCU and AU execute the Linux operating system. Software for the AU is implemented for the OSGI framework (Knopflerfish). The software is specifically instrumented for the FOT: Relevant components produce log data that are collected and forwarded via the 'ITS testing unit'. A common HMI is used during the execution of the FOT for the impact assessment with driver involvement.

As part of the FOT framework, the software components are integrated and tested in laboratory environment. The system is integrated into vehicles and roadside installations and its functioning verified. The testing of the DRIVE C2X framework is linked to the plug test activities in ETSI for those components, where mature base standards exist.

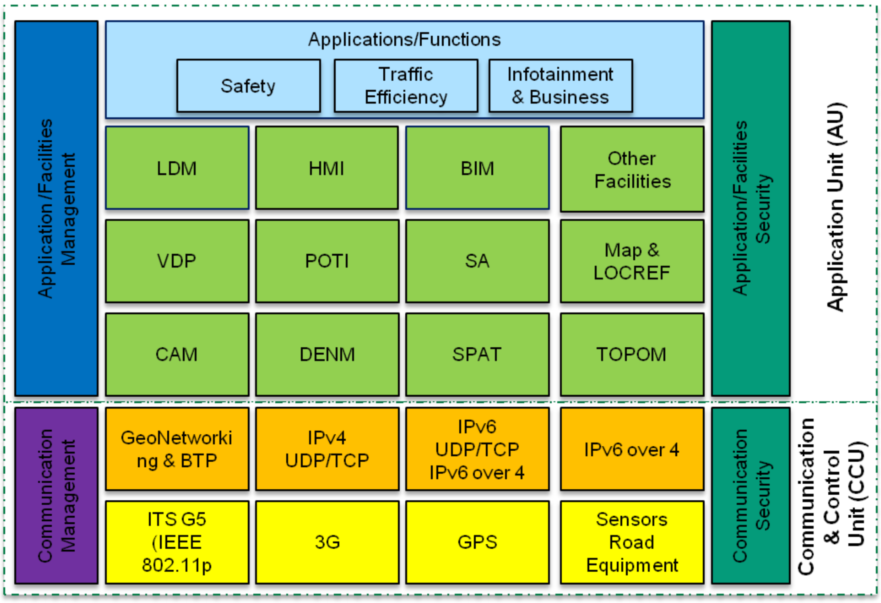

Figure 5: Overview of software components implemented in DRIVE C2X

TESTING TOOLS

Apart from the system implementation test components are provided and part of the FOT framework. These test components are added to ITS stations (vehicle, roadside, and central) for logging and monitoring support during FOT execution. Furthermore, test tools for the creation of test scenarios, support of data management, and test control are created. Figure depicts a condensed overview of all respective components.

The testing tools are tailored to their specific use in one of the FOT phases – test planning, operation, and data collection. All tools should smoothly interchange data with each other and provide a similar user experience in order to minimize training of test operators.

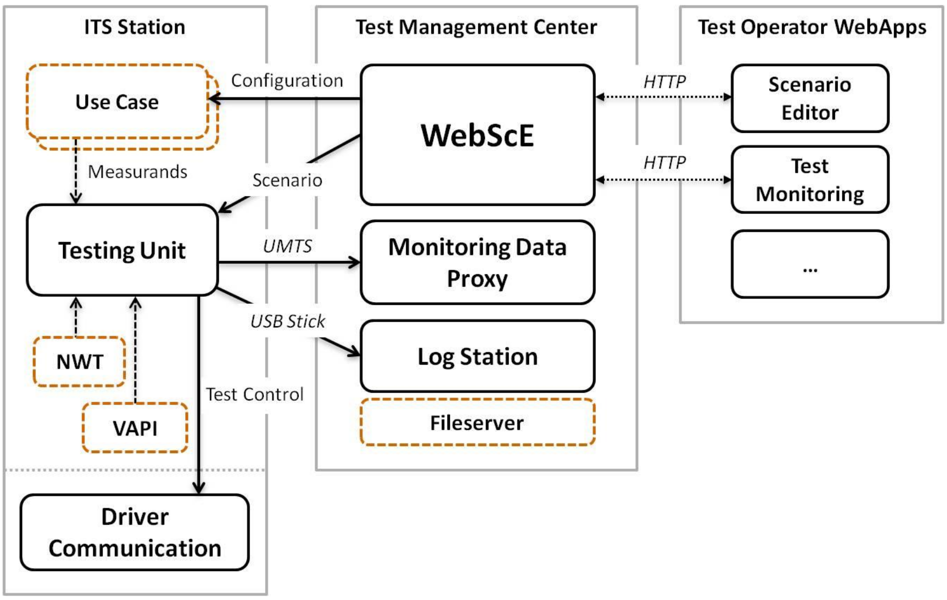

Figure 6: Overview of testing tools

Therefore, the DRIVE C2X test management center (TMC) is built around a multi-user and remote accessible web application, the Web Scenario Editor (WebScE). The first module within the WebScE – the Scenario Editor – allows detailed planning and specification of test scenarios. This includes the specification of measurands, which are the base for the processing of performance indicators for evaluation in the data collection phase, the specification of vehicle routes, driver instructions, and even the specification of necessary pre- or post-conditions, number of required vehicles, etc.

The specification of measurands is vital for the success of the FOT. Generally, two approaches to derive measurands for data collection are applied: in a top-down approach, performance indicators are specified and later broken down into their respective measurands. In a bottom-up approach component and use case developers are requested to provide meaningful measurands. For each measurand defined, a respective measuring technique must be implemented in the corresponding component of the ITS station. This is mostly done via a special purpose API, the DRIVE C2X Logging API. This API allows component developers to transmit measurands easily to the test management centre. The Logging API provides type-safe programming interfaces for each measurands and communicates internally with the ITS Testing Unit (ITU). The ITU is responsible to collect and enrich the measurands with time stamps and positing information and to safely store the logged measurands on internal storage. At specific intervals the locally stored data is transmitted to the test management centre via a dedicated Log Station. Transmission can be done via any means of transport, however, due to the large amount of data, USB sticks proved most successful and easiest to handle. In order to reduce the amount of data that gets collected on the ITS stations, the ITU filters the measurands according to the logging profile specified in the test scenario. Then, only the specific measurands are stored that can later be used to calculate the performance indicators. The logging profile is transmitted at the beginning of the test execution individually to each ITS station together with configuration parameters for use cases and other information such as driver instructions.

Driver instructions are mostly used in controlled testing and communicated to the driver either through the integrated vehicle HMI or a dedicated device connected to the ITU. During controlled testing drivers are provided with more or less specific routes (via the Driver Communication Unit) and test operators start and stop test scenarios explicitly. Since FOT for cooperative driving usually involve large number of vehicles and drivers, DRIVE C2X utilizes a dedicated monitoring tool. This monitoring tool utilizes data that the ITU sends to the test management centre via a dedicated UMTS link. The monitoring data is comprised of selective measurands, which are sent to the Monitoring Data Proxy in the TMC with a frequency of 1Hz and visualized in test monitoring module of the WebScE.

The above testing suite supports each phase of a FOT (planning, execution, data acquisition) with a dedicated tool.

OPERATIONAL AND TECHNICAL GUIDELINES

Considering the overall goal of the DRIVE-C2X project that is to evaluate the cooperative driving functions, different types of assessment will be provided: technical assessment, impact assessment and user acceptance. The collection of the data for the assessment is resulting from the execution of FOT operations by the functional test sites, which requires adapting and using complex cooperative systems as well as dedicated tools for controlling the test execution and logging the vehicle data. Furthermore, the execution of FOT operations needs to manage many other operational and logistical issues.

With regard to these issues, DRIVE-C2X has paid particular attention to plan creating detailed and comprehensive guidelines, enabling all test site leaders to carry out successful FOT operations. These guidelines will address the different roles of the test sites during the FOT execution phase. In particular the guidelines aim to explain how to use the cooperative DRIVE-C2X system and the tools for test control and logging. Moreover, practical information is provided about how to proceed with the test operations and how to collect and handle the data resulting from the logging.

In order to be useful for the test sites, the guidelines need to be comprehensive, easy to read and have to present the information in a clear and logical way. According to these objectives, DRIVE-C2X decided to handle these guidelines like a user manual following the chronology of the different operations. Thus the guidelines start first with the preparation of the test site, followed by the test operations and end with the data collection (Figure).

Re-using past experience is a key factor of success. FOT operations are already ongoing in the EUROFOT project, enabling to use the lessons learned. Thus EUROFOT guidelines are likely to provide very useful inputs for DRIVE-C2X, in particular for the organization of the FOT operations from logistical and legal point of views.

Last but not least, the guidelines will be the reference document of the whole project for the terminology. All definitions and abbreviation used in the project are gathered in the glossary of the guidelines, ensuring a common and consistent understanding of terms.

The technical and operational guidelines are critical for the success of the project, enabling to proceed with FOT operations in a consistent way across the different test sites, which are then likely to provide compatible data for the assessment of the cooperative driving functions.

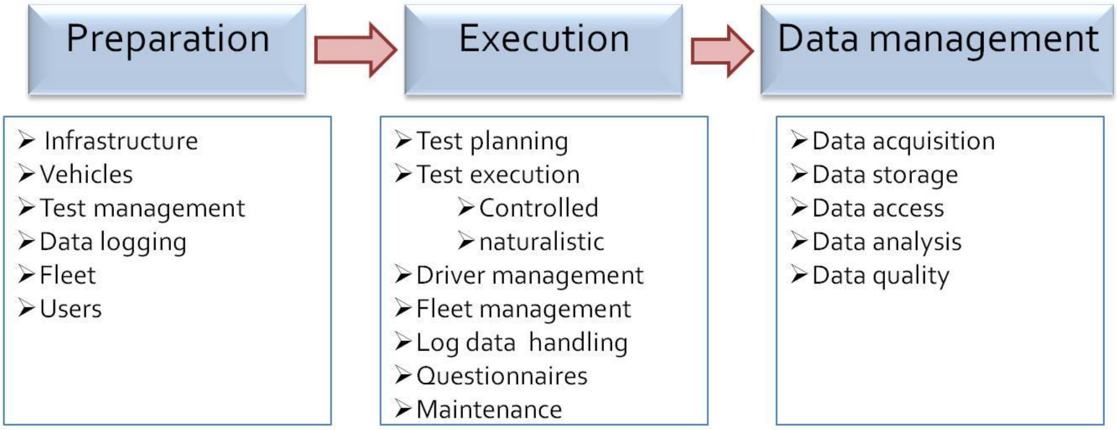

Figure 7: Overview of technical and operational guidelines

SUMMARY AND OUTLOOK

DRIVE C2X is the major pan-European field operational test on cooperative systems based on CAR-2-X communication using WLAN and 3G communication technologies. The project has started in 2011 and carries out an assessment of technology and functions over the next three years. The functions to be studied cover a selected set of road safety, traffic efficiency and infotainment/business-related functions. These functions will be assessed by corresponding metrics. Following the FESTA V-model for planning and execution of field tests, the DRIVE C2X project currently defines the FOT framework. This paper has presented details about the framework covering test methodology, system specification and implementation, tools for test execution and control, as well as operational and technical guidelines.

The DRIVE C2X reference system developed by the project fully complies with the standards that are developed in ETSI Technical Committee ITS as part of the mandate M/453 of the European Commission to develop a minimum set of standards for cooperative systems. In this context, the project is strongly linked to the ETSI plug tests for Cooperative Mobility Services, which first event will take place in November 2011. After completion of the framework, it will be used in subsequent phases of the project for FOT operations and FOT evaluation. These phases will be conducted at a system test site and several functional test sites across Europe. This procedure ensures that the framework is validated before test execution and creates a solid basis for the impact assessment.

ACKNOWLEDGEMENTS

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