DRIVing implementation and Evaluation of C2X communication technology in Europe

DRIVE C2X

Accelerate cooperative mobility

Deliverable D42.1

DRIVE C2X FOT research questions and hypotheses and experimental design

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SEVENTH FRAMEWORK PROGRAMME

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Executive summary

This document describes the process and the results of the activities carried out for the design of experiments to be conducted in the DRIVE C2X FOT. The objective of the experiments is to enable the impact assessment of a number of functions based on cooperative systems. The design process followed the FESTA methodology which includes the identification of functions and use cases, research questions and hypotheses formulation, identification of performance indicators and measures and the study design.

Function Selection

The functions to be assessed and the related use cases, mainly derived from the previous PRE-DRIVE C2X project, have been selected out a total of 22 (which will be technically evaluated) according to a number of criteria and are mainly safety related, but they can have also an impact in efficiency, mobility and environment.

The selected functions are the following:

1. *Road works warning (RWW)*: vehicles approaching a road works are warned in due time before they are reaching the road works area. The function works for stationary road works as well as for moving road works as they can be found typically on motorways.
2. *Traffic jam ahead warning (TJAW)*: the driver is warned if he/she is approaching an end of a traffic jam to avoid running into the last vehicle in the queue.
3. *Car breakdown warning (CBW)*: approaching traffic is warned in due time before reaching a broken down vehicle to avoid running into the broken down vehicle or endangering people in the vicinity of the broken down vehicle.
4. *Weather warning (WW)*: information about bad weather conditions ahead is communicated to oncoming traffic to avoid entering of areas with adverse weather conditions at a speed too high.
5. *Emergency electronic brake light (EEBL)*: in case of a hard braking manoeuvre following traffic is warned to avoid rear end crashes and backing up.
6. *Approaching emergency vehicle warning (AEVW)*: approaching emergency vehicles warn surrounding traffic about their presence to ensure that they can proceed quickly even in very dense traffic.
7. *Post crash warning (PCW)*: if an accident has occurred oncoming traffic is warned to ensure that drivers slow down and do not run into the vehicles that had an accident.
8. *In-vehicle signage & regulatory and contextual speed limit (IVS)*: traffic sign information such as “ban on passing” is communicated into the vehicles and indicated in the *instrument cluster or in the head unit. Information on fi*xed and variable speed limits as well as on the recommended optimal speed is communicated into the vehicles and indicated in the instrument cluster or in the head unit. This application does in particular address variable message signs.
9. *Green-light optimal speed advisory (GLOSA)*: signal phases of traffic lights are communicated into vehicles in order to inform their drivers about the optimal speed to pass traffic lights at green.

Research questions , hypothesis formulation, performance indicators and measures

From previous field studies (e.g. TeleFOT, EuroFOT) there already is significant amount of experience how FESTA methodology was applied in the definition of research questions and hypotheses. This experience was utilized in developing the DRIVE C2X approach which aims to be a systematic and efficient way to provide a consistent and well-motivated list of research hypotheses for the different functions. The FESTA handbook proposes a list of basic general research questions. However a specific formulation for each function is needed to generate a wider set of research questions.

In DRIVE C2X four impact areas are considered: *safety*, *efficiency*, *mobility* and *environment*. The approach is based on the consideration that the impact produced by a function is always due to the reaction/behaviour of the driver after the reception of a message generated by the function itself. It was decided, hence, to follow a two-steps process: at first think and measure changes in driver behaviour - then decide how to interpret these changes in terms of traffic *safety*, *efficiency*, *mobility* and *environment*. For example if a driver is warned about the presence of an accident 300 meters before the location it is probable that he reduces speed gradually and approaches the accident scene smoothly. Without the warning he would probably realize the presence of the accident later and emergency braking is likely. The function could provide a significant improvement of the *safety*, but also efficiency could be improved. Decreasing speed in general has effects on *safety*, *efficiency* and *environment*.

Based on this approach, research questions and related hypotheses were generated for the *travel and driver behaviour* classified into three classes: strategic, tactical and operational. The strategic level defines the general planning stage of a trip, including the determination of trip goals, route and modal choice plus an evolution of costs and risks involved. At tactical level drivers exercise manoeuvre control, allowing them to negotiate the direct prevailing circumstances. At this stage hypotheses were defined as open statements (e.g. *There is an increase/decrease in the event mean speed because...*).

Research questions were defined aiming to systematically cover all impacts on *travel and driver behaviour*. At each research question at least an hypothesis as been associated.
Then it was decided which changes in driver behaviour are relevant for each impact area, relating the change with the impact area. As a result we had a consistent pattern of impacts: change 'a' in driver behaviour results 'b' in safety, 'c' in environment, 'd' in efficiency, 'e' in mobility (note that b, c, d, e can also be 'not relevant'). The outcome was an Excel file called the *hypotheses tool*.

The *hypotheses tool* was complemented with the performance indicators and measures for each hypothesis. Objective measures are essentially obtained from CAN (vehicle dynamics parameters, consumption, pedals, steering,...), GPS (position, time) , V2V messages (necessary to reconstruct the event) and situational variables(weather, light condition,...). Questionnaires are used to answer at research questions relating acceptance, comfort, willingness to pay and other subjective items.

As next step the *hypotheses tool* was applied to each function to be assessed. In this process we deleted all hypotheses not relevant for the function under consideration. For relevant research questions, we completed the open statements as hypotheses (e.g. for Weather Warning function: *There is a decrease in the event mean speed because driver is warned about adverse weather condition*), obtaining testable sentences relating the assumed change to the function indicating also the impact mechanism. As a result we had the lists of hypotheses for each function and for each impact area, assuming behavioural changes in a consistent way.

Hypotheses were then prioritized for each function considering three priority levels:

At the end of the compilation the prioritization process started. It was decided to assign hypotheses to three priority classes:

- High – very important
- Medium – important
- Low - nice to have

All the results (basic template and compiled templates) are reported, for editorial reason, in a reduced version (only most relevant fields) as annexes to this document.

Experimental Procedure

The experimental procedure is designed to ensure that the results of the evaluations are statistically robust, valid, and free from any bias caused by confounding factors. In addition, the results need to be transferable to European roads and road users.

In the studies are defined and identified *events* both when the driver receives the DRIVE C2X function (*treatment)* and when not (*baseline).* These *events* are specific driving occurrence relevant to a considered function. Time-wise, the *event* begins when the driver reaches the distance at which the function is activated or would be activated, and ends when the driver encounters/leaves the location/situation that triggered the activation of the function, or deviates to an alternative route.

The study provides insight to what should be measured and when, the number of vehicles required, the choice of experimental design, driver tasks in the tests and test scenarios.

The proposed first choice for experimental design is *within subject design*, that is all the different levels (*baseline* and *treatment*) are administered to the same people but at different times. The alternative approach is *between subject design* that considers separate control and treatment groups.

In DRIVE C2X, two different test approaches will be adopted: *controlled* and *naturalistic* approach.

In the *controlled* approach, the test drivers are called into the test and they are asked to drive the test route with some arrangements. Preferably, the tests will be conducted in real traffic. However, to guarantee drivers safety, some use cases should be performed only on a closed test track.

In the *naturalistic* approach, the test drivers' behaviour is monitored in their daily driving, and the routes and driving times are based on drivers' needs. The collected data is later organized according to the relevant variables. In this approach, the design is applied to main part of the data afterwards. Even in the *naturalistic* approach some situations can be organized – e.g. test drivers can be asked to drive or tempted to drive to a specific location in same time. This approach was called *semi-naturalistic*. The *naturalistic* approach is better from ecological and external validity viewpoint and it is more convenient to forecast what would happen in real traffic when the systems will be implemented and used widely.

The *controlled* tests may, however, be more practical to organize, especially when several equipped vehicles are needed in the same location to provide V2V services. *Controlled* tests are optimally performed in real traffic. The tasks in the *controlled* studies may vary from a preliminary fixed route to a task in which the driver is allowed to choose the route freely for a given task. The later could be called *semi-controlled* and it resembles the *naturalistic* approach.

The sample size estimation is another key issue of the experimental design. In the document this estimation is made considering as impact the reduction of 5Km. in the spot speed measured 100m. before the location of the *event* that generated a warning message. Applying the Cochran formula the obtained sample size (*events* to be collected for a single function) is about 1000 in *naturalistic* tests 250 in controlled tests.

It is acknowledged that there is uncertainty in the estimates, and the suggested sample sizes are indicative. Furthermore, the suggested number of *events* should be needed together from all Test Sites for a function to be able to have statistically significant results for the main impacts.

In parallel, a first estimation of the number of *events* that can be collected in the different Test Sites for each function, is reported, based on the types of tests, the number of cars and people involved and the duration of the tests.

The studies cover different circumstances and situations, for this reason *test scenarios* are defined for each selected function. The *test scenarios*, structured as tables, indicate choices to be made for the controlled tests; in which circumstances they should be done, which situations should be covered.

For each function		
Base line	same route with the event but without the service	
Use of control (trend)	comparable drivers without service	
Event	Definition	
	sent/received	distance to the incident/target
	nr of events /route	estimate
	nr of events / test person	
Test environment (only for controlled tests)	Description	description
	length of the base line route	x km
	length of the test route (partly equipped)	x km
Road type	Urban	yes / no
	Rural	yes / no
	one-carriageway highway	yes / no
	Motorway	yes / no
Speed limit	xx km/h	
Location	Link	yes / no
	Intersection	yes / no
Lighting	Daylight	yes / no
	Night	yes / no
Weather	Good	yes / no
	adverse/visibility	yes / no
	adverse/slippery	yes / no

The *test scenarios* provide guidance for detailed planning of the tests. They are reported in the annex 5. Each *scenario* starts with a short description of the function.

For the function that will be tested both in *naturalistic* and *controlled* conditions separate *test scenarios* are reported.

The *test scenarios* represent a first guideline for the real implementation, however the details will be decided in the Test Sites when the tests are planned in more detailed in the future on the map and utilizing the Scenario Editor Tool designed for this purpose. Because of the iterative nature of this planning process it is important that there will be expertise in study designs available in the Test Sites and good communication and share of information between the Test Sites and those who will conduct the analyses for the impact assessments. Some more detailed practical guidelines and description of different phases in the test arrangements are provided in a table with associated suggested planning.

The chapter about experimental procedure is closed with some considerations/hints relating to the combination of functions.

Technical experimental design and methodology

This chapter reports an outline of the Technical experimental design and methodology which is dealt more in depth in an internal report developed in another work-package of the project. Technical evaluation is aimed (1) to verify that the DRIVE C2X system meets the technical requirements of the selected use cases and (2) to gain detailed insights into the DRIVE C2X system's technical performance. The technical core of the system is the V2V and V2I communication. The most important measurement data are communication range, packet reception rate as a function of the geographic distance between sender and receiver and communication delay. General recommendations are provided about testing equipment, test metrics and testing procedure.

User acceptance

The chapter is an outline of the activity that will be performed in a dedicated work-package.

The investigation of the subjective outcome (in the sense of a change in assessment or possible behaviour) is a key element for the overall evaluation of the functions developed in DRIVE C2X. All the functions that are selected can be analysed within the context of a user survey. However, the functions differ in terms of the extent to which they can be checked in the methods that are applied.

After a brief description of three methods (questionnaires, focus groups and user forum) a table with applicability of the methods to each function is reported.

Boundary Conditions/ Legal and ethical issues

DRIVE C2X will carry out Field Operational Testing of vehicle communication technologies. The outline of legally relevant boundary conditions is meant to advise test management and raise awareness on the issues to take into account for test accomplishment.

Therefore the advice is meant to estimate the effort needed on boundary conditions for further planning after the analysis of the technical background of systems and measures from a legal point of view to identify critical aspects to be dealt with. In particular contractual agreements, data privacy, insurance, liability, special licences and ethical approval are treated. The legal advice is provided as a general guideline limited by the fact that specific national law and regulations will usually apply in many legal aspects. Therefore detailed actions to be taken over will be the task of legal experts with special knowledge on the legal system in the countries where the specific testing will be accomplished which should support the test site managers at national level.

Conclusions

The aim of the work package was to define research questions, hypotheses and indicators, to specify the experimental design and to define boundary conditions. The deliverable has two audiences: Test Sites on one hand expecting guidance how to conduct the tests, on the other hand the research scientists responsible for analyses. Indeed, the purpose of designing the experimental procedure is to guide and make solid and consistent analyses possible.

It should be underlined that the matter dealt in the deliverable is quite challenging due to the intrinsic complexity of cooperative systems , the large number of functions and Test Sites which will test them. For this reason a structured approach derived from FESTA and the TeleFOT experience was followed, and a special attention was dedicated to the integration and harmonization aspects. The experimental procedures designed in this report as well as definition of common research hypotheses harmonize the tests and data collection and create the basis for harmonized analyses and thereby contribute in integration of FOTs in different national Test Sites.

Finally, it is obvious that all details cannot be guided in advance without knowing the circumstances in detail in the Test Sites. The Test Sites must start to implement the plans suggested in the document. It is anticipated that the activities will lead to new questions and need to adapt the plans and agree about common approaches.