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Impact Assessment of Cooperative Systems in the DRIVE C2X Project

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Abstract

This paper presents the impact assessment of the Cooperative Intelligent Transport Systems piloted in the 7th Framework Program project DRIVE C2X. In this project, eight cooperative systems were developed and evaluated in Field Operational Tests (FOTs). This paper presents the methodology used in the impact assessment of the eight systems in the areas of safety, traffic efficiency, and environment and mobility impacts, at the European level. The DRIVE C2X functions, which mostly targeted safety impacts, achieved safety improvements but with some adverse effects on traffic efficiency and slight positive effects on fuel consumption and CO2 for the environment. On reflection, greater impacts could have been achieved if traffic and human factors specialists had been involved in the system design and prototype phases.

Keywords:

Cooperative systems, impact assessment, scaling up

Introduction

The assessment used data measured in Field Operational Tests (FOTs) carried out on several test sites located in different EU countries. DRIVE C2X addressed four major technical objectives:

1. Create and harmonise a European wide testing environment for cooperative systems
2. Coordinate the tests carried out in parallel throughout the DRIVE C2X community
3. Evaluate cooperative systems
4. Promote cooperative driving

The project built on previous and on-going work on cooperative systems. The FOT operations were carried out by a Europe-wide testing community including seven test sites in Finland, France, Germany, Italy, the Netherlands, Spain, and Sweden.

DRIVE C2X aimed at delivering a comprehensive assessment of so called Day-one cooperative functions which are primarily focused on improving road safety. The tested functions comprised both vehicle-to-vehicle (V2V) and infrastructure-to-vehicle (I2V) communication. Eight of the functions tested in the FOTs were included in the impact assessment:

- Approaching Emergency Vehicle Warning (AEVW)
- Traffic Jam Ahead Warning (TJAW)
- In-Vehicle Signage (IVS)
- Road Works Warning (RWW)
- Obstacle Warning (OW)
- Car Breakdown Warning (CBW)
- Weather Warning (WW)
- Green Light Optimal Speed Advisory (GLOSA)

In addition, the German test site simTD also tested Emergency Electric Brake Light (EEBL).

This paper reports on the impacts and user acceptance of the DRIVE C2X functions. It is based on the DRIVE C2X Deliverable “Impact Assessment and User Perception of Cooperative Systems” (Malone et al., 2014).

Method

Test sites

Six test sites (TSs) operated FOTs and collected data for impact assessment and user acceptance[1]. The coordination of the FOT operations was left under the responsibility of the test site leaders. However, the FOT organisation followed a common and harmonised methodology, in order to preserve the conditions for combining data from all test sites for the impact assessment and user acceptance analyses. This presented a challenge to the assessments, because the local circumstances needed to be understood in the assessment.

There were some differences in the FOT execution between test sites, for instance the Swedish test site applied the “naturalistic driving” (ND) method while the others used “controlled tests” (CT). In the controlled tests, the drivers were called into the test and followed the driving instructions provided by the test-site instructor, allowing the driver to encounter specific test situations, such as a traffic jam. In the naturalistic approach, the test drivers' behaviour was logged in their daily driving, and the routes and driving times are based on drivers’ needs. The conclusions that can be drawn differ between

1 The seventh TS in Helmond, the Netherlands, performed validation testing of the DRIVE C2X systems.

naturalistic driving studies and controlled tests differ in short vs long-term acceptance, driver behaviour, and ultimately the impacts on traffic efficiency, safety, environment and mobility. The analyses carried out in DRIVE C2X focus on the short-term impacts.

Each test site determined which functions would be tested. Table 1 provides an overview of the functions per Test Site. Guidance for the experimental procedure was given to the test sites in the form of the D42.1 "DRIVE C2X FOT research questions and hypotheses and experimental design" (Brignolo et al., 2011) and in several common meetings and workshops. The Test Site implemented their experimental designs, identified and contacted the test persons, carried out the tests and submitted the data to the DRIVE C2X ftp site for checking, processing and analysis.

Table 1 - Overview of functions tested at Test Sites (CT = Controlled test; ND = Naturalistic Driving)

Function	Finland (CT)	Italy (CT)	Spain (CT)	Sweden (ND)	Germany (CT)	France (CT)
IVS/Speed limits	X	X	X	X	X	X
IVS/Other signs	X	X	X	X		X
TJAW		X	X		X	
AEVW		X	X		X	
EEBL					X	
OW/RWW/CBW	X	X	X	X	X	X
WW	X		X	X		
GLOSA	X		X	X	X	

Impact Assessment Methodology

Impact assessment and user acceptance made use of different data and methodologies in their assessment. User acceptance analysis used of subjective data in the form of questionnaires. Part of the driving behaviour and the mobility impact assessments integrated objective and subjective results to come to a final result.

Impact assessment aimed to draw conclusions about the use of the DRIVE C2X functions and their effect on driving behaviour, safety, mobility, traffic efficiency and environment. The methodology for carrying out the impact assessment used the research questions, hypotheses and indicators defined earlier in the project, using the FESTA methodology (FESTA Handbook, edition 2013).

Figure 1 shows an overview of the steps in impact assessment. FOT data provided the input for the impact assessment (see top of Figure 1), which fed the driver behaviour analyses. The safety, traffic efficiency, environmental and mobility analyses used the driver behaviour analyses results as well as other data and tools. Safety impacts also made use of previous expert assessments found in the literature and expert assessment of DRIVE C2X. Traffic efficiency and environmental impact assessment made use of simulation models. The scaling up of the effects to the EU-level made use of external data.

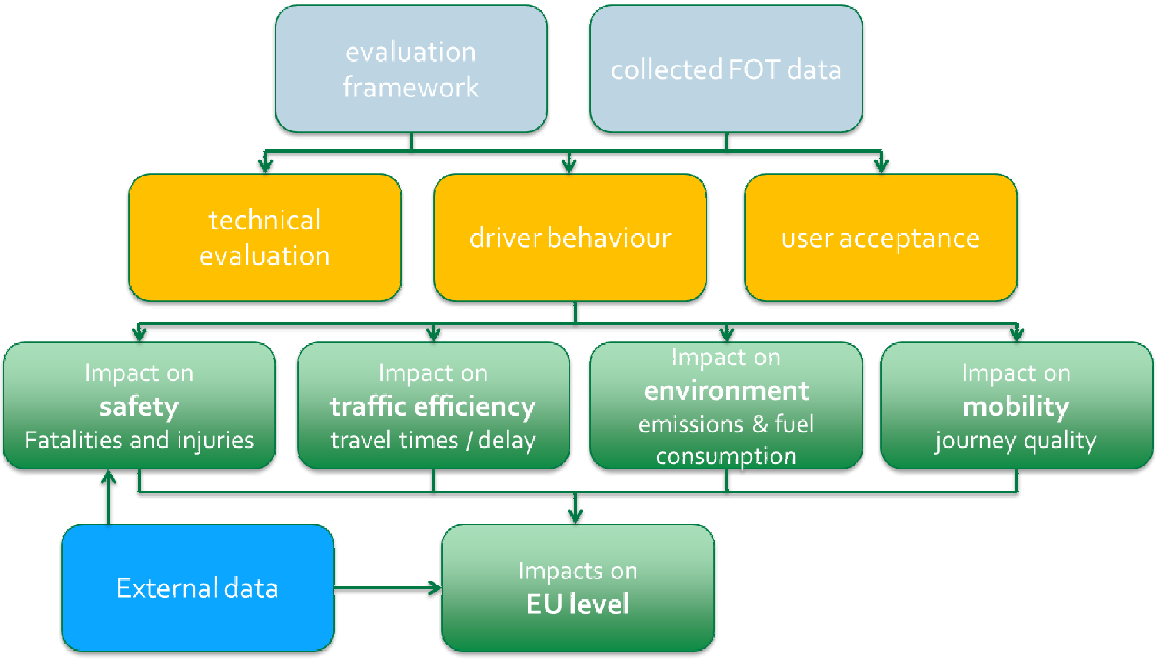


Figure 1 - Overview of impact assessment process

Thus, from the FOT data, first the impact of the function on driver behaviour was assessed, using a large set of hypotheses on speed choice, car-following behaviour, braking behaviour, and so on. Driver behaviour was critical to the impact assessment. Because only a small percentage of all vehicles on the road was equipped at any time in the DRIVE C2X FOTs, the effect on a traffic flow level or on a road network level was not directly measurable using detector loops, cameras or similar infrastructure-based sensors. Direct measurements from within the equipped vehicles were necessary to determine the effects of a function. The impact depends on what the driver does with this information or warning provided by the function. Is the driver more aware of the situation or does he/she take his/her foot off the accelerator, thus increasing safety and decreasing fuel consumption, or not? Thus, assessment of driver behaviour was necessary as a first step in assessment or evaluation for all impact areas. The driving behaviour task analysed the FOT data to determine the difference between how drivers drove with and without the DRIVE C2X functions. For each test site and each function, indicators such as speed patterns, speeding, acceleration and braking for different circumstances were analysed (event-based analysis), and then pooled with data from other test sites and analysed again. These analyses provided input for the assessments of the impact areas safety, traffic efficiency, environment and mobility. Effects on these impact areas could be split into direct and indirect effects. Direct effects are caused directly by the function (for example longer travel times caused by lower speeds). Indirect effects are caused by the function in an indirect way (for example a decrease in congestion caused by a decrease in number of accidents). Impact assessment covered mostly direct effects, but e.g. safety and mobility included also some indirect impacts.

The purpose of the scaling up task was to carry out the crucial step of translating the results of the FOTs to the European level. The DRIVE C2X FOTs addressed situations limited in time, scope and geographical scale. Even large FOTs with thousands of vehicles only represent a tiny percentage of the vehicle kilometres and of the traffic composition at any given time. Hence, scaling up the results to the EU-level is necessary to understand the effects of the functions in the European context. The results at the EU level are valuable in and of themselves, and were also used as input to the Cost-Benefit Analysis (CBA).

A tool called SCENIC was used to scale up the local impacts of the Drive C2X ITS systems of traffic efficiency and environment to the EU-level. This tool aims to:

- Provide a standard method for scaling up local impacts to higher-level regions in time and space, and considering possible and relevant situations.
- Save effort on assembling data and performing calculations.

The general setup of the tool is as follows:

- The tool assumes that the impacts of an ITS are known for one or more *local scenarios*. These are called the *local impacts*. A local scenario describes a *situation*, which is a set of circumstances characterized by the values of several *situational variables*. Typically, the impacts are known only for a small region in time and space.
- As output, the tool provides the impacts of this ITS for a *target scenario*. These are called the *target impacts*. The target region can be a much larger region in time and space, and may cover a range of values for the situational variables. The user chooses the target scenario. In the case of Drive C2X, this is the EU-level and covers the period of a year.
- Both local impacts and target impacts are given as changes in certain *performance indicators*. The same performance indicators are used for input and output, and the tool works irrespective of the choice of indicators.
- Each performance indicator corresponds to a certain traffic problem, which has a certain *problem size* in the target scenario – for example, the problem size of the indicator “delay” is the total delay in the target scenario. In order to translate the local impacts into target impacts, *external data* are needed to weight the local scenarios in the target scenario. The weights reflect the fraction of the problem size in the target scenario that corresponds to the local scenario.

Figure 2 shows how the SCENIC tool calculates the target impacts. The required aggregated input data consist of the problem size in the target scenario for each situation, the local impact and the target scenario choice. The impact of the ITS in the target scenario is calculated as the weighted average of the impact of the ITS in local scenarios, where the weights are given by these problem sizes. The tool has various ways to handle missing data, or mismatches between the situations where the local impacts are known, and the situations for which the problem sizes are known.

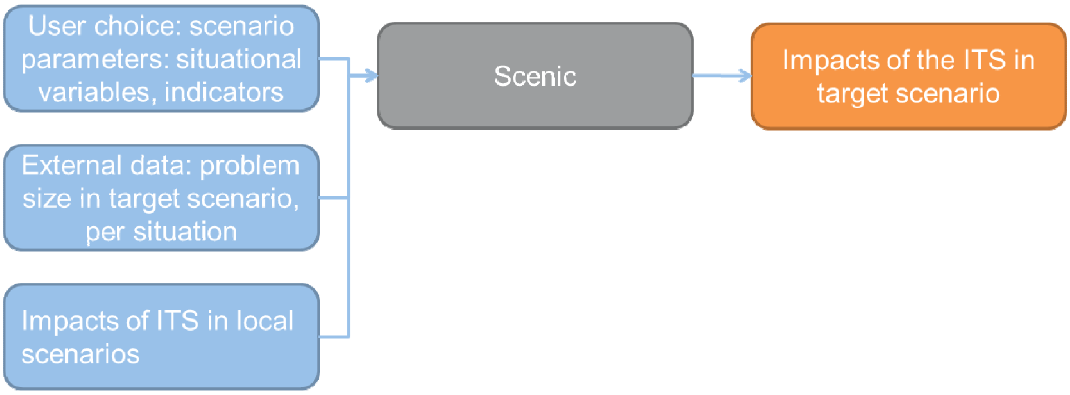


Figure 2: Conceptual model of the SCENIC tool. Inputs are in blue, outputs are in orange.

When assessing the impact of DRIVE C2X function on the European level, scenarios were used. They took into account most important aspects that affect the impacts of DRIVE C2X systems: penetration level of the cooperative system in Europe, road types, traffic composition and traffic demand (peak or off-peak). Scenarios assumed that heavy goods vehicles were not equipped, since no DRIVE C2X functions were tested on heavy goods vehicles. However, the results shown in this paper assume 100% of the infrastructure needed for the functioning of the system is equipped. Results were also calculated for lower penetration rates of infrastructure equipment. For these and more detailed results, the reader is referred to Malone et al. (2014).

Results

Driver Behaviour Impacts

The driver behaviour results showed that for most of the functions, changes in driving behaviour were observed that were in line with the intended and expected changes. The functions were primarily safety functions, and the impacts, when found, were mostly changes in speed, and its derivatives. No changes in strategic behaviour (route choice, mode choice) were expected nor found due to the nature of the functions. The data was successfully pooled over test sites to strengthen the statistical significance of the tests. In summary:

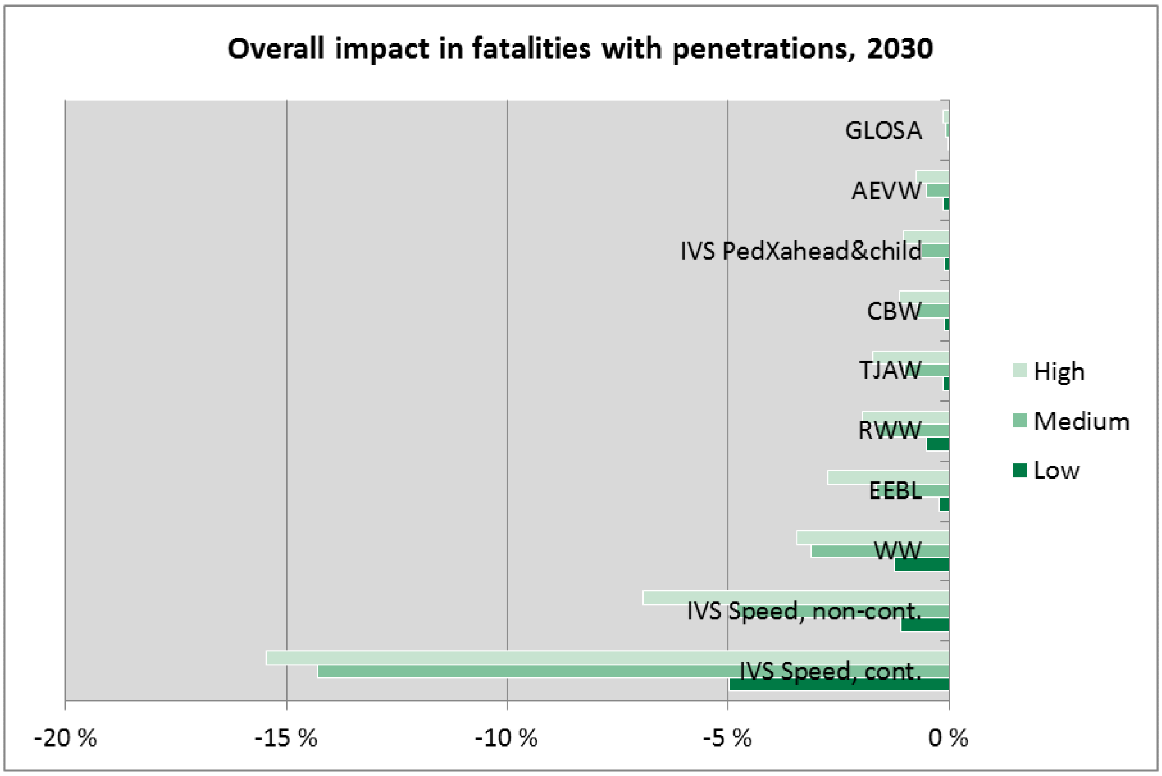
- For In-vehicle signage / Speed limits, the overall tendency is that average speed decreased when passing speed signs in treatment, although not significantly at each test site. The impact is also present in a higher portion of time when driver the decelerates harder.

- The function In-vehicle signage / Other signs had positive impacts on driver behaviour in areas where special attention should be paid to vulnerable road users (pedestrian crossing ahead, child sign). Mostly the impact is seen in small decelerations in speeds in the critical areas.
- With the Obstacle warning / Road works warning / Car breakdown warning function, drivers showed an improved hazard awareness by slowing down close to the broken car / road works, conducted fewer sudden manoeuvres, and became more alert (aborting non-driving related secondary tasks).
- When driving with Traffic Jam Ahead Warning, drivers who reached the tail of the traffic jam reduced their speed earlier with less harsh braking.
- Drivers showed somewhat smoother driving behaviour when approaching a traffic light when driving with Green Light Optimal Speed Advisory.
- The FOT results did not demonstrate a clear effect of Weather Warning / Rain and Slippery road / Ice&Snow on speed. It seems that drivers only followed the warning by reducing speed, if they perceived the warning as reliable and relevant, i.e. if they found indications for risky conditions which matched the warning received. The results suggest that drivers do not follow the warning provided by Weather Warning if vehicle speed is at a resonsible level and weather situation is not severe.
- When driving with Approaching Emergency Vehicle, drivers adapted their speed in a more appropriate way.
- Although the Electronic Emergency Brake Light Warning field tests showed no statistically significant impacts on driver behaviour, the results indicated that the first driver behind the braking vehicle benefited from the function.

Safety Impacts

The main safety results was that the functions affected traffic safety in a positive way by preventing fatalities and injuries. The most effective functions from the safety point of view were In-vehicle signage/ Speed limit and Weather warning. The next were Electronic emergency brake light, Traffic jam ahead and Road works warning functions. However, even the Green light optimal speed advisory function developed primarily for improvement of environmental impacts enhanced safety slightly.

Figure 3 shows the estimated percentage reduction in fatalities and injuries in 2030 for the low (26%), medium (91%) and high (100%) passenger car penetration rates due to the DRIVE C2X functions in the EU-28. Thus, the findings are based on equipping only passenger cars. It is expected that equipping heavy goods vehicles will result in a larger percentage improvement in safety.



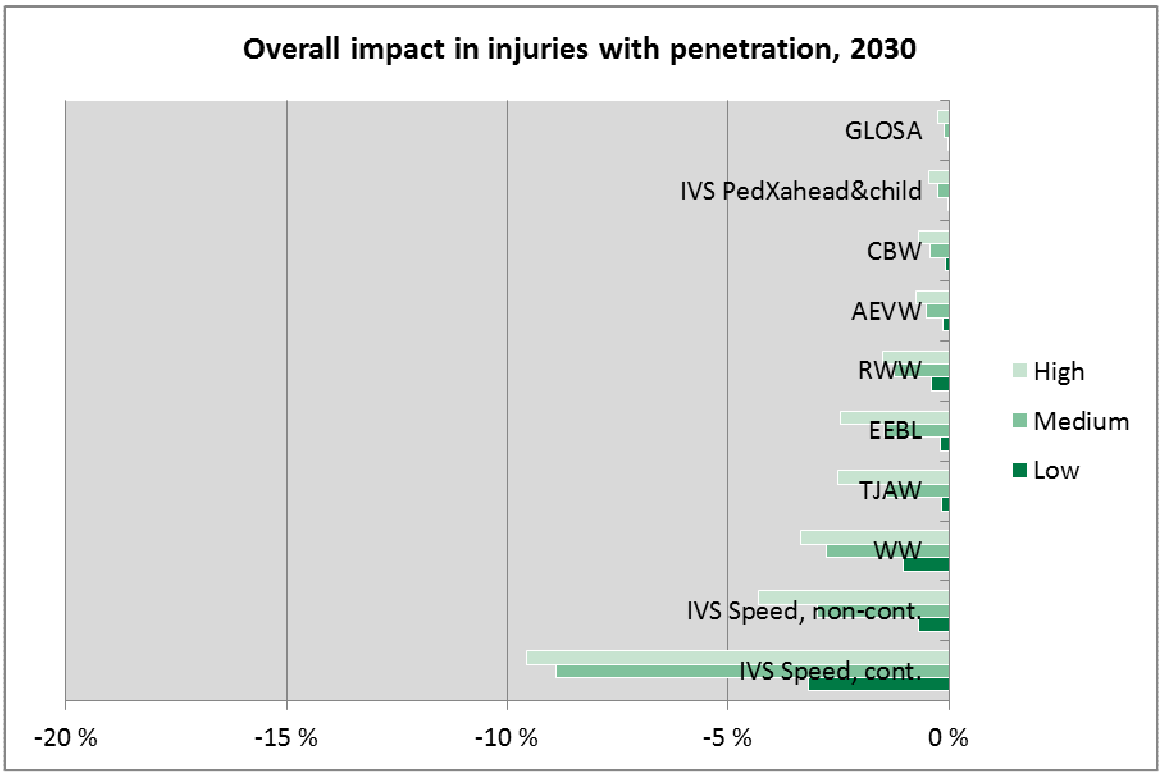


Figure 3 - The overall safety impacts of cooperative functions in 2030 with vehicle penetration scenarios: low, medium and high

Traffic Efficiency Impacts

Traffic efficiency effects have been estimated for the Drive C2X functions that may have a significant effect on traffic efficiency, namely In-vehicle signage / Speed limits, Obstacle warning / road works warning / car breakdown warning, Traffic jam ahead warning, Green light optimal speed advisory and Weather warning.

Of all the functions examined, Traffic jam ahead warning, Green light optimal speed advisory and In-vehicle signage / Speed limits were expected most likely to have traffic efficiency and environmental impacts, in addition to safety impacts. Nevertheless, Traffic jam ahead warning had no statistically significant change in delay and this results in no effect on the traffic efficiency.

Figure 3 shows the change in delay per function in the EU-27 only for statistically significance results. It is expressed as a percentage of the EU-27 forecast, for low, medium and high car penetration levels and with 100% of the infrastructure equipped.

Significant change in delay ($p<0.05$) were found in the scenarios with low demand and medium and high penetration level. The low demand and low penetration scenario had close to significant results ($p \sim 0.1$) and were used in the scaling up analysis. Green light optimal speed advisory had a very small increase in delay, assuming 100% of the traffic lights are equipped. Like Traffic jam ahead warning, Green light optimal speed advisory also had a limited geographic area: intersections equipped with traffic lights, and no Green light optimal speed advisory on motorways. Therefore, Green light optimal speed advisory functions were expected to have an impact only in limited geographic areas.

The scaling up results (for European level) made use of all the statistically significant results from In-vehicle signage / Speed limits. These were the low demand high speed and rural roads. The In-vehicle signage / Speed limits drivers lower their speed using In-vehicle signage / Speed limits. This translates into an increased travel time and thus increased delay. The In-vehicle signage / Speed limits function differs from Traffic jam ahead warning and Green light optimal speed advisory in an important way: it can be applied on all public roads, as each road has a legal speed limit. In-vehicle signage / Speed limits therefore is a function that is useful all the time and on all roads. Given the potentially universal applicability of In-vehicle signage / Speed limits, the delay shown in Figure 4 is small in comparison.

In conclusion, Traffic jam ahead warning, Green light optimal speed advisory and In-vehicle signage / Speed limits increased safety with some adverse effects on traffic efficiency. The scaling up results shown for traffic efficiency assume that only passenger vehicles are equipped with these systems. The functions Traffic jam ahead warning, Green light optimal speed advisory and In-vehicle signage / Speed limits have the potential to provide greater contributions to traffic efficiency than the current implementations in DRIVE C2X indicate.

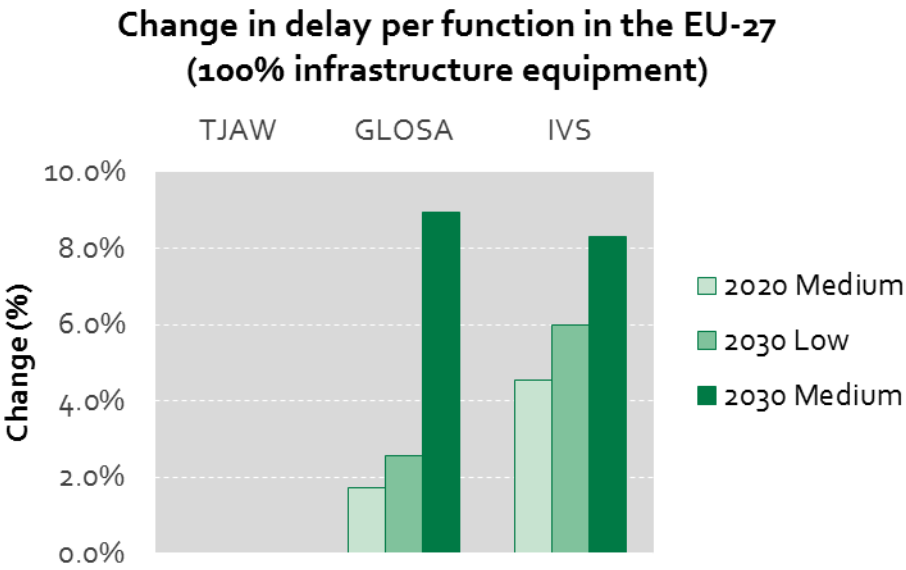


Figure 4 - Change in delay as compared to European reference situation (%). Only the statistically significant results were used.

Environmental Impacts

The environmental impact assessment was carried out for the functions Traffic jam ahead warning, Green light optimal speed advisory and In-vehicle signage / Speed limits. To indicate the effects on a higher geographic scale, the effects were scaled up to EU-27 level. This means that the frequency of the situations, e.g. in terms of vehicle kilometres per relevant situation, was taken into account. This implies that a large effect in an infrequent situation may lead to an extremely small, maybe even negligible effect if such a situation is rare. In contrast to safety effects, where each and every accident prevented or mitigated, counts, the reduced emissions may be very small when viewed on a national or European level; this is due to the fact that emissions in all other traffic situations remain unchanged.

However, it must be noted that this depends also on the nature of the emission components. While CO2 has a global effect and it does not matter where and when it is emitted, other components such as NOx or PM have a local effect. Especially the latter two may show critical levels in urban hotspots. In such conditions, any reduction is welcome if legal limits are surpassed, even if the reduction is negligible on a national level.

The influence of two of the three functions investigated here, namely Traffic jam ahead warning and Green light optimal speed advisory, is limited to very specific situations, the approach to a traffic jam and the approach to traffic lights. IVS in contrast operates on longer road sections and also on all types of roads, urban, rural and motorway. Therefore, Traffic jam ahead warning and Green light optimal speed advisory do not show changes in the environmental impact when scaled up to EU27-level. IVS in contrast does show some positive impact. For most environmental indicators the impact is less than

1%. The impact grows with penetration rate, and is biggest for fuel consumption and CO2 (-2,3 % in the high passenger-car penetration rate).

Mobility Impacts

The main results of the mobility impact assessment showed positive implications for the quality of travel. Cooperative functions did not have implications for amount of travel or travel patterns on personal level mobility, except for IVS speed limit signs which lead to such a decrease in average speed that it had an impact on overall duration of the journeys due to more continuous nature of the function and high frequency of events.

Most functions did cause small increases in duration (in magnitude of up to 5 seconds per event). On the personal level these infrequent increases are insignificant. However, at the European scale, that would already correspond to larger impacts on duration of time spent on road. However, if the decrease in delays caused by a decrease in accidents and other incidents due to decreased speed and increased situational awareness is taken into account, the overall impact on duration on time spent on road might be zero.

Test participants assessed no changes in the number of journeys or modal choice. However, they assessed positive implications for the quality of travel. This may in the long-term increase the number of car journeys.

The positive implications for the quality of travel were, specifically, the impacts on journey quality seen as changes in comfort, feeling of safety, stress, fatigue, and uncertainty. The focus groups assessed the functions to decrease fatigue and stress, and increase comfort. In the questionnaires, the users assessed the use of cooperative systems to increase comfort slightly. Green light optimal speed advisory, Approaching emergency vehicle warning and Traffic jam ahead warning received the strongest agreement in increased comfort. There was a complete agreement to the increased feeling of safety for all of the functions and test sites. Obstacle warning, Approaching emergency vehicle warning, Car breakdown warning and Traffic jam ahead warning all had quite strong impacts on increased feeling of safety. The cooperative systems seemed also to have a mild positive impact on stress in most cases. However, there were some countries and functions where there was no visible impact of stress decrease. The most effective functions to decrease stress were assessed to be Green light optimal speed advisory and Approaching emergency vehicle warning. Uncertainty while driving was assessed to decrease slightly for all of the functions and test sites. The two most effective functions to decrease uncertainty were Obstacle warning and Green light optimal speed advisory.

Discussion

The DRIVE C2X project investigated Day-one cooperative functions which are primarily focused on improving road safety. The analysis revealed that the safety results are promising for the DRIVE C2X functions individually. When the cooperative systems are brought to the market, they will be offered in bundles of systems on vehicles. That is, multiple systems will be offered in a package. Because all functions contributed in safety, the safety impacts of the bundles will be larger than the impacts of the individual systems analysed, however, lower than the sum of individual effects because the targeted accidents are partially overlap.

The DRIVE C2X functions achieved safety improvements with some adverse effects on traffic efficiency and slight positive effects on fuel consumption and CO2 for the environment. It is assumed that greater improvements to traffic efficiency and the environmental can be achieved with modifications to the DRIVE C2X function implementation. The eCoMove project (eCoMove, 2014) showed that the combination of addressing driver behaviour and the traffic control algorithm leads to significantly larger environmental effects. Furthermore, the DRIVE C2X user survey revealed that the optimization of traffic flow is as important to drivers as safety issues. Addressing traffic flow as well as safety in cooperative functions would expand the system experience and make the functions more attractive to consumers.

The qualitative mobility assessment revealed positive impacts. Specifically, journey quality was improved in terms of user stress, user uncertainty, feeling of safety and comfort.

The impact assessment findings provide lower bounds on the impacts for environment and safety for the given penetration rates. Only passenger vehicles were equipped in the analyses. It is assumed that if heavy goods vehicles were equipped as well, the impacts would be positive for this class of vehicles, too, which represent a significant amount of CO2 and other emissions.

User acceptance indicated a huge potential for the market introduction of DRIVE C2X technology. Still, it can also be noted that major improvements are needed related to the implementation towards the driver. Information accuracy needs to reach a clearly higher level in a market-ready solution. At the same time, innovative concepts are needed to provide appropriate HMI solutions that do not lead to distraction of the driver.

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References

1. R. Brignolo, Rama, P., Cosenza, S., Innamaa, S., Gasser, T., Rappold, N., Le, L., Bergman, J., Schindhelm, R., Benz, T., Brouwer, R., Jonkers, E. & Möller, M. 2011. *FOT research questions and hypotheses and experimental design*, DRIVE C2X Deliverable D42.1, Version 0.5, August 4 2011.
2. DRIVE C2X proposal, 2010, DRIVing implementation and Evaluation of C2X communication technology in Europe, Grant agreement no.: 270410.
3. eCoMove, 2014. http://www.ecomove-project.eu/news-events/final-event/conference/.
4. *FESTA Handbook* Version 4. 2013. Available: http://fot-net.eu/download/festa_handbook_rev4.pdf.
5. K. Malone, Rech, J., Hogema, J., Innamaa, S., Hausberger, S., Dippold, M., Van Noort, M., De Feijter, E., Rämä, P., Aittoniemi, E., Benz, T., Burchert, A., Enigk, H., Giosan, I., Gotschol, C., Gustafsson, D., Heinig, I., Katsaros, K., Neef, D., Ojeda, L., Schindhelm, R., Sütterlin, C., Visintainer, F., 2014, *Impact Assessment and User Perception of Cooperative Systems*, DRIVE Deliverable D11.4, Grant agreement no.: 270410.
6. Transport and Mobility Leuven, 2010. TREMOVE model. Leuven: Transport and Mobility Leuven. [referred 4.6.2014]. Available: http://www.tmleuven.be/methode/tremove/home.htm