CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF TRANSPORTATION SCIENCES

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DESIGN OF SYSTEM SOLUTION FOR REALIZATION OF EVALUATION OF THE C-ROADS CZ

Master thesis

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MASTER'S THESIS ASSIGNMENT

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Guides for elaboration

During the elaboration of the master's thesis follow the outline below:

- Perform analysis of cooperative systems and their practical use
- Perform analysis of realized C-ITS projects with a focus on their evaluation and assessment
- Design and develop a system solution for realization of evaluation within the C-Roads Czech Republic project
- Verify the functionality of the designed solution on the pilot implementation of C-Roads Czech Republic
- Evaluate the achieved results and describe further developments in the field of C-ITS systems evaluation

Declaration

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Michal Mlada

In Prague 30. 7. 2020

signature ....

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Abstract

The subject of this diploma thesis is the design the robust framework for evaluation of cooperative systems in C-Roads from the point of view of their impact and benefit for users. The thesis contains a proposal of evaluation framework and its functionality verification for C-Roads CZ. Subsequently, the framework is disassembled, and an experiment is performed for two selected use-cases. The results of the evaluation are analysed and the impact of individual use cases on the tested drivers is evaluated.

Key words:

Cooperative systems, Evaluation, Impact Assessment, User Acceptance, C-Roads, C-ITS

Contents

List of the Abbreviation

Abbreviation	Description
API	Application Programming Interface
BO	Back Office
CAM	Cooperative Awareness Message
CAN Bus	Controller Area Network bus
CEN	European Committee for Standardization
C-ITS	Cooperative Intelligent Transport System
CSV	Comma-Separated Values
CZ	Czech Republic
DBC	CAN database
DCC	Decentralized congestion control
DENM	Decentralized Environmental Notification Message
DSRC	Dedicated Short Range Communication
DT	Deployment and Tests
EC	European Commission
ECU	Electronic Control Unit
ETSI	European Telecommunications Standards Institute
EVA	Emergency Vehicle Approaching
FESTA	Field operation test networking and data sharing support
FOT	Field operational tests
GLOSA	Green Light Optimal Speed Advisory
GPS	Global Positioning System
GUI	Graphical User Interface
HLN	Hazardous Location Notification
HMI	Human Machine Interface
IEEE	Institute of Electrical and Electronics Engineers
INEA	Innovation and Networks Executive Agency
INTERCOR	Interoperable corridors
IoT	Internet of Things
ISO	International Organization for Standardization
ISV	Intersection Signal Violation
ITS	Intelligent Transport System

Abbreviation	**Description**
ITS-G5	Intelligent Transport System – G5
ITS-S	Intelligent Transport System Station
IVI	In Vehicle Information
LTE	Long Term Evolution
MAP	Map data
OBD2	On-Board Diagnostics
OBU	On-Board Unit
Pcap	Packet capture
PTP	Public Transport Preference
PTS	Public Transport Safety
RDS-TMC	Radio Data Signal – Traffic Message Channel
RLX	Railway Level Crossing
RSU	Road-side Unit
RVU	Road-Vehicle Unit
RWW	Roadworks warning
SAE	Society of Automotive Engineers
SCOM	Steering Committee
SISCOGA	Spanish C-ITS pilot
SPAT	Signal Phase and Timing
SSV	Slow and Stationary Vehicle
TEN-T	Trans-European Transport Networks
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
WCW	Weather Condition Warning
WG	Work Group

1. Introduction

With the development of communication technologies and autonomous vehicles comes new possibilities of use. One of them is communication between vehicles, vehicles and infrastructure and vehicles and others such as cyclists or pedestrians. This communication is generally called Cooperative Intelligent Transport Systems or C-ITS. A number of projects focus on this communication and standards are created and implemented in Europe and America. The most important institutions dealing with the standardization of C-ITS systems include, for example, European Telecommunications Standards Institute (ETSI), Institute of Electrical and Electronics Engineers (IEEE) or European Committee for Standardization (CEN). These standards are subsequently enforced both by individual states, which install the infrastructure that enables this communication, and by car manufacturers, which use these standards in their cars.

One of the largest C-ITS projects in Europe is C-Roads. This is a project which, with the help of national pilot projects, implements C-ITS with the same standards and technologies in 18 states of the European Union. One of the main goals of such a project implemented in the European Union is to unify C-ITS technologies in the European countries so that a car purchased in Germany, for example, can use C-ITS across borders throughout Europe.

The goal of C-ITS is to help drivers prepare for unexpected events by alerting them to impending events sooner than would be possible without use. A driver without C-ITS could only react to these unexpected events, such as a broken-down vehicle or a passing ambulance, in close proximity after seeing it. This will allow the driver to react faster and more accurately to sudden situations and events that happen on the road. C-ITS thus brings great potential to increase safety and efficiency of transport. This is accompanied by an increase in driving comfort and a reduction in emissions, for example due to frequent braking.

There are many assistance systems in today's cars, such as the blind spot monitor, line assistant and adaptive cruise control. Drivers are accustomed to using modern navigation such as Google maps and Waze. The idea is therefore that the driver may be overwhelmed by this information and may not be fully engaged in driving. As C-ITS can be considered as another of the assistance systems, it is necessary to assess its usefulness and benefit for drivers.

This is the purpose of evaluation and testing of individual services provided. Evaluation as part of the newly developed system implementation should be one of the last steps before the project is completed and the C-ITS system is put into live operation. Such testing should explore the usefulness, implementation of the new system, and point out shortcomings that could be corrected in subsequent phases.

1.1. Aim of the Thesis

The aim of this work is to propose a robust evaluation framework for services implemented within C-Roads CZ project. This proposed system solution will focus on organizational, technical, and evaluative aspect of these tests. The evaluation design will be guided by acquired knowledge from the theoretical part, which will focus on the documents dealing with the development of evaluation methodology and similar projects that have already carried out the evaluation. The proposed evaluation will then be verified in terms of feasibility and functionality. In the next part of the work, experiments will be performed, according to the part of the evaluation design and their course will be described. The data collected from the performed experiments will be further evaluated and recommendations for further development of these tested use-cases will be proposed.

2. Description of C-ITS systems

C-ITS is a system based on the transition of different ITS messages through different ITS stations. This communication is unified by international agencies as ETSI, IEEE, ISO, CEN, and SAE to ensure the compatibility across all different equipment makers. ITS station's transmission of messages can be divided into three configurations.

V2V

Vehicle to Vehicle communication (V2V) is the exchange of the different C-ITS messages between two On-Board units inside vehicles in communication range. It is used mainly for safety, transport efficiency and the environment. In Europe, ITS-G5 with DSRC 5.9 communication technology is used for V2V. The use of V2V communication can be, for example in traffic jam warning, emergency vehicle approaching or stationary vehicle.

V2I

Vehicle to Infrastructure communication (V2I) includes the exchange of C-ITS messages between an On-Board Unit in the vehicle and a Roadside Unit installed near the road. These messages could cover warnings of adverse weather conditions, roadwork, or other potentially dangerous situations as traffic accident ahead. V2I communication in Europe is operated by ITS-G5 technology with a combination of cellular networks.

V2X

Vehicle to everything communication (V2X) is a concept covering the transfer of information between a vehicle and any other entity affected by vehicle. This includes two previous types of communications as well as communication between a vehicle and devices, a vehicle and pedestrians, a vehicle and a network, a vehicle and grid etc. This device could be a mobile phone or simplified type of OBU for cyclists. This concept follows the modern trend of the Internet of Things (IoT). [1]

2.1. Technology

The C-ITS uses different technology standards in the USA and Europe. Many different communication technologies can be used in ITS. An example is Mobile cellular technology, IEEE 802.11 Wi-Fi, satellite communication, radio broadcast. Some of these technologies have already been used for message transfer like radio broadcast RDS-TMC Radio data system Traffic message channel. The C-ITS in Europe uses a combination of ITS-G5 technology and Cellular technology and takes advantage of higher coverage of cellular communication and low latency of ITS-G5. In this section, these two technologies will be further described in terms of their functionality and benefits.

ITS-G5

ITS-G5 is the name of a C-ITS wireless short-range communication technology standardised by ETSI which consists of several other existing standards. This ITS-G5 is mainly based on the standard IEEE 802.11p Wi-Fi developed for vehicular ad-hoc networks. This technology is used for V2V and V2I installed in vehicles and on infrastructure and is significant mainly in the safety and latency-critical services.

ITS-G5 provides geonetworking enabling distribution of packets based on positions and geographical areas. It allows resending messages between different vehicles and infrastructure to increase its range but limits its spread to the number of hops or zone of validity. Decentralized congestion control (DCC) is an elemental part of ITS-G5 that avoids unstable behaviour controlling the station's communication resources like transmitting power, data transfer rate and minimal packet interval based on channel load. This prevents overloading of the channel dedicated for transmission of ITS communication. In Europe, this channel is allocated on frequency 5875 MHz to 5935 MHz, divided into four frequency range based on their usages like safety, traffic efficiency and future ITS services. The allocated frequency range is further divided into six service channels and one control channel all with 10 MHz channel spacing. Due to possible interference between ITS-G5 and DSRC 5.8 installed on toll gates, ITS-G5 implemented measures reducing transmitting power in proximity with DSRC 5.8 to ensure the coexistence of both technologies together. [2] [3] [4] [5]

Cellular technology

Cellular communication is a technology that has been developed and improved for many years and provides wireless connection originally for voice and today mainly data connection. This technology enjoys high coverage and increasing download speeds and decreasing delays every year. High coverage ensures the placement of transmitters with different power for different coverage. These transmitters are distributed according to the use of potential users where with a higher density of users there is a higher number of transmitters over a shorter distance. This ensures good coverage with a higher speed provided. Currently, 4G LTE, LTE-A and 5G are the most important for C-ITS services. The biggest advantage and disadvantage of this technology is the existing infrastructure owned by mobile operators. If there is no proper competition in the market, the operator may charge disproportionate amounts for the services provided and thus reduce the attractiveness of C-ITS services. On the other hand, the existing infrastructure benefits from high coverage and the promise of increasing the quality of services provided. The already existing cellular infrastructure reduces the investment required to invest in the new technology and thus accelerates the deployment of C-ITS system. In C-ITS, cellular technology is mainly used for communication between infrastructure and data processing servers (back-office). In communication with vehicles, this technology is used for non-critical services without low latency demand.

Hybrid communication

Hybrid communication is called the connection of several other technologies used together to provide the offered services. These technologies can be, for example, Wi-Fi, Bluetooth, satellite communication or radio communication. The most common combination of technologies used in C-ITS called hybrid communication is ITS-G5 and cellular technology. [6]

2.2. Intelligent transport systems stations (ITS-S)

In cooperative intelligent transport systems, communication takes place between two or more ITS stations in order to exchange C-ITS messages. The ITS-stations could be divided into four ITS sub-systems: [7]

ITS stations in ITS central systems

ITS station installed in central system concentrate all ITS messages from Road-side unit (RSU) processed and analysed. In C-Roads the Central system is composed of two main components, C-ITS Back-office (BO) and Central C-ITS. C-ITS back-office as a central component collect, process, and distribute data to other ITS-stations like Road-side unit, On-board Units (OBU) and to Traffic Control centres. Based on the processed data collected from all sources, the Back-office also generates ITS messages that distribute to the OBU drivers as warnings and notifications. The second component of ITS Central system Central C-ITS unify all C-ITS back-office connections from different partners involved. [8] [9]

ITS stations in trucks and cars

ITS-Ss in vehicles and trucks commonly known as OBUs are devices installed in the vehicle allowing communication with the vehicle's environment through other ITS stations. OBU is connected to the Electronic Control Unit (ECU) in cars via Controlled Area Network (CAN) bus which also connects other components of the vehicle like sensors and displays. The OBU collects all the necessary data about the vehicle with the help of the ECU. The visual output for the driver is usually solved via the Human Machine Interface (HMI) interface integrated in the vehicle or with an external device and is connected via CAN bus or Wi-Fi. The OBU could use standard ITS-G5 technology to communicate with other ITS-S or hybrid solution combining ITS-G5 and cellular network communication technology. [7] [9]

A special type of ITS-S in the vehicle (trailer) is Road vehicle unit (RVU). This unit is installed in the road sign maintenance trailer and distributes warnings to other ITS-S (RSU/OBU) about its position and its sign warning. RVU could operate in connection with Back-office via the cellular network and send more detailed information to OBU and Back-office. The RVU can also operate as a stand-alone unit using the ITS-G5 to send messages to the OBU. [10]

ITS stations in gantries and poles

ITS stations attached to gantries, poles, and other traffic infrastructure, also called Road-Side Units (RSU), are stationary devices enabling communication between mobiles units OBUs/RVUs and back-office. The RSU collects data from each mobile OBU / RVU in range, process it and then send it to the back-office. Aggregated data received by the back-office are processes for other more complex services, such as traffic congestion prediction and traffic management, and is transmitted back to the OBU via the RSU. The RSU use ITS-G5 communication technology with OBU and connected via cellular network or other existing data communications (SOS stations) to back-office. RSU also disseminates information directly from vehicles about ongoing events including Stationary and slow vehicles, roadworks ahead that were captured from OBU. [7] [9]

ITS stations in personal devices

ITS stations in personal devices as mobile phones and other personal device assistants is designed to enable communication between this device and other ITS stations. The ITS-S in personal devices could be used additional functionalities or as a replacement for HMI in vehicles. This type of communication is still in its early stages. [7]

2.3. C-ITS Messages

There are various types of C-ITS messages some used more than others. In this section the most important C-ITS messages which have an impact on this thesis will be presented.

CAM

Cooperative Awareness Messages (CAM) are the most common messages exchanged between different ITS-S in broadcast mode (to all possible recipients) within the communication range. The frequency with the CAMs are transmitted by OBU in vehicles depends on the change of vehicle state and radio channel load, but should always be between 100 Ms and 1 000 Ms. The content of the message depends on the ITS-S and is divided in three parts, ITS header, high frequency container and low frequency container. These containers for vehicle OBU contain information about the originating ITS-S, highly variable data such as position, velocity and acceleration, and data changing with low frequency like state of lights. CAMs can be used to mitigate the collision risks with other vehicle or send to back-office and processed for further complex services. [11]

DENM

Decentralized Environmental Notification Message (DENM) is used to notify users about various events detected which could be relevant to them. DENMs are created by ITS stations (OBU/BO) upon detecting a specific event and disseminate to other ITS-S. For the dissemination of DENMs to/from OBU and BO serves RSU. DENMs are broadcasted periodically with the position of this event is defined relevancy range and until this event is valid. [12] [9]

MAP

Map data (MAP) messages contain detailed information about geometry, topology of lines of one or more road segments and Intersections. It includes information about line restrictions, links between lines and their types. [9]

SPAT

Signal Phase and Timing (SPAT) messages transmit information about the state of traffic controller, durations of phases and priority of urban public transport and emergency vehicles on intersections with traffic lights. One SPAT message could include data from more than one intersection. Together with the MAP messages, the SPAT messages are processed in the OBU and provide the driver with services such as Intersection Signal Violation (ISV) and Green Light Optimal Speed Advisory (GLOSA). [9]

IVI

In-Vehicle Information is a type of C-ITS message that transfer information about static and dynamic Traffic signs and variable message signs. This message can transfer image and text information about the given traffic sign. IVI message is created by Back-office and periodically broadcasted by RSU in range, valid only for a defined zone and for a certain time according to the given traffic sign. [9]

2.4. C-ITS services

C-ITS services also called use-case in C-Roads project are predefined scenarios that serves generally one similar purpose. The C-ITS platform, the association bringing together national authorities and aims to coordinate and share the deployment of C-ITS in Europe, created list of Day 1 and Day 1.5 services. Day 1 services are the services that C-ITS platform considers being most beneficial for their safety and society contribution and their implementation comes first. The second group of Day 1.5 services is the group that is focused on support and comfort, but some services might not be still fully developed. There are slightly different services specifications and their distribution by different standardization bodies. In this chapter, C-Roads CZ services will be described in terms of their functionality and benefits. The choice of these services is in terms of their general relevance within C-ITS and significance for this work. [13]

RWW - Road works warning

The purpose of Road Works Warning is to inform the driver about road works in advance with additional information about the restriction on his route. Road maintenance trolley will contain special Road-Vehicle Unit (RVU) which will broadcast RWW messages. This message could be broadcasted further by adjacent RSU. This use-case promises the decrease of accidents on the side of road works, increase safety for the road maintenance workers and the comfort and awareness of drivers. [10]

IVI – In Vehicle Information

In-Vehicle Information is a use-case that transfer the traffic signs to the driver and informs him on the HMI. This comes with additional information about the validity of the road sign, directional validity etc. The advantage of this use-case is that it is shown only to drivers, that this sign is relevant and do not distract others. This use-case aims to increase the attention of drivers, reduce the possibility of overlooking traffic signs and subsequent non-compliance with traffic regulations. [10]

HLN – Hazardous Location Notification

Hazardous Location Notification warns the driver about dangerous areas in his path. This may be an obstacle, people or animal on the road, traffic accident, bad conditions on the communication or general danger. This aims to improve the driver's response time by informing the driver before the driver encounters this dangerous area. [10]

EVA - Emergency Vehicle Approaching

An Emergency Vehicle Approaching is a use-case that focuses on passing through ambulances, fire brigades and the police. The Emergency vehicle sends warning to the surrounding vehicles in advance via the DENM message in its route and relevant zone of transit. This speeds up the transmission of information about the passing emergency vehicle to the driver, and the passage of the emergency vehicle can be accelerated by freeing up space more quickly. The implementation of this use-case promises to speed up the travel times of Emergency vehicles to the place of intervention while increasing the safety of passage. [10]

RLX - Railway Level Crossing

Railway Level Crossing is used for train passing warning. A driver arriving in the vicinity of a railway crossing is alerted by the RLX on the HMI that a train is currently passing or going to pass through the crossing. In another scenario, the driver is warned by RLX that the railway crossing is out of order and he should pay increased attention to the possibility of a passing train. This use-case aims to increase the safety on the railway crossing, raise driver awareness and decrease the possibility of overlooking the road sign. [10]

WCW - Weather Conditions Warning

Weather Conditions Warning is used to alert the driver to potentially dangerous weather conditions that may cause poor visibility, skidding or overturning of the vehicle due to strong crosswinds. The use-case aims to reduce the possibility of accidents due to weather conditions, increase driver comfort and awareness. [10]

SSV - Slow and Stationary Vehicle

Slow and Stationary Vehicle use-case warns drivers on expressways and motorway of slow and stationary vehicles ahead of them. SSV is generated by OBU in the stopped or slow vehicle that records a decrease in speed on the motorway and transmits it as DENM to other vehicles nearby. DENM is also further transmitted by the RSU if there is one nearby. SSV aims to reduce the number of accidents caused by slow and stationary vehicles by informing the drivers ahead and increase the continuity and comfort of driving. [10]

ISV - Intersection Signal Violation

Intersection Signal Violation alert drivers on the intersection with traffic lights that a vehicle is violating traffic lights and they should pay attention to it. The RSU installed at the light-controlled intersection constantly sends MAP and SPAT messages with a signal plan to all surrounding vehicles. If the OBU of the vehicle arriving at the intersection evaluates that the vehicle is unable to stop at the red light, the DENM message about a possible violation is sent to the other vehicles. This warning is displayed on the vehicle HMI. ISV aims to reduce the accidents caused by vehicles violating red lights on traffic lights by informing other drivers about this violation. ISV also shows information about the green/red phase on the vehicle's HMI to increase the driver's comfort and smoothness of traffic at traffic lights. [10]

PTP – Public Transport Preference

Public Transport Preference is used by vehicles of public transport to alter the signal plan on intersections with traffic lights and get preference. RSU on the intersection records the arriving public transport vehicle through CAM. RSU has information about the actual state on the intersection, locations, and speed of public transport vehicles on the intersection and its delays. With this information, RSU evaluates the options, and if necessary, adjust the signal plan at the intersection. PTP aims to increase comfort and competitiveness of public transport against individual transport, reduce its energy consumption and the gathered information could be used to optimise the public transport timetables. [10]

PTS – Public Transport Safety

Public Transport Safety use-case warns drivers passing near a public transport stop about the public transport vehicle standing on it. In this defined area, there is an increased risk of a collision with a public transport vehicle leaving the stop, as well as a collision with a pedestrian crossing the road. PTS seeks to reduce this risk by informing drivers in time about that risk. Second PTS scenario is useful for sending the information about a possible collision with a public transport vehicle as tram, bus, trolley bus. At places intersecting roads and public transport routes this PTS warn crossing vehicles about arriving public transport vehicle in advance through nearby RSU. This scenario aims to increase safety on the crossing, driver's awareness and helps the continuity of traffic. [10]

2.5. Practical application of C-ITS

The Cooperative ITS systems were developed with a vision to increase safety, traffic efficiency and decrease the environmental impact of traffic. Many specifications have been developed and large numbers of projects have been launched, in different parts of the world where a considerable amount of money has been invested. This technological and monetary complexity of such projects is the reason why these efforts must be justified by the benefits that C-ITS brings now or in the future.

Traffic safety is a much-discussed topic with an effort to reduce road fatalities each year. Transport is one of the few areas where fatality rates are considered to be partly acceptable precisely because of the importance of mobility in our lives. However, countries aim to reduce this trend every year by introducing systems that reduce this level. Many countries have adopted Vision Zero in its strategic objectives, which aim to reduce road deaths to zero. One of these systems is C-ITS and the use-cases in day one release that is mainly focused on traffic safety and have higher implementation priority. The main idea of C-ITS is to increase the driver's awareness of the following unexpected events in advanced to increase his attention and readiness. This allows, for example, a use-case SSV to alert drivers to slow and stationary vehicles ahead so that he can be prepared ahead and initiate an evasive manoeuvre. Another example is a traffic jam ahead that warns the driver about the forthcoming traffic jam. The informed driver could also change his route and help reduce traffic congestion. This address another area C-ITS has an impact on traffic efficiency.

Today's increasing traffic volumes could not be solved only by increasing the road capacity but must be further addressed with the help of traffic management, efficient vehicle routing and public transport and its preference. C-ITS aims to address these challenges with different use-cases helping drivers with better decision making about the routing and making traffic management efficient and easier. Shockwave damping use-case aims to smoothen the traffic flow by giving the driver a speed recommendation on the same principle as road line traffic control recommend speed to avoid a drop in capacity in high-density conditions. In this way, the cost of installing gates for road line traffic control can be reduced. As another example, green light optimal speed advisory use-case recommends the driver the optimal speed that he should follow in order to turn green at the next junction. This aims to positively influence the flow of traffic at intersections but also to reduce the number of accelerations and braking in cities and thus reduce car emissions.

Transport is responsible for almost 30% of total CO2 emissions in Europe, and there is great pressure from both Europe and the Member States to reduce total emissions as much as possible. Europe is striving to meet the higher demands on combustion efficiency, but also through better traffic management and smart systems such as C-ITS. Along with traffic optimization, which many use-cases aim for, goes hand in hand with reducing vehicle emissions and also reducing noise emissions. This effect will increase with higher penetration of vehicles using C-ITS and will reach a higher level when combining C-ITS with future autonomous systems. [14]

The transport efficiency, safety and vehicle routing are addressed by many different information-based systems. Linear traffic control shows the driver the optimal speed he should follow to maintain the maximum capacity of the traffic. Google and Waze application on mobile phones shows traffic jams and have effective routing. However, compared to these systems, C-ITS has other added features such as:

- precise information about the positions of traffic signs and its space and daily validity,
- usage in low latency scenarios like EVA and emergency electronic brake light,
- more descriptive information about signs,
- personalised information, for example, display for trucks only (reduction of information overload),
- more services that no other assistant system could offer (EVA, GLOSA),

- once the C-ITS service is already installed, extending other features is much easier than developing a new system,
- the future advanced combination with autonomous driving.

On the other hand, there are concerns about attracting the driver's attention from driving, overwhelming the driver with information, bad priority display of various information etc. For this reason, evaluations are performed for C-ITS assessing the driver's response to these systems together with his opinion about the C-ITS.

2.6. Evaluation of C-ITS

Evaluation is an essential part of system development in the final process. The purpose is to determine the worth and quality of the developed system using mathematical, simulation tools and the study of human behaviour. The evaluation is performed on an already fully functioning car assistance system in order to evaluate only the real added value of the system and not its current functioning. The evaluation of C-ITS is crucial for stakeholders and car manufacturers to obtain feedback from potential users and to assess the implemented system and its functionalities to improve the performance of developed segments. Evaluation is one of the main sources of evidence of the effect of the new system. When the change of driver's behaviour is evaluated and safety, efficiency benefits are calculated it could be transformed into the cost per vehicle hour lost, damage, injury, or fatality for economic assessment. The evaluation is carried out with the aim of:

- discover implementation shortcomings,
- bring the service closer to the end user and capture his feedback,
- improve C-ITS services to their maximum benefit based on observations of driver behaviour,
- verify the demand for these services on the market.

One of the most important documents dealing with the evaluation of transport systems and the course of testing preparation is the FESTA handbook.

2.6.1. FESTA handbook

FESTA (Field operation test networking and data sharing support) handbook is a guideline document created by FESTA consortium in 2008 with intentions to gather all knowledge from experts, stakeholders, workshops, and seminars about Field operational tests (FOT) to create a common methodology. Field operational tests are an evaluation and assessment method for driver support systems testing newly developed or implemented systems to provide a real-world impact and benefits. The FOT is generally a large-scale test taken for weeks to years with tens to hundreds of participants. FESTA provides guidelines to overcome the obstacles accompanying FOT in the organisation, methodology, data acquisition and evaluation providing common methodology on National, European, and even international level. FESTA handbook was mainly developed for evaluation of Advanced Driver Assistance systems and in-vehicle information systems in autonomous and cooperative systems. [15]

FESTA handbook presents V-diagram, also shown in 1 containing all the steps needed to perform a FOT. This sequence of steps, also called FOT chain, is recognized as a commonly recommended procedure for Field operation testing. The V FOT chain is divided into three Zones and multiple levels. The FOT chain starts with the preparation of the Test as setting up goals of the study, research team, defining use-cases and research questionnaires and finally preparing the measurements and sensors. The second vertical part of the FOT chain belongs to the field testing itself and acquisition of all data. The third part is focused on the analysis of the acquired knowledge, evaluation of questionnaires, impact assessment and conversion to real-life benefits. This step sequence is constructed so that the following steps are highly dependent on previous steps. However, this does not mean that this process is only linear, but iterations may be necessary. [15]

The FESTA handbook describes the whole Field operation test in one document. All FOT steps are further generally described in separate sections and their solutions are proposed. Given that the aim of this work is to focus on the evaluation of the C-Roads Czech Republic project, key parts of the V-diagram for this work are preparation of the evaluation, data acquisition, data analysis, impact assessment. [15]

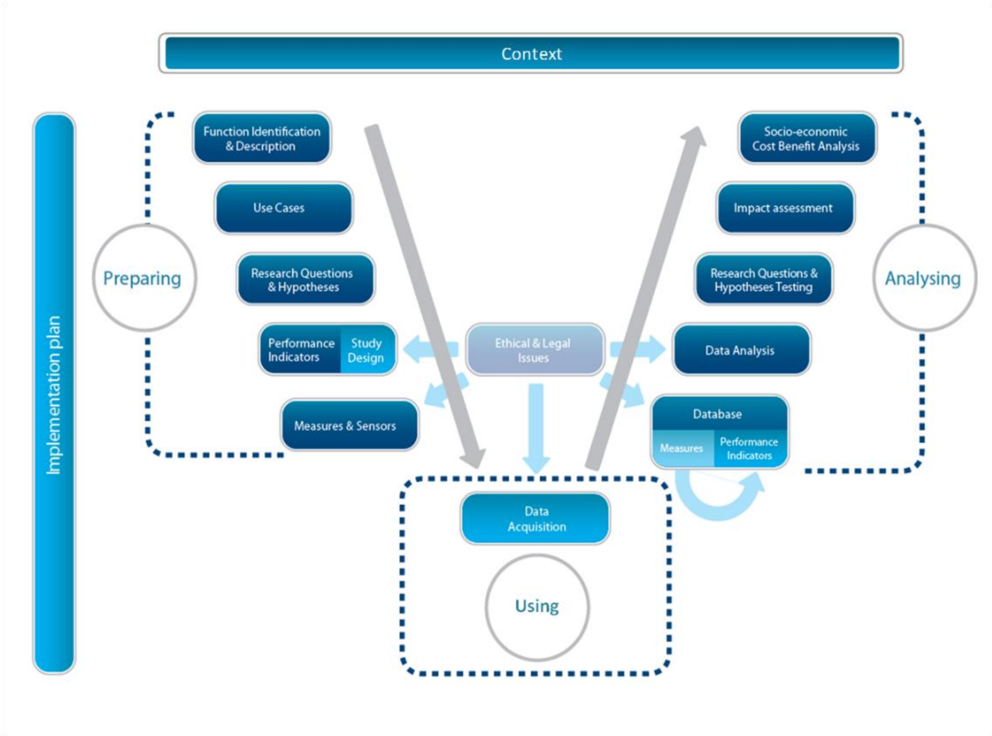

Figure 1 FOT chain [15]

The first step in the evaluation of the developed system based on FESTA handbook is to realise, what function of this tested car assistance system that is going to be evaluated. Some of the functions can be very difficult to evaluate, given their nature. Based on these functions and connected use-cases the research questions can be identified. These research questions are of a general nature questioning the impact of the whole system. It may ask about Impact on the safety, mobility, environment, public and how the drivers characteristic and other factors affect usage of these functions. Based on this general research question, the hypothesis can be further specified. Hypotheses are statistically testable statements that evaluate how different measurement parameters change due to the system. Defining hypotheses is an iterative process of selecting the most important hypotheses from a larger number of all. [15]

The next step is to select a performance indicator suitable for specific hypotheses. In this process, it is necessary to consider all factors influencing the ongoing testing, its budget, and limitations. The performance indicators are measurements of the success of the system and are related to the real measurements that are aggregated and processed by mathematical tools. The measurements can be 4 different types. Direct measurements are logged directly from vehicle sensors and do not need any further processing like speed and fuel consumption from CAN bus. Derived measurement, on the other hand, depends on the measurement of another quantity for their subsequent calculation. The example is calculated to travel tam from GPS sensors. The third Self-reported measurement is dependent on questionnaires and interviews for subsequent processing. The last is situational variables that are measured in different conditions to get an overview of the system's behaviour with different weather, traffic conditions and road topology. [15]

The following experimental procedure consists of designing the experiment with scientific quality. This experimental procedure allows researchers to test the created hypothesis and accepted or rejected them. The experimental procedure could be carried out by different approaches. As part of the within-subjects design, all participants will be tested with and without a tested system to create a comparison level. The between-subjects design is an approach where all participant will experience only one treatment, with or without a tested system. This way the participant is not affected by previous tries, but the double number of participants is needed. [15]

FESTA handbook list conditions that have an effect on the result of the evaluation and divide them into two areas. Every participant in evaluation has a different characteristic like demographics, driving experience and personality. These characteristics affect their behaviour and have to be taken into account. For the evaluation to have a statistically significant effect, there is a minimum number of participants required for the evaluation of different functions. This number can be determined by power analysis. The second area of influencing evaluation is an experimental environment. This includes geographical location, road type, traffic conditions, weather conditions and time and seasonal effect. All these parts can bring unwanted effects to the evaluation result and need to be addressed. [15]

After the study is completed and all data from it are collected and stored in the database, it is time for data analysis. It is necessary to take into account that the obtained data will most likely contain missing data, outliers, and errors. Therefore, before starting any analysis, it is necessary to start with data quality analysis and make sure that the data is consistent and suitable for further processing. Data processing as a next step aims to prepare the data for addressing predetermined hypotheses. This step consists of data filtering, defining new signals from the raw data, marking events of interest, and defining new more suitable time scale. After preparing the data, it is time to calculate predefined performance indicators and test hypotheses. Hypothesis testing often comes with null hypothesis against the alternative. The next optional step of data analysis is Data mining. Data mining are usually pattern searching techniques revealing the relationship between data that is not visible by common analysis. The last step of analysis is to generalise the results to properly capture their true nature. [15]

The last part of Field operation tests is the Impact Assessment. Impact Assessment of any Intelligent transport system consists of four parts: Safety benefits, mobility benefits, efficiency benefits and environmental benefits. The safety benefits would be best calculated by summing all accidents with and without ITS. The sum of accidents as an indicator of safety benefit in a controlled test is impossible to assess due to the low number of accidents during testing, it is suggested to look for other safety indicators. [15]

FESTA handbook suggests the most used expert methods how this area of safety benefits can be addressed. The easiest safety impact assessment is the speed – accident relationship assessment. Speed is an influencing factor on the likelihood of the accident occurred as well as to its severity and is easy to log and analyse. An event-base analysis is estimating the safety benefits by deeply evaluating one short segment in which the crash risk is the highest. This analysis is best for dangerous event warning. The safety benefit could be also addressed by eIMPACT method that takes safety as a combination of exposure of collision, collision risk while driving and collision risk resulting in accident. All methods have essentially similar objectives, namely, to assess whether the use of the tested system is less likely to result in an accident, injury, fatality, or the injury is less severe with the use of the system. [15]

According to Festa handbook, mobility can be affected in three areas. The first area consists of the number of journeys, their duration and length. This affects the amount of time the driver spends in the vehicle. Travel patterns are composed of routes, modes, and journey timing. The third area is the quality of travel that is affected by the driver’s comfort and safety feeling. The best way to assess driver's mobility is via user acceptance through questionnaires and interviews. [15]

Efficiency assessment is composed of direct and indirect efficiency effects. The direct effects affect the drivers directly by reducing travel times, fuel consumption and, for example improving mean speed. The indirect effect is caused by other benefits that this system transmits, for example when reducing the number of traffic jams due to driver's better route selection, travel time will be reduced. The overall impact of C-ITS systems on traffic efficiency is affected by penetration level. [15]

Air pollution and noise pollution reduction is a part of the impact assessment providing Environmental benefits. The environmental benefit is highly affected by other impact areas and is the result of all together. Air and noise pollution are usually evaluated using simulation software. [15]

3. Realized C-ITS projects

In this section, the realised C-ITS projects will be discussed to approach their work in terms of their functionality and evaluation. C-Roads will be the first to be introduced as a platform, and due to the importance of this project, its structure, operation, and the overall approach of this large project to Evaluation will be discussed. In the second part, three of the implemented projects will be analysed, which have already performed evaluations at their pilot sites.

3.1. C-Roads

C-Roads is a massive European platform with the aim to develop and implement C-ITS in harmonised coordination between the European Union and its Member States. The C-ROADS platform was launch 4th of October 2016 by eleven of its core members (Belgium, France, Germany, Austria, Czech Republic, Finland, Hungary, Italy, Netherlands, Slovenia, and the United Kingdom). Since then, seven new members have joined (Denmark, Greece, Ireland, Norway, Sweden, Portugal, Spain), in a total of 18 members of the C-Roads platform to this day. [16] [17]

Each of its core member states are implementing their pilot sites and installing C-ITS for Day 1 and Day 1.5 services. All pilot sites are harmonized by C-Roads Platform and focus on interoperability across all member states. The final product with base in the same technical specifications will be usable across the borders. The common technical solution for C-Roads developed and used for communication V2V and V2I is a combination of the existing cellular network and ETSI ITS-G5 in all pilot projects. [18]

C-ITS Platform is managed by a Steering Committee (SCOM) consists of representative from State Members and infrastructure operators. The Steering Committee with the help of Supporting Secretary takes decisions on higher objectives, achievements tactical decisions and approves the specifications and definition work proposed by Working Groups. The C-Roads is composed of five Working Groups with different tasks. The technical solutions designed by Working Groups are essential for all the pilot projects and ensures the compatibility and interoperability among them. The European Commission (EC) and the Innovation and Networks Executive Agency (INEA) are closely related to SCOM through the legislative and policy guidance of C-ITS. The organizational structure of C-Roads is shown on Figure 2. [8]

The most important working group for evaluation and assessment is WG 3. The main tasks of Working group 3 are to define the methodology for Evaluation and Assessment, Assess the impact of C-ITS implementation and Transmit the achievements to the real environment. Working group 3 has prepared an Evaluation and Assessment plan with the intention of unifying the evaluation across all pilot projects in the C-Roads. This document serves as the main guidelines for evaluation and assessment in all pilot projects. [19]

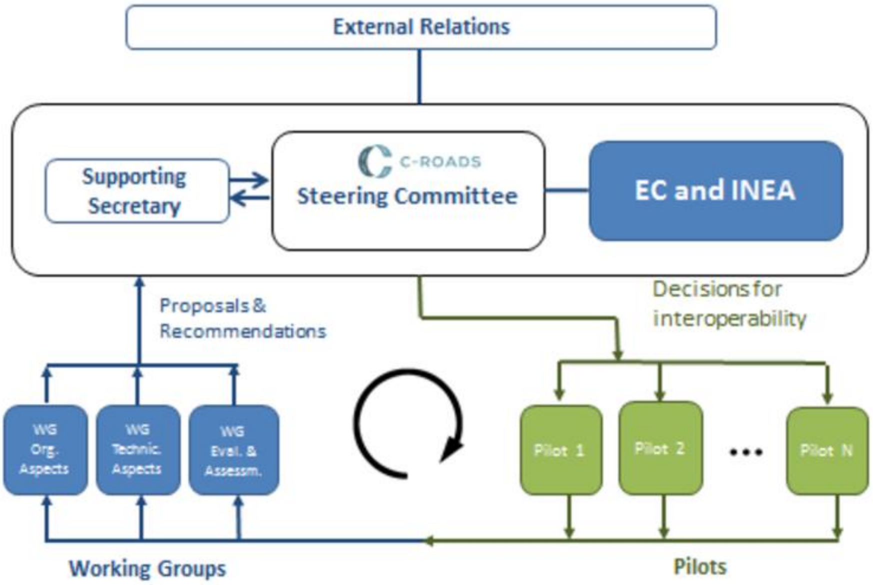

Figure 2 Organizational structure of C-Roads [20]

3.1.1. Evaluation and assessment Plan

Evaluation of implemented use-cases is a mandatory task of each pilot project within C-Roads. Since all pilot projects are different in implementations of various scenarios, pilot projects have different funding and its distribution, even evaluations could be taken from different perspectives. Aspects of evaluation are left to individual pilot implementations to fulfil the contractual contract. At the beginning of each pilot project, the contract agreement included what will be implemented and what impact areas of the pilot will be the pilot evaluating. Even though differences within different pilot projects, the WG3 Evaluation plan should be taken as a guideline and pilot sites should stick to it as much as it is possible. The Evaluation and Assessment plan recognized six different impact areas: [21]

- User acceptance
- Safety
- Traffic efficiency
- Environment
- Organizational
- Socio-economy

3.1.1.1. User Acceptance

User Acceptance is an important part of Evaluation where the users express their views and perceived experiences with the system so that researchers could determine whether it is accepted or not. Thanks to User Acceptance, the final product could be modified to suit the expected use for the end-user. In C-ITS, this could mean an adjustment of the output for the driver such as message display information, size, different picture, or also other parts of use-case evaluation such real-life usability of tested use-case, how soon the event should appear on HMI, its audio reminder or message display priority. User Acceptance is performed using questionnaires or interviews during a real evaluation with test drivers. [21]

Based on the Evaluation and assessment Plan, the level of users acceptance is divided into priori acceptability, acceptance, and appropriation. The priori acceptability is users view on the C-ITS before the first testing by the driver. User Acceptance is recorded after the first encounter with the C-ITS system during evaluation testing. Appropriation is the users view on the system based on several weeks or months of using it. [21]

There are three main topics that every user acceptance should address. General information is focused on the driver, his age, gender, education, drivers experience, driving style and the knowledge about C-ITS etc. The main purpose of this part is to cover everything about the driver's background that might influence its view and performance. The second topic aims to cover the perceived view on the general C-ITS, its usability, efficiency, and usefulness. The last topic is covering the individual use-cases and its own usability, efficiency, and usefulness. [21]

In the Evaluation and assessment plan WG3 proposed general guidelines for performing user acceptance analysis via theoretical background, sample questionnaires and guidelines for aspects that researchers should focus on. The provided guidelines are not mandatory, and the entire implementation of the user's acceptance is carried out according to pilots' own interests and limits. [21]

3.1.1.2. Impact Assessment

The primary task of an Impact assessment is to capture the behavioural response of individual drivers and assess the impact of the tested system on them. These data are further aggregated from all tested drivers and presented for certain selected performance indicators (KPI).The Impact assessment in C-ITS could be summarised into impact areas based on real data captured during the evaluation tests with test drivers to:

- Safety
- Traffic efficiency
- Environment

The difference representing C-ITS services should be assessed free from other factors affecting non-C-ITS drivers. This allows the comparison of driver behaviour with C-ITS services and a baseline created without C-ITS. There are four different approaches to assess the impact of C-ITS for evaluation based on Evaluation and assessment plan. [21]

Comparison before and after C-ITS implementation

This approach compares previously measured behaviour of drivers without C-ITS and the behaviour of drivers when C-ITS is deployed. It is one of the most robust approaches ever to show the true effect of C-ITS in real conditions. [21]

Comparison without and with C-ITS on the same road

Comparison with and without C-ITS is an approach in which a baseline level of driver behaviour without C-ITS service is created and is compared with his behaviour using C-ITS service. This is also called simple difference in differences statistical technique. The difference could be evaluated from the data in the case of similar conditions (traffic level, weather, visibility, road topology). [21]

Regression difference in difference

Similar to previous technique, Regression difference in difference compares the outcome of testing with and without C-ITS, but this approach uses statistical tools to compare the differences. [21]

Randomized control trials

In this approach, the driver is randomly assigned to a control group without C-ITS or to a group with C-ITS. This assignment could change after the encounter with C-ITS message. This scientific approach reduces the selection bias and is suitable for small numbers of participants. [21]

3.2. Pilot projects analysis

The C-Roads project is in its finishing phase in a final year, where implementation is already deployed, and the evaluation and assessment of every pilot projects takes off. This does not mean, that every state and its pilot sites have already carried out an evaluation. In the next part the methodology of different C-Roads pilot sites that already performed evaluation will be analysed. Only two Member States, Spain, and the Netherlands, already have an evaluation and available report.

3.2.1. C-Roads Czech Republic

C-Roads CZ consists of 7 different parts Deployment and Tests (DT0 - DT6) implemented in different locations in the Czech Republic. These DTs differ both in location, implemented use-cases and partners cooperating in these locations. DT0 is already deployed part from project

MIRUD on outer ring in Prague connecting highways D1 and D5. DT1 is located in the second largest city of the Czech Republic, Brno on the D1 motorway connecting with Prague at a distance of 28 km. Brno city is also part of section DT2 on the southern part of the city ring road. DT3 is the largest segment on highways D1, D11 and D5 between the cities of Prague, Brno, Pilsen, and Hradec Králové. The Czech Republic is connected to Rotterdam, Frankfurt am Main and Vienna by this part of DT3. Another part DT4 tests the implementation of scenarios with trams in the cities of Ostrava and Pilsen. The next DT5 is unique thanks to the testing of one of the few railway crossings with C-ITS at two locations in the Pardubice region. The last part DT6 includes cross-border testing of international compatibility at the Austrian and German borders. [9] [10]

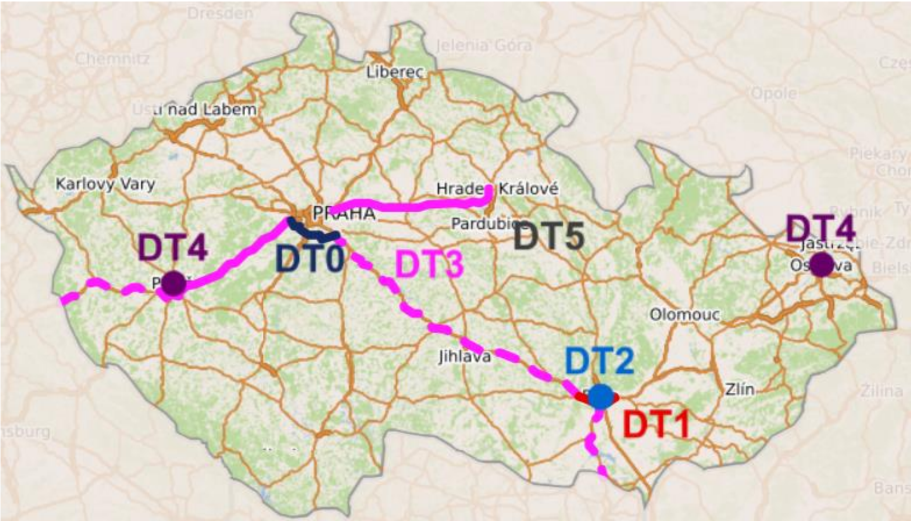

Figure 3 Pilot sites in C-Roads CZ [22]

The requirements for performing the C-Roads CZ Evaluation are discussed in the Scope of the C-Roads contract. This document contains details on the process, implementation, and evaluation of C-Roads CZ that the partners of the project should follow. The evaluation in the Czech Republic should include at least 100 tested persons and is focused mainly on the safety impact of C-ITS. For each part of the DT, the evaluation should be performed on at least two scenarios assessing safety aspects. Currently, C-Roads CZ is in the phase of field tests that test the functionality of individual implemented parts and the evaluation part of the project is underway. [9]

3.2.2. C-Roads Spain

The Spain consists of five pilot implementing different day 1 and day 1.5 services on TEN-T core network corridors and urban nodes. The main impact areas in the Spain project is User Acceptance, Safety, Traffic Efficiency, Environmental and Technical. As there is a big difference between the individual projects, the evaluation is divided according to these five different pilot projects. [23]

The implemented services in the Spain pilot are: In Vehicle Signage, Hazardous Locations Notification, Road Works Warning and Signalized Intersections. For these use-case, the Key Performance Indicator was created and the state without the C-ITS and with the C-ITS was compared base on these parameters. Defined impact areas were examined on all use-cases following the Festa Handbook guidelines [15]. The main research question was created for every impact area and every use-case followed by sub-research questions. This was the baseline for the creation of KPIs. Can bus data, GPS, OBU and other ITS-S data were used for data collection. Technical evaluation was designed by data collection from the OBU in vehicles to evaluate its performance and functionality. [23]

SISCOGA Extended

SISCOGA Extended uses cellular and hybrid communication on 130 km of urban and interurban roads in Vigo Centre and motorways connecting Vigo with surrounding cities. The data for evaluation was collected via OBU and RSU. User acceptance was performed via questionnaires for five participated groups of drivers (private drivers, taxi drivers, bus drivers, policemen, and firefighters). For the total of 60 people participating in this evaluation, the driver's profile was created separately for different groups. This profile contains a basic information about the driver like age, salary, monthly income, and education. Participating groups were evaluated dividedly for different KPIs about perceived environment, safety, traffic efficiency etc. Technical evaluation captured assessment related to latency, coverage on road and C-ITS services coverage. The impact assessment was evaluated based on impact areas and defined Research sub-questions for every use-case. The results were positive with the expected reduction in average speed in all test groups as well as a reduction in the number of accidents and hard braking. Only in the speed violation the speed was not lowered below the speed limit. [23] [24]

Madrid

Madrid pilot installed C-ITS on 32 km on urban highway around the central district on M30 with hybrid communication technology. Currently released report of Madrid pilot evaluation consists only of the environmental evaluation of RWW and other areas of impact assessment will be added in the future. Data about vehicle emission for environmental evaluation was recorded by remote sensing device installed on roadsides. This emission recorder has been installed at three locations and calculates the average pollutant concentration. Further environmental impact assessment and traffic efficiency was performed in a simulated environment using Aimsun. The evaluation of RWW was performed on the simulated Madrid M-30 ring road with and without the C-ITS. The result showing increase in average speed, decrease in Travel time and lane changes. This all changed positively, and its magnitude increase with higher penetration of OBU in vehicles. [25]

Cantabrian

Cantabrian pilot uses ITS-G5, cellular communication as well as Wi-Fi and Bluetooth communication technologies for day 1 and day 1.5 services on 75 km stretch. It is divided into three sub-pilot projects implementing different services in different places. The Cantabria evaluation main focus is technical with partial regard to safety and traffic efficiency. The research report and relevant KPIs are defined in the current report and the results and analysis will be part of other releases. [26]

Mediterranean

In Mediterranean pilot, the C-ITS systems are deployed on AP-7 motorway for 127 km along the Mediterranean Coast. Pilot is composed of two sub-pilots implementing day 1 and day 1.5 services by hybrid technology. The Catalan evaluation was performed by microscopic network model in Aimsun with real 1-year toll gate data. RWW was selected to evaluate the impact of RSU placement and OBU penetration rates with and without C-ITS. This was tested on 12 different scenarios concerning traffic demand level, composition and OBU penetration. The results indicated a positive impact of RWW on traffic flow by increasing the average speed with higher OBU penetration rate and decrease in the number of lane changes and travel time at highway section. The emissions showed a slight decrease and shift further from the closure of the lane. [27]

3.2.3. C-Roads Netherlands

C-ITS in the Netherlands is installed on the TEN-T core network from the Belgian border to Rotterdam with a total length of 268 km. Netherland use both ITS-G5 and Cellular as communication technology, implementing day 1 services like RWW, ISV and GLOSA. C-Roads in Netherlands is closely related to another realised project INTERCOR. This project as a partner with C-Roads provides help with organizational, technical issues and evaluation assessment. INTERCOR is active in Belgium, France and United Kingdom where it assists with implementation and coordination between these countries. [28] [29] [30] [31]

3.2.3.1. Evaluation

The evaluation of the Dutch C-Roads is presented in the document C-Roads National Evaluation Report for The Netherlands: RWW, IVS and GLOSA [30]. The Netherland evaluation focus on user behaviour in three main impact areas: Safety, Traffic efficiency and Environment. The User Acceptance of the tested drivers was also evaluated to capture the acceptability of C-ITS system. The evaluation was performed separately for each of the three tested use-times. As a data source for impact assessment was used from Can Bus, GPS logger and ITS-S in vehicle. [30]

Road work warning

RWW has been tested by closure of a lane on A16 motorway on 140 users in controlled test and 14 users in naturalistic driving test. The main impact area was safety, which examined driver speed fluctuations, speed compliant to the situation, lane change point and lane change manoeuvre. The controlled test was conducted for 7 nights. The drivers completed two runs, one without C-ITS for comparison and the other with C-ITS. The order was changed during the test with different users. The test drivers were tested on a long stretch with DENM messages comes from different sections with different traffic characteristics. The Dutch project recommends avoiding comparing the driver's speed profile on different parts of the road with other traffic characteristics so the relation of driver's response to the DENM warning is directly linked. The naturalistic driving test was conducted within 4 months finding the compliance of the drivers with the RSS use-case during the longer period and only with C-ITS. The speed data was analysed according to the first DENM activation time and lasted 30 seconds after this message in both controlled and naturalistic test. The speeds distribution analysis for all drivers was conducted with normalized time 30 before and 30 after the DENM message. The mean speed was also tested through statistical t-test determining the significance of the difference before and after DENM. The significance was not proven and DENM was not accepted as influential factor in controlled testing. In the naturalistic driving tests, the drivers were accelerating, and the significance was proven. [30]

The user acceptability and acceptance found that users were more concern about the service delays after the test. The feeling of usefulness of this service was also reduces as well as feeling of security. A high rate of people (68.5%) that did not see the warning on HMI was recorded in the user acceptance. Most users indicated that they are more relaxed when using the HMI and found it useful and trustworthy. [30]

In-Vehicle Signage

IVS use-case used for in vehicle information about static or dynamic traffic signs was evaluated on A16 motorway together with RWW on 140 users in controlled test and naturalistic drivers test. The main research examination was about speed fluctuations change and drivers speed limit compliance. The IVI message of different speed limits on A16 motorway was analysed with and without HMI for controlled test drivers and with HMI for naturalistic drivers. As with RWW, the median speed comparison method within normalised time of 30 sec before and after was used. In the controlled driver test, the data analysis was performed for each speed limit separately. The results were different base on speed. [30]

For the lower speed limit, the measured speed was observed significantly higher and for the higher speed limit the opposite in both groups. The statistical t-test showed that the mean speed change after IVI message arrival have severe significance (except at a speed of 70 km/h) and had a larger magnitude when reducing the speed. Counterintuitively, all speeds in controlled driver test were higher with the HMI than without, as was the speed after receiving the warning. The mean speed after the message in naturalistic driver test was lower in speed limit 70 and 90, and higher in 50 and 100. [30]

The acceptance of the user showed a change from a positive perception before use to a more negative one in terms of a sense of security and vigilance. On the other hand, a sense of usefulness and trustworthiness increased. [30]

3.2.4. NordicWay

NordicWay is a C-ITS project taking place in Denmark, Finland, Norway, and Sweden. It started in 2015 with a focus on the implementation of day 1 and day 1.5 applications for the Nordic environment. Now the project is in its third phase continuing in development and ending in 2023. NordicWay has embarked on the path of implementing the entire C-ITS system based on cellular communication of mobile operators in order to reduce the installation cost of expensive infrastructure. Communication between vehicles (V2V) is using ITS-G5. Evaluation of NordicWay was focused on Technical performance and quality assessment, impacts and benefits and user acceptance. NordicWay evaluation was divided into four test sites. [32] [33] [34]

Evaluation Sweden

The Swedish evaluation was focused on communication performance between vehicles, the infrastructure and the cloud. The main task was to evaluate the interoperability and interchange network. This interchange node (cloud) is a borderline between National Traffic Management centres, car manufacturers (Volvo, Scania) and telecommunications operators. High demands are placed on this node in terms of latency between clouds and vehicles. Latency, together with message success rate and communication range of ITS-G5, was tested on Swedish pilot in technical performance evaluation by transmission RWW message between cloud and vehicles. Detection of vehicle events and transmission of messages to other vehicles was studied in the evaluation of the behaviour of a Swedish pilot user using Vissim microsimulation with different penetration rates. C-ITS penetration above 5% was found to be partially saturated and beneficial. [33] [34]

Evaluation Norway

Technical evaluation in Norway was based on the use of road surface information for road maintenance from vehicle friction data. Road surface information use-case has been shown to be insufficient due to the low ability of cars to detect slippery road conditions with current low-quality data with comparison to the existing system. This use-case was also evaluated in terms of the impact assessment discussed with the contractors and was received very positively due to its higher geographical accuracy and potential for prioritizing maintenance. [33] [34]

Evaluation Finland

Technical evaluation in Finland tested delays of messages transmitted between the Finnish service cloud, the Finnish node, and mobile users. It was also tested whether the message is delivered to a user heading around the site of the incident, with 100% success. User behaviour with C-ITS was tested during one-year field test and discovered, that when the driver is in contact with traffic related warning, he changes his behaviour by reducing speed (with different results depending on the type of use-case) and it also influence the driver's route choice. The benefits and impact analysis presented three main benefits of C-ITS: Speed reduction in dangerous areas, helping drivers avoid dangerous areas and help with drivers focus. Another advantage is the Traffic Management Centre and its sharing of information on road events with higher accuracy and better specification. The Socio-economic assessment focused on costs and benefits of C-ITS implementation with two different future implementation scenarios. The benefits considered focused on expected fatal accidents, injuries and non-injury accidents, travel time changes and was compared to expected costs. The evaluation looked at effects of C-ITS as direct effects influencing driving tasks and indirect related to speed changes. User acceptance assessment found that drivers with less vehicle experience are generally more satisfied with C-ITS than drivers with more experience. The timing of the incoming situation proved to be the most important aspect of driver satisfaction. [33] [34]

Evaluation Denmark

The technical evaluation tested latencies with different volumes through the Danish Traffic Management Canter, an interchange node, and showed an increase in delay with a larger message size. The functional evaluation was designed to test transmission between Finnish, Swedish and Danish node. Performance over a longer period of time for one month where 80% messages was transmitted successfully and 75% returned back. This was further tested by load test sending one million messages through interchange node that discovered the reasons for the leak. [33] [34]

Practical part

The practical part consists of design of evaluation, verifying of design and execution of individual experiments with subsequent evaluation of testing. The evaluation design will suggest an ideal way to perform an evaluation for C-ITS. In section 5 Verifying the design, this method will be verified on field for two specific use-cases and for the recording equipment that was available. The following practical experiments with selected use cases, which took place within the C-Roads CZ and was conducted according to the proposed design and organizational possibilities. The choice of use-cases and their evaluation was influenced by the Czech C-Roads scope and the framework agreement that the C-Roads CZ evaluation adheres to. In the part of the experiments, the plan of individual tests and their course will be presented, as well as their evaluation and results.

4. Design of evaluation within the C-Roads Czech Republic

The design of evaluation follows gathered knowledge from previous chapter about important methodologies, guidelines, and realised projects in theoretical part. The previous chapters show that evaluation can be done in different ways. However, it is important to take into account the very principle of the individual tested use-cases. Organizational, time and hardware constraints can also significantly affect the evaluation process. In the next part, the individual possibilities of evaluation, which would meet the requirements and have an acceptable output will be discussed. These methods will be analysed in terms of their advantages and disadvantages for use in C-Roads CZ and in terms of their time, resources, and organizational complexity. Subsequently, the method of evaluation will be selected, which will be performed in chapter 5. and its results will be evaluated in chapter 6. The evaluation itself on a general use-case will continue in part 4.3.

The selection and setting of the evaluation design must follow the set requirements. The requirements for the evaluation, which is part of the C-Roads CZ project, are defined in a document describing its implementation and are mentioned below this section. The main requirements for evaluation are:

- the evaluation must be always executed for two use-cases which are implemented for each DT (mentioned in 3.2.1),
- the evaluation must contain the evaluation of user acceptance,
- the evaluation must be performed in the pilot area of implemented use-case.

4.1. Evaluation design options

In this section, four selected evaluation designs will be analysed, and one suitable evaluation of C-Roads CZ will be selected. Its design will then be discussed in detail in the next part 4.2.

4.1.1. Controlled testing

In the controlled test, drivers are invited to perform a test drive that tests their reaction in pre-prepared scenarios on a pre-selected route. This can be done in real traffic or in a closed or isolated road segment. Each of the drivers passes the test one or more times so that the driver's reaction and behaviour with the tested system can be captured and distinguished as best as possible. During controlled testing, logging devices are set up to capture important information about the progress of the test. These include, for example, GPS position, speed, acceleration of evaluated vehicles or also the communication of OBUs and RSU.

As controlled testing is performed in a shorter period of time, compared to other design variants, it is easiest to include the diversity of tested drivers of their age, gender, and education. Such groups of people may have different views on the evaluated system. Evaluated drivers have the opportunity to try the system live and can communicate their opinions and comments directly after personal experience. These opinions can be recorded both before the testing, where it is shown what drivers have a view of such a system and after testing where it will be seen how this view has changed. This method is less time consuming in terms of preparation and performing subsequent data analysis. The logging device is easier to set up in this type of experiment and can be modified or repaired in the event of a device failure unlike in the Naturalistic Driving Study.

In a controlled test, it is generally difficult to get rid of the unintentional intervention during the testing. The driver must be tested in as natural an environment as possible so that they behave as in normal life. However, this is very difficult with this type of test when the driver is exposed to a situation that he does not normally encounter. The driver is told exactly what to do and where to go. The tested person is also seated in a foreign car, which can be very difficult for some people. As the driver is also exposed to these influencing factors, it is difficult to recognize the true effect and benefit of the new system. The driver's experience with the system is also relatively short, so his true opinion cannot be captured. It may be that before the driver becomes familiar with the new system, the testing is over. It follows that for this type of test it is possible to record a priori a user acceptance and not appropriation according to FESTA handbook. [15]

4.1.2. Naturalistic driving sturdy

Naturalistic driving study is another possibility of C-ITS evaluation, which, unlike controlled testing, takes longer. The driver usually has an OBU with HMI installed in his car for a longer period of time using this system. Drivers thus encounter situations on a daily basis in their normal environment and can get used to it better. Data from the vehicle for subsequent analysis are captured using a logger installed in the car, or with the help of an RSU that captures the communication of the units.

Such a design solution has the advantage that the driver has enough time to get acquainted with the system. At the same time, the driver is not exposed to another distracting effect as with controlled testing. His reactions and opinions after a longer period of use are therefore closer to the reality of the actual use of the system by a real user. This method of implementation further brings a different level of view of the driver in obtaining his opinion in questionnaires and interviews such as user appropriation. In a naturalistic driving study is possible to evaluate the number of accidents without and with the C-ITS system which is a direct indicator of safety impact. However, this would require a very extensive study on a large number of people and for many months.

The disadvantage of evaluation performed in this way is the time-consuming nature of this implementation. This can mean a month to several months of evaluation, depending on the number of drivers, their daily driving time, and the frequency with which they encounter the tested use-cases. It may also be the case that drivers will encounter these use-cases so little that the study will not be evaluable. The data collected from the logs in the naturalistic driving study can be very extensive in this case and may not have the same detail and sampling frequency as the other options. A robust database structure is needed to store and subsequently analyse such an amount of data. Another disadvantage is that if the recording device or OBU fails, it may not be known for a long time. For this reason, regular checks and data retention should be carried out to reduce this likelihood.

4.1.3. Simulator testing

Testing on a car driving simulator is a way to test the driver for situations that would not be possible in real conditions. In the case of C-ITS, this may involve testing the driver's response under conditions approaching an accident, or conditions that are not easily simulated as a traffic congestion and an animal on the road. A car driving simulator, software simulating the environment and a selected use case are used to test drivers.

The advantage of such evaluation is safe testing in a laboratory environment, which can take place for a longer period of time. The driver can thus drive through the simulated environment several times for more use-case. The driver is not endangered in any way. Evaluation of the driver's reaction is possible directly in the simulation program, which records the outputs from the driver, as well as, the time when a warning message is displayed. It is also possible to use other types of recording devices in the evaluation, evaluating the driver's attention and when the driver registered a warning message, such as an eye-tracker.

The disadvantage of testing on a simulator is the lack of approach to reality. It very much depends on the type and design of the simulator itself. However, the driver is aware of this difference and may not behave as in a normal situation, so the driver's reactions may be distorted. As the driver does not have real experience with the tested system and its operation in a real situation, the questionnaire evaluation is not as beneficial as in the previous two methods. Another disadvantage is that the car driving simulator is a very expensive affair and even if it is accessible, another study may be performed on it and it will be staffed. It is also necessary to simulate an environment suitable for testing drivers for a given use-case in the appropriate program used by the simulator. Many people may not have access to this, and it may incur additional costs.

4.1.4. Traffic simulation

Simulation programs such as PTV Vissim, AIMSUM and CORSIM are used for traffic simulations. These are used mainly for microsimulations to mimic the real behaviour of drivers and subsequent evaluation of changes in their behaviour with the implementation of the new system. In the simulation program, the roads are designed according to the original area with the same parameters as in reality so that they are as close to reality as possible. Subsequently, the model of driver behaviour is calibrated according to historical data from the place of evaluation. The program can be then repeated in several runs with different parameters and thus capture the change in driver behaviour before and after the implementation of C-ITS.

The advantage of this design is the possibility of testing the use of C-ITS as in a real situation when put into normal operation. Thus, it is possible to experiment and change parameters, for example the penetration rate and the amount of shown use-cases and their length and time relevance of the zone. Because it is a simulated environment, the data is automatically recorded and is more detailed. Thus, an additional analysis can be performed to evaluate the environmental, noise and emission consequences. It is also possible to evaluate the consequences of the information on the change of the driving route and the consequently caused traffic congestion.

The disadvantage of traffic simulations is that this type of evaluation does not imply any of the types of use-acceptance required in the requirements. Another additional experiment would have to be performed to obtain the user's opinion of the system under test. A well-calibrated model according to the collected data is needed for the simulation to work properly. If data are not available for a given territory, their collection can be time-consuming or costly. Likewise, the calibration itself can take a great deal of time to be performed correctly.

4.2. Selection and description of evaluation

After considering the possibilities of evaluation and the requirements arising from the assignment, controlled testing was selected as the best design option. This decision was made mainly from the time and organizational benefits it brings. The naturalistic driving study was due to its time-consuming nature and the need for several OBUs and recording devices that were not available for evaluation, found to be an unsuitable option. One of the requirements for evaluation was that the evaluation must take place on site. For the evaluation method using a car driving simulator, this would mean simulating the environment of the implementation site under the same conditions. This was assessed as a more challenging way than carrying out an on-site evaluation. As this method also brings other disadvantages such as detachment from reality and busyness of vehicle simulators, this variant was not accepted as optimal. Traffic simulation was the second-best option for the evaluation. However, the reason why the traffic simulation was not selected as satisfactory compared to the controlled testing was that additional experiments with drivers would have to be performed in order to evaluate their opinion on C-ITS.

The evaluation will be performed by controlled testing on a pre-prepared route. For better analysis, two test drives will be performed with each driver. If possible, the first ride will be made without the use of C-ITS and the driver will respond to an upcoming event without any message being displayed. The second journey will be made using C-ITS with HMI and the driver will be shown a warning in advance about the use-case. In this way, it will be easiest to compare the benefits of C-ITS and the driver's response to it. The HMI will be represented in the car by a tablet with an application that displays the driver information about the upcoming event, its direction and distance.

4.3. Preparation of general design for evaluation

In this part, the general procedure of designing an evaluation for the tested use-case within the framework of C-Roads CZ will be discussed. This part will be divided into three parts. The preparation of the evaluation contains the necessary preparation for the implementation of the evaluation as proposed in this work. The Technical Equipment section has the task of presenting the possibilities of technical design and the possibilities of recording devices within C-Roads CZ and their parameters. The description section outlines the structure of the description of the tested use-cases and their evaluation, which in this document follows from section 5.

4.3.1. Preparation of evaluation

Before the evaluation tests, it is necessary to carry out a number of steps and preparations so that the evaluation can be execute as proposed in this work. It is desirable before performing an evaluation to test the functionality of each use-case via field testing. Field testing finds whether the individual use-cases work correctly as they are designed, that the OBUs communicate in the correct formats and that the HMI display works. This reduces the likelihood that the use-case will not work properly and in a timely manner when evaluating use-cases with invited drivers.

To plan the evaluation, it is recommended to prepare a detailed map and organizational plan. For controlled testing, it is necessary to have a planned route of passages and prepare a program of passages of individual drivers. This method will ensure the arrival of drivers for such planned time and so they will fill out a questionnaire before the ride and then travel the proposed route without much delay. The passage should be tested before the evaluation and thus estimate its time duration. However, it must be kept in mind that each driver travels at a different speed and a time reserve must be taken into account. Drivers need to have time to get acquainted with the driving characteristics of the vehicle, so it is not advisable to schedule a use-case event too soon in the route.

Several people are needed for the evaluation to work properly. It is recommended that one person helps to fill in the questionnaires for new arriving drivers and one person drives with the drivers in the vehicle. The person in the vehicle can navigate the evaluated driver and help with the timing of individual use cases by announcing the passage of the vehicle by two-way radio or mobile phone. This is useful if it is difficult to coordinate the test use case and another person initiating the event must be at event place.

To evaluate the user acceptance, the questionnaires has to be printed before the start of the evaluation. It is also necessary to charge and test the recording equipment for proper operation and thus eliminate errors and subsequent delays in evaluation.

4.3.2. Technical equipment

During controlled testing, which was selected as the ideal option, the driver's response, and the effect of C-ITS on the driver's behaviour will be evaluated. This will be evaluated according to the recorded driving data during the controlled testing. A logging device is required that will record position, speed, acceleration data and other data suitable for evaluating the results. In this part, three possible recording solutions will be presented, which are used for evaluation at C-Roads CZ.

HMI

The HMI is the only C-ITS output for displaying information in the vehicle. The HMI can be implemented as integrated in the dashboard, external tablet or mobile with an application that is able to display C-ITS messages. It was used in the evaluation in this work tablet connected to the OBU via Wi-Fi. What the display on the HMI will look like is shown on Figure 4.

Figure 4 HMI with Slow and stationary vehicle

OBU logger

The OBU logger is a recording device for capturing communication between individual OBUs and the RSU. OBU used in the evaluation is shown in Figure 5 and antenna for GPS communication in Figure 6 below. This device is able to record CAM, DENM and all other defined messages within C-Roads specifications. To record such communication, an OBU connected to a laptop is required, which can capture the communication using the Wireshark program. In order to decode the message, it is necessary to have the appropriate dissector plugins installed in Wireshark, which will allow reading the communication. The recording device has also the ability to record the communication of other vehicles with OBU, so it does not have to be physically in every vehicle. The distance that the logging device can record the communication depends on the environment and the signal interference, but it is around 500m.

Figure 5 OBU used in evaluation

Figure 6 Antenna for GPS communication

The transmission frequency of CAM message vehicles by vehicles should be between 100 ms and 1000 ms. This depends on the change in vehicle state and signal congestion. There can be a lot of information inside the sent CAM message, unfortunately not all of them are obligatory to send and only some can be used. Mandatory information contained in CAM messages and usable in the analysis of driver behaviour are GPS position, speed and direction.

The Wireshark program can be used for subsequent analysis of data from the OBU. The data collected in it can be filtered, for example, to CAM and DENM messages and these, together with selected data columns (as speed, longitude, latitude), transferred to CSV format. The CSV format is then easily parsed in any other program.

Table 1 Parameters of logging device OBU logger

Parameters	**Values**
Recorded data	*Timestamp, GPS position, speed, direction
Record on	The memory of the connected computer
Sampling frequency	100 ms – 1000 ms
Position accuracy	2.5 – 10 m
Velocity accuracy	depends on the accuracy of the GPS
Operating time	Connected to the car battery
Analysis in	Wire-shark

*Depends on communication setting of individual OBU

OBD2 logger

Modern vehicles are equipped with many sensors. These sensors communicate with the control unit and can be evaluated for the purposes of display and assistance systems in the vehicle. Communication takes place via the CAN bus inside the car and can be intercepted via the OBD2 logger. Within the project, it was possible to use the OBD2 logger CANedge1 from CSS electronics purchased for evaluation reasons. The CANedge1 is shown in Figure 7. CANedge1 can capture the communication taking place on the SD card for further data analysis.

Figure 7 OBD2 device used in evaluation.

The content of the data depends on the individual vehicles, their year of manufacture and brand. The OBD2 logger can only capture communication, but not subsequently decode it into a human readable form like km / h, %. This requires the DBC library, in which parts of the code and their interpretations are written. Different carmakers use different DBCs, so it is necessary to find a specific library for a given make and type of car. The GUI / API Asammdf, supplied with the OBD2 logger, can be used for subsequent decoding.

Table 2 Parameters of logging device OBD2 [35]

Parameters	**Values**
Recorded data	*Timestamp, speed, acceleration, steering wheel turn, pedal depressing, fuel use
Record on	Micro SD card
Sampling frequency	Depends on the communication frequency of individual sensors
Velocity accuracy	depends on the car
Operating time	Connected to the car battery
Analysis in	Asammdf GUI

*Recorded data depends on the vehicle

GPS logger

A GPS logger can be used to record GPS and speed. As part of the project, the GPS logger CANMORE GP-102+ was purchased for evaluation purposes. This recording device can log position and speed data. This data can then be analysed and converted to csv in a very simple program CANWAY supplied with the unit. CANMORE GP-102+ has the ability to switch between individual data recording modes and select, for example, the recording of a moving vehicle. The recording parameters such as the sampling frequency of the GPS logger are adjusted accordingly. GPS logger is shown in Figure 8.

Figure 8 GPS logger used in evaluation

Table 3 Parameters of logging device - GPS logger [36]

Parameters	Values
Recorded data	Timestamp, GPS position, speed, altitude, barometer
Record on	Internal memory
Sampling frequency	Every 1 – 5 sec
Position accuracy	2.5m
Velocity accuracy	0.1m/sec
Operating time	17 – 20 h
Analysis in	CANWAY

4.3.3. Evaluation description

The evaluation of individual use-case will be described in this document in the chapter 5 and analysed in chapter 6. The course of the evaluation will be described in the introductory part together with the situation map, where the evaluation took place and which route was chosen. This chapter will discuss the general conditions and at what time and on how many drivers were evaluated. This will be accompanied by a situation map to better illustrate the evaluation place.

The Test scenario part will be used to zoom in on the course of the proposed test scenario and display the route and use-case events on the map. In the following testing process section, it will be analysed how the individual testing took place in the given locality and how the passages of drivers were organized. Testing will be preferably done in two passes, one without C-ITS and the other with C-ITS. This will make it possible to compare the effect of C-ITS on drivers in the evaluation. The conditions under which the evaluation was performed will be shown in the table Evaluation condition table, illustrated in Table 4.

Table 4 Model for evaluation conditions

Conditions	**Description**	**Details**
Weather		
Hour		
Light visibility		
Situation clarity		
Tested subjects		
Road topology (highway, rural, urban)		
Traffic restrictions		
Used Car		
Traffic flow		
Logging device		

The next part Data processing will focus on the use of recording devices and what methods were used in data processing in the evaluation. The OBU logging unit will be the main data logging device, recording the communication between the OBU units, its position and speed. An OBD2 and GPS logger will be used to collect additional data. All used recording devices and data obtained from them will be listed for individual use-case as they may differ depending on the test conditions. Data analysis will be performed in the R programming language in the Rstudio environment. For this purpose, scripts will be developed that modify the form of the data into an acceptable form. As the recording equipment runs throughout the whole test, the data will be broken down into time windows using the scripts, in which the driver's behavioural reactions at the individual passage are best seen. Subsequent time windows will be aggregated and evaluated using the impact assessment analysis described in section 4.3.3.1.

The last part will be focused on the evaluation of chosen use-cases and will consist of two parts. The first part of the evaluation is an impact assessment focusing on evaluating the driver's response according to the data collected, comparing his behaviour with and without the use of C-ITS. The second part will be the evaluation of user acceptance via questionnaires and is discussed in detail in section 4.3.3.2.

4.3.3.1. Impact assessment

For each evaluated use-case, key performance indicators will be selected, which evaluate the driver's behaviour according to the specified parameters. These parameters will then be compared in passages with and without C-ITS and the results will be evaluated. The selection of KPIs and their evaluation is subject to the capabilities of recording equipment and data processing. For each use-case, a list will be displayed of which KPIs are evaluated in this use-case. Possible KPIs are:

Compliance of driver's reaction with the situation

The driver's reaction to an unexpected situation may vary from driver to driver. This KPI examines how the driver's behaviour comply with the warning. The driver's reaction after the arrival of the warning message might be:

- No change in driving speed behaviour
- Deceleration
- Acceleration

Driver's reaction is measured a few seconds before the arrival and a few seconds after the arrival of the message. A linear regression line of the few-second time window was used to determine the driver's response. This linear regression is created through this time window and its slope of the line shows the driver's behaviour.

- Driver does not react if the slope of the interleaved line is the same a few seconds after the arrival of warning message as few seconds before.
- The driver is decelerating if the slope of the interleaved line is lower few seconds after the arrival of warning message as few seconds before.
- The driver is accelerating if the slope of the interleaved line is higher few seconds after the arrival of warning message as few seconds before.

Average speed comparison

Average speed is calculated from the time window selected from the data for vehicles arriving at the event receiving the warning message. This KPI examines how does the current speed change immediately after message reception.

Driver's compliance with the traffic restrictions

The difference between the maximum possible speed allowed by law on a traffic road, and the maximum speed reached by vehicles.

Driver's acceleration changes comparison

The average and maximum acceleration and deceleration changes of a vehicle after a warning message is calculated in the time window to monitor the speed changes. This KPI examines how the current acceleration changes immediately after message reception.

The vehicle acceleration could not be obtained from the CAM message and is calculated as the difference between the actual and previous speeds divided by the delta time between the two messages. This approach may contain errors as the sampling rate is not consistent and varies.

Standard speed deviation, maximal and minimal speed

Maximum, minimum speed and the standard deviation is calculated during the time window for all vehicles.

4.3.3.2. User acceptance

User acceptance will examine all participants in the experiment using a questionnaire. The prepared questionnaires are filled in by the driver before the test and subsequently after the test. The pre-test questionnaires are intended to capture the test person's opinion before the test without the person's experience with the system. In this way, the a priori acceptability of tested subjects and their ability to accept C-ITS is captured.

Questionnaires design

The questionnaires will be divided into three parts in the evaluation. Before performing the controlled test, the driver can be filled out a general information questionnaire about his age, education, driving skills, etc. Then he fills in a section on the opinion on the tested scenario and its usefulness and thus captures the driver's priori acceptability. The questionnaires, after performing controlled testing, are intended to capture user acceptance as well as a change in the driver's opinion. In these questionnaires, the user can also express his opinion on the functioning of C-ITS and any comments or proposed improvements. The questionnaires are designed using the 5 Likert scale method, where the test subject can tick one of the five answers for each statement (Likert item) as to how much he agrees with the statement. These answers start with Strongly agree and end with Strongly disagree. Each of these answers has a number from 1 to 5 for subsequent analysis. The Likert scale questions in questionnaires will be supplemented with multiple choice questions to better cover the opinion of the tested subjects.

The questionnaire before the test is divided into three parts. The general part of this questionnaire is filled in by the driver first. It has the task of obtaining information about the driver such as:

- personal information (gender, age, education),
- drivers experience (professional driver, length of possession of a driving license, mileage per year),
- current use of information systems in the vehicle,
- preferences in the use of information systems.

The second part of the questionnaire before the test deals with the use case itself. In this sector, the user's view of the use-case and the opinion on its usefulness are evaluated. The third part contains general questions about C-ITS and the driver's opinion on distracting C-ITS from driving, increasing comfort and the user's willingness to pay for this service.

The questionnaires after the test are divided into two parts. The first part of the questionnaires will deal with the display of information on the HMI and whether the driver was able to register the information. Subsequently, it will ask the driver's opinion on the use-case itself, its usefulness and whether it increases comfort and safety while driving. The second part of the questionnaire after the test will contain general questions about C-ITS related to distracting the driver, the suitability of the location of the tablet and the willingness to pay for the service.

4.4. Guideline for evaluation

This chapter deals with the course of the general implementation of the evaluation as it should be developed according to the evaluation design proposed above. The general steps will be listed in points so that when preparing the evaluation for the selected use-case in C-Roads, it will be possible to proceed in this way and nothing will be forgotten. To execute a use-case evaluation, it is necessary to perform:

- select test use-case,
- arrange evaluation team according to the needs of the use-case,
- suggest the place where the test use-case will be evaluated,
- plan an evaluation route and the course of the testing,
- suggest the time, date when the test use-case will be evaluated,
- drive or estimate the route as it will be evaluated and find out the time requirements for one driver,

- schedule testing drivers for predetermined time slots (recommended 2 drivers per hour, but it depends on the tested use-case),
- organize evaluation staff operating the use-case (road maintenance, police, railway maintenance),
- arrange the evaluation vehicle (s) together with the appropriate amount of HMI and OBU,
- consider the possibilities of logging devices and suggest a method of data evaluation,
- agree on or provide a method of communication between the team for use-case demanding synchronization,
- design and print questionnaires,
- test the functionality and battery life of recording equipment before evaluation,
- provide power and spare batteries for the recording equipment so that it lasts throughout the evaluation,
- check the site before testing for roadworks or other repairs that could make testing difficult,
- charge the device before testing.

5. Verifying the functionality of the designed system solution

In this part, the implementation at pilot sites and the way they were subsequently evaluated will be discussed. The results of the evaluation are shown in the chapter 6. Verification of the evaluation design functionality will be performed for two use-cases. The first is intersection signal violation aimed at warning the driver about another driver driving on a red light. The second use-case deals with execution of experiment on Railway level Crossing. This use-case shows the drivers arriving to the railway crossing if it is closed and train is passing. Testing will be performed by the CVUT evaluation team.

5.1. Intersection signal violation evaluation ISV

Intersection signal violation has been evaluated on the intersection with real traffic in Brno. This intersection was chosen due to its lower traffic during the early hours and the existence of an RSU that the ISV can perform. Due to potential risk of collision passing vehicles with tested vehicles, the intersection was alternately closing and opening each time the test vehicles were driven. For this reason, the test was also performed early in the morning between 5 and 6 o'clock in the morning and with a relatively small number of test drivers grouped together. ISV use-case has been tested by 9 test subjects. Originally, 15 vehicles were planned, but due to delays and increasing traffic on the intersection, the evaluation had to be shortened.

Figure 9 Situation map, ISV use-case

5.1.1. Test scenario

The evaluated drivers (vehicles A) had the task of passing from segment number 1 to segment number 2 on the green signal on the traffic lights. Vehicle A always came from segment number 1 and stopped at a red light. When the signal turned green at the traffic lights for segment 1, vehicle A continued to the segment 2. In this moment, the vehicle from segment 3 drove vehicle B to the red signal also to the segment 2. The OBU in vehicle B calculated that this vehicle would not be able to stop at traffic lights and started sending warnings about the passage of the ISV. This warning message is shown in vehicles A on the HMI display.

5.1.2. Testing process

Drivers completed questionnaires before the test about their general information and a section to capture a view of the test scenario. The drivers then got into the vehicle and prepared in front of the intersection in segment 1. The traffic light control staff signalled vehicle B and switched the signal plan to green for segment 1. Communication between vehicles using the OBU was recorded by a recording device near the intersection marked in Figure 9. After passing the intersection, the drivers stopped at the adjacent parking lot and completed the third part of the questionnaire after the test. The testing took place in three parts, the first passage was completed by two A vehicles, the second passage by two other vehicles and the third by five. The evaluation conditions are shown in Table 5.

Table 5 Evaluation conditions ISV

Conditions	**Description**	**Details**
Weather	Partly cloudy	
Hour	5AM – 6AM	
Light visibility	Streetlights	
Situation clarity	vehicles A had visibility to the arriving vehicle B	
Tested subjects	9	
Road topology (highway, rural, urban)	Urban	The first road segment contains 4 lanes, the first turning left, the second straight, the third right and opposite lane. The second road segment is consisting of three lanes, one straight, one left and opposite lane. Third road segment contains only one lane allowed to turn left and straight.
Traffic restrictions	50 km/h	

Conditions	Description	Details
Used Car	Road maintenance vehicle (work vehicles), Skoda city go	All test subjects used their own towing vehicle used in work for the evaluation. The vehicle B was Skoda Citigo.
Traffic flow	None	The intersection was stopped by the police.
Logging device	OBU logger	The OBD logger was the only logging device due to the difficulty with installation the multiple devices into different vehicles used by tested drivers.

5.1.3. Data processing

The data captured by nearby standing logging device in packet capture (pcap) format in the vehicle was filtrated to CAM and DENM messages with the program Wireshark. This filtrated data was transferred to csv format and processed with the R programming language in RStudio. The data was prepared for analysis and converted to the correct format (km/h, longitude and latitude, timestamp). The next step was to filter CAM messages to individual vehicles according to Station_ID. Finding the messages sent to vehicles A and B was done manually by sorting the messages according to the number of received messages. 7 out of 9 vehicles were found using this method. Two of the vehicles may have malfunctioned unit or was not detected by our recording equipment. The created script for data processing and analysing is shown in Annex 3.

The following OBU logger communication data was found applicable for evaluation.

- Position – source: CAM
- Speed – source: CAM
- Acceleration - source: calculated from GPS position
- C-ITS ISV warning message – source: DENM

5.2. Railway Level Crossing RLX

The Railway Level Crossing was evaluated at one of two level crossings, equipped with an RSU and capable of sending an RLX use-case. It was located in the Pardubice region in the village Úhřetice. The situation map and the evaluation route are shown in Figure 10. Due to the low number of passing vehicles and trains, the evaluation could be carried out in the usual time between 9 am and 3 pm. The evaluation was performed for two days and 16 drivers. Drivers used a Ford C-max equipped with recording devices during a 20-minute drive. Unfortunately, the first day of evaluation, the logging device failed and log from the communication between the car and RSU was not recorded. For this reason, only questionnaires can be used from the first day.

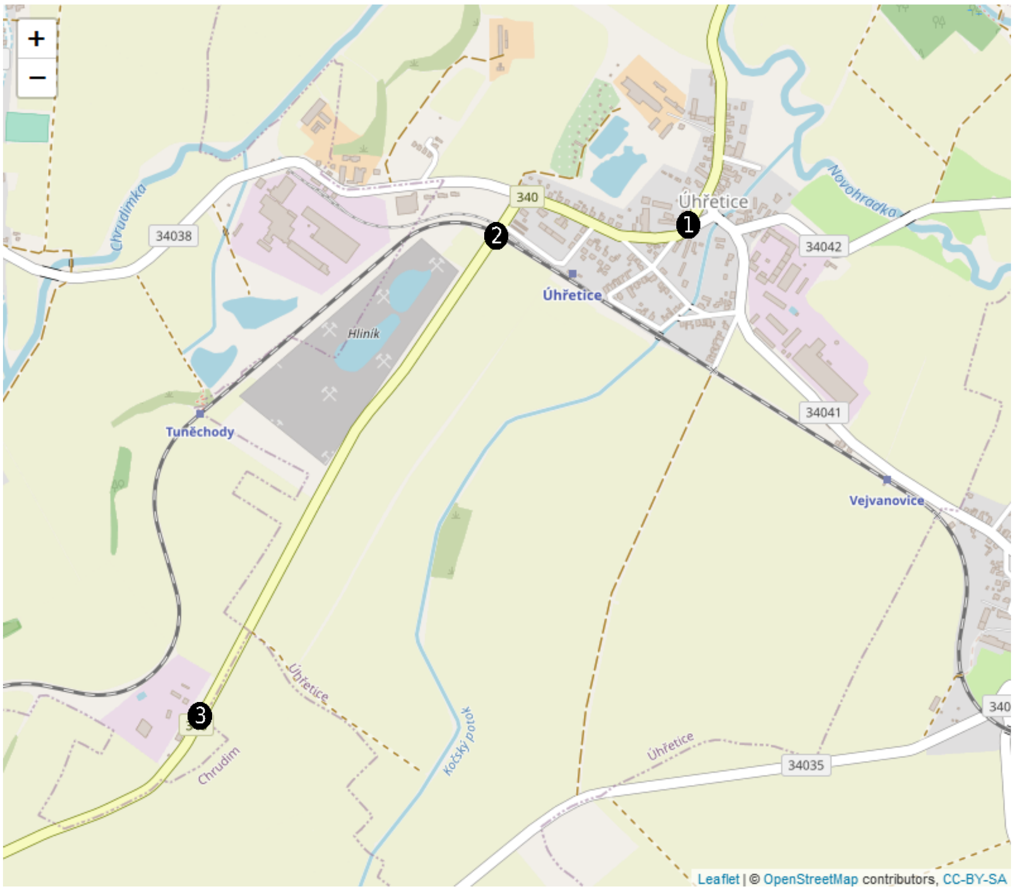

Figure 10 Situation map, RLX use-case

5.2.1. Test scenario

During the RLX evaluation, the drivers boarded the vehicle in Úhřetice at point 1 and from there they continued to railway crossing at point 2. During this passage, the driver had the HMI switched off and his normal behaviour was recorded as a baseline without using C-ITS. The level crossing was in warning and the red lights were flashing. The railway crossing was opened after the time period and the driver continued to drive to point 3 where he turned around. When driving back over point 2, the level crossing was open, and the HMI was still switched off. The driver arrived at point 1, where the HMI was switched on.

The second run was from point 1 to point 2, where the driver was shown a warning message on the HMI Caution Train! After opening the crossing, the driver followed again to point 3 where he turned around. When driving back at a level crossing, the driver was warned on the HMI Drive with extra caution, approaching railway level crossing. The driver ended the ride at point 1, where another driver was recruited and then another ride was made.

5.2.2. Testing process

Drivers filled out a questionnaire about their general information and questionnaire before the test focusing on the test scenario. They got into the vehicle at point one and drove the route twice, once with the HMI off and the second time with the HMI on. The railway staff always switched on and then switched off the warning lights at the railway level crossing after a signal from an arriving vehicle. Before driving, the vehicle was equipped with a logging unit recording communication and a GPS logger. After passing both rides, the driver was given a questionnaire to fill in after the ride. The evaluation conditions are shown in Table 6.

Table 6 Evaluation conditions RLX

Conditions	**Description**	**Details**
Weather	Sunny	
Hour	9AM – 2PM	
Light visibility	Natural light	
Situation clarity	Clear visibility to the level crossing 100 m before	
Tested subjects	16	5 passes the first day, 11 passes the second day.
Road topology (highway, rural, urban)	Extra - urban	
Traffic restrictions	50 km/h	When approaching a railway crossing with a signalling system, the driver must observe a speed limit of 50 km / h in the Czech Republic.
Used Car	Ford C-Max	All test subjects used vehicle ready for testing and equipped with sensors.
Traffic flow	Light traffic	max 1800 veh / day, 15 trains per day
Logging device	OBU logger, OBD2, GPS logger	

5.2.3. Data processing

The data captured by OBU logging device in pcap format in the testing vehicle was filtrated to CAM and DENM messages with the Wireshark program. This filtrated data was transferred to csv format and processed with the R programming language in RStudio. The data was prepared for analysis and converted to the correct format (km/h, longitude and latitude, timestamp). The most CAM messages belonging to the evaluation vehicle were identified by finding the most common Station_ID captured by the logging unit. With the help of the times recorded at the beginning and end of the passage by the evaluation staff, the log was divided into individual passages. In this way, all 11 passages were found. DENM messages have been divided into Caution Train! And Drive with extra caution, approaching railway level crossing. This was done using Subcausecode inside DENM. The individual passages of the drivers were sorted according to the time recorded by the passenger of the vehicle, who recorded the beginning and the end of the journey. To compare the drivers reaction when approaching the crossing, GPS data were filtered according to the proximity of the crossing. A polygon has been created near the crossing, and if the GPS data falls into this polygon, it is then analysed. The polygon and GPS data falling into it are shown in Figure 11.

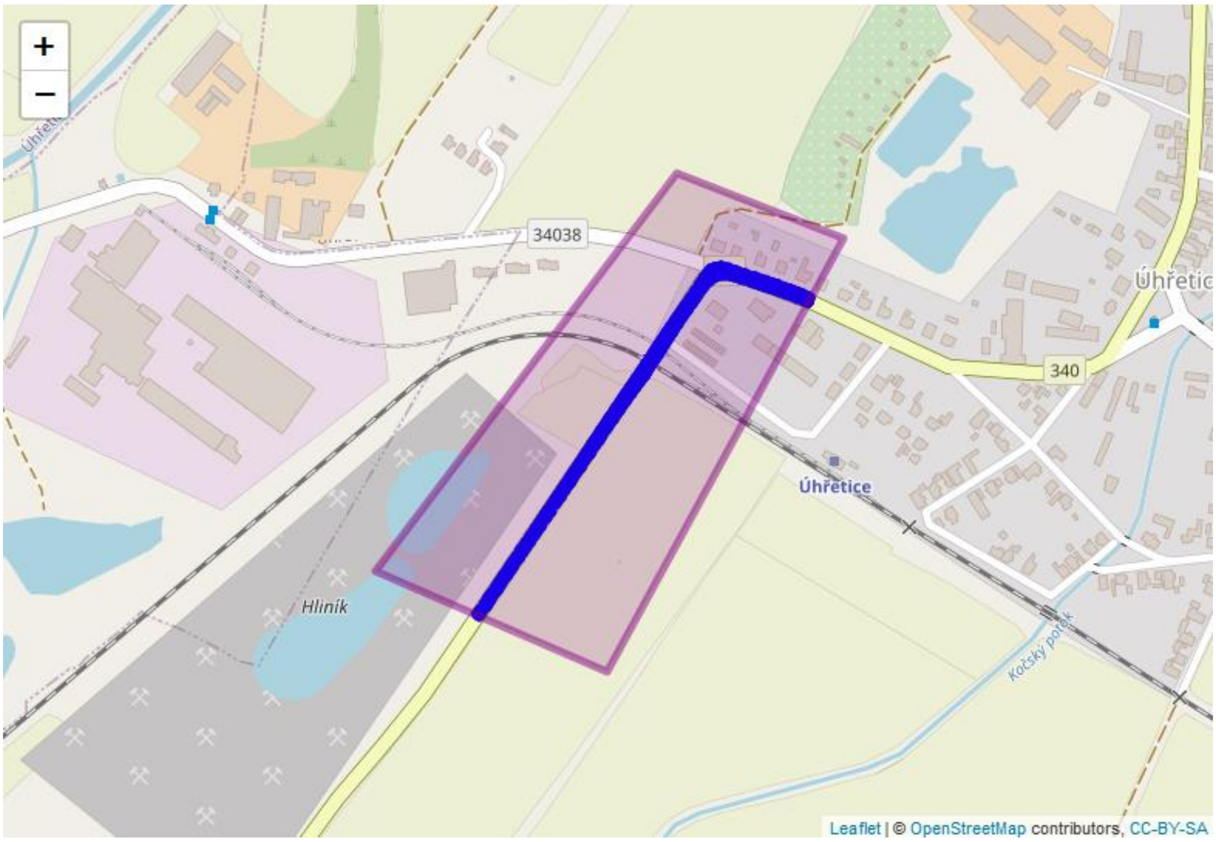

Figure 11 Polygon map - RLX

The data belonging to this polygon were then divided into a passage from point 1 to point 3 and a passage from point 3 to point 1. The experiment was set up to always compare the same passages under similar conditions. First transit from 1 to 3, the display of the “Attention, railway crossing!” is compared. Second transit from point 3 to 1, the display of the warning message “Passing train!” is compared. In order to compare the driver's behaviour with and without C-ITS, these journeys had to be made twice. These passages were distinguished using the heading parameter in CAM messages. A threshold was found to distinguish the passage to point 3 and to point 1, which divides them. An example is shown in Figure 12. These passages were then compared in the impact assessment section. The script created for data processing and analysis is shown in Annex 4.

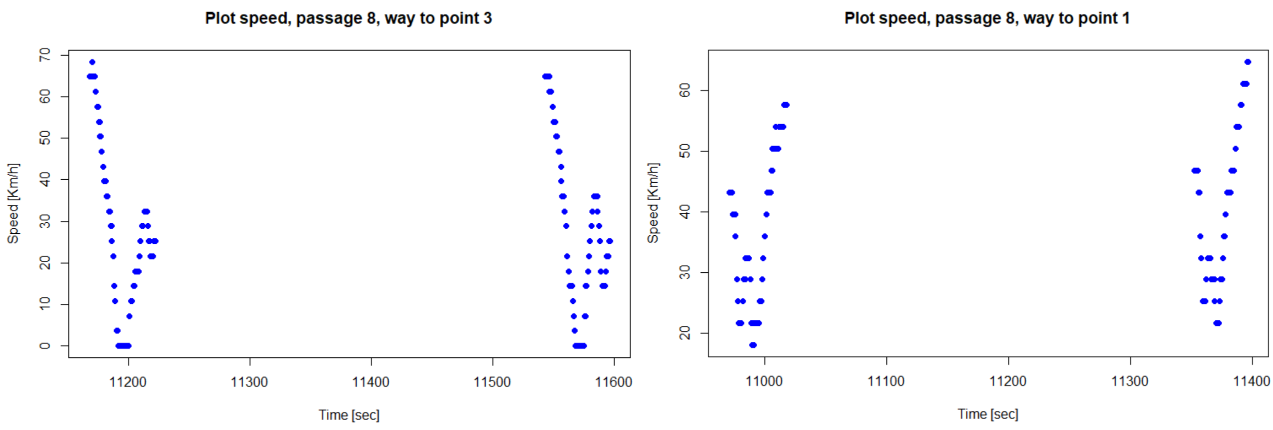

Figure 12 Passage to point 1 and back to point 3

An OBD2 logger from CSS electronics was purchased to analyse data directly from the car. Preliminary round before tests were performed with the Ford C-Max test vehicle to determine the capabilities and functionality of the OBD2 logger. A database format structured (DBC) library containing the definition of CAN messages and signals is required to decode the data recorded from the CAN bus communication. This may be different for each manufacturer and may not be accessible. For the test vehicle Ford C-Max, the data collected by the OBD2 logger proved to be unusable due to insufficient detail in the description of the data and units in which the recorded quantity is located. Most types of messages from the CAN bus also could not be decrypted. This was due to the fact that the manufacturer of this vehicle and for this type did not publicly provide the original DBC library and it was necessary to use unofficial ones.

Position and speed data were also recorded using the CANMORE GPS logger. Data from the OBU logger on GPS position and speed were preferred over it due to their higher frequency. The average frequency of recording the position of the OBU logger was about 1 sec, while data from the CANMORE GPS logger was recorded after 5 sec.

The following data from OBU logger communication was found applicable for evaluation.

- Position – source: CAM
- Speed – source: CAM
- Acceleration - source: calculated from GPS position
- C-ITS RLX warning message – source: DENM

6. Evaluation of achieved results

Evaluation of chosen use-cases was conducted base on chosen design described in chapter 4.2.

6.1. Evaluation of Intersection signal violation evaluation ISV

For organizational reasons and relatively short time possibilities, the evaluation of ISV was not performed on two passages with and without C-ITS but only on a passage with C-ITS. For these reasons, a method was chosen to compare the driver's response a few seconds before receiving the message and a few seconds after. Unfortunately, two vehicles in the third group sent data inconsistently, and no CAM was received in the time window 2 seconds after receiving the ISV message. Therefore, they are not included in the analysis. This limits the analysis to 5 vehicles.

The vehicle position and speed were plotted in graphs to visually assess their reaction. Further analysis was performed on data aggregated from all vehicles. Based on the available data, the following KPIs were selected:

- visual evaluation,
- compliance of driver's reaction with the situation,
- average speed comparison,
- driver's compliance with the traffic restrictions,
- driver's acceleration changes comparison,
- standard speed deviation, maximal and minimal speed comparison.

6.1.1. Impact assessment

Visual evaluation

The visual comparison was performed for all vehicle speeds and position. An example of the behaviour of one driver can be seen in Figure 13. On plot of car #3 speed it is visible the driver's reaction after the DENM arrival and its speed adaptation. On Plot speed graph the driver #3 reduced the speed during the encounter with Car B. The driver A had a fairly high speed, given that it is an intersection. Vehicle B was moving at a slower speed and there was also a greater deceleration when encountering vehicle A. This is most likely caused by the route of vehicle B, which turned left, while vehicle A was driving straight in the left lane. This trend applies to other vehicles as well. The first two vehicles are similar in the speed reaction.

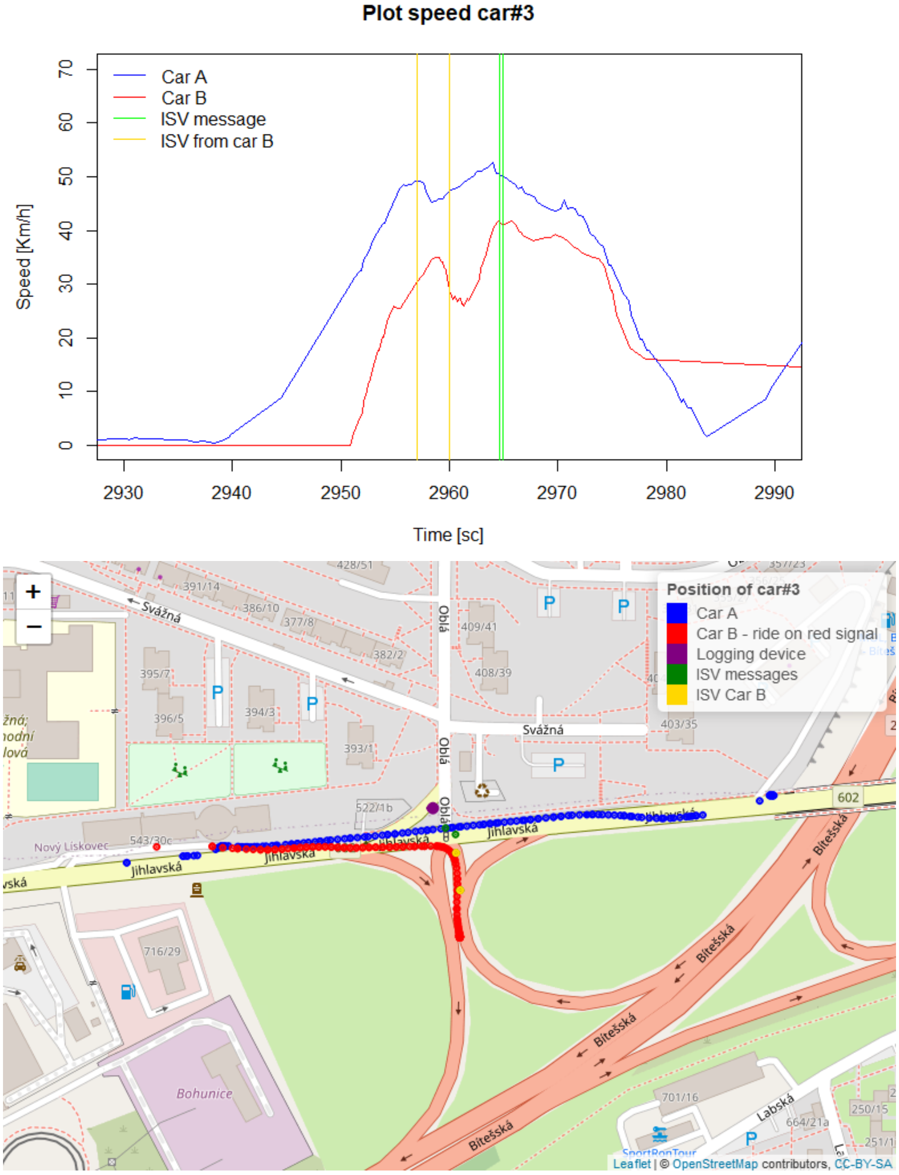

Figure 13 Speed and position of car #3

Compliance of driver's reaction with the situation

The driver's reaction to the unexpected event and ISV message is acceleration four out of five drivers as shown in Table 7. The drivers reacted to the unexpected even by decrease in acceleration but in the overall result they kept accelerating. This can be caused by the start of an evasive manoeuvre or by enough space for the vehicle to pass freely.

Table 7 ISV Compliant drivers

Car	Measurement ISV	Linear regression slope [-]	Drivers adaptation
#1	Before	1,47	Acceleration
	After	1,19	

Car	Measurement ISV	Linear regression slope [-]	Drivers adaptation
#2	Before	1,46	Acceleration
	After	2,28	
#3	Before	0,30	Deceleration
	After	-0,65	
#4	Before	0,36	Acceleration
	After	0,33	
#5	Before	1,95	Acceleration
	After	0,68	
Mean All vehicles	Mean before	1,11	
	Mean after	0,77	

Driver's compliance with the traffic restrictions

During the evaluation, drivers did not have an average measured speed lower after receiving the ISV message as shown in Table 8. A greater difference between the speed limit and the average speed in each vehicle can be seen in the Driver speed adaptation. One of the five vehicles mean speed exceeds the speed limit. The low values of mean speed for vehicle 4 and 5 was caused by delayed start for these vehicles. This group of vehicles started from the intersection in fours, always two in a row due to the time constrains. This space and time delay compared to vehicle B violating traffic lights is visible in Figure 13 for one vehicle.

Table 8 ISV Mean speed and Drivers speed adaptation for all vehicles

Car	Measurement ISV	Mean speed [km/h]	Driver compliance with the traffic restrictions [km/h]
#1	Before	40,32	9,68
	After	50,51	-0,51
#2	Before	31,20	18,80
	After	41,35	8,65
#3	Before	48,20	1,80
	After	47,45	2,55
#4	Before	1,47	48,53
	After	1,69	48,31
#5	Before	5,00	45,00
	After	12,52	37,48
Mean All vehicles	Before	28,98	21,02
	After	31,36	18,64

Average speed

Figure 14 shows that the average speed and is higher in 2 sec after. The vehicles did not reduce their average speed when crossing the intersection after the message arrival. This is most likely due to the vehicles gradually accelerating as they passed the intersection, or to have enough room for an evasive manoeuvre.

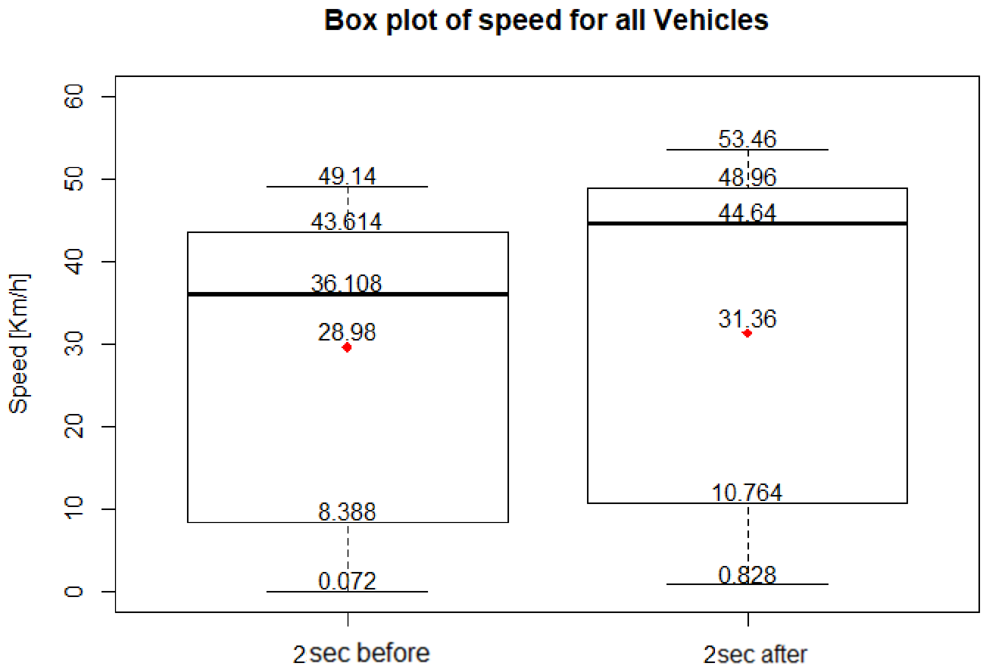

Figure 14 ISV Box plot for speed for all vehicles

Driver acceleration changes

The Figure 15 shows the instantaneous acceleration changes for all vehicles in a Box plot before the ISV message and after the arrival of this message. The drivers mainly reacted to Vehicle B with lower mean acceleration, but have the overall higher speed as shown in Figure 14. The boxplot after the ISV is cantered more towards negative values and indicates more deceleration manoeuvres.

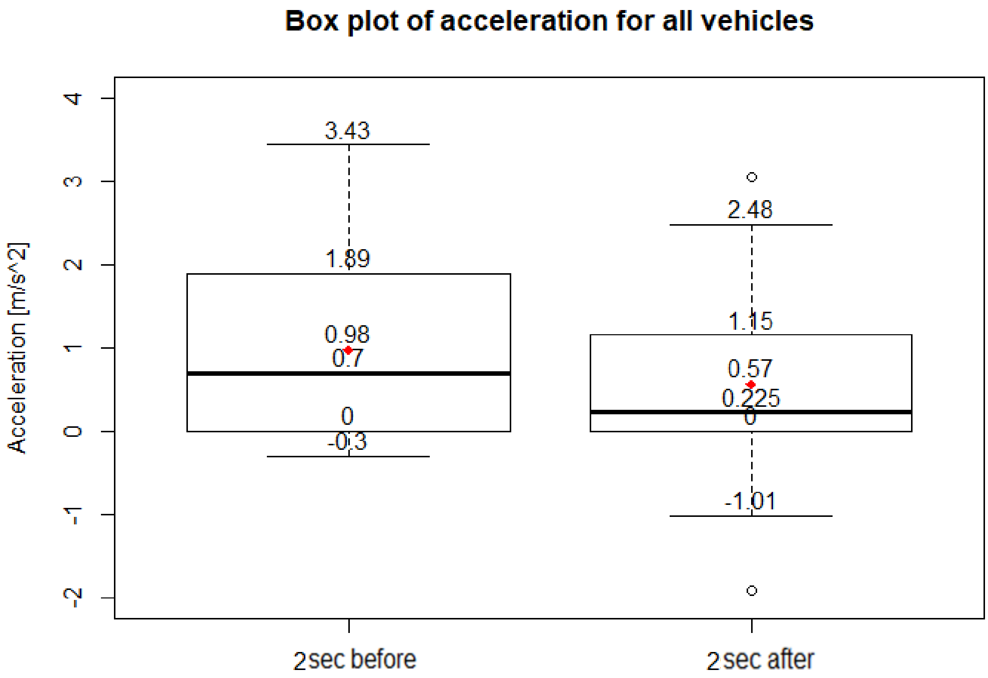

Figure 15 ISV Box plot for acceleration for all vehicles

Standard speed deviation, maximal and minimal speed

In both cases, the maximum and minimum speeds after the ISV message were higher than before. Standard speed deviation was also greater in the state after the ISV message as shown in Table 9. The standard deviation appears to be relatively large and indicates greater differences between vehicle speeds in different driving groups.

Table 9 Mean, Maximal, Minimal, and standard speed deviation for all vehicles ISV

	Mean speed	Maximal speed	Minimal speed	Standard speed deviation
	[km/h]	[km/h]	[km/h]	[km/h]
Before	28,98	49,14	0,07	18.37
After	31,36	53,46	0,83	20.88

6.1.2. User acceptance

The user acceptance was performed via questionnaires before and after passing the vehicle as described in chapter 4.3.3.2. A sample and results of questionnaire are attached in Annex 1.

6.1.2.1. Driver's profile

All participants in the tests were employees of Brno Roads. Due to the specific requirements of these tests and the need to equip OBUs in vehicles, it was not possible for the public to participate. The test subjects were therefore all professional drivers with a good knowledge of the local environment. For this reason, the tested drivers could have a higher speed than if they were driving in an unfamiliar environment. The Drivers profile is show in Figure 16.

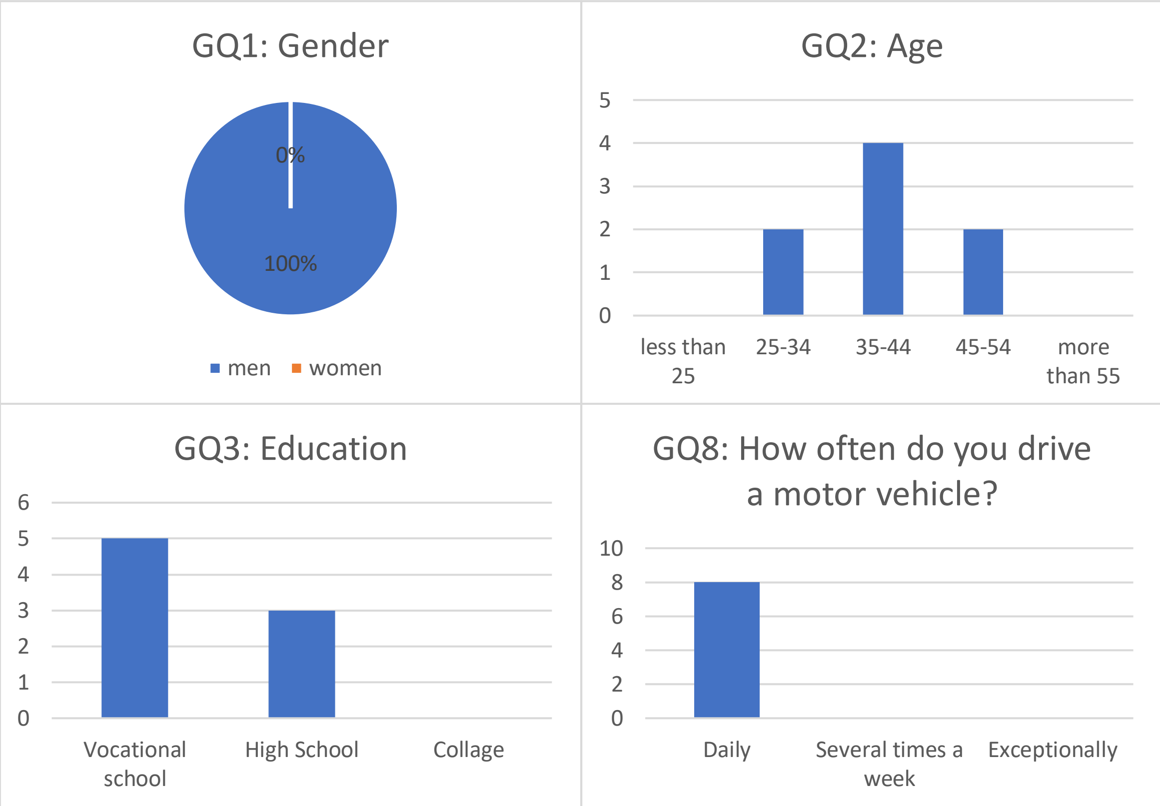

Figure 16 General questions ISV

Table 10 shows the responses of the tested drivers to the C-ITS system and the tested ISV use-case before testing. It showed a slightly increased interest in displaying a warning about the dangerous passage on red at traffic lights. Drivers have found this information useful from a safety point of view, but they also expect distractions due to the HMI. Drivers assume that if they receive such information, they will also adapt their driving, which can be seen in the answers in Figure 17.

Table 10 Pre-test questionnaires results ISV (1 – strongly disagree, 5 – strongly agree)

Question number	Question	Average value	Standard deviation
Q1	I would like to have HMI in my vehicle warning me about "dangerous vehicle", passing the traffic light on red signal.	3,75	0,88
Q2	I always want to be informed about the status of the SSZ of the next intersection.	4,00	0,93
Q3	Dangerous vehicle information increases driving safety.	4,50	0,97
Q4	I expect the HMI to distract me from driving.	3,75	1,17

Question number	Question	Average value	Standard deviation
Q5	When using the HMI, I will feel safer when driving through an intersection.	3,75	0,88
Q6	I assume that driving with HMI will be less demanding.	3,00	1,48

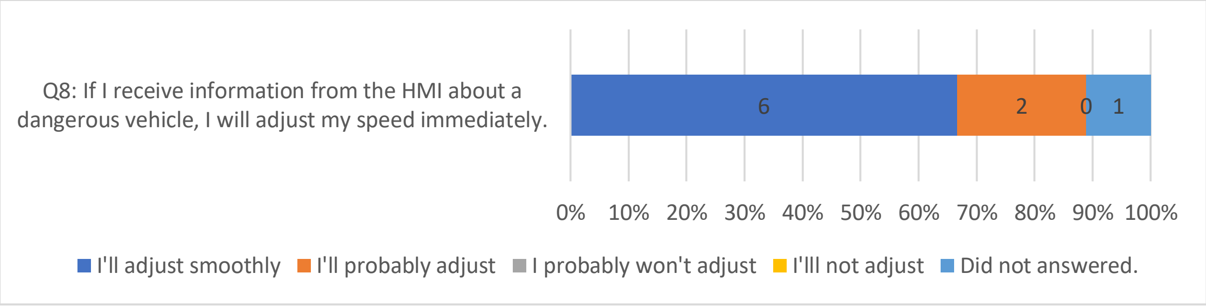

Figure 17 Pre-test question - Driver adaptation ISV

6.1.2.3. Post-test questionnaire

Table 11 shows the results from questionnaires after the evaluation test. Drivers are more inclined to believe that warning about a dangerous vehicle was useful and understandable. On average, drivers would like to have an HMI permanently in the car, but there are large differences between opinions in standard deviation. Similarly, there is the integration of HMI into dashboard. Drivers also expressed concern that the HMI would distract them during the driving. This view has risen after the test compared to the driver's expectations before the test. All drivers registered the warning, but 3 out of 9 paid no attention to it. 4 of the 9 drivers tested registered a warning before entering an intersection and 2 at an intersection. One of the drivers changed his mind and would pay for this service after testing. The rest would not pay for the service or is not decided.

Table 11 Post-test questionnaires results (1 – strongly disagree, 5 – strongly agree)

Question number	Question	Average value	Standard deviation
Q11	"Dangerous vehicle" warning was useful.	4,00	0,78
Q12	The information from the HMI was understandable.	4,38	0,50
Q13	I am satisfied with the information I received from HMI.	4,13	0,71
Q14	I would like to have this HMI in the car permanently.	3,88	1,59
Q15	I would like to have HMI integrated in the dashboard.	4,00	1,50
Q16	I would recommend this service to others.	3,63	1,33

Question number	Question	Average value	Standard deviation
Q17	The warning clarifies dangerous situation.	3,88	1,41
Q18	I had enough time to react to the "dangerous vehicle".	4,00	1,27
Q19	Dangerous vehicle information increases driving safety.	4,25	1,22
Q20	The HMI distracts me from driving.	3,88	1,12
Q21	Using HMI, I will feel safer driving through intersection.	3,50	1,12

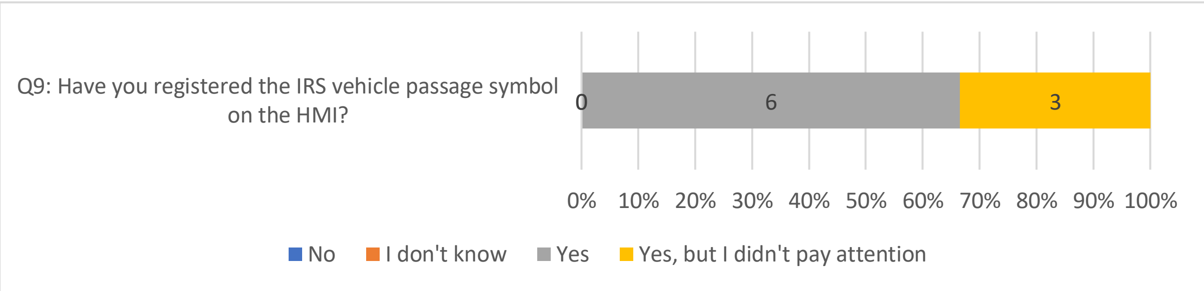

Figure 18 Did the driver register the symbol? ISV

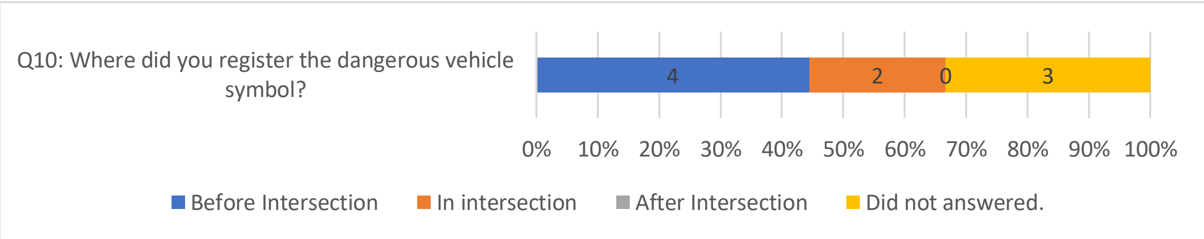

Figure 19 Where did driver register symbol – ISV

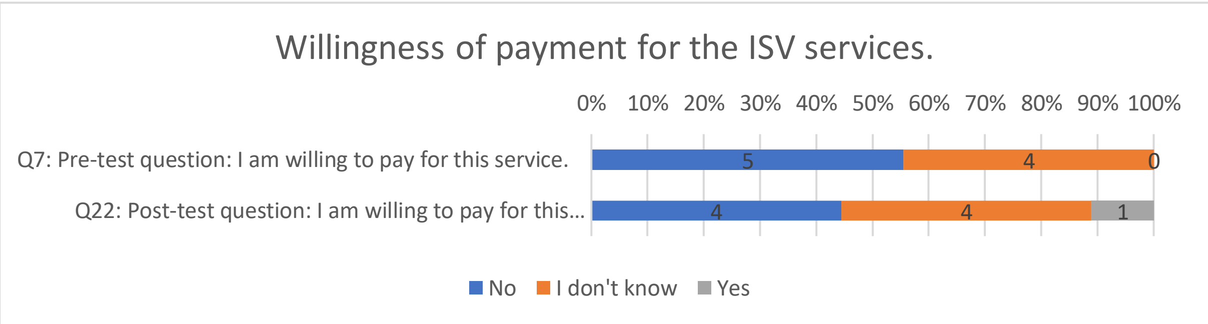

Figure 20 Payment willingness ISV

6.1.3. Conclusions

The ISV experiment was difficult to organize and execute. As this was a test at a real intersection, it was not possible to test as many subjects or select them from the general public. For this reason, only employees of Brno Roads with their own vehicles, which were equipped with their own OBUs, were tested. This significantly accelerated the testing process and thus shortened the waiting time for drivers to reopen the intersection. Due to this time constraints, a testing method with and without C-ITS could not be performed to compare its benefits. Because the vehicle-to-vehicle communication was intercepted from the third OBU near the intersection and not logged directly from the test vehicles, communication problems occurred, and some data was lost.

The results of the evaluation of the data from the logging unit showed that the drivers did not reduce their speed after receiving the message. This can be caused by an evasive manoeuvre, or by enough space to pass both vehicles at once, which had to be left for safety reasons. The drivers were also well acquainted with the environment in which they drove and there was no traffic, for these reasons they could behave differently than they would behave in real situations. Drivers reduced their acceleration after receiving the message but was still accelerating. During the passage of one vehicle, there were also violations of regulations and a speed higher than 50 km / h was recorded, which is the permitted speed. The assessment of drivers' reactions is less telling in this case, as no comparison has been made of how drivers behave without C-ITS. This could not be done for time reasons. For this reason, it was difficult to analyse the results of evaluation and draw strong conclusions.

According to the questionnaires, the interest in the services provided by the ISV use-case is and people find it useful. The use of ISVs increases safety when crossing an intersection, but they are concerned about distractions. This should be addressed through the correct implementation of the HMI and the design of the notification to the driver so that he understands the message as fast as possible and distracts the driver minimally. This could be done by an audible, vibrating, or light warning. According to the questionnaires, the display of the ISV on the HMI was understandable and timely.

6.2. Evaluation of Railway Level Crossing RLX

Analysis for RLX was performed on data aggregated from all vehicles. Based on the available data, the following KPIs were selected:

- Average speed comparison
- Drivers acceleration changes comparison
- Standard speed deviation, maximal and minimal speed comparison

6.2.1. Impact assessment

Average speed comparison

The comparison of passage with warning “Attention, railway crossing!” shown in Figure 21 indicate slightly increased mean speed with C-ITS. The median and upper and lower quartile is the same. In second scenario with “Passing train!” Warning in Figure 22, the passage with C-ITS displays mean speed. In both scenarios, the passage with and without C-ITS is very similar.

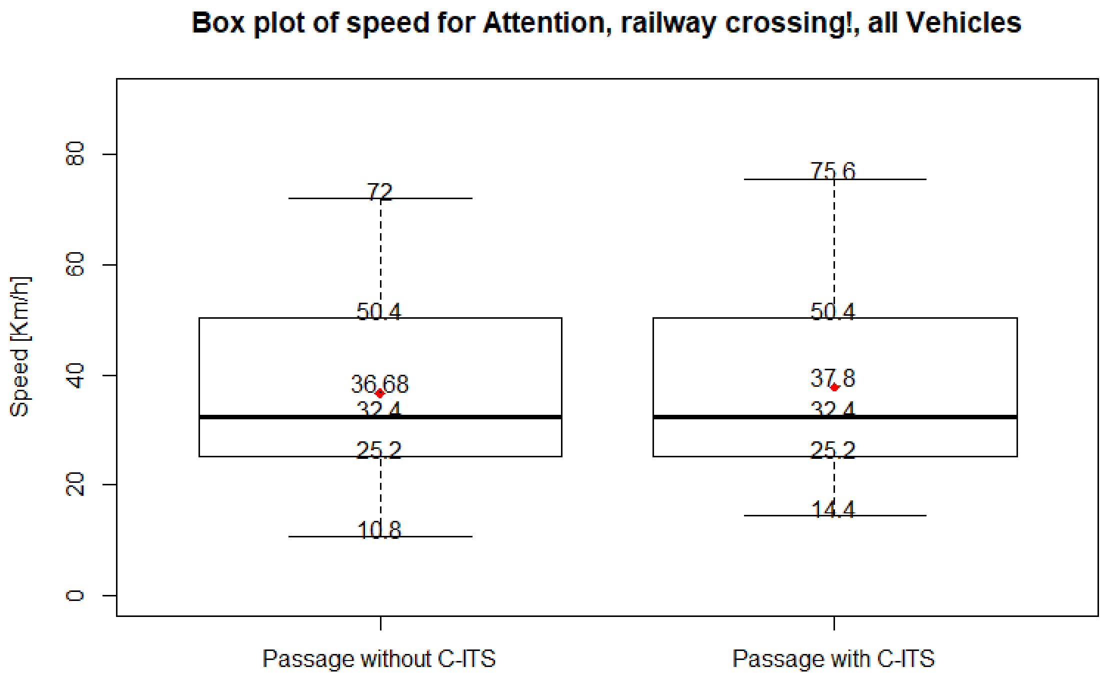

Figure 21 Speed box plot for "Attention, railway crossing!" RLX

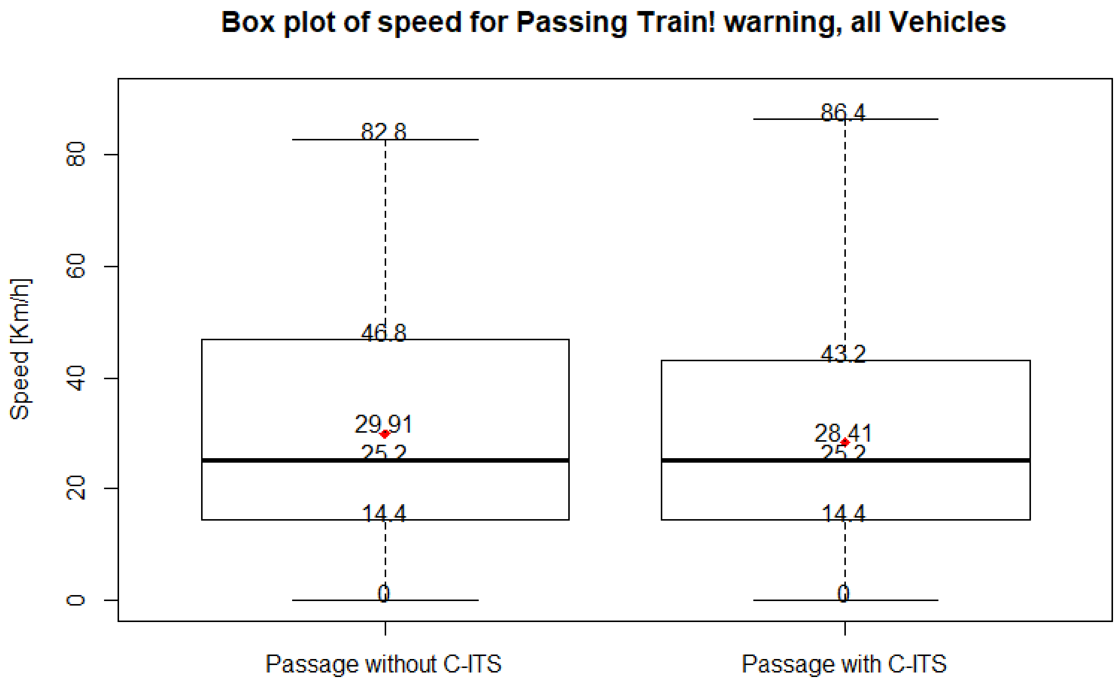

Figure 22 Speed box plot for "Passing Train!" RLX

Driver acceleration changes

The first box plot shows the acceleration Figure 23 shows the acceleration in scenario "Attention, railway crossing!". This scenario drivers accelerate slightly higher in the passage with C-ITS, had higher mean and median. The second boxplot in Figure 24 contains data from "Passing train!" Warning and indicates similar driver's behaviour in both with and without C-ITS passage. For this warning, the drivers decelerate slightly more without C-ITS system. This may be due to earlier information that the railway crossing is closed and drivers on average braked less aggressively.

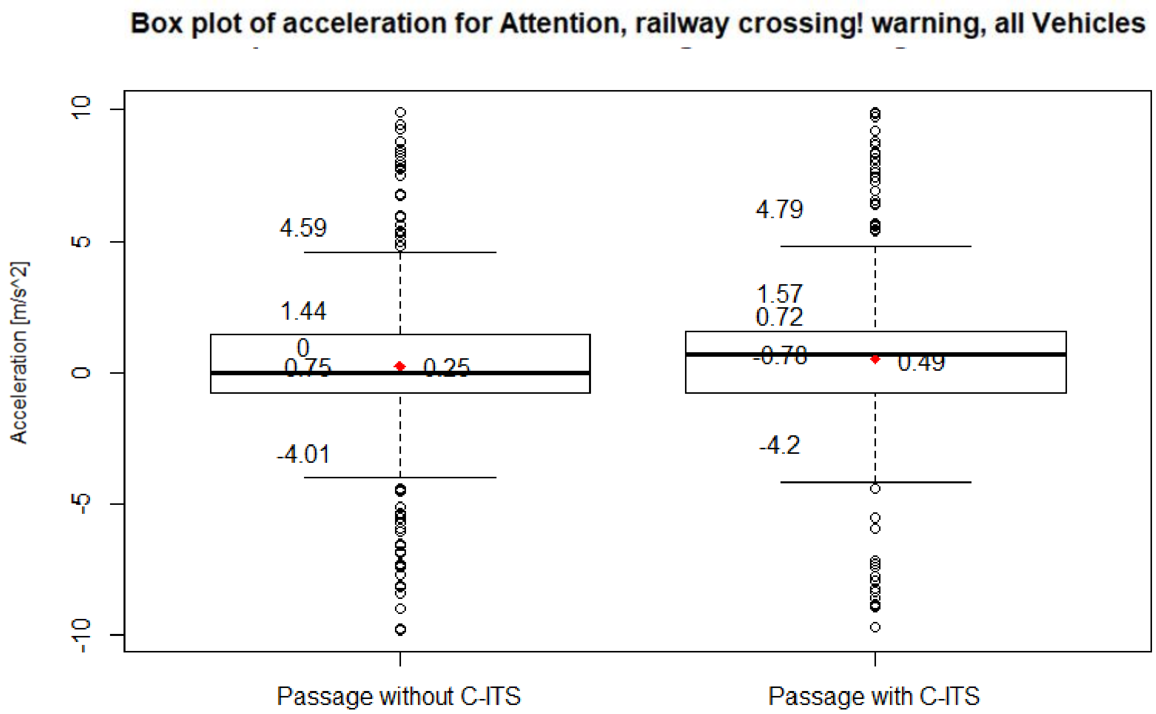

Figure 23 Acceleration box plot "Attention, railway crossing!" warning RLX

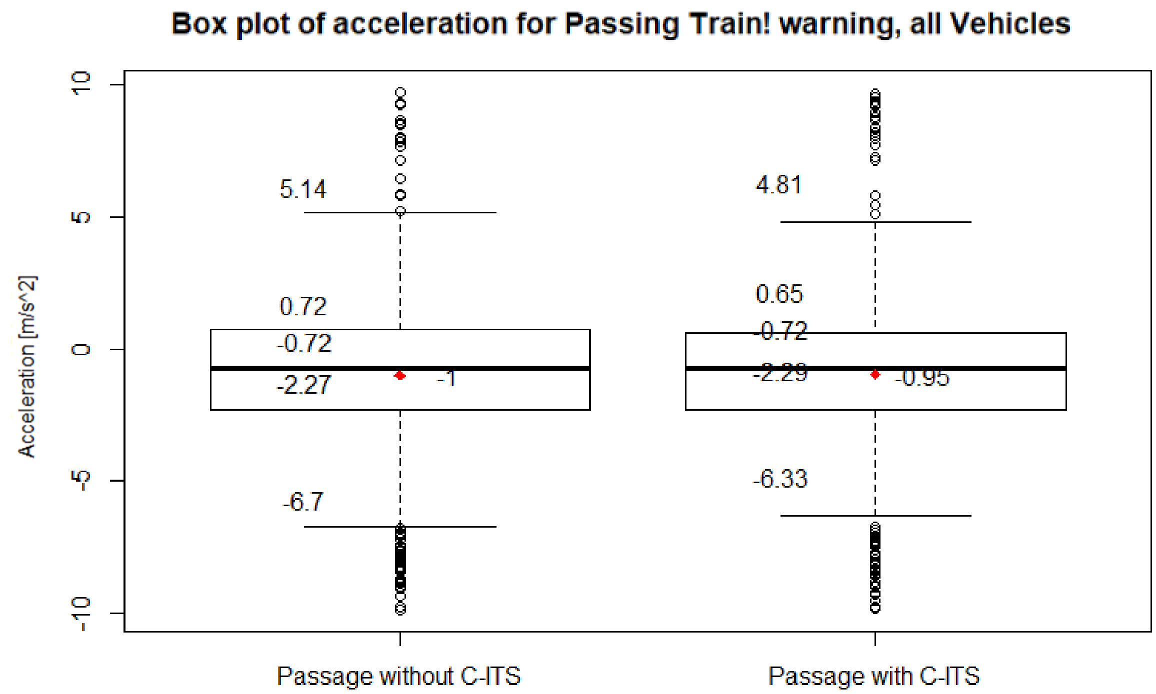

Figure 24 Acceleration box plot "Passing train!" warning RLX

Standard speed deviation, maximal and minimal speed

Figure 3 shows the mean, maximum, minimum speed, and standard speed deviation results for the RLX use-case. It can be seen that the average speed in the warning "Attention, railway crossing!" was slightly higher when passing with C-ITS and had higher variance. On the other hand, in the Train passing! warning, the driver had an average speed lower with less variance. This may be due to the driver knowing the information in advance and driving slower on average. The minimum speed in this scenario was zero as the driver always had to stop.

Table 12 Mean, maximal, minimal, and standard speed deviation - RLX

	Mean speed	**Maximal speed**	**Minimal speed**	**Standard speed deviation**
	[km/h]	**[km/h]**	**[km/h]**	**[km/h]**
"Attention, railway crossing!" without C-ITS	36.71	72	10.8	14.98
"Attention, railway crossing!" with C-ITS	37.80	75.60	14.40	15.50
Train passing! Without C-ITS	29.53	82.80	0.00	22.35
Train passing! with C-ITS	28.41	86.4	0.00	20.09

6.2.2. User accaptance

The user acceptance was performed via questionnaires before and after passing the vehicle as described in chapter 4.3.3.2 User acceptance. A sample and results of questionnaire are attached in Annex 2.

6.2.2.1. Driver's profile

The test drivers were selected from the public in an effort to be as diverse as possible in age, education and driving skills. This is illustrated in Figure 25. At the RLX use-case, 16 people completed questionnaires in both days.

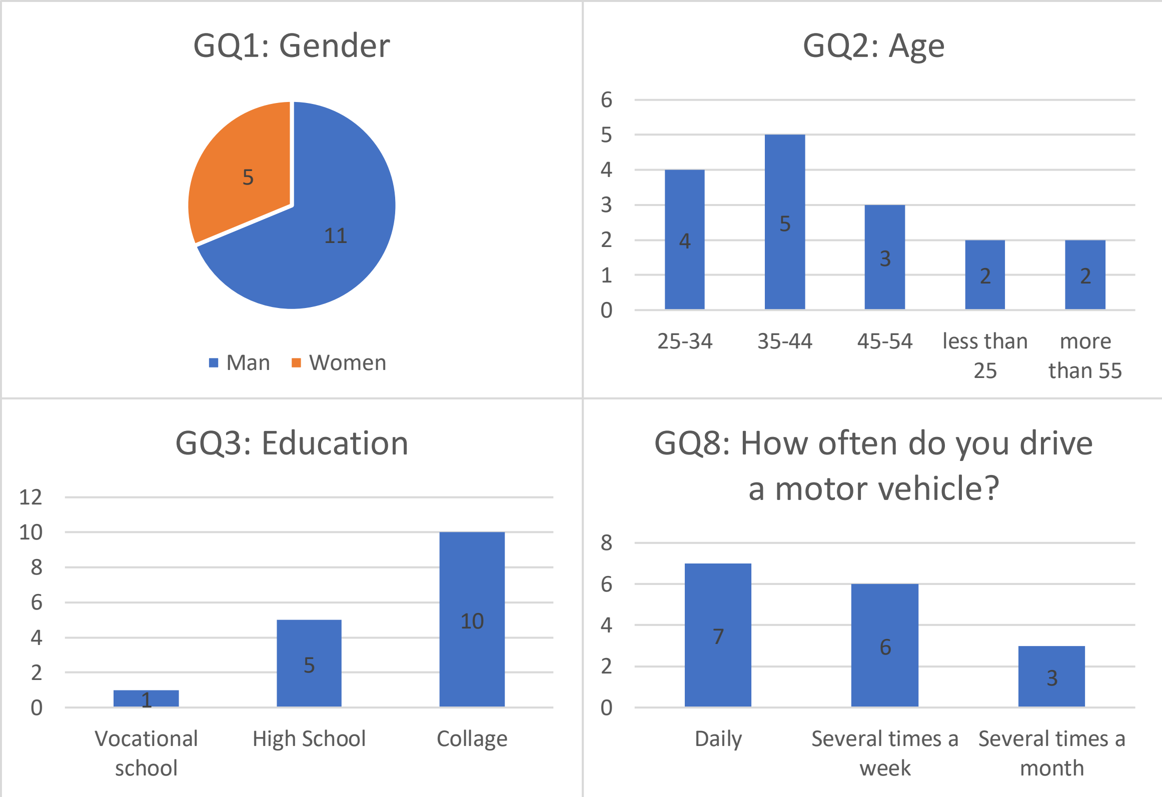

Figure 25 General questions RLX

6.2.2.2. Pre-test questionnaires

The drivers filled in the questionnaires that the order would be informed about the passage. Drivers also expressed uncertainty as to whether the crossing could be overlooked or whether it would be distracted by a tablet in the car. However, they tend to think that the information the tablet will provide them will improve their safety and an overview of the situation at the level crossing.

Table 13 Pre-test questionnaires results RLX (1 – strongly disagree, 5 – strongly agree)

Question number	Question	Average value	Standard deviation
Q1	I would like to have HMI in my vehicle warning me about the state of railway crossing lights.	4.13	1.31
Q2	The state of railway crossing lights could be overseen in some situation.	3.19	1.22
Q3	Information about the state of railway level crossing lights could improve safety.	3.81	1.11
Q4	I assume the tablet will distract me from driving.	3.06	1.18
Q5	When using a tablet, I will have a better overview of the crossing status.	4.06	1.18
Q6	I assume that driving with the tablet will be less difficult.	3.25	1.13

6.2.2.3. Pre-test questionnaires

In post-test questionnaires, visible in Table 14, drivers rate the use of RLX as useful and useful in improving the overview and safety in a dangerous situation. Drivers did not express concern about the possibility of false information provided by the HMI. Drivers are not entirely sure if they would like an HMI in their car but would recommend it to others. Drivers would prefer a more design with a built-in HMI on the dashboard over a tablet.

Drivers are generally satisfied with the RLX version and what the HMI displays. Almost all tested drivers noticed the reports and had enough time to react. 4 out of 12 drivers in the questionnaire said that information about the approaching crossing was displayed too soon. In this scenario, there is an increased interest to pay for these services and is even higher after the test.

Table 14 Post-test questionnaires results RLX (1 – strongly disagree, 5 – strongly agree)

Question number	Question	Average value	Standard deviation
Q13	Information on the status of RLX was useful.	4.50	0.89
Q14	Information about the status of RLX will increase my overview of the dangerous situation.	4.19	0.98
Q15	I had enough time to react to the state of the crossing.	4.94	0.25
Q16	RLX status information increases driving safety.	4.38	0.89
Q17	I am afraid of false information about the state of PZZ.	2.69	1.35
Q18	When using a tablet, I will feel safer when crossing the crossing.	3.63	1.02
Q19	I am satisfied with the information I received from the tablet.	4.38	0.62
Q20	I would like to have this tablet in the car permanently.	3.63	1.31
Q21	I would like to have these services integrated in the dashboard.	4.88	0.34
Q22	I would recommend this service to others.	4.56	0.63
Q23	The tablet distracts me from driving.	2.69	1.35

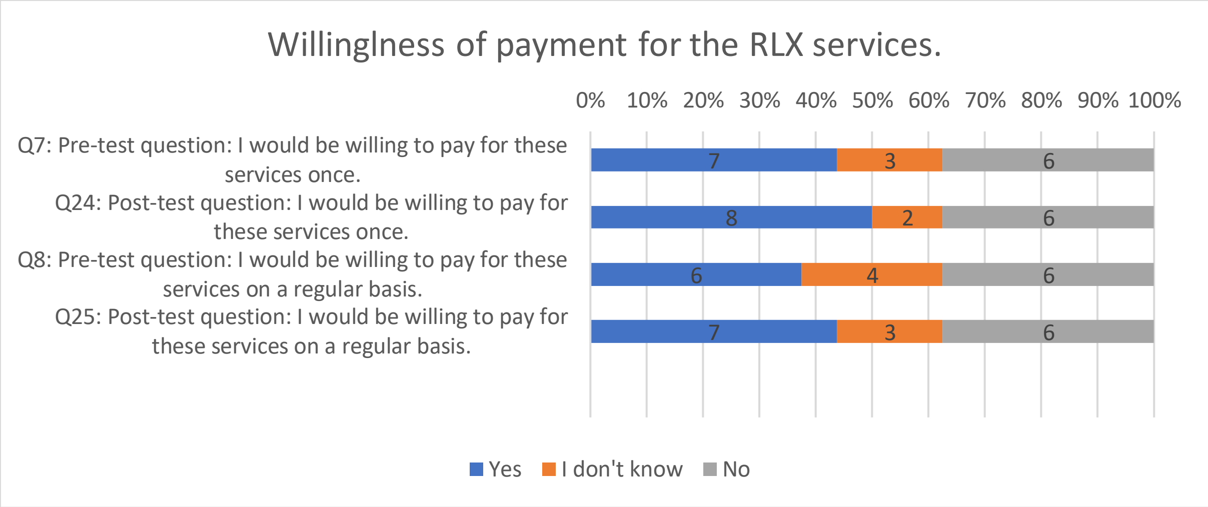

Figure 27 Payment willingness - RLX

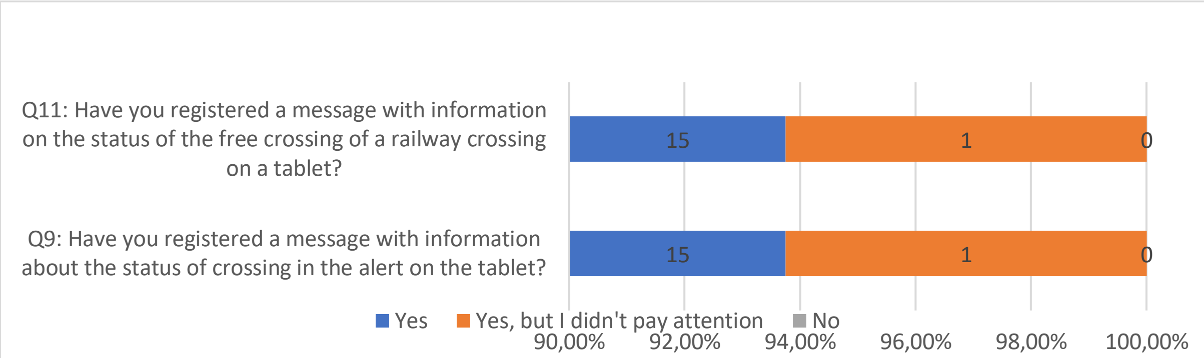

Figure 26 Did the driver register the symbol? – RLX

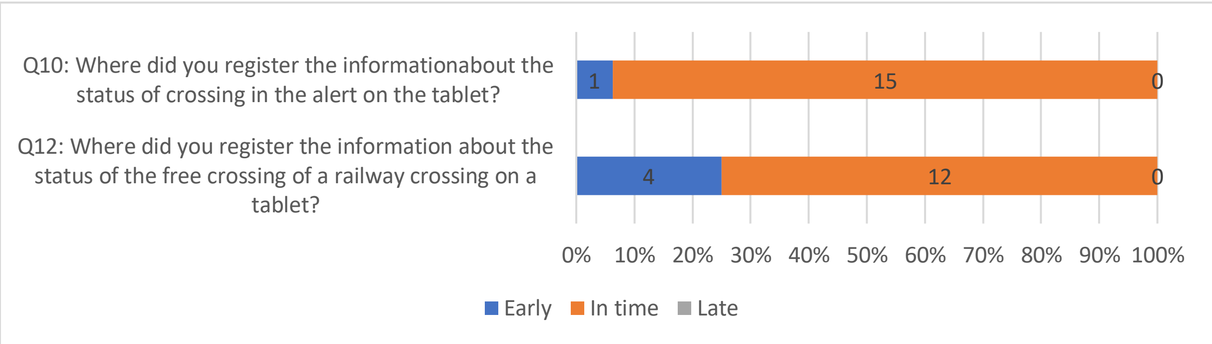

Figure 28 When did the driver registered the warning?

6.2.3. Conclusion

The RLX use-case was relatively simple in terms of complexity of organization and implementation. This was mainly due to the fact that it was possible to ensure the staff of the railway lines who operated the warning lights at the level crossing. With the staff operating the railway signalling equipment, it was possible to evaluate two different warning messages that the installed RSU can send. Warning messages “Attention, railway crossing!” and “Passing Train!” were evaluated in two passes using C-ITS and without C-ITS. The RLX use-case was evaluated over two days and 16 drivers. Unfortunately, due to a hardware error, the data obtained from the first day of the evaluation were lost and only questionnaires from 5 drivers could be evaluated from that day.

The results of the evaluation gathered second day was logged by communication logger in vehicle via the OBU. The analysis of speed and acceleration of data near the crossing was performed and the passage without and with C-ITS was compared. Speed analysis showed that drivers drove faster on average with C-ITS for the "Attention, railway crossing!" Warning. In the "Passing Train!" warning drivers drove slower, which may be due to the fact that they knew the information in advance and thus adapted the driving. However, this difference is not so great. In the acceleration analysis, drivers had on average higher acceleration at "Attention, railway crossing!" using C-ITS. In the "Passing Train!" warning C-ITS drivers had less deceleration using C-ITS. This, in turn, may be due to the fact that the driver knew the warning in advance and did not have to brake so aggressively.

According to surveys conducted in the questionnaires, drivers would like to be warned about the crossing and think that this information will improve their overview of the situation. Drivers are not sure whether such information will distract them and make driving less difficult. After the passage, the drivers were satisfied with the design and found the information useful. Most agreed that they had enough time to react and recorded both warning messages on the tablet. 25% of the tested subjects found that the information "Attention, railway crossing information was displayed too soon. Most tested drivers would welcome dashboard integration instead of a tablet and recommend service to others. After the crossing, fewer drivers think that such information could distract them. Almost 50% of the tested drivers would pay for this service.

6.3. Summary of results

The results of the evaluation analysis of speed and acceleration from the data collected in both use-cases indicate that the use of C-ITS generally does not reduce the driver's average speed or braking. The ISV showed that drivers accelerated rather than slowed down after receiving the message. This was probably caused by an evasive manoeuvre or enough space for passage and a free route. However, the visual analysis of the individual speed curves indicates the reaction to the second vehicle by deceleration. The speed of all drivers was on average 2.38 km / h faster after receiving the message. However, due to the configuration and complexity of performing such a test, a comparison with a passage without C-ITS was not possible. Acceleration results shows a reduction, but still acceleration in 4 out of 5 drivers. The RLX assessment showed that when the driver was alerted by warning "Attention, railway crossing!", his acceleration did not decrease and he had higher speed using C-ITS. In contrast, in the "Passing Train!" warning message, drivers slowed down by 1.5 km / h on average. Their deceleration also decreased, but not so significantly.

User Acceptance was performed by a questionnaire survey before and after the tests. Thus, the driver's opinion before the test and the change of the driver's opinion after the first test could be recorded. Drivers also completed a general questionnaire about their age, gender, education and driving skills before the test. In general, drivers are satisfied with the execution of the application and the display of information on the screen. Drivers find it useful to display information from both ISV and RLX use-time. The tablet implementation, which was tested at both locations, seemed distracting to some of the drivers evaluated and would prefer the built-in dashboard displayed. Drivers are not entirely sure if they would like such a system with this two use-cases in their car, and there are conflicting views as to whether they would pay for it. With an ISV use-case, drivers was negative about whether they would pay for this service. At RLX, the interest in the drivers payment was greater.

The conclusions of the Impact assessment and questionnaires from tested drivers show that the evaluated use-cases ISV and RLX, rather than the safety of driving tested based on change of speed and acceleration, are useful for increasing driver comfort and information. This can increase the added value provided by automakers when installing in cars, along with integration into GPS dashboard navigation. The future potential will also be shown in the gradual involvement of C-ITS systems in combination with autonomous systems.

7. Recommendation in further development

Experiments performed by C-ITS showed that performing similar tests is not easy both in terms of time, organization and for subsequent evaluation. Each tested use-case and pilot site has its own parameters and requirements that the evaluation must follow. It is therefore necessary to find a balance in the use of allocated resources and maximizing the utility value of evaluation.

Performing tests can be difficult work and it is good to have it planned in detail. Before performing the test, it is necessary to test the functionality of the given scenarios as well as the hardware. In this way, the chances of hardware failure or malfunction and subsequent downtime and delays are minimized during the tests. For a good time estimate of how long the passage with the driver can take, it is good to try the passage before performing the tests. However, it must also be taken into account that some drivers drive slower than others. Testing can be shortened in time, when using multiple vehicles and parallel driving. However, this also requires a larger number of recording devices and OBUs. For timing-prone scenarios (such as timing in the RLX use-case of warning message Beware of Moving Train!), it is necessary to provide communication between the evaluation staff. This can be, for example, with the help of two-way radio transceiver or mobile phones.

User-acceptance can be a source of very valuable information about the opinion and perspective of future users on the tested system. It is appropriate to take this view into account for the future development of HMI applications and the implementation of individual use-cases. To obtain the best possible view from the population on the tested use case, as many participants as possible with the greatest possible diversity in terms of age, education, residence, and gender are suitable. Such test can then subsequently represent a part of the population and will be statistically significant. To analyse the reaction of drivers to the tested scenario, it is best not to rely on only one recording device. It is recommended to always try everything before the test. If possible, data evaluation directly from the vehicle and CAN bus communication is a very suitable option for analysing the sensor's behaviour, for example from an environmental point of view. Data directly from the vehicle on throttle use, steering wheel turning, and braking are much more accurate than recalculations and estimates of this data from GPS data. To evaluate the driver's attention, it might also be interesting to evaluate the record from using an eye tracker sensor. This sensor records where the driver is looking and could thus be analysed, for example, how long and how often the driver focuses on the HMI. The same method could be obtained by recording the driver with a GoPro camera or similar. In this way, for example, the HMI application could be optimized on the simulator so that the driver does not have to look at it for a long time in order to find out what is on it.

8. Conclusion

The aim of this final work was to design a framework for evaluation in the project C-Roads CZ. From four designs inspired by the acquired knowledge from the previous theoretical part and similar already performed projects, controlled testing was selected as the most convenient. Controlled testing has been designed for the general use-case in C-Roads CZ and to meet both the initial assessment requirements and the technical equipment options that could be used in the assessment. The designed framework was verified on two selected use-cases, Intersection Signal Violation and Railway level Crossing. The evaluation for each scenario took place separately on a different day, and with different test drivers.

The controlled testing evaluation was divided into two parts: Impact assessment and User Acceptance. Part of the Impact assessment dealt with the evaluation of the driver's behaviour together with C-ITS. An OBU logger capturing the communication of OBUs in vehicles was selected as the main recording device. In this way, GPS position and speed data were captured. Other variants of recording devices such as GPS logger and OBD2 logger were used in the RLX evaluation. The data from the OBD2 logger was found unusable due to incompatibility between the device and the car's communication. There was no public DBC library for the test vehicle that would decode the CAN communication in the car. Before using the GPS logger data, the OBU logger data was preferred due to the higher recording frequency.

The performed use-case experiments showed that the proposed evaluation framework can be used in the use-case evaluation in the C-Roads project. The selected methodology of controlled testing had the advantage of real testing with drivers, who could directly touch the C-ITS and thus give a more accurate view of its implementation. The method was also suitable from the point of view of time, financial and material (number of OBU, HMI) allocated for the implementation of evaluation in C-Roads CZ. However, if a statistically significant benefit of C-ITS on human behaviour were to be demonstrated, evaluations would have to be carried out to a greater extent with more tested drivers and over a longer period of time. If an environmental impact assessment is to be carried out, it would be necessary to use a vehicle that can record the data from the CAN bus. It is also worth considering evaluating using simulation software such as AIMSUM or VISIM. Using this method, it is possible to perform a traffic efficiency impact assessment and experiment with different degrees of C-ITS penetration. In this method, it is necessary to obtain user acceptance by another method of evaluation.

Scripts created for individual use cases can be used in further evaluations and reports in C-Roads CZ after a slight modification. However, it is important to pay attention to the nature of individual use cases as they may not have the same type of evaluation. For example, in the ISV experiment, it was not possible to install recording devices in all test vehicles, as it was necessary to use the vehicles of Brno road maintenance workers. In this case, the communication was captured by the OBU logger near the road and not directly from individual vehicles. Drivers could also cross the intersection only once due to time constraints. Unfortunately, these cases are not related to the definition of use-case but to the evaluation itself and must be solved during its implementation and the created framework must be operatively modified. To assess the use of defined KPIs in the evaluation of other use-cases, it is possible to draw from a document Evaluation and Assessment plan describing their evaluation [21]. The knowledge and design of evaluation presented in this work can be used to perform testing and designing the evaluation in C-Roads CZ project.

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Annex 1

Testing scenario: ISV

The vehicle is free on the SSZ and is alerted to the passage of the vehicle to the STOP

Abbreviations:

HMI - interface for displaying relevant information - tablet or mobile phone

SSZ - traffic lights - lights at the intersection

Fill in before performing the test:

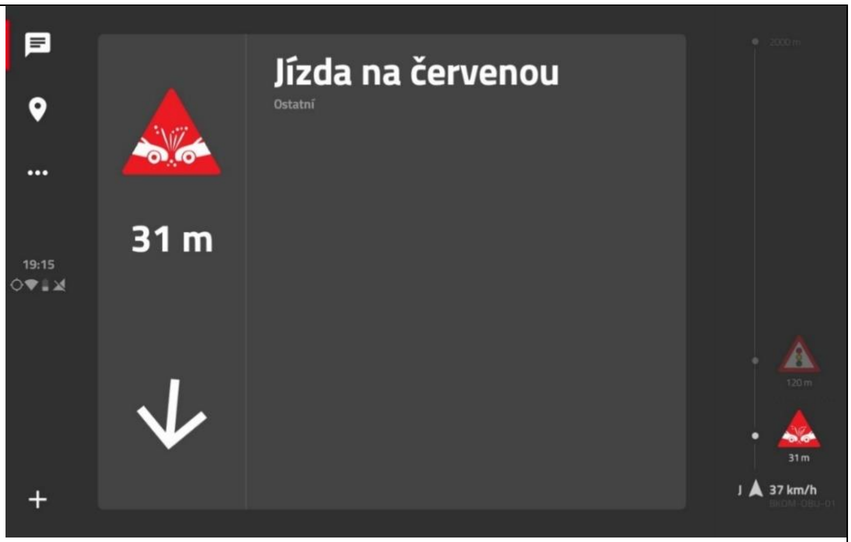
Please circle your chosen answer to the following questions:

	Question:	Strongly Disagree	Rather Disagree	Neutral Attitude	Rather Agree	Strongly Agree
1	I would like to have HMI in my vehicle warning me about "dangerous vehicle", passing the traffic light on red signal.	1	2	3	4	5
2	I always want to be informed about the status of the SSZ of the next intersection.	1	2	3	4	5
3	Dangerous vehicle information increases driving safety.	1	2	3	4	5
4	I expect the HMI to distract me from driving.	1	2	3	4	5
5	When using the HMI, I will feel safer when	1	2	3	4	5

	driving through an intersection.					
6	I assume that driving with HMI will be less demanding.	1	2	3	4	5
7	I am willing to pay for this service.	Yes (how much? ___________)		No		I do not know
8	If I receive information from the HMI about a dangerous vehicle, I will adjust my speed immediately.	Yes, I will adjust smoothly	I will probably adjust	I probably will not adjust		No

Fill in after the test:

Please circle your chosen answer to the following questions:

<table>
<tr><td rowspan="2">9</td><td rowspan="2">Have you registered the dangerous vehicle symbol on the HMI?</td><td colspan="4">


</td></tr>
<tr><td>1
Yes</td><td>2
Yes, but I did not understand what the symbol meant</td><td>3
Yes, but I did not pay attention</td><td>4
No</td></tr>
</table>

10	Where did you register the dangerous vehicle symbol?	1 in front of an intersection	2 at the crossroads	3 behind the crossroads

	Question:	Strongly Disagree	Rather Disagree	Neutral Attitude	Rather Agree	Strongly Agree
11	"dangerous vehicle" warning was useful.	1	2	3	4	5
12	The information from the HMI was understandable.	1	2	3	4	5
13	I am satisfied with the information I received from HMI.	1	2	3	4	5
14	I would like to have this HMI in the car permanently.	1	2	3	4	5
15	I would like to have HMI integrated in the dashboard.	1	2	3	4	5
16	I would recommend this service to others.	1	2	3	4	5
17	The warning clarifies dangerous situation.	1	2	3	4	5
18	I had enough time to react to the "dangerous vehicle".	1	2	3	4	5
19	Dangerous vehicle information increases driving safety.	1	2	3	4	5
20	The HMI distracts me from driving.	1	2	3	4	5

21	Using HMI, I will feel safer driving through intersection.	1	2	3	4	5
22	I am willing to pay for this service.	Yes (how much? ___________)		No		I do not know

Annex 2

Testing scenario: RLX

Fill in before performing the test:

	Question:	Strongly Disagree	Rather Disagree	Neutral Attitude	Rather Agree	Strongly Agree
1	I would like to have HMI in my vehicle warning me about the state of railway crossing lights.	1	2	3	4	5
2	The state of railway crossing lights could be overseen in some situation.	1	2	3	4	5
3	Information about the state of railway level crossing lights could improve safety.	1	2	3	4	5
4	If I receive information about the state of railway level crossing lights on the tablet, I will immediately adjust my behaviour according to the situation.	Yes, I will adjust smoothly	I will probably adjust	I probably will not adjust	No	

General questions

	Question:	Strongly Disagree	Rather Disagree	Neutral Attitude	Rather Agree	Strongly Agree
8	I assume the tablet will distract me from driving.	1	2	3	4	5
9	When using a tablet, I will have a better overview of the crossing status.	1	2	3	4	5

10	I assume that driving with the tablet will be less difficult.	1	2	3	4	5
11	I would be willing to pay for these services once.	Yes (how much? ___________)		No	I do not know	
12	I would be willing to pay for these services on a regular basis.	Yes (how much? ___________)		No	I do not know	

Testing scenario: RLX

Fill in after the test:

13	Have you registered a message with information about the status of crossing in the alert on the tablet?				
		1 Yes	2 Yes, but I did not understand what the symbol meant	3 Yes, but I did not pay attention	4 No
15	Where did you register the information about the status of crossing in the alert on the tablet?	1 early	2 in time	3 late	4 not at all

16	Have you registered a message with information on the status of a railway crossing on a tablet?				
		1 Yes	2 Yes, but I did not understand what the symbol meant	3 Yes, but I did not pay attention	4 No
18	Where did you register the information about the status of crossing in the alert on the tablet?	1 early	2 in time	3 late	4 not at all

	Question:	Strongly Disagree	Rather Disagree	Neutral Attitude	Rather Agree	Strongly Agree
19	Information on the status of RLX was useful.	1	2	3	4	5
20	Information about the status of RLX will increase my overview of the dangerous situation	1	2	3	4	5
21	I had enough time to react to the state of the crossing.	1	2	3	4	5
22	RLX status information increases driving safety.	1	2	3	4	5
23		1	2	3	4	5

	I am afraid of false information about the state of PZZ.					
24	When using a tablet, I will feel safer when crossing the crossing.	1	2	3	4	5

General questions

	Question:	Strongly Disagree	Rather Disagree	Neutral Attitude	Rather Agree	Strongly Agree
31	I am satisfied with the information I received from the tablet.	1	2	3	4	5
32	I would like to have this tablet in the car permanently.	1	2	3	4	5
33	I would like to have these services integrated in the dashboard.	1	2	3	4	5
34	I would recommend this service to others.	1	2	3	4	5
35	The tablet distracts me from driving.	1	2	3	4	5
36	I am willing to pay for this service.	Yes (how much? ___________)			No	I do not know
37	I would be willing to pay for these services on a regular basis.	Yes (how much? ___________)			No	I do not know

Annex 3

```
############### CAMs BRNO ISV ################
#load the libraries that will be used in the script
library(leaflet)
library(dplyr)
library(mapview)


#options
rm(list = ls()) #delete all previous variables
options(digits.secs=9) #setting the number of decimal places

###########load  ###########
# Data from original-sim
original_cam <- read.csv("C:/Users/micha/Desktop/Skola/Magistr/Diplomova_pr
ace/Zkousky/ISV_zkouska/ISV_SIM/WS_ISV_Brno_sim_cam.csv")
original_denm <- read.csv("C:/Users/micha/Desktop/Skola/Magistr/Diplomova_p
race/Zkousky/ISV_zkouska/ISV_SIM/WS_ISV_Brno_sim_denm.csv")



############ Data preparation ############ x
#edit data from original messages for CAM and DENM messages

############ CAM
#long_latitude
original_cam$latitude = gsub("unavailable","",original_cam$latitude)
original_cam$longitude = gsub("unavailable","",original_cam$longitude)
original_cam$longitude <- as.numeric(original_cam$longitude)
original_cam$latitude <- as.numeric(original_cam$latitude)
original_cam$longitude <- original_cam[, "longitude"]/10000000
original_cam$latitude <- original_cam[, "latitude"]/10000000
#speedValue
original_cam$speedValue = gsub("standstill","0",original_cam$speedValue)
original_cam$speedValue = gsub("oneCentimeterPerSec","1",original_cam$speed
Value)
original_cam$speedValue = as.numeric(original_cam$speedValue)
original_cam$speedValue <- original_cam[, "speedValue"]/100
original_cam$speedValue <- original_cam[, "speedValue"]*3.6
#timestamp
original_cam$timestamp <- strptime(original_cam$timestamp, "%Y-%m-%dT%H:%M:
%OS")

############ DENM

#Long_lat
original_denm$longitude <- original_denm[, "longitude"]/10000000
original_denm$latitude <- original_denm[, "latitude"]/10000000
original_denm$timestamp <- strptime(original_denm$timestamp, "%Y-%m-%dT%H:%
M:%OS")
# Selection of DENM messages for ISV
Denm_ISV = original_denm[original_denm[, "causeCode"]== 'signalViolation',]
```

```
############ DATA FILTRATION############
# sorting data base of cars
#as.data.frame(sort(table(original_cam$stationID), decreasing = TRUE))  ##
frequency of unique
#Denm_ISV[Denm_ISV$timestamp < "2020-02-26 04:56:25", ]


########### 1st
#Car #1
# time1 = "2020-02-26 04:29:00.0"
# time2 = "2020-02-26 04:31:00.0"
# ID_auta="1755095438"
# car="car#1"

#Car #2 and
# time1 = "2020-02-26 04:29:00.0"
# time2 = "2020-02-26 04:31:00.0"
# ID_auta="1167327666"
# car="car#2"



########### 2nd
# # # #Car #3
# time1 = "2020-02-26 04:40:00.0"
# time2 = "2020-02-26 04:43:00.0"
# ID_auta="1485787311"
# car="car#3"



########### 3rd
# #Car #4
# time1 = "2020-02-26 04:56:10.0"
# time2 = "2020-02-26 04:58:00.0"
# ID_auta="1597924932"
# car="car#4"

#Car #5
# time1 = "2020-02-26 04:56:00.0"
# time2 = "2020-02-26 04:58:00.0"
# ID_auta="797409753"
# car="car#5"

#Car #6
# time1 = "2020-02-26 04:56:00.0"
# time2 = "2020-02-26 04:58:00.0"
# ID_auta="1628817637"
# car="car#6"

# #Car #7
# time1 = "2020-02-26 04:56:00.0"
# time2 = "2020-02-26 04:58:00.0"
```

```
# ID_auta="570983516"
# car="car#7"

#test auto # car A and subselection base on time
test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= t
ime2 ,] # Pro auto 1

#Stratil # car B and subselection base on time
ID_stratil='1724969678'
stratil = original_cam[original_cam[, 'stationID'] == ID_stratil,]
stratil = stratil[stratil$timestamp >= time1 & stratil$timestamp <= time2,]

#ISV subselection base on time
ISV_actual = Denm_ISV[Denm_ISV$timestamp >= time1 & Denm_ISV$timestamp <= t
ime2,]
#ISV subselection based on time and stationID
denm_stratil = ISV_actual[ISV_actual$stationID == ID_stratil ,]


#predefined colors
log_dev_col = "purple"
Car_A_col = "blue"
Car_B_col = "red"
ISV_col_col="green"
ISV_car_B_col = "gold"

#position of logging device = 49.173945, 16.557941
############ Leaflet - map representation ############
m= leaflet() %>%
  # adds map tiles
  addTiles() %>%
  # adds circle in map based on location of car A
  addCircles(lat=test_auto$latitude, lng=test_auto$longitude, color = Car_A
_col, radius = 0.5, opacity =1, fillOpacity = 100) %>%
  # adds circles in map base on location of car B
  addCircles(lat=stratil$latitude, lng=stratil$longitude, color = Car_B_col
, radius = 0.5, opacity =1, fillOpacity = 100) %>%
  # adds circle in map based on location of logging device
  addCircles(lat = 49.173945, lng =  16.557941, color = log_dev_col, radius
= 2, opacity = 1, fillOpacity = 100) %>%
  # adds circles in map based on location of ISV DENM messages
  addCircles(lat = ISV_actual$latitude, lng = ISV_actual$longitude, color =
ISV_col_col, radius = 0.5, opacity = 1, fillOpacity = 20) %>%
  # adds circles in map based on location of ISV DENM messages from vehicle
B
  addCircles(lat = denm_stratil$latitude, lng = denm_stratil$longitude, col
or = ISV_car_B_col, radius = 0.5, opacity = 1, fillOpacity = 20)
m

# add legend to map
addLegend(map = m,position = "topright", title = paste0("Position of ",car)
, colors = c(Car_A_col, Car_B_col, log_dev_col, ISV_col_col, ISV_car_B_col)
, opacity = 1, labels = c( "Car A","Car B - ride on red signal", "Logging d
```

```
evice", "ISV messages", "ISV Car B"))
mapshot(m, file = "World.png")


########### Plots ###########
# Speed plots
plot(stratil$Time, stratil$speedValue,type = "l", col = Car_B_col, main = p
aste0("Plot speed ", car), xlab = "Time [sc]", ylab = "Speed [Km/h]", ylim
= c(0,70), xlim = c(2925,3000))
lines(test_auto$Time, test_auto$speedValue, type = "l", col = Car_A_col)
abline(v=ISV_actual$Time, col=ISV_col_col)
abline(v=denm_stratil$Time, col = ISV_car_B_col)
legend("topleft", legend = c("Car A", "Car B", "ISV message", "ISV from car
B"), col = c(Car_A_col, Car_B_col, ISV_col_col, ISV_car_B_col), lty = c(1,1
,1,1), bg="transparent", bty = "n" )


############ Speed analyses
test_time = 60 # time for reaction testing for 60 sec

# reaction after first DENM message
reaction=test_auto[test_auto$timestamp >= ISV_actual$timestamp[1] & test_au
to$timestamp <= ISV_actual[1,3]+test_time,]
reaction_ISV_stratil = test_auto[test_auto$timestamp >= denm_stratil$timest
amp[1] & test_auto$timestamp <= denm_stratil[1,3]+test_time,]

plot(reaction_ISV_stratil$Time, reaction_ISV_stratil$speedValue,type = "b",
cex=.4, col = Car_A_col, main = paste0("Plot speed ", car), xlab = "Time [s
c]", ylab = "Speed [Km/h]", ylim = c(0,70))
lines(stratil$Time, stratil$speedValue, type = "l", col = Car_B_col)
abline(v=ISV_actual$Time, col=ISV_col_col)
abline(v=denm_stratil$Time, col = ISV_car_B_col)
legend("topleft", legend = c("Car A", "Car B", "ISV message", "ISV from car
B"), col = c(Car_A_col, Car_B_col, ISV_col_col, ISV_car_B_col), lty = c(1,1
,1,1), bg="transparent", bty = "n" )


##speed few sec before/after
sec = 2 # time for reaction testing for 2 sec

# 2 seconds before and after together, and divided
reaction_4sec = test_auto[test_auto$timestamp >= ISV_actual$timestamp[1]-se
c & test_auto$timestamp <= ISV_actual[1,3]+sec,]
reaction_2sec_before = test_auto[test_auto$timestamp >= ISV_actual$timestam
p[1]-sec & test_auto$timestamp <= ISV_actual[1,3],]
reaction_2sec_after = test_auto[test_auto$timestamp >= ISV_actual$timestamp
[1] & test_auto$timestamp <= ISV_actual[1,3]+sec,]


# plot of 4 seconds reaction
plot(reaction_4sec$Time, reaction_4sec$speedValue,type = "b",cex=.4, col =
Car_A_col, main = paste0("Plot speed ", car), xlab = "Time [sc]", ylab = "S
peed [Km/h]", ylim = c(0,70))
lines(stratil$Time, stratil$speedValue, type = "l", col = Car_B_col)
abline(v=ISV_actual$Time, col=ISV_col_col)
```

```
abline(v=denm_stratil$Time, col = ISV_car_B_col)
legend("topleft", legend = c("Car A", "Car B", "ISV message", "ISV from car
B"), col = c(Car_A_col, Car_B_col, ISV_col_col, ISV_car_B_col), lty = c(1,1
,1,1), bg="transparent", bty = "n")


# fitting linear regression into the 2sec before and after
fit1 <-  lm(reaction_2sec_before$speedValue~reaction_2sec_before$Time, data
= reaction_2sec_before)
abline(fit1,col="black")

fit2 <-  lm(reaction_2sec_after$speedValue~reaction_2sec_after$Time, data =
reaction_2sec_after)
abline(fit2,col="purple")

#Difference deceleration before

#counting the difference in speed and time to calculate acceleration after

differ_car3=diff(reaction_2sec_before$speedValue)
differ_car4=diff(reaction_2sec_before$Time)
differ_car_before=data.frame(reaction_2sec_before$Time[1:length(differ_car3
)+1],reaction_2sec_before$Time[1:length(differ_car3)+1]-reaction_2sec_befor
e$Time[1],differ_car4,differ_car3, differ_car3/differ_car4)
colnames(differ_car_before) = c("time","time_from_ISV", "delta_time","speed
_difference", "acceleration")
#plot(differ_car[,2], differ_car[,1])
rm(differ_car3,differ_car4)


#Difference deceleration after

#counting the difference in speed and time to calculate acceleration after
differ_car1=diff(reaction_2sec_after$speedValue)
differ_car2=diff(reaction_2sec_after$Time)
differ_car_after=data.frame(reaction_2sec_after$Time[1:length(differ_car1)+
1],reaction_2sec_after$Time[1:length(differ_car1)+1]-reaction_2sec_after$Ti
me[1],differ_car2,differ_car1, differ_car1/differ_car2)
colnames(differ_car_after) = c("time","time_from_ISV", "delta_time","speed_
difference", "acceleration")
#plot(differ_car[,2], differ_car[,1])
rm(differ_car1,differ_car2)

############ results
# mean , max, min for speed and acceleration before and after for one vehic
le
results = data.frame(fit1$coefficients[2],mean(reaction_2sec_before$speedVa
lue*3.6), max(reaction_2sec_before$speedValue*3.6), min(reaction_2sec_befor
e$speedValue*3.6), mean(differ_car_before$acceleration), max(differ_car_bef
ore$acceleration), min(differ_car_before$acceleration), mean(differ_heading
_before$heading_difference), min(differ_heading_before$heading_difference),
max(differ_heading_before$heading_difference))
colnames(results) = c("Coeff","Mean_speed", "max_speed", "min_speeed", "mea
n_acceleration", "max_acceleration", "min_acceleration", "Mean_heading_diff
erence", "min_heading_difference", "max_heading_difference")
```

```
#sum(differ_car$acceleration)/(tail(reaction_2sec_after$Time,1)-reaction_2s
ec_after$Time[1])
results = rbind(results, list( fit2$coefficients[2], mean(reaction_2sec_aft
er$speedValue*3.6), max(reaction_2sec_after$speedValue*3.6), min(reaction_2
sec_after$speedValue*3.6), mean(differ_car_after$acceleration), max(differ_
car_after$acceleration), min(differ_car_after$acceleration), mean(differ_he
ading_after$heading_difference), min(differ_heading_after$heading_differenc
e), max(differ_heading_after$heading_difference)))
rownames(results) = c("before", "after")


#boxplots for speed and acceleration for all vehicles
boxplot(main = paste0("Box plot of speed for ", car),ylab="Speed [Km/h]", n
ames = c("2sc before", "2sc after"),reaction_2sec_before$speedValue*3.6, re
action_2sec_after$speedValue*3.6)
boxplot(main = paste0("Box plot of speed for ", car),ylab="Acceleration", n
ames = c("2sc before", "2sc after"),differ_car_before$acceleration, differ_
car_after$acceleration)

# speedbox_before = reaction_2sec_before$speedValue
# accbox_before = differ_car_before$acceleration
# speedbox_after = reaction_2sec_after$speedValue
# accbox_after = differ_car_after$acceleration

speedbox_before = c(speedbox_before,reaction_2sec_before$speedValue)
accbox_before = c(accbox_before,differ_car_before$acceleration)
speedbox_after = c(speedbox_after,reaction_2sec_after$speedValue)
accbox_after = c(accbox_after,differ_car_after$acceleration)


box_speed = cbind(speedbox_before*3.6,speedbox_after*3.6)


#boxplots for speed for all vehicles plot
boxplot(x=box_speed,main = "Box plot of speed for all Vehicles",ylab="Speed
[Km/h]", names = c("2sc before", "2sc after"), ylim=c(0,60))
points(c(mean(box_speed[,1]),mean(box_speed[,2])),col="red",pch=18)
#boxplots text
text(x=1:2,c(round(mean(box_speed[,1]),digits=2), round(mean(box_speed[,2])
,digits=2))+2, labels = c(round(mean(speedbox_before*3.6),digits=2), round(
mean(speedbox_after*3.6),digits=2)))
text(x=1,y=boxplot.stats(box_speed[,1])$stats+1.5,labels = boxplot.stats(bo
x_speed[,1])$stats)
text(x=2,y=boxplot.stats(box_speed[,2])$stats+1.5,labels = boxplot.stats(bo
x_speed[,2])$stats)

box_acc = cbind(accbox_before,accbox_after)


#boxplots for acceleration for all vehicles plot
boxplot(x=box_acc,main = "Box plot of acceleration for all vehicles",ylab="
Acceleration [m/s^2]", names = c("2sc before", "2sc after"), ylim=c(-2,4))
points(c(mean(box_acc[,1]), mean(box_acc[,2])),col="red",pch=18)
```

```
text(x=1:2,c(round(mean(box_acc[,1]),digits=2), round(mean(box_acc[,2]),dig
its=2))+0.2, labels = c(round(mean(box_acc[,1]),digits=2), round(mean(box_a
cc[,2]),digits=2)))
text(x=1,y=boxplot.stats(box_acc[,1])$stats+0.2,labels = boxplot.stats(roun
d(box_acc[,1],2))$stats)
text(x=2,y=boxplot.stats(box_acc[,2])$stats+0.2,labels = boxplot.stats(roun
d(box_acc[,2],2))$stats)
```

Annex 4

```
############### UHRETICE RLX ################
library(leaflet)
library(dplyr)
library(mapview)
library(sp)
library(pracma)
#options
rm(list = ls()) #clear all
options(digits.secs=9)

# #orignal sim
original_cam <-
read.csv("C:/Users/micha/Desktop/Skola/Magistr/Diplomova_prace/Data/Log/Uhretice/CAM
_Uhretice_ctvrtek.csv")
original_denm <-
read.csv("C:/Users/micha/Desktop/Skola/Magistr/Diplomova_prace/Data/Log/Uhretice/DEN
M_Uhretice_ctvrtek.csv")

############# Data preparation ############# x
#edit data from original messages for CAM and DENM messages
#######CAM
#long_latitude
original_cam$latitude = gsub("unavailable","",original_cam$latitude)
original_cam$longitude = gsub("unavailable","",original_cam$longitude)
original_cam$longitude <- as.numeric(original_cam$longitude)
original_cam$headingValue <- as.numeric(original_cam$headingValue)
original_cam$latitude <- as.numeric(original_cam$latitude)
original_cam$longitude <- original_cam[, "longitude"]/10000000
original_cam$latitude <- original_cam[, "latitude"]/10000000
#speedValue
original_cam$speedValue = gsub("standstill","0",original_cam$speedValue)
original_cam$speedValue = gsub("oneCentimeterPerSec","1",original_cam$speedValue)
original_cam$speedValue = as.numeric(original_cam$speedValue)
original_cam$speedValue <- original_cam[, "speedValue"]/100
original_cam$speedValue <- original_cam[, "speedValue"]*3.6
```

```
#timestamp
original_cam$timestamp <- strptime(original_cam$timestamp, "%Y-%m-%dT%H:%M:%OS")

#Adding 2 h because the original data was in different time-zone
original_cam$timestamp <- original_cam$timestamp + 2*60*60

#######DENM
#Long_lat
original_denm$longitude <- original_denm[, "longitude"]/10000000
original_denm$latitude <- original_denm[, "latitude"]/10000000
original_denm$timestamp <- strptime(original_denm$timestamp, "%Y-%m-%dT%H:%M:%OS")
# Selection of DENM messages for RLX divided into two scenarios
DENM_Stop = original_denm[original_denm[, "subCauseCode"]== '1,0',]
DENM_other = original_denm[original_denm[, "subCauseCode"]== '0,0',]
#### DATA FILTRATION

#as.data.frame(sort(table(original_cam$stationID), decreasing = TRUE))  ## frequency of unique messages
# searching for the station ID of tested vehicles base on frequency of send messages
# Var1          Freq
# 1  1726842680 22428
# 2   397610556  1731
# 3   500310218  1284
# 4   309173311   791
# 5  2098328000   235
# 6   756461984   177
# 7   230940972   170
# 8  1302793035   106
# 9  1116297231   102
# 10  879388097    84
# 11 1703603653    57
# 12  948521590    49
# 13 1967531335    44
# 14 1138152208    41
# 15  942557557    37
```

```
# 16  675094830    31
# 17   28276231    19
# 18 1777378248    17

#colors
log_dev_col = "purple"
Car_A_col = "blue"
Car_B_col = "red"
ISV_col_col="green"
ISV_car_B_col = "gold"
#################### Data selection####################
#passage 1
time1 = "2020-07-09 8:40:00.0"
time2 = "2020-07-09 8:58:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "1")
names(test_auto)[19] <- "passage"
passage_matrix = test_auto

#passage 2
time1 = "2020-07-09 09:01:00.0"
time2 = "2020-07-09 09:17:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "2")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)

#passage 3
time1 = "2020-07-09 09:22:00.0"
```

```
time2 = "2020-07-09 09:36:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "3")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)

#passage 4
time1 = "2020-07-09 09:52:00.0"
time2 = "2020-07-09 10:07:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "4")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)

#passage 5
time1 = "2020-07-09 10:23:00.0"
time2 = "2020-07-09 10:46:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "5")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)


#passage 6
time1 = "2020-07-09 10:53:00.0"
```

```
time2 = "2020-07-09 11:12:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "6")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)


#passage 7
time1 = "2020-07-09 11:20:00.0"
time2 = "2020-07-09 11:39:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "7")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)


#passage 8
time1 = "2020-07-09 11:40:00.0"
time2 = "2020-07-09 11:55:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "8")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)

#passage 9
```

```
time1 = "2020-07-09 11:55:00.0"
time2 = "2020-07-09 12:09:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "9")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)


#passage 10
time1 = "2020-07-09 12:09:00.0"
time2 = "2020-07-09 12:21:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "10")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)


#passage 11
time1 = "2020-07-09 12:21:00.0"
time2 = "2020-07-09 12:32:00.0"
ID_auta="1726842680"

test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,] # Pro
auto 1
test_auto=data.frame(test_auto, "11")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)
```

```
#passage 12
time1 = "2020-07-09 12:40:30.0"
time2 = "2020-07-09 12:51:30.0"
ID_auta="1726842680"


#test auto # car A and subselection base on time
test_auto = original_cam[original_cam[, 'stationID']== ID_auta,]
test_auto=test_auto[test_auto$timestamp >= time1 & test_auto$timestamp <= time2 ,]
#data frame for all passages
test_auto=data.frame(test_auto, "12")
names(test_auto)[19] <- "passage"
passage_matrix = rbind(passage_matrix, test_auto)

#################### proximity selection####################
#selection of data that is in the polygon
polygon_lat = c(49.979496, 49.980084, 49.976539, 49.975639)
polygon_long = c(15.862556, 15.860236, 15.856063, 15.859281)

prejezd_matrix = passage_matrix
#function that checks is longitude and latitude is in the defined polygon
testFunc <- function(a,b) point.in.polygon(a, b, polygon_lat, polygon_long,
mode.checked=FALSE)
prejezd_matrix$polygon <- apply(prejezd_matrix,1,function(x)  testFunc(x[9], x[10]))
#plot of the polygon and data from passage 3
subdata = prejezd_matrix[prejezd_matrix$polygon == "1" & prejezd_matrix$passage == "1"
& prejezd_matrix$headingValue > 1200,] #zpet
plot(subdata$Time, subdata$speedValue, pch = 19, col = Car_A_col, main ="Plot speed,
passage 8, way to point 3", xlab = "Time [sec]", ylab = "Speed [Km/h]")

#halving the data in time so the data could be analysed base on the passage

half_time = (tail(subdata$Time,1)-subdata$Time[1])/2 +subdata$Time[1]
fist_half = subdata[subdata$Time < half_time, ]
second_half = subdata[subdata$Time > half_time, ]
```

```r
#################### Analysis####################

#########acceleration#########

#### passage to point 3####
#subselection of data from
subdata = prejezd_matrix[prejezd_matrix$polygon == "1" & prejezd_matrix$passage == "12"
& prejezd_matrix$headingValue > 1200,]
half_time = (tail(subdata$Time,1)-subdata$Time[1])/2 +subdata$Time[1]
fist_half = subdata[subdata$Time < half_time, ]
second_half = subdata[subdata$Time > half_time, ]

#Difference in deceleration fist_half
differ_car1=diff(fist_half$speedValue)
differ_car2=diff(fist_half$Time)
differ_car_fist_half=data.frame(fist_half$Time[1:length(differ_car1)+1],fist_half$Time[1:leng
th(differ_car1)+1]-fist_half$Time[1],differ_car2,differ_car1, differ_car1/differ_car2)
colnames(differ_car_fist_half) = c("time","time_from_ISV", "delta_time","speed_difference", "
acceleration")
#plot(differ_car[,2], differ_car[,1])
rm(differ_car1,differ_car2)

differ_car_fist_half$acceleration=movavg(differ_car_fist_half$acceleration, 5, type=c("s"))
differ_car_fist_half=differ_car_fist_half[differ_car_fist_half$acceleration < 10 & differ_car_fist
_half$acceleration > -10, ]

#Difference deceleration second_half
differ_car1=diff(second_half$speedValue)
differ_car2=diff(second_half$Time)
differ_car_second_half=data.frame(second_half$Time[1:length(differ_car1)+1],second_half
$Time[1:length(differ_car1)+1]-second_half$Time[1],differ_car2,differ_car1, differ_car1/differ
_car2)
colnames(differ_car_second_half) = c("time","time_from_ISV", "delta_time","speed_differen
ce", "acceleration")
#plot(differ_car[,2], differ_car[,1])
rm(differ_car1,differ_car2)

differ_car_second_half$acceleration=movavg(differ_car_second_half$acceleration, 5, type=
c("s"))
differ_car_second_half=differ_car_second_half[differ_car_second_half$acceleration < 10 &
differ_car_second_half$acceleration > -10, ]


#subdata selection of passage with different scenarios for acceleration
acc_prujezd_tam_BEZ = c(acc_prujezd_tam_BEZ,differ_car_fist_half$acceleration)
acc_prujezd_tam_SE = c(acc_prujezd_tam_SE,differ_car_second_half$acceleration)

acc_prujezd_tam_BEZ = differ_car_fist_half$acceleration
acc_prujezd_tam_SE = differ_car_second_half$acceleration


#Box plot of accelerations
box_acc = cbind(acc_prujezd_tam_BEZ,acc_prujezd_tam_SE)
boxplot(x=box_acc,main = "Box plot of acceleration for Attention, railway crossing! warning,
all Vehicles",ylab="Speed [Km/h]", names = c("Passage without C-ITS", "Passage with C-ITS
```

```
"))
points(c(mean(box_acc[,1]),mean(box_acc[,2])),col="red",pch=18)

text(x=1.1:2.1,c(round(mean(box_acc[,1]),digits=2), round(mean(box_acc[,2]),digits=2)), la
bels = c(round(mean(box_acc[,1]),digits=2), round(mean(box_acc[,2]),digits=2)))
text(x=0.8,y=boxplot.stats(box_acc[,1])$stats+1,labels = round(boxplot.stats(box_acc[,1])
$stats, digits = 2))
text(x=1.8,y=boxplot.stats(box_acc[,2])$stats+1.5,labels = round(boxplot.stats(box_acc[,2
])$stats, digits = 2))

#### passage to point 1####
#subselection based on passage and proximity
subdata = prejezd_matrix[prejezd_matrix$polygon == "1" & prejezd_matrix$passage == "12"
& prejezd_matrix$headingValue <1200 & prejezd_matrix$headingValue >500, ] #zpet
half_time = (tail(subdata$Time,1)-subdata$Time[1])/2 +subdata$Time[1]
fist_half = subdata[subdata$Time < half_time, ]
second_half = subdata[subdata$Time > half_time, ]

#Difference deceleration fist_half
differ_car1=diff(fist_half$speedValue)
differ_car2=diff(fist_half$Time)
differ_car_fist_half=data.frame(fist_half$Time[1:length(differ_car1)+1],fist_half$Time[1:leng
th(differ_car1)+1]-fist_half$Time[1],differ_car2,differ_car1, differ_car1/differ_car2)
colnames(differ_car_fist_half) = c("time","time_from_ISV", "delta_time","speed_difference", "
acceleration")
#plot(differ_car[,2], differ_car[,1])
rm(differ_car1,differ_car2)

differ_car_fist_half$acceleration=movavg(differ_car_fist_half$acceleration, 5, type=c("s"))
differ_car_fist_half=differ_car_fist_half[differ_car_fist_half$acceleration < 10 & differ_car_fist
_half$acceleration > -10, ]

#Difference deceleration second_half
differ_car1=diff(second_half$speedValue)
differ_car2=diff(second_half$Time)
differ_car_second_half=data.frame(second_half$Time[1:length(differ_car1)+1],second_half
$Time[1:length(differ_car1)+1]-second_half$Time[1],differ_car2,differ_car1, differ_car1/differ
_car2)
colnames(differ_car_second_half) = c("time","time_from_ISV", "delta_time","speed_differen
ce", "acceleration")
#plot(differ_car[,2], differ_car[,1])
rm(differ_car1,differ_car2)

differ_car_second_half$acceleration=movavg(differ_car_second_half$acceleration, 5, type=
c("s"))
differ_car_second_half=differ_car_second_half[differ_car_second_half$acceleration < 10 &
differ_car_second_half$acceleration > -10, ]



acc_prujezd_tam_BEZ = c(acc_prujezd_tam_BEZ,differ_car_fist_half$acceleration)
acc_prujezd_tam_SE = c(acc_prujezd_tam_SE,differ_car_second_half$acceleration)

acc_prujezd_tam_BEZ = differ_car_fist_half$acceleration
```

```
acc_prujezd_tam_SE = differ_car_second_half$acceleration


#box plot of acceleration passage to point 1
box_acc = cbind(acc_prujezd_tam_BEZ,acc_prujezd_tam_SE)
boxplot(x=box_acc,main = "Box plot of acceleration for Passing Train! warning, all Vehicles",
ylab="Speed [m/s]", names = c("Passage without C-ITS", "Passage with C-ITS"))
points(c(mean(box_acc[,1]),mean(box_acc[,2])),col="red",pch=18)

text(x=1.1:2.1,c(round(mean(box_acc[,1]),digits=2), round(mean(box_acc[,2]),digits=2)), la
bels = c(round(mean(box_acc[,1]),digits=2), round(mean(box_acc[,2]),digits=2)))
text(x=0.8,y=boxplot.stats(box_acc[,1])$stats+1,labels = round(boxplot.stats(box_acc[,1])
$stats, digits = 2))
text(x=1.8,y=boxplot.stats(box_acc[,2])$stats+1.5,labels = round(boxplot.stats(box_acc[,2
])$stats, digits = 2))


########### speed boxplot###########

#######passage to point 3
#subselection of passage based on approximation and heading
subdata = prejezd_matrix[prejezd_matrix$polygon == "1" & prejezd_matrix$passage == "12"
& prejezd_matrix$headingValue <1200 & prejezd_matrix$headingValue >500, ] #tam
half_time = (tail(subdata$Time,1)-subdata$Time[1])/2 +subdata$Time[1]
fist_half = subdata[subdata$Time < half_time, ]
second_half = subdata[subdata$Time > half_time, ]

prujezd_zpet_BEZ = c(prujezd_zpet_BEZ,fist_half$speedValue)
prujezd_zpet_SE = c(prujezd_zpet_SE,second_half$speedValue)

prujezd_zpet_BEZ = fist_half$speedValue
prujezd_zpet_SE = second_half$speedValue

box_speed = cbind(prujezd_zpet_BEZ,prujezd_zpet_SE)
boxplot(x=box_speed,main = "Box plot of speed for Attention, railway crossing!, all Vehicles"
,ylab="Speed [Km/h]", ylim=c(0,90), names = c("Passage without C-ITS", "Passage with C-IT
S"))
points(c(mean(box_speed[,1]),mean(box_speed[,2])),col="red",pch=18)

text(x=1:2,c(round(mean(box_speed[,1]),digits=2), round(mean(box_speed[,2]),digits=2))+
2, labels = c(round(mean(box_speed[,1]),digits=2), round(mean(box_speed[,2]),digits=2)))
text(x=1,y=boxplot.stats(box_speed[,1])$stats+1.5,labels = boxplot.stats(box_speed[,1])$s
tats)
text(x=2,y=boxplot.stats(box_speed[,2])$stats+1.5,labels = boxplot.stats(box_speed[,2])$s
tats)


#### passage to point 1
#subselection of data based on
subdata = prejezd_matrix[prejezd_matrix$polygon == "1" & prejezd_matrix$passage == "12"
& prejezd_matrix$headingValue > 1200,]
half_time = (tail(subdata$Time,1)-subdata$Time[1])/2 +subdata$Time[1]
fist_half = subdata[subdata$Time < half_time, ]
second_half = subdata[subdata$Time > half_time, ]
```

```
prujezd_tam_BEZ = c(prujezd_tam_BEZ,fist_half$speedValue)
prujezd_tam_SE = c(prujezd_tam_SE,second_half$speedValue)

prujezd_tam_BEZ = fist_half$speedValue
prujezd_tam_SE = second_half$speedValue


box_speed = cbind(prujezd_tam_BEZ,prujezd_tam_SE)
boxplot(x=box_speed,main = "Box plot of speed for Passing Train! warning, all Vehicles",yla
b="Speed [Km/h]", ylim=c(0,90), names = c("Passage without C-ITS", "Passage with C-ITS")
)
points(c(mean(box_speed[,1]),mean(box_speed[,2])),col="red",pch=18)

text(x=1:2,c(round(mean(box_speed[,1]),digits=2), round(mean(box_speed[,2]),digits=2))+
2, labels = c(round(mean(box_speed[,1]),digits=2), round(mean(box_speed[,2]),digits=2)))
text(x=1,y=boxplot.stats(box_speed[,1])$stats+1.5,labels = boxplot.stats(box_speed[,1])$s
tats)
text(x=2,y=boxplot.stats(box_speed[,2])$stats+1.5,labels = boxplot.stats(box_speed[,2])$s
tats)




#write.csv(box_speed,"C:/Users/micha/Desktop/Skola/Magistr/Diplomova_prace/box_plot_ta
m.csv", row.names = FALSE)


#results of evaluation for all vehicles in box plot for speed and acceleration
results = data.frame(mean(fist_half$speedValue), max(fist_half$speedValue), min(fist_half$
speedValue), mean(differ_car_fist_half$acceleration), max(differ_car_fist_half$acceleration),
min(differ_car_fist_half$acceleration))
colnames(results) = c("Mean_speed", "max_speed", "min_speeed", "mean_acceleration", "
max_acceleration", "min_acceleration")

results = rbind(results, list(mean(second_half$speedValue), max(second_half$speedValue)
, min(second_half$speedValue), mean(differ_car_second_half$acceleration), max(differ_car
_second_half$acceleration), min(differ_car_second_half$acceleration)))
rownames(results) = c("before", "after")

accbox_before = differ_car_before$acceleration
accbox_after = differ_car_after$acceleration

speedbox_before = c(speedbox_before,reaction_2sec_before$speedValue)
accbox_before = c(accbox_before,differ_car_before$acceleration)
speedbox_after = c(speedbox_after,reaction_2sec_after$speedValue)
accbox_after = c(accbox_after,differ_car_after$acceleration)
```