SAFESPOT INTEGRATED PROJECT - IST-4-026963-IP

DELIVERABLE

SP4 – SCOVA – Cooperative Systems Applications Vehicle Based

D4.6.4 – Evaluation of accident impact through simulation

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Abbreviation List

ADAS	Advanced diver assistance systems
BLADE	Business models, Legal Aspects, and Deployment
CAR	Correct Alarm Rate
COSSIB	Cooperative Safety Systems Infrastructure Based
FAR	False Alarm Rate
ESPOSITOR	SAFESPOT SYSTEM MONITOR
FCW	Frontal Collision Warning
FN	False Negative (or Missed Alarms)
FP	False Positive (or False Alarms)
GW	Gateway
HF	Human Factors
HIL	Hardware In the Loop
HLO	High Level Objective
HMI	Human Machine Interface
HURR	SAFESPOT High level objectives, User needs, Requirements and Risks
HW	Hardware
IP	Integrated Project
ISO	International Standard Organisation
ITS	Intelligent Transportation System
JDVS	Joint Driver Vehicle System
LAN	Local Area Network
LDM	Local Dynamic Map
LIVIC	Laboratoire sur les interactions vehicules-infrastructure-conducteurs: Research laboratory for advanced driving assistance systems and cooperative systems
LR	Long Range
MAR	Missed Alarm Rate
MARS	Multi Agent Real-Time Simulation Technology
NASA TLX	National American Space Agency – Task Load Index
PC	Personal Computer
PReVENT	Preventive and Active Safety Applications (EU-Project)
R&D	Research and Development
RIS	Road Intersection Safety
RSU	Road Site Unit
SAFEPROBE	In-Vehicle Sensing and Platform
SBC	Single Board Computer

SCOVA	Cooperative Systems Applications Vehicle Based
SINTECH	Innovative Technologies
SMA	Safety Margin Assistant
SP	Subproject
SUS	System Usability Scale
SW	Software
TN	True Negative
TP	True Positive
TTC	Time To Collision
TTT	Total Travel Times
UDP	User Datagram Protocol
VANET	Vehicle Ad Hoc Network
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V&V	Verification and Validation
WP	Work Package
WT	Work Task

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EXECUTIVE SUMMARY

The present deliverable D4.6.4 – "*Evaluation of accident impact through simulation"* reports on the impact of different SMAs (Safety Margin Assistants) on traffic in the sense of accident reduction and throughput improvement. The results have been generated using a traffic simulator, since currently not enough vehicles are equipped to perform real-life testing for this kind of evaluation.

To evaluate the SAFESPOT system against the HURR (SAFESPOT High level objectives, User needs, Requirements and Risks), the ITS modeller simulation environment is used. The reason for using simulation is that some of the evaluation cannot be done on the road due to either safety of the vehicle and its passenger or due to the fact that many vehicles are required, which are obviously not available, since it is a novel system.

Three applications are evaluated. These applications are the Congestion Warning, as extension of the General Use Case of the Speed Limitation and Safety Distance Application, the Road Condition Status application, and the Frontal Collision Warning application as described in SAFESPOT deliverables D4.2.3 – "*Use case and typical accident situation*" [4] and D4.3.1 – "Safety Margin Application Parameters Analysis and Characterization" [6]. These applications are selected because they comply with the modelling possibilities in the ITS modeller simulation environment. Some limitations of the ITS modeller are the disability to model overtaking and detailed safety statistics at intersections. Therefore, intersection applications and overtaking applications are not evaluated.

Overall it can be concluded that the evaluated safety warning system have a positive effect on traffic safety, that can realise societal benefits. As expected, the slow and timely braking due to safety warning reduce traffic efficiency. Vehicles take more 'space' on the road. Especially in congested situations, this means a trade off with traffic efficiency. The increase in travel time varies from 6% in free flow traffic to as much as 50% on a highly congested road.

It should be noted that these results are based on 100% compliance to a safety warning system that is optimised for safety only. Optimisation for traffic efficiency is advised to reduce the traffic efficiency loss and improve acceptability of the system.

An important limitation of modelling traffic safety is the inability to quantify the statistical relation between dangerous situations and traffic accidents. A statistical model by [10] was implemented, but this model is calibrated for a U.S. highway, and turned out to be unsuitable for the European motorway situation. European incident data for calibrating the model based on video data is not yet available.

Penetration levels of equipped vehicles that were evaluated in this study are 0%, 15%, 50%, 85% and 100%. Especially relevant for deployment strategies are the effects of penetrations between 0% and 15%.

1. Introduction

SAFESPOT aims to develop a platform for V2V (vehicle to vehicle) and V2I (vehicle to infrastructure) communication. Such a system would extend by far the possible environmental recognition of current sensor technologies. Any individual on-board sensor system will meet its limits at some extend (i.e. detection of objects around curves) so the SAFESPOT approach will enable vehicles to communicate relevant information such as ego-vehicle and surrounding environment parameters to other vehicles and to the infrastructure. In SAFESPOT SP4 (SCOVA) the consortium developed applications that use this cooperative technology, with the main focus on V2V cooperation. Together with the cooperative V2I applications developed in SP5 (COSSIB) and the basic platforms assembled in SP1 (SAFEPROBE) and SP2 (INFRASENS) which contain sensing modules, positioning, communication and the local dynamic map developed in SP3 (SINTECH), it aims to develop and evaluate the functionality of a number of safety applications such as:

- Road Intersection Safety (RIS)
- Lane Change Manoeuvres (LCM)
- Safe Overtaking (SO)
- Head On Collision Warning (HOCW)
- Rear End Collision Warning (RECW)
- Frontal Collision Warning (FCW)
- Vulnerable Road User detection and Accident Avoidance (VRUAA)
- Road Condition Status (RCS)
- Curve Warning (CUWA)
- Predictive Speed Limitation and Safety Distance (SLSD)

SAFESPOT WP4.6 is dedicated to evaluate these SP4 applications in terms of:

- Technical evaluation of the SAFESPOT vehicle to vehicle technology.
- Human factors evaluation of the applications with system users (so called ‘subjects’).
- The impact of a SAFESPOT system on the complete traffic situation.

The present deliverable D4.6.4 – “*Evaluation of accident impact through simulation”* reports on the impact of different SMAs (Safety Margin Assistants) on traffic in the sense of accident reduction and throughput improvement. The results have been generated using a traffic simulator, since currently not enough vehicles are equipped to perform real-life testing for this kind of evaluation.

The test case definition form of this evaluation can be found on the project web site under: http://bscw.safespot-eu.org/bscw/bscw.cgi/194854 and is contained in this deliverable in the Annex.

1.1. Innovation and Contribution to the SAFESPOT Objectives

This deliverable reports the results of the accident impact evaluation. The main innovation is the novel approach used in the evaluation. A cooperative vehicle / road system is tested in a traffic simulation. This kind of simulation is novel. The modelling tool was adapted to be able to cope with the SAFESPOT systems. The vehicle to vehicle communication based on IEEE 802.11p was added and different behaviour from drivers is expected as a consequence from the adoption of the cooperative systems. These adaptations are described in chapter 3, section 3.1.

This deliverable clearly contributes to the SAFESPOT objectives as it is part of the evaluation of the SAFESPOT system. One objective in SAFESPOT [1] is to evaluate the SAFESPOT system against the HURR (SAFESPOT High level objectives, User needs, Requirements and Risks) that were set up at the start of system design. This will be done both in real-life tests on the road and on test tracks. However, some of the evaluation cannot be done on the road due to either safety of the vehicle and its occupants or due to the fact that many vehicles are required, which are obviously not available, since it is a novel system. Latter is the case here. Hence the simulation tool *ITS Modeller* has been adapted to perform traffic simulations with cooperative systems (between vehicles only and between vehicles and the infrastructure).

1.2. SAFESPOT SP4 objectives

This deliverable reports on task T4.6.3 of the workpackage WP4.6. SAFESPOT WP4.6 has as main objective the evaluation of SP4 applications with respect to pre-defined success criteria. These success criteria are distributed in 4 clusters of pre-defined objectives:

- High Level Objectives
- User Needs
- Requirements
- Risks.

These objectives are further referred to as HURR, taking their initials as acronym. The evaluation aims to prove the success of SAFESPOT SP4 by complying with the HURR.

The evaluation in this Deliverable reports on the impact of the SAFESPOT system on traffic (safety and throughput). The following user needs (UN) are addressed in the evaluation:

1. The driver is warned when approaching a vehicle from behind with a significantly lower speed than its own vehicle.
2. Accurate distance to preceding vehicle is known.
3. Advising drivers on hazardous situations in front and around.
4. Informing the driver about road condition (influencing the grip of the tyres on the road) in the future expected path of the vehicle.

The addressed high level objectives (HLOs) in the evaluation are:

1. Showing the feasibility and benefits of Co-operative Systems solutions in terms of road safety improvements well beyond the level which can be achieved with autonomous solutions (vehicle or infrastructure based) (HLO1).
2. Demonstrating the benefits for accident types with a calculated potential safety impact in terms of saving of lives (HLO2).
3. Showing that the safety impact can be achieved without affecting transport efficiency (HLO3).

1.3. Link with other SPs and WPs

This deliverable is closely linked to a number of SPs and WPs. Starting with SP4 (SCOVA), WP4.6 is the completion of the development process of applications, evaluating the final applications in terms of technical function (WT4.6.4), human factors (WT4.6.5) and traffic impact (WT4.6.6) and it is expecting verified applications and technical systems at the test sites, provided by WP4.5.

SP4 (SCOVA) applications are mainly based on subsystems developed in SP1 (SAFEPROBE) and SP3 (SINTECH) (see **Figure 1**).

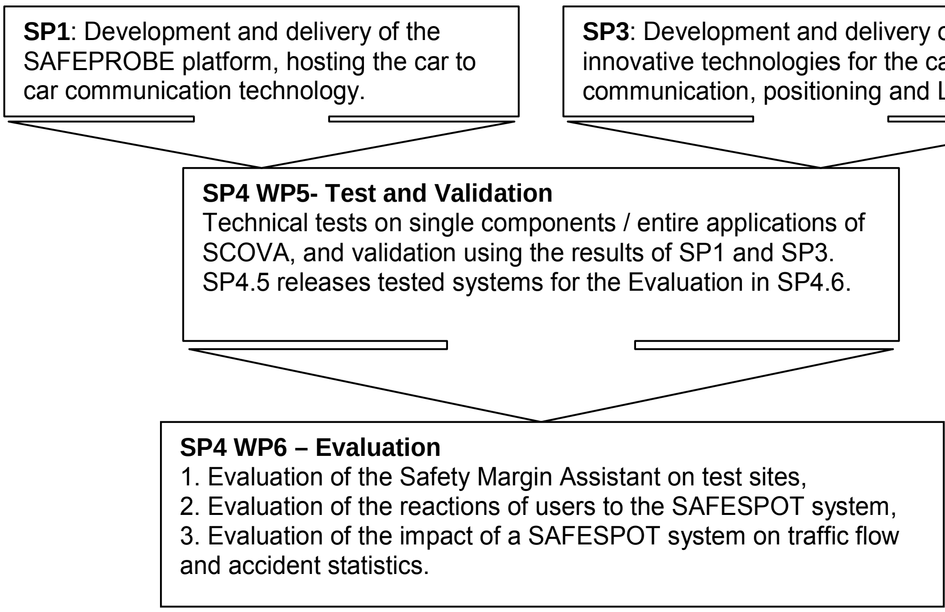


Figure 1: Interdependency of SP1 and SP3 towards WP4.6

SP5 (COSSIB) is dedicated to applications based on the communication between vehicles and infrastructure. These applications will be evaluated in a similar approach by SP5 (COSSIB) and thus a close contact was established to the counterpart WP5.6.

SP6 (BLADE) contributes to the success criteria by defining the risks that might jeopardize the success of the applications. Different penetration ratios are used in

D4.6.4 compared to the ratios that are used in the market analysis and the impact analysis. The purpose of the market analysis and the impact analysis is to provide a insight in the deployment aspects of the SAFESPOT system. The figures used for this analysis are derived from sales figures of new cars sold, adapted for the different configurations and scenarios used in the deployment analysis. The analysis performed in SP4 has a different purpose: validation of the technical concept. In this respect the research question is: does the application improve vehicle or traffic safety, as it was intended in the technical design and the selected use case? To estimate the safety effect this is tested for different traffic conditions.

Although at first sight the identification of the different penetration rates used in the deployment work packages (BLADE) and the validation work packages (SCOVA & COSSIB) seem odd, there is a good explanation for this. For BLADE the low penetration rates are reported because these follow from the market analysis scrutinizing market effects in great detail. The reason for these penetration rates is coherent with the goal of BLADE: to show the feasibility of SAFESPOT from a business point of view.

Within SCOVA (and COSSIB) the goal is to validate the designed system and demonstrate (amongst others) the effect of the system on traffic efficiency. The research was directed to analyse how the implementation of the designed cooperative safety warning applications affect throughput and the environment. Because of the technical focus, the validation of the impact on traffic efficiency, the business point of view is left aside.

1.4. Methodology

The methodology of design and testing of the SAFESPOT system has been detailed in D4.6.1 – "*Pilot Plan*" [2] with the focus on system evaluation. For completeness the V-model of SCOVA is repeated here, see the next page. The branch for this deliverable (D4.6.4 – "*Evaluation of accident impact through simulation*") is highlighted in the figure.

The SAFESPOT vehicle behaviour for simulation is derived from the SMA concepts, use cases and first results of the impact analysis.

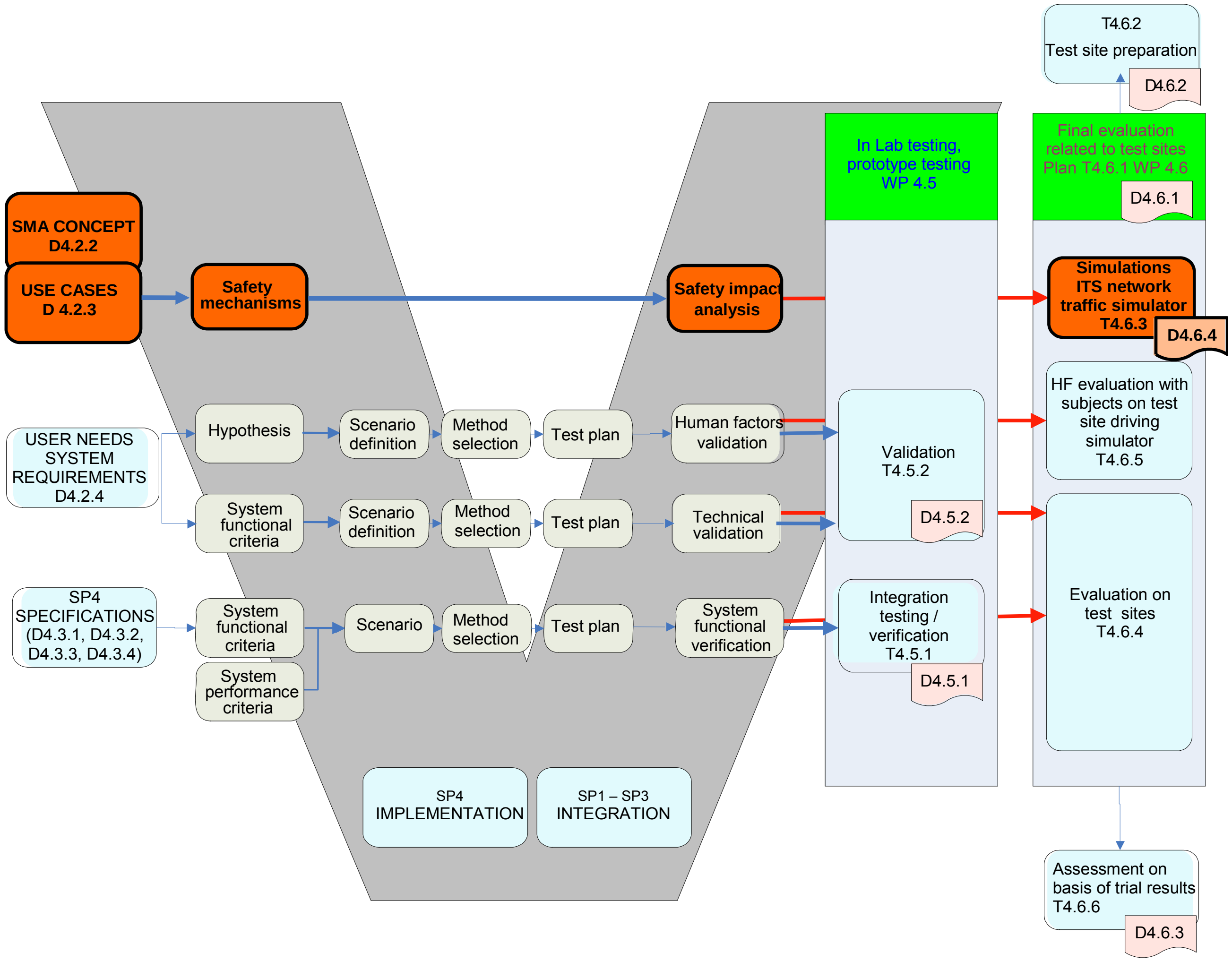


Figure 2: The V-model for SP4 with D4.6.4 - "*Evaluation of accident impact through simulation*" highlighted

1.5. Deliverable structure

In chapter 2 the tools used for the analysis are described. This includes a description of the ITS Modeller as well as the necessary implementations for the SAFESPOT-project that have been made.

In chapter 3 the research design is being discussed, including the applications which are selected for the assessment and the hypotheses used for these various applications.

Chapter 4 describes the implementation of the applications and scenarios in the ITS modeller and lists the assumptions made for this implementation.

Chapter 5 shows the results for the selected applications on safety, traffic efficiency and environment.

In chapter 6 the conclusions for the applications are reported.

2. Tools used

To evaluate the SAFESPOT system against the HURR (SAFESPOT High level objectives, User needs, Requirements and Risks), the ITS modeller simulation environment is used. The reason for using simulation is that some of the evaluations cannot be done on the road due to either safety of the vehicle and its passenger or due to the fact that a significant number of equipped vehicles would be needed, which are obviously not available, since SAFESPOT is a novel system. The ITS modeller is described in section 2.1 below.

The simulation tool *ITS Modeller* has been adapted to perform traffic simulations with cooperative systems (between vehicles only and between vehicles and the infrastructure). The improvements to the ITS modeller are described in section 2.2.

2.1. ITS Modeller

Future roadside and in-vehicle cooperative Intelligent Transport Systems require new modelling environments to predict their impact on traffic throughput, traffic safety, noise and emissions. TNO's ITS Modeller provides such an environment [12].

Roads and vehicles are both getting smarter. At the roadside, traffic management systems are used to ensure safe, efficient and reliable traffic flow on the road network. Vehicles are increasingly being equipped with systems that support a driver's journey from A to B efficiently, safely and comfortably. Drivers are well-informed about current and expected traffic conditions and are able to respond to changing conditions.

The ITS Modeller is a modelling environment that can simulate intelligent transport systems. It contains a traffic network, where each vehicle, driver and Intelligent Transport System (ITS) has its own individual model. Several roadside and in-vehicle systems, as well as cooperative systems, are available as standard.

The ITS Modeller is well equipped to deal with the innovative ITS solutions of today and the future. New in-car, roadside or cooperative systems and new developments in traffic management can easily be modelled and added to the system because of its flexible modular structure. Innovative ITS solutions can be simulated to assess their impact at any desired level of deployment.

It can also be used to determine the effects of ITS systems at network level. The modelling environment has several evaluation modules for this purpose. Highlights:

- Various models for vehicle, driver and ITS systems, based on realistic data from the TNO test labs.
- A message-based communication model.
- Evaluation modules for throughput, safety and noise, and calculation of emissions

2.2. Improvements for SAFESPOT

To be able to model the specific SAFESPOT applications, the following improvements are made to the ITS modeller simulation environment.

2.2.1. Implementation of SAFESPOT safety warnings

The SAFESPOT warning is based on the deceleration that is required to brake for the hazardous situation. As specified in D4.2.2 – "*Safety Margin concept*" [3], warnings are issued from a required deceleration of 0.1g (0.1 times the gravity acceleration). The warning distances (boundaries of the zones) are calculated by the following function.

$$D_W = T_r V_0 + \frac{V_0^2 - V_C^2}{2\gamma_d}$$

where

- D_w is the distance to warn the driver
- T_r is the reaction time of the driver (distribution around 0.3 sec in the ITS Modeller)
- V_0 is the vehicle speed.
- V_c (the critical speed) is the speed at which the hazard is moving.
- γ_d is either 0.1g, 0.3g and 0.6g (where g is the gravity acceleration of 9.81)

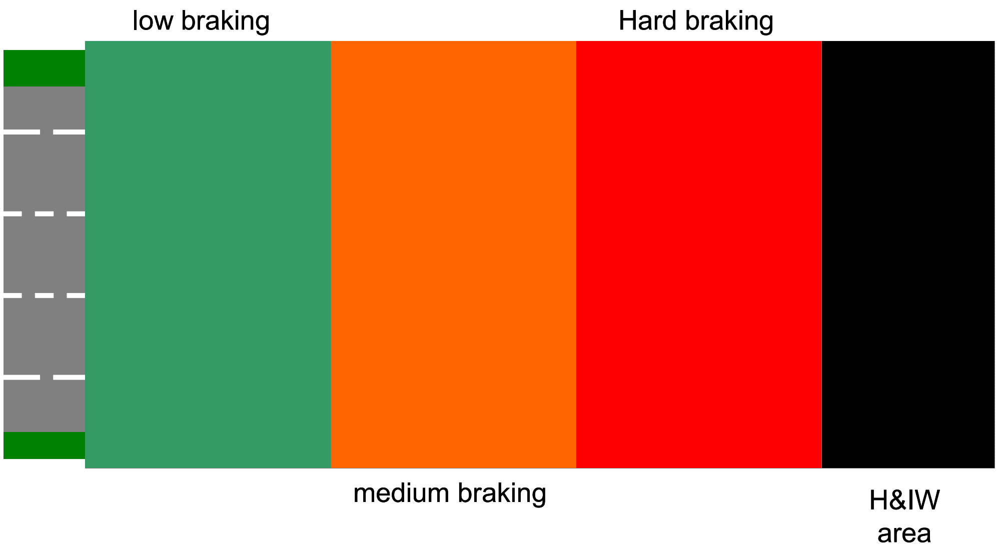


Figure 3: Different areas of warning

Three zones for braking are distinguished representing different levels of deceleration. In the green area, the deceleration is set at 0.1g. The orange area has a deceleration set at 0.3g. Finally, the red area is for a hard braking with a deceleration at 0.6g.

However in the simulation the driver that received a warning applies the exact deceleration that is required to prevent the hazardous situation. The boundaries of the zones have thus become a gradual scale.

In the simulation runs all drivers comply with the advised deceleration. This assumption was used while the driver behaviour in response to this SAFESPOT warning system is still being analysed (analysis performed by University of Stuttgart in T4.6.5).

2.2.2. Communication

The communication (both V2V and V2I) has been added to the ITS modeller simulation environment for the purpose of this study.

The communication of individual SAFESPOT warning messages is modelled. The messages contain the hazard location and the critical speed for passing that location.

The probability of packet reception in an IEEE 802.11p network is modelled after [7] and [8]. In these papers the probability of packet reception is a function of the sending distance and the vehicle intensity between sender and receiver. The VANET as described in SP3 is largely based on IEEE 802.11p communication technology [13].

The SAFESPOT applications [4] send warning messages when the sender detects that the speed drops below 50% of the speed limit (this has been identified as a significant difference in speed as specified in the User Needs & Requirements). The sender (either a vehicle or an intelligent road side unit) broadcasts the message every 0.1 second (every time step in the simulation).

For reasons of simulation performance, other SAFESPOT vehicles stop receiving messages when their speed is reduced to 20% of the speed limit.

According to [6], the following function and specifications were implemented:

- Max sending range modelled: 450 meter
- Protocol: CALM (802.11p)
- Payload per packet: 200 bytes

The function that describes the probability that a packet is transmitted successfully is described by [6] as the following:

$$P_{R,approx}(d, CR) = e^{-3\left(\frac{d}{CR}\right)^2} \left(1 + \sum_{i=1}^{4} x_i \left(\frac{d}{CR}\right)^i\right)$$

Where:

- $P_{R,\,approx}(d,CR)$ is the expected probability that a message arrives;
- d is the distance between the sender and the receiver (meters);
- x_i are estimated as a function of the density of equipped vehicles (in simple words the penetration rate);
- CR is the intended transmission range, which is assumed 500 meter.

The estimated x_i's as function of the density of equipped vehicles (δ) are the following:

- x_1 = 0δ
- x_2 = -0.031255δ
- x_3 = -0.0115δ + 3
- x_4 = -0.01δ + 4.5

2.2.3. Safe Headway Distance

To be able to better assess the impact of the safety margin assistant on the fatality risk an attempt was made to implement the Safe Headway Distance(SHD) as a safety measure. In the U.S. the SHD was translated directly into fatality risk based on a U.S. accident database. This would be an improvement compared to the currently used risk measure Time To Collision (TTC). The TTC is an indirect risk measure in the sense that there is no quantitative relation between the TTC and the fatality risk. Using the SHD in the ITS Modeller risks could be defined in terms of fatality risk (instead of the indirect measure TTC).

A traffic conflict can be defined in several ways depending on the research purpose and design ([8, 9]). These papers define the conflict as a condition of two consecutively moving vehicles having inadequate safe headway distance such that the following vehicle will crash into the leading vehicle when it makes an unexpected stop. It assumes that the leading vehicle abruptly reacts to a stimulus resulting in an emergency stopping manoeuvre, while the following vehicle reacts to such a braking manoeuvre of the leading vehicle. Based on these assumptions, a safe (i.e., collision free) condition of the two consecutive vehicles can be defined as a condition where a minimum stopping distance of the leading vehicle is greater than that of the following vehicle. Hence, using the minimum stopping distance formula [11] (AASHTO, 2004) the safe condition can be mathematically expressed as:

Minimum Stopping Distance (leading vehicle) > Minimum Stopping Distance (following vehicle) ≡

$$\left(V_{Leading} \times h\right) + \left[\frac{V_{Leading}^2}{20 \times \left(\frac{acc}{g} \pm Gr\right)}\right] > \left(V_{Following} \times PRT\right) + \left[\frac{V_{Following}^2}{20 \times \left(\frac{acc}{g} \pm Gr\right)}\right] \quad \text{Eq. (1)}$$

Where

- $V_{Leading}$ = leading vehicle's speed in meter per second (m/s);
- $V_{Following}$ = following vehicle's speed in m/s;
- *acc* = deceleration rate in m/s^2;
- *g* = gravity acceleration (9.81 m/s^2);
- *Gr* = grade in percentage;
- *h* = time headway in second;
- *PRT* = perception reaction time of the following vehicle in second.

Using the above equation, an individual safe headway distance (SHD) for a pair of two consecutive vehicles can be defined as a difference of the two minimum stopping distances as follows:

$$SHD_i = \max\left[-Diff_i, 0\right] \text{ and}$$

$$Diff_i = (V_{Leading} \times h - V_{Following} \times PRT) + \left[\frac{V_{Leading}^2 - V_{Following}^2}{20 \times \left(\frac{acc}{g} \pm Gr \right)} \right] \qquad \text{Eq. (2)}$$

where:

- i = index of a pair of two consecutive vehicles;
- SHD_i = safe headway distance of the ith vehicle pair;
- $Diff_i$ = difference of two minimum stopping distances of the ith vehicle pair.

As noted, the individual SHD reflects a crash risk between the two consecutive vehicles. A larger SHD is translated into greater deficiency in safe distance suggesting a crash-prone case.

The calibration of the safe headway distance on the available American accident database however didn't prove to give viable results. This was mostly due to differences between the American and the European traffic situation (difference in driving style, but also driving behaviour), and the fact that the database on which the formula was built came from the U.S. Also the attempt to use the SHD as a relative measure did not prove to deliver viable safety results. Fatality risks are varying largely for similar simulation runs therefore the relation between the traffic situation and the actual fatality risk could not be shown. This resulted in the Safe Headway Safety measure not to be used in this evaluation study; instead the time to collision parameter was used as described in the next chapter.

In the table below the calibration results of the Safe Headway Distance indicator are presented. The three sections of the table represent the variation in demand growing from 2500 to 5500. For every demand different reactions times from 0.2 to 0.6 seconds have been used. Following this the variation of accidents during a 60 minutes simulation has been calculated. The numbers shown under P(y=0), P(y=1 or 2) and P(y=3 or more) add up to 1 (100%). As can be seen the expected crashes are way too high for such a short period. Moreover the division of the accidents over the different categories is rather questionable (and contrary to what would be expected). In the low demand (2500) the number of 0 crashes is close to 0, whilst in the demand of 5500 these numbers are present, but there the number of expected crashes is off again.

The result of implementation would have resulted in a large number of predicted crashes, which are way of from reality. Therefore the results from the SHD wouldn't add to the goal: identify the effect on traffic safety using traffic simulation.

Table 1 Calibration of Safe Headway Distance indicator

demand	2500	**interval**	60 minutes	
reactiontime	**P(y=0)**	**P(y=1 or 2)**	**P(y=3 or more)**	**Expected crashes**
0,2	0,00	0,64	0,36	2,79
0,3	0,00	0,53	0,47	3,90
0,4	0,00	0,42	0,58	6,15
0,5	0,00	0,32	0,68	11,15
0,6	0,00	0,24	0,76	23,30

demand	4000	**interval**	60 minutes	
reactiontime	**P(y=0)**	**P(y=1 or 2)**	**P(y=3 or more)**	**Expected crashes**
0,2	0,00	0,82	0,18	1,75
0,3	0,00	0,77	0,23	1,95
0,4	0,00	0,72	0,28	2,26
0,5	0,00	0,64	0,36	2,75
0,6	0,00	0,56	0,44	3,53

demand	5500	**interval**	60 minutes	
reactiontime	**P(y=0)**	**P(y=1 or 2)**	**P(y=3 or more)**	**Expected crashes**
0,2	0,21	0,76	0,04	0,99
0,3	0,15	0,81	0,04	1,07
0,4	0,11	0,85	0,04	1,14
0,5	0,07	0,88	0,05	1,20
0,6	0,04	0,91	0,06	1,25

3. Research setup

This chapter describes the applications and the scenarios for which the applications are tested in section 3.2. The indicators, the effects on safety traffic efficiency and emissions, are explained in section 3.1. Finally the research questions are described in section 3.3.

3.1. Safety, traffic efficiency and emission indicators

3.1.1. Safety indicator

The safety effects are expressed by using the 'Time To Collision' parameter (TTC) as a surrogate safety measure to assess the effects of the Safety Margin Assistant principle applied in the applications described below. Using the TTC as an indicator allows for an independent assessment of the actual applications in the simulation environment. If the distances and times of the SMA were to be used a 'perfect' score of the assessed applications would be the result, but this would mean absolute nonsense in terms of simulation results. This TTC is the time within which two succeeding vehicles will crash if they both maintain their motion characteristics. E.g., a TTC <= 1 s means that the driver of the following vehicle has less than one second to brake in order to prevent a crash. This safety indicator allows only qualitative conclusions on traffic safety. To be able to determine quantitative results, it was attempted to implement the direct safety measure called the Safe Headway Distance [10]. However, this measure is only validated for U.S. highways, and the safety effects turned out to be unreliable for European situation (see section 2.2.3). It was therefore not possible to use this safety measure in this study.

The table below gives an indication of the values of the time to collision in relation to the speed of the ego vehicle and the speed of the predecessor. This results in distances between the two vehicles and the table is intended to give an idea about the TTC parameter.

Table 2: Examples of TTC versus speed difference and the actual distance as a result

your speed:	**100**	**70**	**100**
predecessor speed:	**80**	**30**	**0**
TTC	distance (m)	distance (m)	distance (m)
1	6	11	28
2	11	22	56
3	17	33	83
4	22	44	111
5	28	56	139

3.1.2. Traffic efficiency indicator

The throughput effects are expressed in total travel times (TTT). This is the sum of the travel times of al vehicles in the simulation. If a vehicle spends more time on the same trip in one scenario, then the traffic efficiency for him is less. The total time for all vehicles spend on the network reflects directly the traffic efficiency.

3.1.3. Emission indicators

The emission effects are expressed by indirect indicators, and are therefore only qualitative.

Four traffic parameters which are needed to accurately determine the emission are the vehicle type, travelled distance, average speed and a measure for the drive cycle dynamics.
Since the vehicle type and the travelled distance are not directly affected by the SAFESPOT system, we use the drive cycle dynamics and the average speed as indicators for the effect on emissions.

As an example, the calculated emission of CO2 and the traffic parameters average speed and TAD are calculated for some time-speed cycles are plotted in figure 2 (TNO report: MON-RPT-033-DTS-2007-02502, Statistical Driving Pattern Analysis by R. Smit). This example shows that, with an unchanged drive cycle dynamics (TAD), an increase in average speed results in an increase in CO2 emissions. The same can be said about the effect of the drive cycle dynamics on CO2 emissions. With an unchanged average speed, an increase in the driving cycle dynamics (TAD) results in an increase of CO2 emission. The assumption is that decreases in the speed variation result in less emissions, and that decreases in average speed result in less emissions.

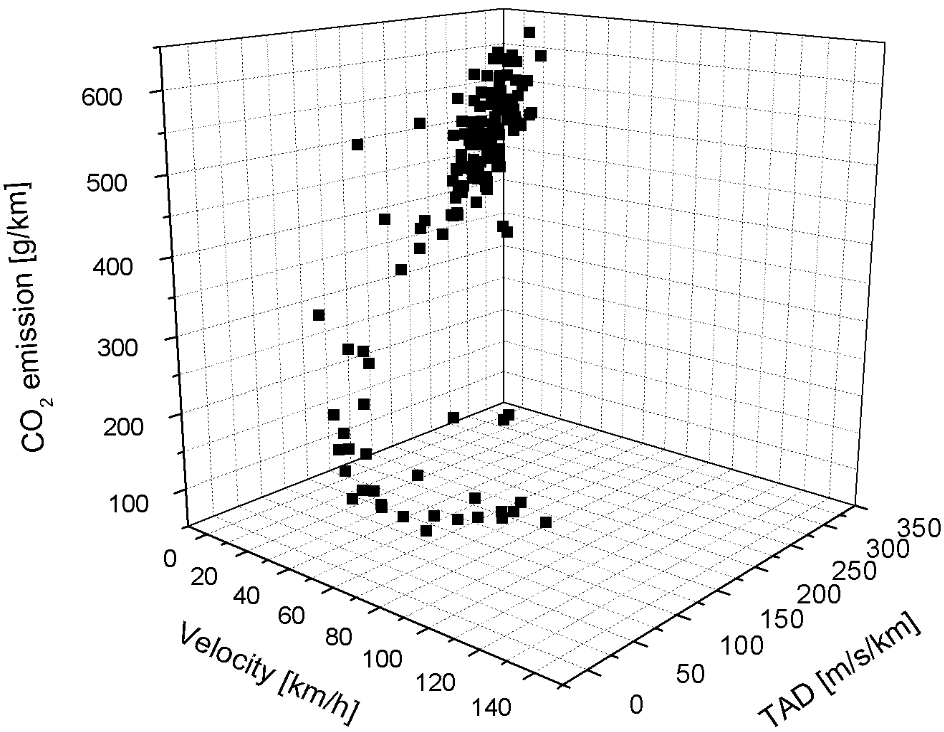


Figure 2: The relation between the CO2 emission and the average speed and TAD for a petrol driven euro 4 car.

3.2. Selected applications and scenarios

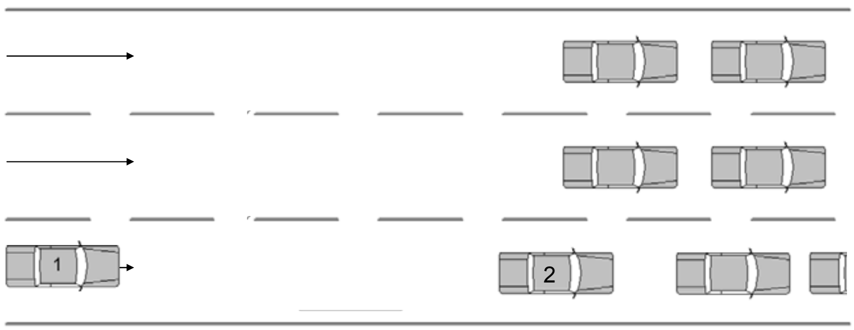
Three applications are evaluated. These applications are the Congestion Warning Application as extension of the General Use Case of the Speed Limitation and Safety Distance Application, the Road Condition Status application, and the Frontal Collision Warning application. The detailed description of these applications is given in SAFESPOT deliverables D4.2.3 -– "*Use case and typical accident situation*" [4] and D4.3.1 – "Safety Margin Application Parameters Analysis and Characterization" [6]. These applications are selected because they comply with the modelling possibilities in the ITS modeller simulation environment. Some limitations of the ITS modeller are the disability to model overtaking and detailed safety statistics at intersections. Therefore, intersection applications and overtaking applications are not evaluated.

The scenarios that are simulated are described for each application.

Congestion Warning V2V:

The congestion warning is an extension of the Speed Limitation and Safety Distance General Use Case – 6GC (D4.3.1 – "*Safety Margin Application Parameters Analysis and Characterization*", [6], p.78).

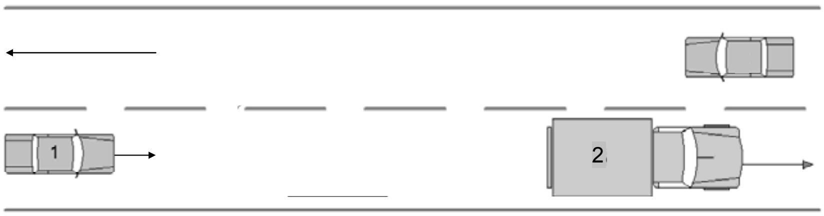
Table 3: Safety Margin Assistant for Speed Limitation and Safety Distance – Motorway Congestion Use Case

Case Name	Safety Margin Assistant for Speed Limitation and Safety Distance – Motorway Congestion
Short description	Driver of vehicle V1 gets speed recommendations before it enters congestion. The warning is based on the speed and location that is communicated by the vehicles in congestion. 
Purpose	To help driver of vehicle V1 being timely informed of reducing its speed in order to keep the safety distance from the vehicles preceding.
Vehicle type	Vehicle, ptw, truck
Risk's source	The reduction of speed in congestion on motorways creates a speed difference with the upcoming vehicles.
Trigger	When vehicle 2 has to reduce its speed to below 50% of the legal speed limit, it sends (broadcasts) a warning
Successful end condition	The speed difference between vehicle V1 and V2 is reduced by timely deceleration of V1.

Road Condition warning V2V:

The Road Condition warning (fog warning) is based on the scenario SP4_UC_RoadConditionStatusV2V – 8b (D4.2.3 – "*Use case and typical accident situation*", [4], p.65).

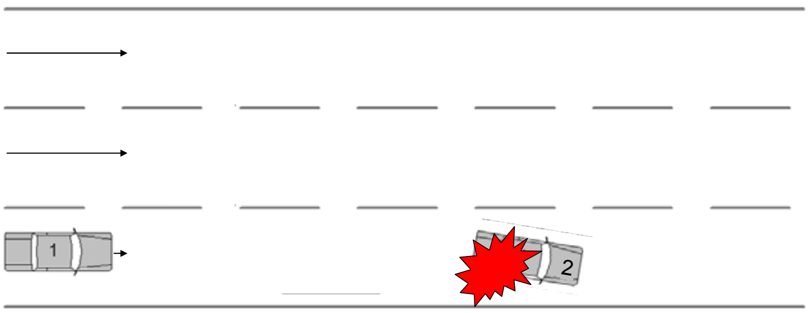
Table 4: Road Condition Status V2V Based – Fog warning Use Case

Case Name	Road Condition Status V2V Based – Fog warning
Short description	Vehicle V1 is approaching the slow vehicle V2. The speed difference might be difficult to see due to bad visibility. The driver in V1 is informed early about the slow speed of the vehicle V2 in front. V2 broadcasts its position and speed as a warning message. Therefore V1 can reduce its speed timely. 
Purpose	The purpose is to warn vehicle V1 timely to reduce its speed when approaching the slow vehicle in front
Vehicle type	Truck, motorcycle, vehicle
Risk's source	Roads with bad visibility and possibly low friction may result in accidents (the road is slippery) if the speed and driving style is not adopted correctly.
Trigger	Low visibility is detected by vehicle V2 and communicated to V1
Successful end condition	Information on road condition is presented to the driver of V1.

Frontal Collision Warning V2V:

The Frontal Collision Warning is based on the scenario SP4_UC_FrontalCollisionWarning - 7a: (D4.2.3 – "*Use case and typical accident situation*", [4], p.57).

Table 5: Frontal collision warning due to static obstacle in front Use Case

Case Name	Frontal collision warning due to static obstacle in front
Short description	This scenario aims to inform and/or warn truck drivers about the presence of a stationary obstacle in front. The crashed vehicle V2 warns the approaching vehicle V1 that he is approaching an incident. 
Purpose	Inform and warn the driver about a vehicle breakdown…
Vehicle type	Truck, motorcycle, vehicle
Risk's source	The unexpected appearance of a crashed vehicle can cause other vehicles to have accidents too.
Trigger	Crash
Successful end condition	Approaching vehicle slows down timely and passes the crashed vehicle slowly

3.3. Research questions and hypotheses

To test the HURR (SAFESPOT High level objectives, User needs, Requirements and Risks), the following research questions have been defined for the applications. These have been translated in hypotheses.

Research questions are defined about the effect of different penetration rates of equipped vehicles (for all applications), about different traffic intensities (for the congestion warning), and about different visibilities (for the fog warning).

3.3.1. Congestion Warning V2V

The following research questions have been defined for the Congestion Warning V2V application.

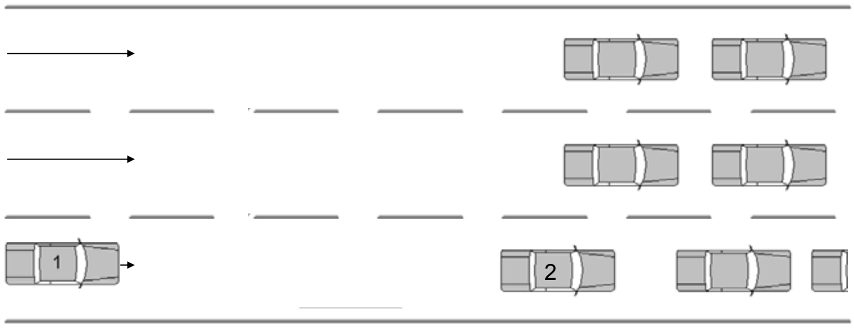


Figure 4: Congestion warning scenario

<u>Research questions</u>

- o What is the effect of the Congestion Warning system on safety and traffic efficiency, for different penetrations of equipped vehicles?
- o What is the effect of the Congestion Warning system on safety and traffic efficiency, for different traffic intensities?

These research questions have been translated into the following <u>hypotheses</u>.

- o The percentage of (vehicles having a) TTC < 5sec (near accident situations) reduces when the penetration of equipped vehicles increases (indicator for safety).
- o The average speed reduces when the penetration of equipped vehicles increases (indicator for traffic efficiency).
- o The total travel time reduces when the penetration of equipped vehicles increases (indicator for traffic efficiency).
- o The speed variance reduces when the penetration of equipped vehicles increases (indicator for traffic efficiency).
- o The percentage of TTC < 5sec (near accident situations) increases when the traffic intensity increases (indicator for safety).
- o The average speed reduces when the traffic intensity increases. (indicator for traffic efficiency).
- o The total travel time increases when the traffic intensity increases (indicator for traffic efficiency).
- o The speed variance reduces when the traffic intensity increases (indicator for traffic efficiency).

3.3.2. Fog Warning

The following research questions have been defined for the Fog Warning V2V application.

Figure 5: Fog warning scenario

Research questions

- What is the effect of the Fog Warning system on safety and traffic efficiency, for different penetrations of equipped vehicles?
- What is the safety effect of the Fog Warning system on safety and traffic efficiency, for different visibilities?

These research questions have been translated into the following hypotheses.

- The percentage of TTC < 5sec (near accident situations) reduces when the penetration of equipped vehicles increases (indicator for safety).
- The average speed reduces when the penetration of equipped vehicles increases. (indicator for traffic efficiency).
- The total travel time reduces when the penetration of equipped vehicles increases (indicator for traffic efficiency).
- The speed variance reduces when the penetration of equipped vehicles increases (indicator for traffic efficiency).
- The percentage of TTC < 5sec (near accident situations) reduces when the visibility increases (indicator for safety).
- The average speed reduces when the visibility decreases (indicator for traffic efficiency).
- The total travel time reduces when the visibility range increases (indicator for traffic efficiency).
- The speed variance reduces when the visibility increases (indicator for traffic efficiency).

3.3.3. Frontal Collision Warning

The following research questions have been defined for the Frontal Collision Warning V2V application.

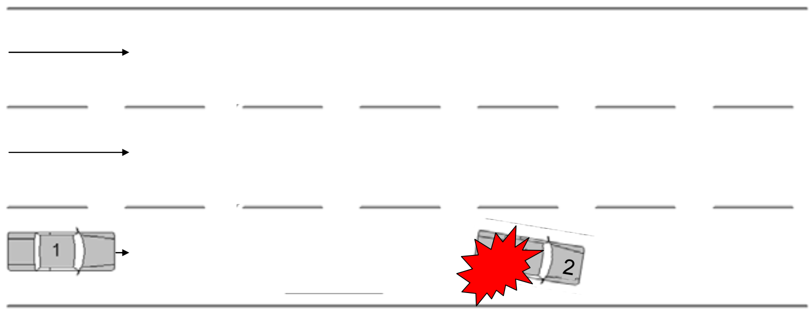


Figure 6: Frontal Collision Warning scenario

<u>Research question</u>

- What is the effect of the Frontal Collision Warning system on safety and traffic efficiency, for different penetrations of equipped vehicles?

This research question has been translated into the following <u>hypotheses</u>.

- The percentage of TTC < 5sec (near accident situations) reduces when the penetration of equipped vehicles increases (indicator for safety).
- The average speed reduces when the penetration of equipped vehicles increases (indicator for traffic efficiency).
- The total travel time reduces when the penetration of equipped vehicles increases (indicator for traffic efficiency).
- The speed variance reduces when the penetration of equipped vehicles increases (indicator for traffic efficiency).

4. Simulation of the applications and scenarios

The implementation of the applications and of the scenarios is described in section 4.1. This is followed by a summary of the assumptions in section 4.2.

4.1. Implementation applications

For each application the implementation is described in terms of the demand, the traffic network, the traffic situation, the communication specifications and the variations in penetration of equipped vehicles, demand and communication range.

4.1.1. Congestion Warning V2V

<u>Experiment setup</u>

Demand: 3500 and 4500 vehicles/hour.

Traffic network: Three lane motorway.

Traffic situation: Driving into the back of congestion (congestion is modelled by a lane drop from 3 lanes to 1 and a speed reduction to 20 km/h for all lanes).

SAFESPOT system: Congestion speed warning based both on I2V (VANET communication) for a fixed location (loop detector) and on single hop V2V communication.

Communication specifications: Single hop communication is modelled. The probability of packet reception is a function of the sending distance and the vehicle intensity between sender and receiver (probability of packet reception is based on:

1. Max sending range modelled: 450 meter,
2. Protocol: CALM - 802.11p,
3. Payload per packet: 200 bytes).

The broadcasting frequency of the applications is every 0.1 second. See also section 2.2.2.

Scenarios: 10 scenarios are compared. These scenarios are a combination of varying penetration of equipped vehicles (0%, 15%, 50%, 85%, and 100%) and demand (3500 and 4500). For each scenario three runs of 30 minutes (10 minutes congestion, then 10 minutes free flow, then 10 congestion again) with different random seeds are done for statistical reliability.

4.1.2. Fog Warning

<u>Experiment setup</u>

Demand: 700 vehicles/hour of which 5% slow driving equipped trucks.

Traffic network: One lane rural road.

Traffic situation: Foggy situation with less viewing distance, when over time slow driving trucks appear on the road driving at less than half the maximum allowed speed.

SAFESPOT system: Warning message based on V2V from the equipped vehicles (VANET communication) as well as from the slow moving vehicle.

Communication specifications: Single hop communication is modelled. The probability of packet reception is a function of the sending distance and the vehicle intensity between sender and receiver (probability of packet reception is based on:

1. Max sending range modelled: 450 meter,
2. Protocol: CALM - 802.11p,
3. Payload per packet: 200 bytes).

The broadcasting frequency of the applications is every 0.1 second. See also section 2.2.2.

Scenarios: 3 scenarios with varying viewing distances (50m, 100m, 400m) compared with 5 scenarios within those with varying penetration (0%, 15%, 50%, 85%, and 100%). For each scenario three runs of 60 minutes with different random seeds are done for statistical reliability.

4.1.3. Frontal Collision Warning

<u>Experiment setup</u>

Demand: 2000 vehicles/hour.

Traffic network: Three lane motorway.

Traffic situation: Stranded vehicle standing on the right lane.

SAFESPOT system: Warning message based on V2V from the stranded vehicle (VANET communication) containing speed and location of the stranded vehicle.

Communication specifications: Single hop communication is modelled. The probability of packet reception is a function of the sending distance and the vehicle intensity between sender and receiver (probability of packet reception is based on

1. Max sending range modelled: 450 meter,
2. Protocol: CALM - 802.11p,
3. Payload per packet: 200 bytes).

The broadcasting frequency of the applications is every 0.1 second. See also section 2.2.2.

Scenarios: 5 scenarios with varying penetration (0%, 15%, 50%, 85%, and 100%) are compared. For each scenario three runs of 30 minutes with different random seeds are done for statistical reliability.

4.2. Assumptions

For the simulations a number of assumptions were made on the driver behaviour:

1) Compliance rate is assumed to be 100%. Everyone equipped with a system reacts to the warning.
2) Reactions to warning are instantly. Once given a warning the drivers immediately reacts by adjusting its acceleration to the advised one

5. Results

This chapter describes the safety effects, the traffic efficiency effects and the emission effects of each application.

The indicators used to express the safety, traffic efficiency and emission effects are respectively the Time To Collision (TTC), the Total Travel Times (TTT), and the standard deviation of the speed. The selection of these indicators is explained in section 3.1.

5.1.1. Congestion Warning V2V

Safety

The Congestion Warning system has been simulated with two different intensities: 3500 and 4500 vehicles per hour. In the latter case the traffic jam that appeared at the lane drop grows significantly faster than with 3500 vehicles per hour.

The results of the two situations are shown in Figure 7 and Figure 8.

In the case of 4500 vehicles an overall decrease of the share of small TTC can be observed when more vehicles are equipped, and thus an increase of the safety benefits of the system. Only for the smallest TTCs (the first two bins from the left) there is a small bump visible for the 15% penetration rate. This effect may be explained by the fact that inhomogeneous traffic flow is created with only a small part of the vehicles equipped with the system.

In the situation with 3500 vehicles per hour this small peak is again seen for the 15 % penetration rate in some of the TTC bins. Overall the Congestion Warning does lead to safer situations, especially with the higher penetration rates.

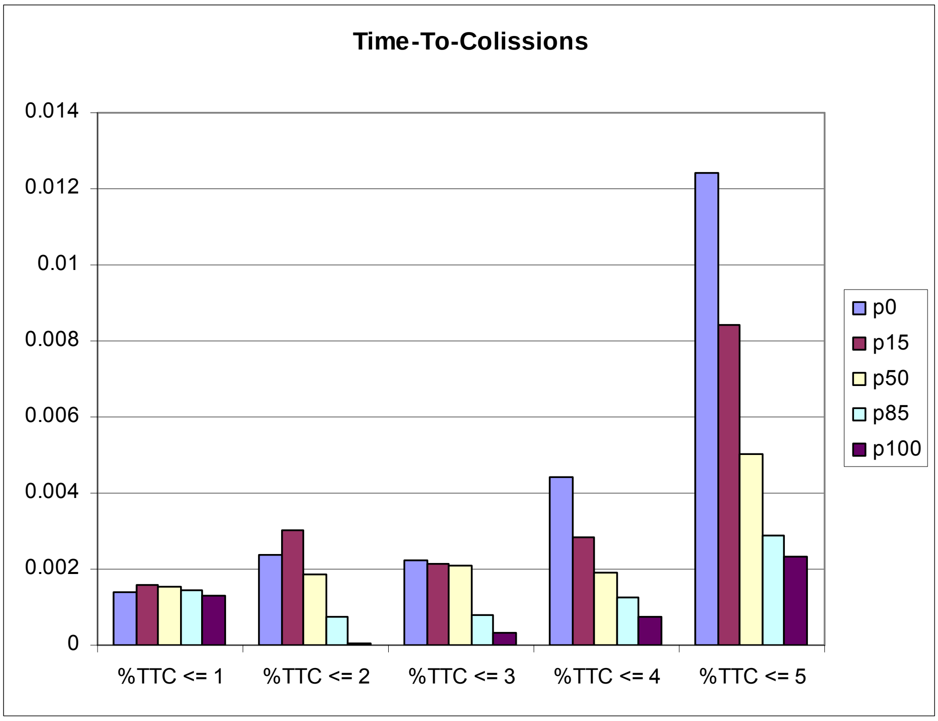


Figure 7: Time to collisions for congestion warning V2V scenario with 4500 veh/h

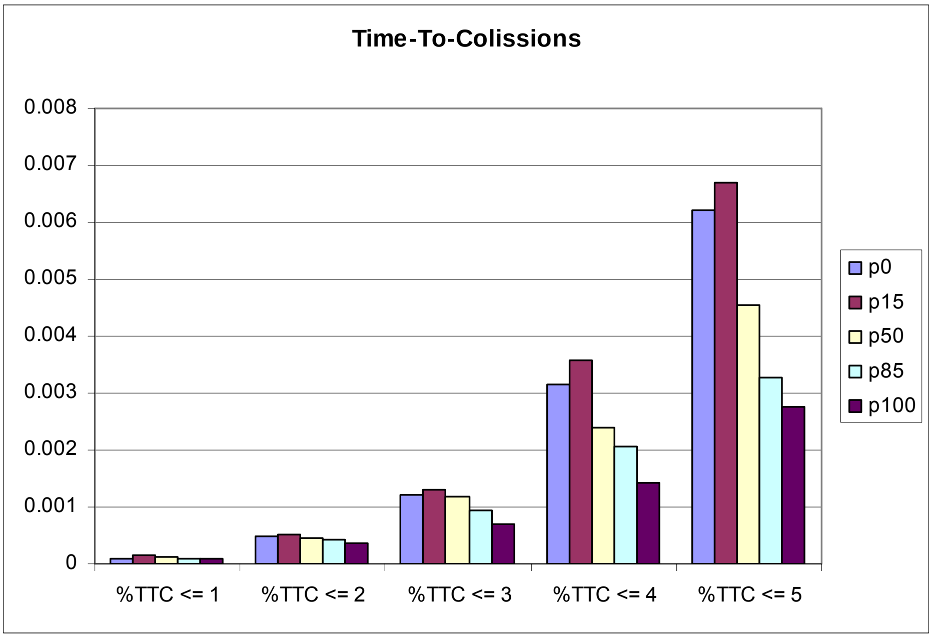


Figure 8: Time to collisions for congestion warning V2V scenario with 3500 veh/h

Traffic efficiency

Figure 9 and Figure 10 show the total travel time for the whole network, and the average speed in the scenarios of 3500 and 4500 vehicles per hour. In both scenarios we see an increase in the total travel time with increasing penetration rates of the Congestion Warning system. This impact can be easily explained. The effect of the SF warning is that followers slow down earlier and keep larger separation distances, thereby decreasing flow and average speed. This effect is bigger when many vehicles drive close behind each other. This can be seen in the figures below.

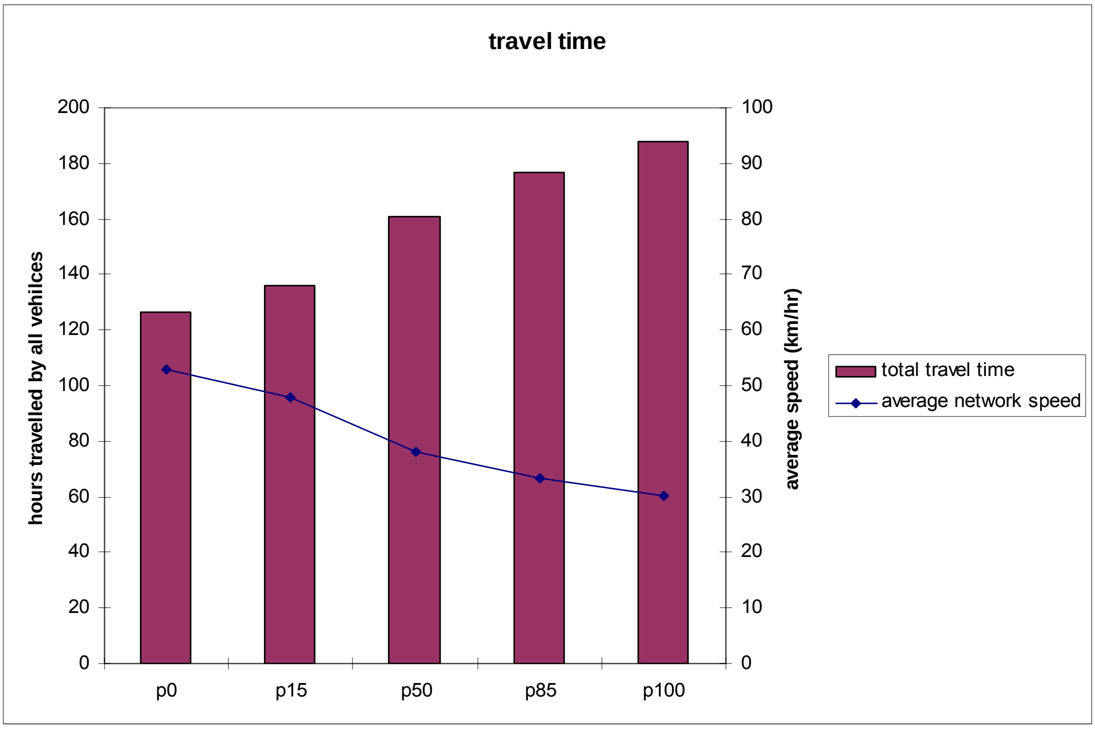


Figure 9: Total travel time for Congestion Warning V2V with 4500 vehicles/hour

The loss of traffic efficiency depends on the traffic conditions. The increase of the total travel time in the congested situation with high demand (52 km/hr, 4500 veh/h) was about 49% comparing the situations with all unequipped vehicles and with all equipped vehicles.

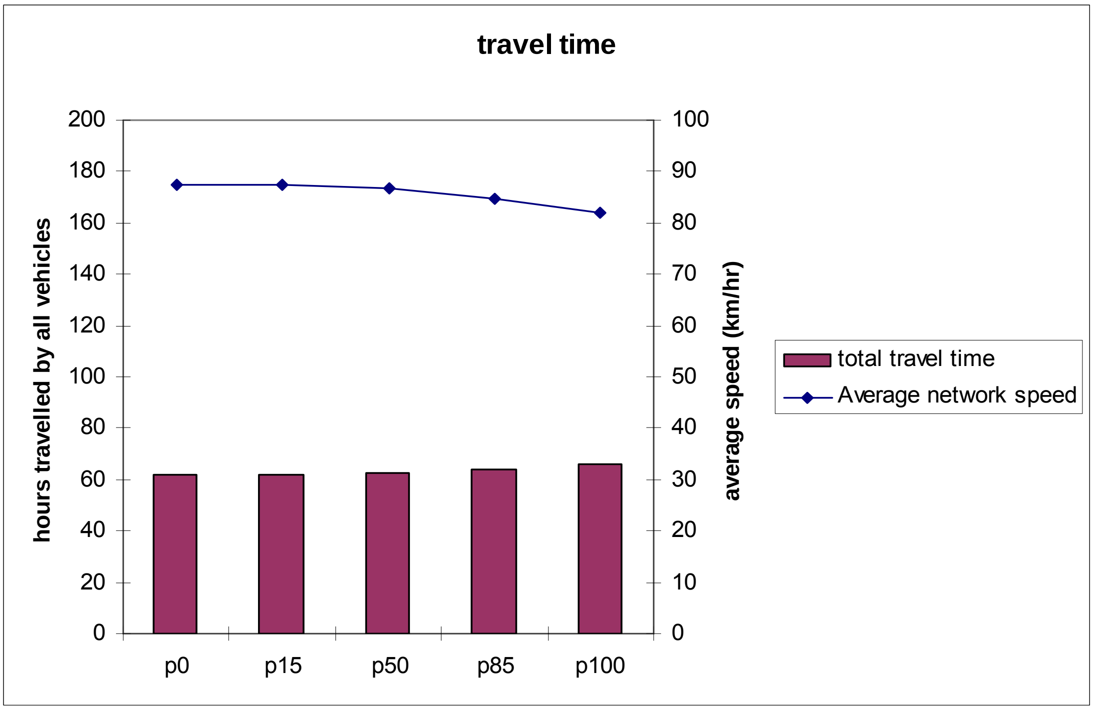


Figure 10: Total travel time for Congestion Warning V2V with 3500 vehicles/hour

The increase of the total travel time in the 'normal' traffic situation with medium demand (87 km/hr, 3500 veh/hr) was about 6% comparing all unequipped vehicles with all equipped vehicles.

These effects on traffic efficiency in a congested situation are the result of 100% compliance to a safety warning system that is optimised for safety only. Optimisation for traffic efficiency is advised to reduce the traffic efficiency loss and improve acceptability of the system.

Beside the direct effect in the congested traffic situation there are two other effects on traffic efficiency that have not been taken into account. One direct effect that has not been assessed is the prevention of shock waves. The system is likely to prevent shockwaves due to the realisation of larger following distances and shorter reaction times. The second effect is the 2nd order effect of the preventing congestion due to incidents. These effects are not further elaborated in this analysis, but just mentioned here to get a better understanding about the complexity of the traffic simulation and the aspects to be taken into account when assessing impacts of ITS applications.

Emissions

Figure 11 and Figure 12 below show the average deceleration and acceleration for the various penetration rates.

In the busy traffic situation (4500 veh/hr), the system decreases the average acceleration (Figure 11). The decrease indicates a smoother traffic flow and consequently fewer emissions. The average speed is reduced from 50km/hr to 30km/hr with all vehicles equipped (Figure 9). This indicates a decrease in emissions as well. Both the reduced driving cycle dynamics and the reduced average speed indicate a reduction in emissions.

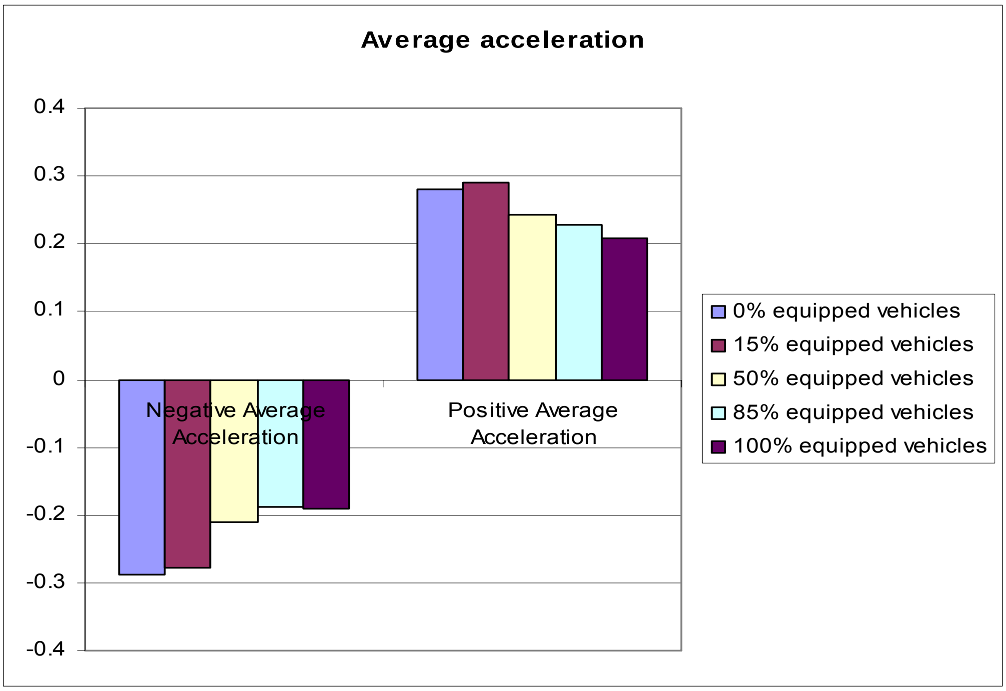


Figure 11: Congestion Warning (4500 vehicles/hour) – average acceleration

In normal traffic situation (3500 veh/hr), the systems increases the average acceleration (Figure 12). This increase indicates a more dynamic traffic flow and consequently higher emissions. The average speed is hardly changed by the system (Figure 10). Since there is no effect of the average speed on emissions, only the increased driving cycle dynamics determines the effect of the system. The the increased driving cycle dynamics indicates an increase in emissions.

The effect of the system on the dynamics in the traffic flow depends on the intensity of traffic on the road. In case of busy traffic (4500 veh/hr) the traffic flow becomes more homogeneous, while in case of normal traffic (3500 veh/hr), the traffic flow becomes slightly less homogeneous.

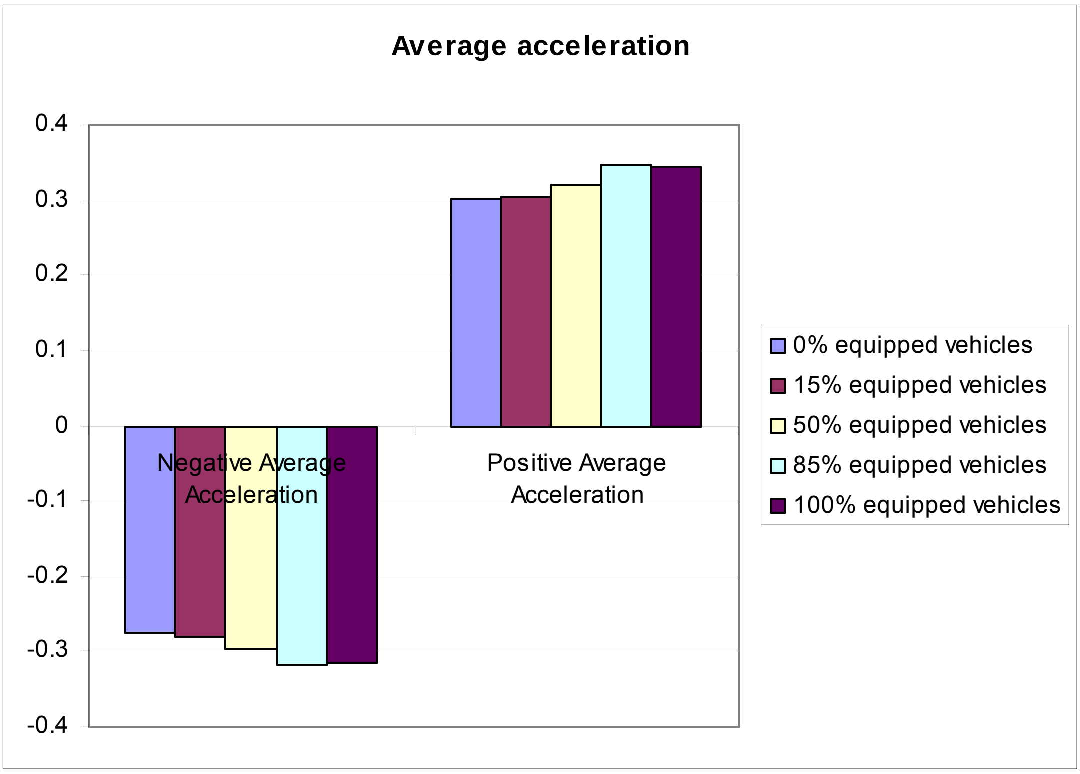


Figure 12: Congestion Warning (3500 vehicles/hour) – average acceleration

5.1.2. Fog Warning

Safety

The Fog Warning system has been simulated with two different visibilities: 50m and 300m. The results of the two situations are shown in Figure 13 and Figure 14.

In the case of 300m visibility, there are very few dangerous situations, even without the Fog Warning system. Therefore, the results of this simulation will not be further regarded.

In the case of 50m visibility we see an overall decrease of the share of small TTC when more vehicles are equipped, and thus an increase of the safety benefits of the system.

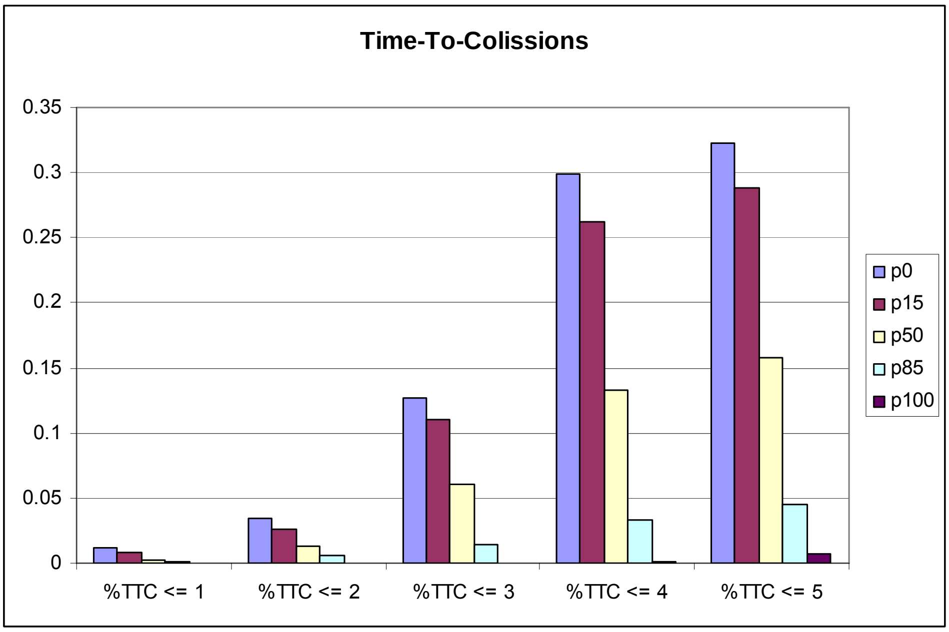


Figure 13: Time to collisions for Fog Warning scenario with visibility of 50m

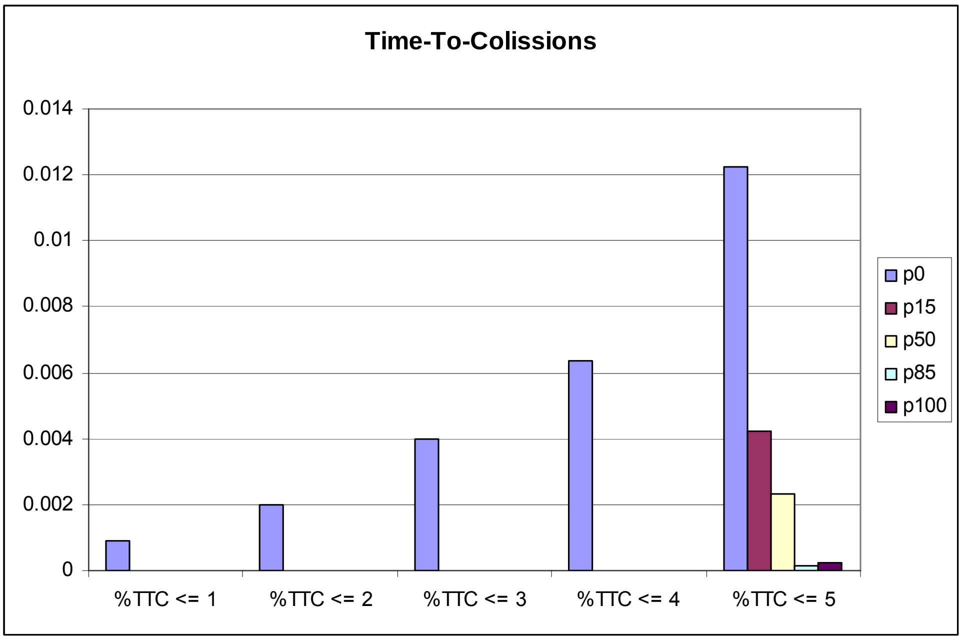


Figure 14: Time to collisions for Fog Warning scenario with visibility of 300m

Traffic efficiency

Figure 15 shows the total travel time for the whole network in the situation of 50m visibility. The total travel time increases with increasing penetration rate of the Congestion Warning system. This impact can be easily explained. With the warnings given, drivers are able to slow down earlier than without the system. Therefore it takes them more time to drive the same distance because of their lower overall average speed. The loss of travel time when 100% of the vehicles is equipped is about 10%.

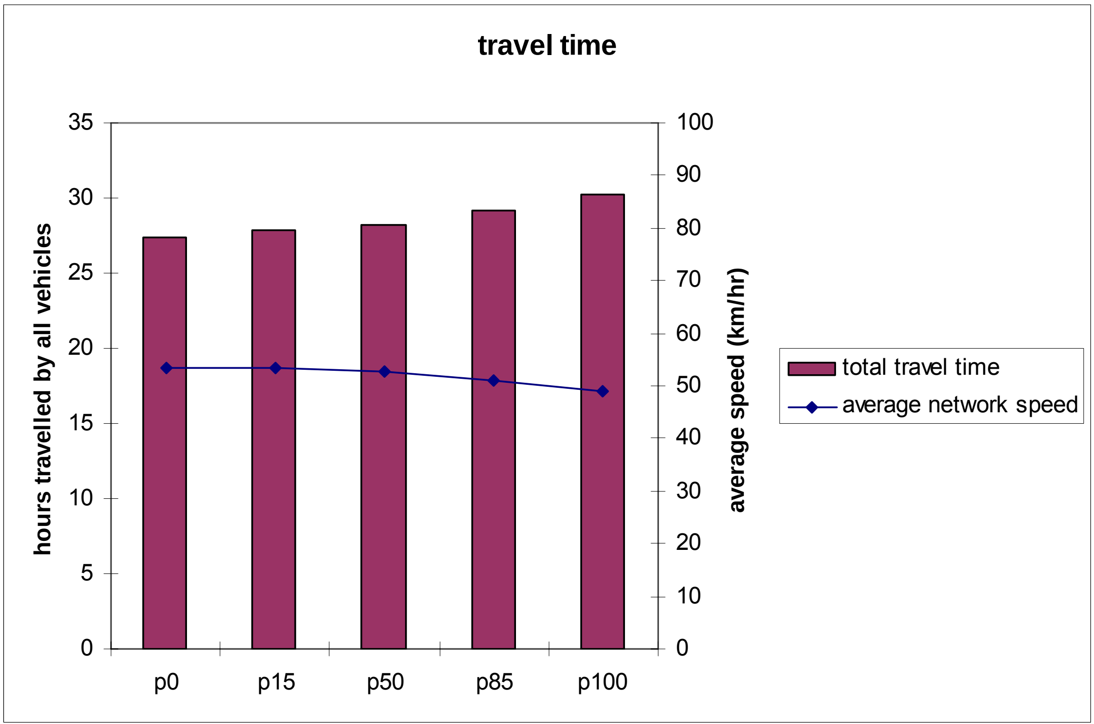


Figure 15: Total Travel time for Fog Warning scenario with 50m visibility

<u>Emissions</u>

Figure 16 shows the average deceleration and acceleration for the various penetration rates.

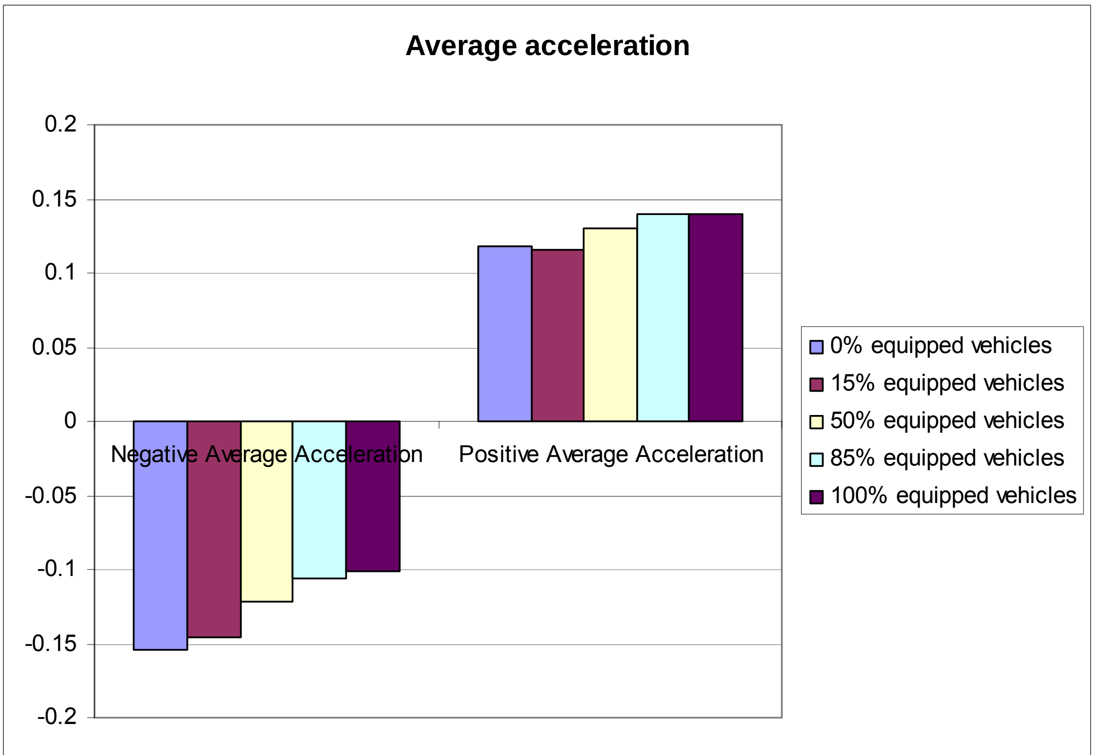


Figure 16: Fog warning – average acceleration

Although the breaking happens more smoothly with the system (Figure 16 and Figure 17), the system increases the average acceleration. The increase indicates more emissions. The average speed is practically unchanged by the system, so this has no effect on emissions (Figure 15). Since there is no effect of the average speed on emissions, only the increased acceleration determines the effect of the system.

The different driving patterns in Figure 17 for 'normal' non equipped vehicles and 'SAFESPOT' equipped vehicles however clearly show that equipped vehicles brake more smoothly. The reduction of the standard deviation of the speed was about 5% at a speed of 50km/h.

The speed profile is on the one have made more smoothly (more smooth deceleration), and on the other hand less smoothly (higher average acceleration). However, the acceleration influences the emissions. Therefore the overall effect on emissions is expected to be slightly negative.

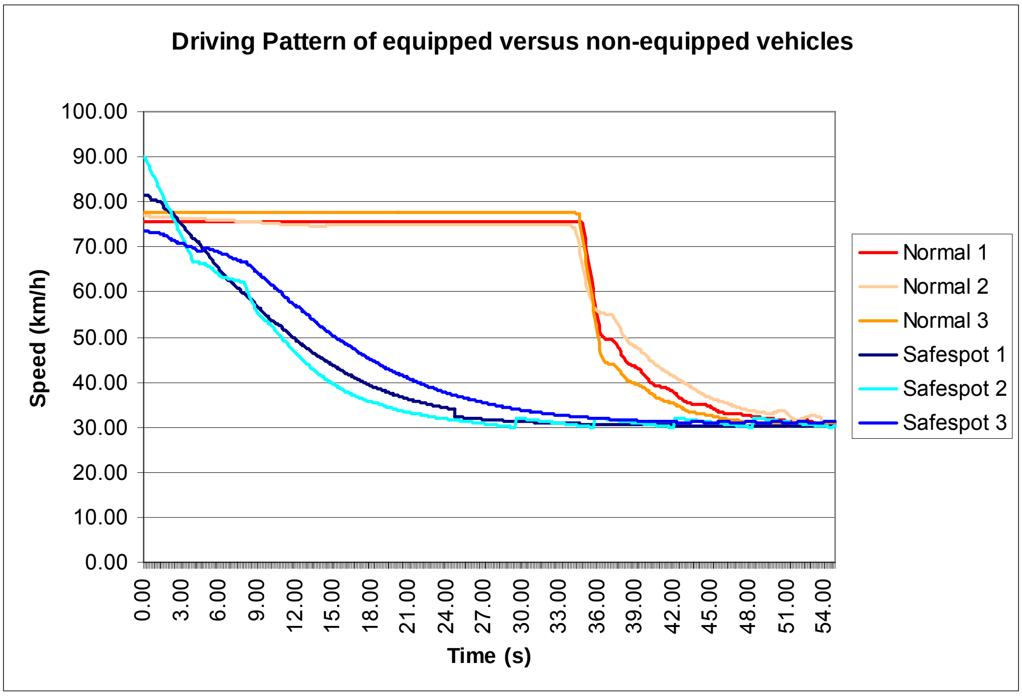


Figure 17: Driving Pattern for Fog Warning scenario with 50m visibility

5.1.3. Frontal Collision warning

Safety

As can been seen from Figure 18, the Frontal Collision warning system improves the safety in every bin of small TTCs. The impact of the system is significant for 100% penetration rate: for example we see a decrease of more than 60% in the category TTC between 4 and 5 compared to the scenario with 0 penetration rate.

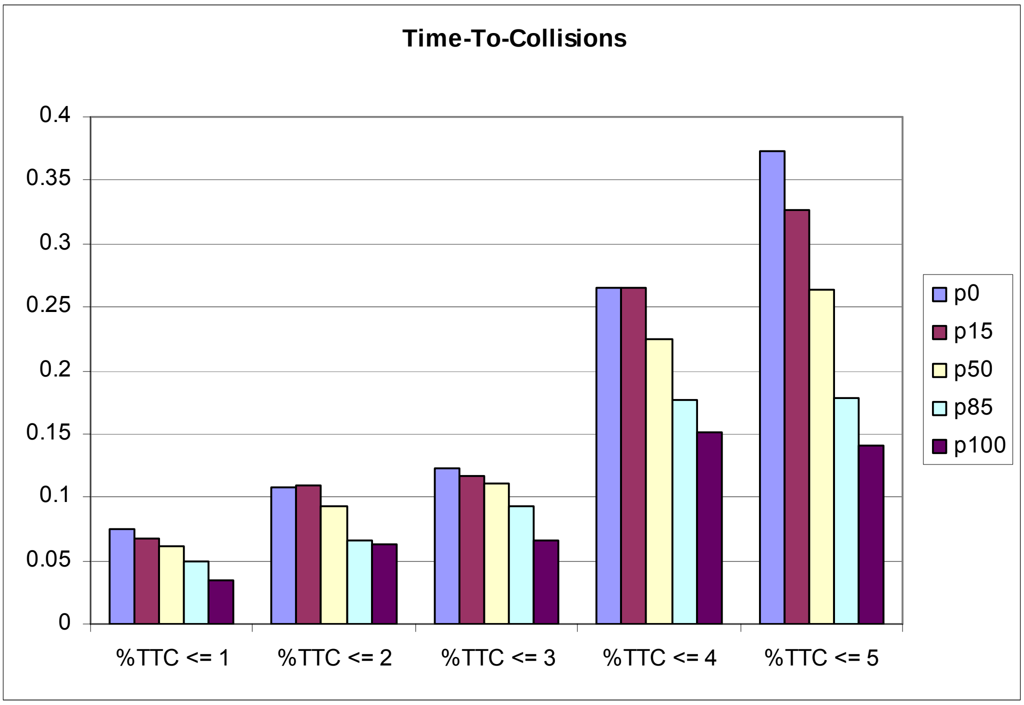


Figure 18: Time to collisions for Frontal Collision Warning

Traffic efficiency

The traffic efficiency is reduced by the Frontal Collision Warning system. This can be seen in the Figure 19 where the total travel times for the whole network are displayed. The total travel times increase with increasing penetration rates. For 100% penetration rate the total travel time is 25% higher than the reference case (0% penetration).

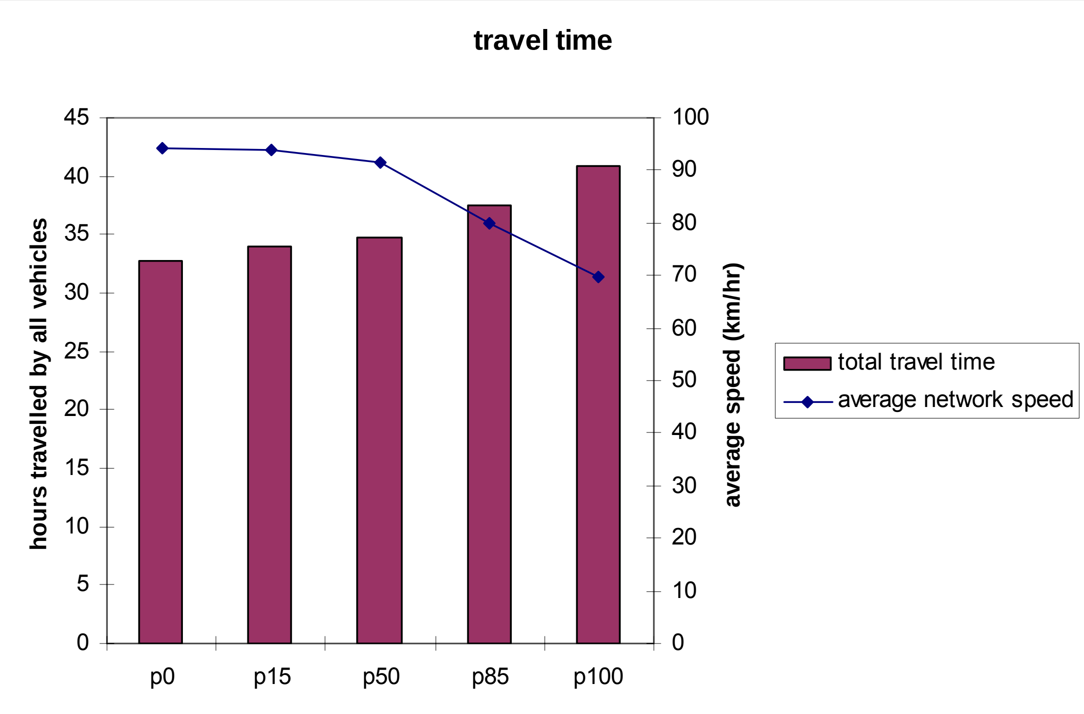


Figure 19: Total Travel Time for Frontal Collision Warning

<u>Emissions</u>

Figure 20 shows the average deceleration and acceleration for the various penetration rates. This figure clearly shows that a mixture of equipped and unequipped vehicles can results in a less homogeneous traffic flow. Both positive and negative accelerations increase with a mixture of equipped and unequipped vehicles and decrease again when 100% penetration is reached. This effect plays a role with the other systems as well, but since it depends on the traffic conditions it show less clearly or not at all.

For the effect of the system on emissions, the acceleration is most relevant. This increase of the average acceleration followed by the decrease to below the initial level indicates that the introduction of the system might results in more emission at first and less emission later when most vehicles are equipped. The average speed is also reducing with higher penetrations of equipped vehicles (Figure 19). This suggests a reduction of emissions with higher penetration as well.

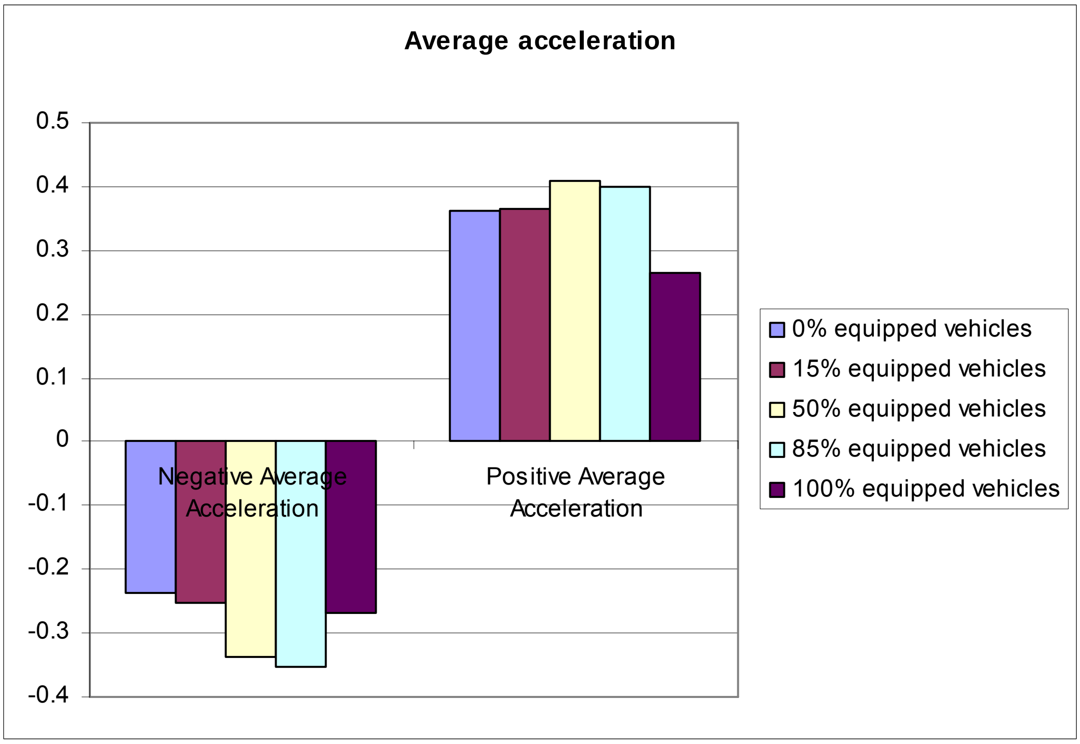


Figure 20: Standard Deviation Speed for Frontal Collision Warning

6. Conclusions

This chapter describes conclusions on the three applications which are evaluated. These applications are the Congestion Warning Application, the Road Condition Status application, and the Frontal Collision Warning application as described in SAFESPOT deliverable D4.2.3 – "*Use case and typical accident situation*" [4] and D4.3.1 – "Safety Margin Application Parameters Analysis and Characterization" [6]. These applications have effect on longitudinal safety on motorways and secondary roads.

6.1. General conclusions

Overall it can be concluded that the evaluated safety warning system have a positive effect on traffic safety, that can realise societal benefits. General conclusions are presented in relation to each of the three high level objectives (HLO).

6.1.1. Feasibility in improving road safety (HLO1)

HLO 1: Show the feasibility and benefits of Co-operative Systems solutions in improving road safety well beyond the level which can be achieved with autonomous solutions.

Modelling communication according to the IEEE 802.11p standard shows that in the tested penetration levels of equipped vehicles (15%, 50%, 85%, 100%) the single-hop communication worked well to reach all equipped vehicles instantly all the time. With a communication frequency of 10Hz, the warnings were successfully transmitted.

In general all three evaluated warning systems (congestion warning, fog warning, forward collision warning) improve road safety. The number of unsafe situations is significantly reduced.

There are two mechanisms that determine the safety improvement. The first, and most important mechanism is the slow and timely braking, due the safety warning. This reduces the number of dangerous situations directly, and thus improves traffic safety. The safety benefits increase linearly with the penetration of equipped vehicles.

The second mechanism is the homogeneity of the traffic flow. This is an important factor for road safety. An inhomogeneous traffic flow means more braking and accelerating, and therefore more unsafe situations. The homogeneity of the traffic flow is not linear with the penetration of equipped vehicles. Introducing a few equipped vehicles (15% equipped scenario), with different driving behaviour such as slow and timely braking, will cause a less homogeneous traffic flow, and unexpected and potentially dangerous situations.

From 15% penetration of equipped vehicles and more, the safety benefits (mechanism 1) are always higher than the safety loss (mechanism 2). For penetrations below 15% the number of unsafe situations increases slightly for specific situations. This depends on the traffic intensity, and the scenario. The total number of unsafe situations is still always reduced.

6.1.2. Calculated potential for safety impact (HLO 2)

HLO2: To demonstrate benefits for accident types with a calculated potential for safety impact in terms of saving lives.

An attempt was made to implement a statistical correlation model for the number of unsafe situations and the incident probability, in order to determine the safety impact in terms of saving lives. However, the model was calibrated for a U.S. highway situation, and was unsuitable for a European situation. Data for calibration of the European situation are currently not available.

6.1.3. Effect on transport efficiency (HLO3)

HLO3: To show that the safety impact can be achieved without affecting transport efficiency

Beside the effects on traffic efficiency, the effects on emissions are discussed as well.

a. Traffic efficiency

As expected, the slow and timely braking due to safety warnings reduce traffic efficiency. Vehicles take more 'space' on the road. Especially in congested situations, this means a trade off with traffic efficiency. The increase in travel time varies from 6% in free flow traffic to as much as 50% on a highly congested road.

It should be noted that these results are based on 100% compliance to a safety warning system that is optimised for safety only. Optimisation for traffic efficiency is advised to reduce the traffic efficiency loss and improve acceptability of the system.

Beside the evaluated effect of early braking there are two other, positive effects, on traffic efficiency that have not been taken into account. A direct effect that has not been assessed is the prevention of shock waves. The system is likely to prevent shockwaves due to the realisation of larger following distances and shorter reaction times. The third effect is the (2nd order) effect of the preventing congestion due to incidents.

b. Emissions

The outcomes with respect to the environment have not been modelled with an emission model, but are based on drive cycle dynamics (variation in speed) and average speed. Expectations coming from the driver behaviour expressed in measures like the variation in acceleration. The assumption is that decreases in the speed variation result in less emissions, and that decreases in average speed result in less emissions (see also section 3.1.3).

The results on emission modelling were different for the three applications. Generally the average speed is unchanged or reduced by the system. The impact on the acceleration is different for the applications and for different traffic conditions. In some situations the warnings cause vehicles to reduce their speed (both more and more slowly), and thus cause extra deceleration followed by more acceleration to get back to the intended speed. This improves safety, but in some cases increases emissions.

For qualitative conclusion on the effects on emissions it is advised to do some further extensive emission modelling.

6.2. System specific conclusions

6.2.1. Congestion Warning V2V

The Congestion Warning system has been simulated with two different intensities: 3500 and 4500 vehicles per hour. In the latter case the traffic jam that appeared at the lane drop grows significantly faster than with 3500 vehicles per hour.

Safety

Overall the Congestion Warning application does lead to safer situations. For a 15% penetration rate of equipped vehicles, a small decrease of safety is visible. This effect may be explained by the fact that inhomogeneous traffic flow is created with only a small part of the vehicles equipped with the system. With busy traffic (4500 veh/h) the safety loss due to disturbing the homogeneity of the traffic flow at 15% penetration rate is higher than with normal traffic (3500 veh/h).

Traffic efficiency

Total travel time increases with increasing penetration rates of the Congestion Warning system. With the warnings given, drivers are able to slow down earlier than without the system. Therefore it takes them more time to drive the same distance because of their lower overall average speed. The loss of traffic efficiency depends on the traffic conditions. The increase of the total travel time in congested situations varied from 50% with high demand (4500 veh/h) to 10% with medium demand (3500 veh/h), comparing all unequipped vehicles with all equipped vehicles.

Emissions

For the congestion warning two scenario with different intensities were simulated. The effect of the system on the dynamics in the traffic flow depends on the intensity of traffic on the road. In case of busy traffic (4500 veh/hr) the traffic flow becomes more homogeneous, while in case of normal traffic (3500 veh/hr), the traffic flow becomes slightly less homogeneous. In busy traffic the results indicate an increase in emissions and in normal traffic the results indicated a slight decrease in emissions.

6.2.2. Fog Warning

The Fog Warning system has been simulated with two different visibilities: 50m and 300m. In the case of 300m visibility, there are very few dangerous situations, even without the Fog Warning system.

<u>Safety</u>

In the case of 50m visibility the safety benefits increase (almost) linearly with the penetration of equipped vehicles.

<u>Traffic efficiency</u>

We see an increase in the total travel time with increasing penetration rates of the Congestion Warning system. This impact can be easily explained. With the warnings given, drivers are able to slow down earlier than without the system. Therefore it takes them more time to drive the same distance because of their lower overall average speed. The loss of travel time when 100% of the vehicles is equipped is about 10%.

<u>Emissions</u>

The speed profile is on the one have made more smoothly (more smooth deceleration), and on the other hand less smoothly (higher average acceleration). However, the acceleration influences the emissions. Therefore the overall effect on emissions is expected to be slightly negative.

6.2.3. Frontal Collision warning

<u>Safety</u>

For all dangerous situations (from 1 to 5 sec time-to-collision), the Frontal Collision Warning application improves safety. For a 15% penetration rate of equipped vehicles, the number of dangerous situations is about equal to 0% penetration. From penetrations of equipped vehicles higher than 15%, the number of dangerous situations reduces linearly with the penetration rate by more than 30% to 60% (from TTC <= 1 sec to TTC between 4 and 5 sec).

<u>Traffic efficiency</u>

The traffic efficiency is reduced by the Frontal Collision Warning system. For 100% penetration rate the total travel time is 25% higher than the reference case.

<u>Emissions</u>

The mix of equipped and unequipped vehicles cause inhomogeneous traffic. The acceleration increases first until 50% penetration of equipped vehicles, followed by a decrease below the initial level for 100% penetration. This indicates that the introduction of the system might results in more emission at first and less emission later when most vehicles are equipped. The average speed is also reducing with high penetrations of equipped vehicles (Figure 19). This indicates a reduction of emissions with high penetration of equipped vehicles as well.

6.3. Reflection and recommendations for further research

Some recommendations are made for further research based on the experiences that was gained during the simulation.

Penetration levels of equipped vehicles that were evaluated in this study are 0%, 15%, 50%, 85% and 100%. Especially relevant for deployment strategies are the effects of penetrations between 0% and 15%.

An important limitation of modelling traffic safety is the inability to quantify the statistical relation between dangerous situations and traffic accidents. A statistical model by [9] was implemented, but this model is calibrated for a U.S. highway, and turned out to be unsuitable for the European motorway situation. European incident data for calibrating the model based on video data is not yet available. A next step is to make these data available and develop a statistical model for the European situation.

A comparison of the simulation results on the V2V safety warning applications (WP 4.6) as described in this document, and the simulation results on the V2I safety warning applications (WP5.6) indicates that with a penetration of 15%, V2I applications perform better than V2V applications. This is an interesting topic for further research.

This document focuses on the impact of cooperative safety systems. The benefit of communication in comparison to stand alone systems was not specifically evaluated and is also an interesting topic for further research.

References

SAFESPOT deliverables:

[1] Technical Annex

[2] D4.6.1 – Pilot Plan

[3] D4.2.2 – Safety Margin concept

[4] D4.2.3 – Use case and typical accident situation

[5] D4.2.4 – User needs and requirements

[6] D4.3.1 – Safety Margin Application Parameters Analysis and Characterization

[13] D3.3.4 - Vehicular Ad-hoc Networks Specifications

Papers:

[7] Killat, Moritz and Hartenstein, Hannes, “An Empirical Model for Probability of Packet Reception in Vehicular Ad Hoc Networks”, *in EURASIP Journal on Wireless Communications and Networking Volume 2009*

[8] Killat M., Schmidt-Eisenlohr F., Hartenstein, H., Rössel, C., Vortisch, P., Assenmacher, S., Busch, F.., “Enabling efficient and accurate large-scale simulations of VANETs for vehicular traffic management”, *in ACM international workshop on Vehicular ad hoc networks, September, 2007*

[9] Park, B. and S. Yadlapati, “Evaluation of Work Zone Posted Speed Limits using Safety and Mobility Measures – A Simulation Approach” *in proceedings ASCE Journal 2003*

[10] Oh, C, S. Park, and S.G. Ritchie. “A Method of Identifying Rear-End Collision Risks Using Inductive loop Detectors” *in Accident Analysis and Prevention 12323*, 2005

[11] AASHTO, 2004: American Association of State and Highway Transportation Officials. Green book - a policy on geometric design of highways and streets; 5th edition, 2004.

[12] ITS Modeller product description, http://www.tno.nl/downloads/productblad%20ITS%20Modeller%202008%20(83294_tno_its_modeller).pdf

Annex

This Annex contains the test case definition file for the impact evaluation.

SAFESPOT COOPERATIVE SYSTEMS FOR ROAD SAFETY	**SAFESPOT SP4 WP6 TEST CASE Definition for Evaluation**	

Task [1]	Task 4.6.3	Company:	TNO	Date	24/10/2008	Sheet No.: [2]	SLSDTS_01
Application(s) tested:	SLSD	Vehicles / RSU: [3]		HW - components to be used in test [3]		SW-components / modules to be used in the test [3]	ITS Modeller

Test Type (multiple possible) [4]		Test Purpose (multiple possible) [5]		Test Environment	
Human Factors	☐	**Usability**	☐	**Traffic Simulation**	☒
Technical Evaluation	☐	**Acceptance**	☐	**Driving Simulation**	☐
Safety and traffic evaluation	☒	**Performance**	☐	**Test Site West**	☐
Other:		**Reliability**	☐	**Test Site Italy**	☐
		Correctness	☒	**Test Site Germany**	☐
		Other:		**Test Site Sweden**	☐
				Test Site NL	☐
				Other:	

Which SF use case(s) do you refer to (derive from D4.2.3 for your application)? Try to fuse different use cases to one test case scenario if possible. [6] Will you evaluate multiple applications simultaneously	SP4_UC_SpeedAndDistance – 6a
Are multiple applications evaluated simultaneously?	☒ No, ☐ Yes

Test setup and scenario [7]

An arbitrary developed test-bed will be a 5 kilometer motorway section with 3 lanes including an on and off ramp, a bottle neck (lane drop) and locations for slippery road and accidents.

The experimental design will explore the following overall configurations:

- ☐ Do nothing case
- ☒ SAFESPOT applications – V2V
- ☒ Traffic conditions (uncongested 2500 vehicles / hour and congested 3500 vehicles / hour)

Assumptions within the simulation are:

- ☒ Cooperative system coverage (in meters) – V2V coverage as well as V2I coverage [assumed to be 300 meters]
- ☒ Compliance rate (%) – We will assume 100%.

Success Criteria [8] :	How considered in the test case?	State what you are going to measure (units) and if possible define a treshold to prove that this success criteria is met.	How are you going to measure this? Define your measuring tools.
Requirements for this application (D4.2.4):			
In order to avoid collision, the safety distance shall be defined with an error of 10cm(0,1m)	The safety distance is considered on a larger scale (compared to 10 cm). Therefore the 10cm is not actively taken into account		
The system should be able to detect the presence of a second vehicle which is approaching from behind	The ITS-Modeller constantly measures the distance between vehicles	Safeheadway Distance Time to collsion. Threshold is defined in time and depends on the speed of the vehicle and the assumed reaction time of the driver	Using the ITS-Modeller
The system shall be able to receive information relative to its environment to decide of the best recommendation: Position Accuracy of obstacles and vehicles -- For vehicles with a range further away than 200 m Longitudinal, 15 m. Lateral, number of lane --For vehicles between a range of 80 to 200 m Longitudinal, 2m Lateral, 0.4 m --For vehicles with a range less than 80 m Longitudinal, 1 m Lateral, 0.1 m	The type of message and the contents is not direct considered inside the ITS-Modeller. The new communication module will however be able to shed some light on these issues	The time to collision and the Safeheadway distance will be the main output here. Also througput will be measured which can indicate if lateral changes were indicated on time	Using the ITS-Modeller

The system shall be able to receive data about road condition from other vehicles located within at least 300 meters in the future expected path of the vehicle.	The range of the messages is currently designed to be 300m. A single stretch of road is being taken into account and the slippery road part is at a constant location. The vehicles receiving these messages will be informed earlier compared to none-equipped vehicles	The effect is measured in earlier braking and longer travel times for the the equipped vehicles.The time to collision and the Safeheadway distance will be the main output here. Also througput will be measured which can indicate if lateral changes were indicated on time	Using the ITS-Modeller
User Needs from D4.2.4:	How considered in the test case?	State what you are going to measure (units) and if possible define a threshold to prove that this success criteria is met.	How are you going to measure this? Define your measuring tools.
Driver of vehicle 1 want to be informed about the dynamic information (including relative speed, acceleration, direction indicators, lateral position) of a second vehicle, approaching from behind at a speed significantly higher speed respect to own vehicle	The relative distance between the vehicles is constantly monitored inside the ITS-Modeller	Safeheadway distance Time to Collision	Using the ITS-Modeller
Most accurate distance from preceding vehicle knowledge	The relative distance between the vehicles is constantly monitored inside the ITS-Modeller	Safeheadway distance Time to Collision	Using the ITS-Modeller
Driver wants to receive some safety driving recommendations regarding the hazardous situation in front and its environment (vehicle around, traffic, type of road…)	On the test track a piece of slippery road will be implemented	Safeheadway distance Time to Collision	Using the ITS-Modeller
The user shall be informed about road conditions in the future expected path of the vehicle. Road condition is defined as the condition that defines the grip between the road and the tire.	On the test track a piece of slippery road will be implemented	Safeheadway distance Time to Collision	Using the ITS-Modeller

High level objectives (HLO) [9]	Is this HLO (partly = a,b,c) considered in the test case?	Describe how your test can be related to this HLO? How can your measurements be related to his HLO?	
	☐ No, ☒ Yes	The improving of road safety will be measured in the number of accidents that is prevented based on the Safe Headway Distance measure.	
	☐ No, ☒ Yes	See above	
	☒ No, ☐ Yes		
	☒ No, ☐ Yes		
	☒ No, ☐ Yes		
To increase safety for all road users in a specific situation.	☒ No, ☐ Yes		
To show that the safety impact can be achieved without affecting transport efficiency.	☐ No, ☒ Yes	A comparison will be made also with the througput numbers in a situation with and without SAFESPOT	
To increase the Safety Margin of vehicles using in-vehicle and infrastructure information.	☒ No, ☐ Yes		
To create applications for extended cooperative awareness by means of real time reconstruction of the driving context and environment.	☒ No, ☐ Yes		
To open the development of new safety applications based on a cooperative approach.	☒ No, ☐ Yes		
Risks of SP6 (BLADE) that are covered? [11]			
None			

Extra success criteria that are worth testing? [10]			
□ Fuel consumption □ Emission □ Total network travel time (e.g., vehicle-hours traveled) □ System throughput □ Average speed, etc.			

Non-Compliance Reporting
None to report
Obtained values / results
See details in deliverable D4.6.4

SAFESPOT COOPERATIVE SYSTEMS FOR ROAD SAFETY	SAFESPOT SP4 WP6 TEST CASE Definition for Evaluation						
Task [1]	Task 4.6.3	Company:	TNO	Date	24/10/2008	Sheet No.: [2]	FWTS_02
Application(s) tested:	SLSD	Vehicles / RSU: [3]		HW - components to be used in test [3]		SW-components / modules to be used in the test [3]	ITS Modeller
Test Type (multiple possible) [4]		Test Purpose (multiple possible) [5]				Test Environment	
Human Factors ☐ **Technical Evaluation** ☐ **Safety and traffic evaluation** ☒ **Other:**		**Usability** ☐ **Acceptance** ☐ **Performance** ☐ **Reliability** ☐ **Correctness** ☒ **Other:**				**Traffic Simulation** ☒ **Driving Simulation** ☐ **Test Site West** ☐ **Test Site Italy** ☐ **Test Site Germany** ☐ **Test Site Sweden** ☐ **Test Site NL** ☐ **Other:**	
Which SF use case(s) do you refer to (derive from D4.2.3 for your application)? Try to fuse different use cases to one test case scenario if possible. [6] Will you evaluate multiple applications simultaneously		SP4_UC_SpeedAndDistance – 6a					
Are multiple applications evaluated simultaneously?		☒ No, ☐ Yes					

Test setup and scenario [7]			
An arbitrary developed test-bed will be about 5 kilometer dual carriageway section with 1 lanes is simulated. On this road the visibility is reduced due to fog and a slow moving vehicle is modelled. Vehicles are not allowed to overtake the slow moving vehicle. The slow moving vehicle sends a message back towards any approaching vehicle. The experimental design will explore the following configurations: ☒ SAFESPOT application – V2V (different penetration rates from 0, 15, 50, 85 and 100%) ☒ Cooperative system coverage (in meters) – V2V coverage as well as V2I coverage [assumed to be 300 meters] ☒ Compliance rate (%) – We will assume 100%. ☒ Traffic conditions (750 vehicles / hour)			
Success Criteria [8] :	How considered in the test case?	State what you are going to measure (units) and if possible define a treshold to prove that this success criteria is met.	How are you going to measure this? Define your measuring tools.
Requirements for this application (D4.2.4):			
In order to avoid collision, the safety distance shall be defined with an error of 10cm(0,1m)	The safety distance is considered on a larger scale (compared to 10 cm). Therefore the 10cm is not actively taken into account		
The system should be able to detect the presence of a second vehicle which is approaching from behind	The ITS-Modeller constantly measures the distance between vehicles	Safeheadway Distance Time to collsion. Threshold is defined in time and depends on the speed of the vehicle and the assumed reaction time of the driver	Using the ITS-Modeller
The system shall be able to receive information relative to its environment to decide of the best recommendation: Position Accuracy of obstacles and vehicles -- For vehicles with a range further away than 200 m Longitudinal, 15 m. Lateral, number of lane --For vehicles between a range of 80 to 200 m Longitudinal, 2m Lateral, 0.4 m --For vehicles with a range less than 80 m Longitudinal, 1 m Lateral, 0.1 m	The type of message and the contents is not direct considered inside the ITS-Modeller. The new communication module will however be able to shed some light on these issues	The time to collision and the Safeheadway distance will be the main output here. Also througput will be measured which can indicate if lateral changes were indicated on time	Using the ITS-Modeller

The system shall be able to receive data about road condition from other vehicles located within at least 300 meters in the future expected path of the vehicle.	The range of the messages is currently designed to be 300m. A single stretch of road is being taken into account and the slippery road part is at a constant location. The vehicles receiving these messages will be informed earlier compared to none-equipped vehicles	The effect is measured in earlier braking and longer travel times for the the equipped vehicles.The time to collision and the Safeheadway distance will be the main output here. Also througput will be measured which can indicate if lateral changes were indicated on time	Using the ITS-Modeller
User Needs from D4.2.4:	How considered in the test case?	State what you are going to measure (units) and if possible define a threshold to prove that this success criteria is met.	How are you going to measure this? Define your measuring tools.
Driver of vehicle 1 want to be informed about the dynamic information (including relative speed, acceleration, direction indicators, lateral position) of a second vehicle, approaching from behind at a speed significantly higher speed respect to own vehicle	The relative distance between the vehicles is constantly monitored inside the ITS-Modeller	Safeheadway distance Time to Collision	Using the ITS-Modeller
Most accurate distance from preceding vehicle knowledge	The relative distance between the vehicles is constantly monitored inside the ITS-Modeller	Safeheadway distance Time to Collision	Using the ITS-Modeller
Driver wants to receive some safety driving recommendations regarding the hazardous situation in front and its environment (vehicle around, traffic, type of road…)	On the test track a piece of slippery road will be implemented	Safeheadway distance Time to Collision	Using the ITS-Modeller
The user shall be informed about road conditions in the future expected path of the vehicle. Road condition is defined as the condition that defines the grip between the road and the tire.	On the test track a piece of slippery road will be implemented	Safeheadway distance Time to Collision	Using the ITS-Modeller

High level objectives (HLO) [9]	Is this HLO (partly = a,b,c) considered in the test case?	Describe how your test can be related to this HLO? How can your measurements be related to his HLO?
	☐ No, ☒ Yes	The improving of road safety will be measured in the number of accidents that is prevented based on the Safe Headway Distance measure.
	☐ No, ☒ Yes	See above
	☒ No, ☐ Yes	
	☒ No, ☐ Yes	
	☒ No, ☐ Yes	
To increase safety for all road users in a specific situation.	☒ No, ☐ Yes	
To show that the safety impact can be achieved without affecting transport efficiency.	☐ No, ☒ Yes	A comparison will be made also with the througput numbers in a situation with and without SAFESPOT
To increase the Safety Margin of vehicles using in-vehicle and infrastructure information.	☒ No, ☐ Yes	
To create applications for extended cooperative awareness by means of real time reconstruction of the driving context and environment.	☒ No, ☐ Yes	
To open the development of new safety applications based on a cooperative approach.	☒ No, ☐ Yes	

Risks of SP6 (BLADE) that are covered? [11]			
None			

Extra success criteria that are worth testing? [10]			
□ Fuel consumption □ Emission □ Total network travel time (e.g., vehicle-hours traveled) □ System throughput □ Average speed, etc.			

Non-Compliance Reporting
None to report
Obtained values / results
See details in deliverable D4.6.4

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Safety and traffic evaluation ☒
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Performance ☐
Reliability ☐
Correctness ☒
Other:</td><td colspan="2">Traffic Simulation ☒
Driving Simulation ☐
Test Site West ☐
Test Site Italy ☐
Test Site Germany ☐
Test Site Sweden ☐
Test Site NL ☐
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</table>

Test setup and scenario [7]			
An arbitrary developed test-bed will be a 5 kilometer motorway section with 3 lanes including an on and off ramp, a bottle neck (lane drop) and locations for slippery road and accidents. The experimental design will explore the following overall configurations: ☐ Do nothing case ☒ SAFESPOT applications – V2V ☒ Traffic conditions (uncongested 2500 vehicles / hour and congested 3500 vehicles / hour) Assumptions within the simulation are: ☒ Cooperative system coverage (in meters) – V2V coverage as well as V2I coverage [assumed to be 300 meters] ☒ Compliance rate (%) – We will assume 100%.			
Success Criteria [8] :	How considered in the test case?	State what you are going to measure (units) and if possible define a treshold to prove that this success criteria is met.	How are you going to measure this? Define your measuring tools.
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In order to avoid collision, the safety distance shall be defined with an error of 10cm(0,1m)	The safety distance is considered on a larger scale (compared to 10 cm). Therefore the 10cm is not actively taken into account		
The system should be able to detect the presence of a second vehicle which is approaching from behind	The ITS-Modeller constantly measures the distance between vehicles	Safeheadway Distance Time to collsion. Threshold is defined in time and depends on the speed of the vehicle and the assumed reaction time of the driver	Using the ITS-Modeller
The system shall be able to receive information relative to its environment to decide of the best recommendation: Position Accuracy of obstacles and vehicles -- For vehicles with a range further away than 200 m Longitudinal, 15 m. Lateral, number of lane --For vehicles between a range of 80 to 200 m Longitudinal, 2m Lateral, 0.4 m --For vehicles with a range less than 80 m Longitudinal, 1 m Lateral, 0.1 m	The type of message and the contents is not direct considered inside the ITS-Modeller. The new communication module will however be able to shed some light on these issues	The time to collision and the Safeheadway distance will be the main output here. Also througput will be measured which can indicate if lateral changes were indicated on time	Using the ITS-Modeller

The system shall be able to receive data about road condition from other vehicles located within at least 300 meters in the future expected path of the vehicle.	The range of the messages is currently designed to be 300m. A single stretch of road is being taken into account and the slippery road part is at a constant location. The vehicles receiving these messages will be informed earlier compared to none-equipped vehicles	The effect is measured in earlier braking and longer travel times for the the equipped vehicles.The time to collision and the Safeheadway distance will be the main output here. Also througput will be measured which can indicate if lateral changes were indicated on time	Using the ITS-Modeller
User Needs from D4.2.4:	How considered in the test case?	State what you are going to measure (units) and if possible define a threshold to prove that this success criteria is met.	How are you going to measure this? Define your measuring tools.
Driver of vehicle 1 want to be informed about the dynamic information (including relative speed, acceleration, direction indicators, lateral position) of a second vehicle, approaching from behind at a speed significantly higher speed respect to own vehicle	The relative distance between the vehicles is constantly monitored inside the ITS-Modeller	Safeheadway distance Time to Collision	Using the ITS-Modeller
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Driver wants to receive some safety driving recommendations regarding the hazardous situation in front and its environment (vehicle around, traffic, type of road…)	On the test track a piece of slippery road will be implemented	Safeheadway distance Time to Collision	Using the ITS-Modeller
The user shall be informed about road conditions in the future expected path of the vehicle. Road condition is defined as the condition that defines the grip between the road and the tire.	On the test track a piece of slippery road will be implemented	Safeheadway distance Time to Collision	Using the ITS-Modeller

High level objectives (HLO) [9]	Is this HLO (partly = a,b,c) considered in the test case?	Describe how your test can be related to this HLO? How can your measurements be related to his HLO?
	☐ No, ☒ Yes	The improving of road safety will be measured in the number of accidents that is prevented based on the Safe Headway Distance measure.
	☐ No, ☒ Yes	See above
	☒ No, ☐ Yes	
	☒ No, ☐ Yes	
	☒ No, ☐ Yes	
To increase safety for all road users in a specific situation.	☒ No, ☐ Yes	
To show that the safety impact can be achieved without affecting transport efficiency.	☐ No, ☒ Yes	A comparison will be made also with the througput numbers in a situation with and without SAFESPOT
To increase the Safety Margin of vehicles using in-vehicle and infrastructure information.	☒ No, ☐ Yes	
To create applications for extended cooperative awareness by means of real time reconstruction of the driving context and environment.	☒ No, ☐ Yes	
To open the development of new safety applications based on a cooperative approach.	☒ No, ☐ Yes	

Risks of SP6 (BLADE) that are covered? [11]			
None			

Extra success criteria that are worth testing? [10]			
□ Fuel consumption □ Emission □ Total network travel time (e.g., vehicle-hours traveled) □ System throughput □ Average speed, etc.			

Non-Compliance Reporting
None to report
Obtained values / results
See details in deliverable D4.6.4

Explanations:

[1]
Task
Detailed descriptions of the different tasks:
Task 4.6.3: Evaluation of the accidents impact through simulation methods and tools
The aim of this task is to determine the effect of the SAFESPOT system on traffic (fleet) safety. This will consist of traffic network simulation to assess the different benefits of applications on a network level based on driver behaviour response. The impact of SMA on road accident situation will be evaluated while varying the penetration rates. The scenario selection will be based on D4.2.3 Use Cases and accident situations and input for driver behaviour could come from Task 4.6.5 HF driving simulator study. Input from T4.5.1 on worst and best performance of the underlying system would improve the results. Within SP5 a similar task is foreseen.

Task 4.6.4: Technical evaluation of the safety margin and related application with expert drivers
The aim of this task is to determine the technical performance under specific situations and technical function of integrated system under realistic conditions at the different test sites. The test cases will primarily be based on D4.2.4 User needs and requirements. The application parameters such as boundaries between safety margin stages will be evaluated. The work will mostly evaluate the technical function of the SAFESPOT system. For some cases a more detailed evaluation will be performed that will evaluate the technical performance of the system. This task plans all evaluation tests that are performed with implemented vehicles at the different test sites and collect the results.
All applications should be evaluated at some level.

Task 4.6.5: Evaluation of the safety margin an related application with subjects (to be updated)
The aim of this task is to determine Human Acceptance of such a system and evaluate human behaviour
Driving Simulation for safety critical situations
Determine human behaviour for specific cases
Determine human acceptance
HMI evaluation
D4.2.4 User needs and requirements.

[2]
Sheet No:
Give this sheet a reference number. The following nomenclature shall be applied.
- Application abbreviation e.g. SLSD (speed limitation and safety distance)
- Test Site abbreviation e.g. IT (Italian test site)
- A continuous number for each test case you run → e.g. for total name: **SLSD_IT_1**

Applications (D4.2.4)		**Test Sites**	
RIS	– Road intersection safety	WE	– West test site
LCM	– Lane change maneuver	IT	– italian test site
SO	– Safe overtaking	GE	– German Test Site
HOCW	– Head on collision warning	SWE	– swedish test site
RECO	– Rear end collision	NL	– Netherlands test site
SLSD	– Speed limitation and safety distance	DS	– driving simulator
FCW	– Frontal collision warning	TS	– traffic simulator
RCS	– Road condition status		
CUWA	– Curve warning		
VRUAA	– Vulnerable road user accident avoidance		

[3]
Vehicle / RSU
List all **vehicles** and **road site units (RSU)** that are applied in the test. For each Vehicle and RSU fill in the installed **Hardware (HW)** and **Software (SW)** components / modules.

[4]
Test Type
Are you going to conduct a technical evaluation or a human factors test or a evaluation to evaluate the effect on safety? If you do a technical evaluation and have e.g. an acceptance questionnaire included please select both.

[5]
Test Purpose:

Usability	Testing how the user interacts with the system.
Acceptance	Testing users acceptance of the system.
Performance	Test about resource usage, throughput, stimulus-response time.
Reliability	The system developed must not fail in unexpected or catastrophic ways. Robustness testing and stress testing are variances of reliability testing based on this simple criterion.
Correctness	Test of functionality.

[6]
Use Cases
Which use case of D4.2.3 is the base for your test case? It is not necessary to have a test case for every use case; therefore you may redefine the use cases if this helps you to fuse some use cases to one general one. This shall help to address as many use cases as possible with less efforts. Please give always the use cases reference number(s).

[7]
Test setup and scenario
Describe the test setup and the scenario you are running in detail.
Refer to the vehicles / RSU applied, their position and movements and the use case(s).
Human factors: How many subjects are you planning? What is the experimental design?
Technical evaluation: How many repetitions are planned?
Describe the variations of you plan. E.g. you may vary factors and within each factor you may vary as well different grades (see table). A recommendation is to have not too much variation in order to reduce complexity of the tests.

Factors	**Grades**
Speed	e.g. 30km/h / 50km/h / 80km/h
Following Distance	e.g. Not yet specified - range from 10m to 50m
SAFESPOT system	Activated / not activated
…	…

[8]
Success Criteria
a) For each application special **Requirements** have been defined in D4.2.4. Please copy the requirements for the application(s) tested. In the case you are testing more than one application, copy the requirements from all applications. You may only copy those requirements that are relevant for this test case, however try taking as many requirements as possible into account.
b) Please describe how you consider this requirement in your test case scenario. You may slightly reformulate the requirement here for better fit.
c) Then state in the next column which results you are going to retrieve will prove that the requirement is met / or not met. Be very specific and precise (numbers / thresholds). If there is no specific threshold, state the measure you will report the performance for.
d) In the last column please specify which methods / tools / measurements you are going to apply in order to achieve your results.

Do the same for all **User Needs** from D4.2.4 that refer to your application(s).

[9]
High level objectives (HLO)
The SAFESPOT Technical Annex (TA) states a number of **High Level Objectives (HLO)** that describe in a very general manner the success criteria for the SAFESPOT project on a “high level”. You find a description of those HLO in the template. Please read them carefully and think how we can prove as many of them by our evaluations tests (pilots) as possible. You may redefine the HLO according to your test case or you may be able to prove the HLO partly or to some extend or just laterally. Many times a performance report for special values can be enough (e.g. Collision warning arrives 8 seconds ttc (time to collision) – this can be compared to a collision warning of other projects that have no C2C communication module. Please try to contribute as much as possible in order to fulfil the HLO.
Sources of HLO:
SAFESPOT-eu.org
TA Chapter Technical objectives and other SAFESPOT objectives, section 2.5 and 2.6
TA SP4 section 8.4.2 objectives

[10]
Extra success criteria that are worth testing.
If you have any further success criteria that you are going to test in the test case please state them here! This may apply especially for multiple application tests or human factors tests (both are underrepresented in the High Level Objectives).

[11]

Risks. Within SP6 several risks are identified by relevant stakeholders for the development of SF like systems. On the BSCW a list of these risks is available. If there are risks for which you think a test case could be defined, at them here