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0.12	2011-11-23	EJ – Results SRS added
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Executive summary

This document provides the traffic efficiency and environmental impacts assessed in the euroFOT project. Traffic efficiency effects on mileage, speed and travel time are assessed, as well as effects on a change in congestion due to a change in number of accidents. The environmental effects on fuel consumption and CO_2 emissions due to a change in mileage and driver behaviour are assessed. FOT data are used to evaluate these effects, in some cases complemented with traffic simulation models. In the euroFOT project the traffic efficiency and environmental impacts of five functions are assessed. For three other functions only the indirect traffic effects are considered. The results are scaled to provide the insight of the impacts projected on a European scale. The EU-27 results are input for the cost benefit analysis carried out in work package 6500.

The eight euroFOT functions are the following:

- Functions for which the traffic efficiency and environmental effects are assessed:

Adaptive Cruise Control (ACC) and Forward Collision Warning (FCW) together in one bundle

Speed Regulation System (SRS): Speed Limiter (SL) and Cruise Control (CC)

  - Navigation Systems (built-in device and mobile device)

- Functions for which only environmental effects are assessed:

  Fuel Efficiency Advisory (FEA)

- Safety warning functions, for which only safety effects and indirect traffic effects are assessed. No direct traffic efficiency or environmental effects were expected:

Lane Departure Warning (LDW)/ Impairment Warning (IW): tested separately and in three different bundles – with ACC, with ACC and FCW, and with ACC, FCW, BLIS and IW. IW is only tested in a bundle together with ACC, FCW, LDW and BLIS

Curve Speed Warning (CS): tested separately

Blind Spot Information System (BLIS): only tested in a bundle together with ACC, FCW, LDW and IW

First the effects of the systems measure in the FOT are presented, followed by the EU-27 level results. As a context for the results, this summary ends with data on system usage.

Effects on FOT level

This section contains an overview of the effects of the systems at the FOT level (the effects on FOT vehicles). Changes in performance indicators between FOT vehicles during the treatment period and baseline period are given.

A '-' means that no significant effect was found, 0% means that there is no effect, and an empty cell means that it was not calculated.

Table 1: Direct traffic efficiency effects of the systems at the FOT level

Direct traffic effects		Navigation system		ACC+FCW		SRS
		Built-in device	Mobile device			
		Cars	Cars	Cars	Trucks	Cars
Change in trip length		-6.8%	-	0%	0%	0%
Change in travel time per trip	**All roads**	-9.4%	-7.0%			
	Motorways			0.3%	0.1%	-1.4%
	Rural roads			-	0.02%	-0.8%
	Urban roads			0.2%	-	-2.4%
Change in number of trips		-	-	-	-	-
Change in average speed	**All roads**	-	-			
	Motorways			-0.3%	-0.1%	1.4%
	Rural roads			-	-0.02%	0.8%
	Urban roads			-0.2%	-	2.4%

Table 2: Direct environmental effects of the systems at the FOT level

Direct environmental effects		Navigation system		ACC+FCW		SRS[1]		FEA
		Built-in device	Mobile device			SL (active)	CC (active)	
		Cars	Cars	Cars	Trucks	Cars	Cars	Cars
Change in fuel consumption	**All roads**	-3%	-					-
	Motorways			-2.8%	-1.9%	-1.6%	-1.1%	
	Rural roads					-3.8%	-13.2%	
	Urban roads					-5.2%	-36.1%	

For the traffic efficiency systems, the most important conclusions are the following:

For ***navigation systems*** there is a decrease in trip length (travel distance) and travel time per trip; these are typically the benefits navigation systems aim to achieve. The effect sizes are larger for built-in navigation devices than for mobile navigation devices. Associated with these results there is a decrease in fuel consumption for the built-in navigation devices. For the mobile devices the effect on fuel consumption is not significant. There is no change in number of trips and average speed when driving with navigation systems. The proportion of time spent in congestion does not change with navigation system usage.

For ***ACC+FCW*** there is a small reduction in average speed for cars. The effect on trucks is minimal. The subjective results show no effect of ACC and FCW on mobility behaviour, route choice and choice of road type. Traffic simulations show that the effect on network speed is

[1] The direct environmental effects for SRS are assessed for the cases that the system is active (on, and used by the driver)

similar in size to the effect found in the FOT and generally linear when more vehicles are equipped. ACC and FCW are used more often at higher speed ranges. When ACC and FCW are active (on and used by the driver), speeds are higher than the average in the baseline period. When ACC and FCW are not active or off speeds are lower than average baseline period. The fuel consumption decreases on motorways.

With ***SRS*** the average speed slightly increased, and the variation of speeds has reduced (speed distributions are narrower with the use of SRS). From the analyses it was concluded that SRS does not affect mobility behaviour, route choice, trip length or choice of road type. Because the analyses show that CC is used at higher speeds, the average speed when CC is active is higher than the average speed. When SL is active, speeds are about the same as the average speed. When SL and CC are off speeds are lower than the average speed. The effects on speed and mobility translate into lower average travel times and less delay. The simulation results show that the average speed increases linearly with the penetration of equipped vehicles. There are no interaction effects on average network speed and average delay.

Effects on EU-27 level

For calculation of the effects on EU-27 level, a 100% penetration rate is assumed for all systems. This is not a realistic assumption, but it can be used to assess the potential of the systems. Also the usage as observed in the FOT is taken into account. The fuel consumption effect of ACC+FCW is a clear cost saving for the user. The effect of ACC+FCW on travel time is marginal and will hardly be experience by the driver. Additionally for ACC+FCW a safety effect was found in terms of a reduction in the number of accidents. This safety effect leads to a reduction in accident related congestion additional to the effect in the table. ACC+FCW can reduce the incidental delay due to accidents by about 3 million lost vehicle hours. It is difficult to put this in perspective, since European numbers on lost vehicle hours caused by accidents are not available. However, from the safety impact assessment it is known that ACC+FCW in cars could potentially affect up to 2.2-5.7% of the injury accidents on motorways, while ACC+FCW in trucks could potentially affect up to 0.2-0.6% of these accidents. This could be used as a very rough estimate for insight into the vehicle lost hours that are prevented. The traffic efficiency effects for the SRS are somewhat higher, and also SRS has a small but clear impact on fuel consumption on EU level. Apart from these fuel consumption benefits, these comfort systems have benefits in terms of comfort to the driver, which is described in D6.3. The monetary benefits will be determined in the cost benefits analysis in D6.7.

Table 3: Effects on EU-27 level

Effects on EU-27 level		**ACC+FCW**	**SRS**		
			Bundle	**SL**	**CC**
Change in total travel time	**All roads**	0.2%	-1.2%		
	Motorways		-1.1%		
	Rural roads		-0.8%		
	Urban roads		-2.2%		
Change in fuel consumption	**Motorways**	-1.4%		-0.3%	-0.7%

For the other systems, no effects on EU-27 level could be calculated.

For ***navigation systems***, the FOT showed that there are large differences between the two tested navigations systems. Predicting the effect of other navigation systems available on EU level would introduce a great deal of uncertainty because of assumptions to be introduced. A second reason that makes it difficult to scale to an EU level effect is that there are differences between the FOT network (Germany) and the total European network, such as differences in density and differences in possibilities for route change. Finally, the scaling up to EU level requires that the current market penetration and usage rate is known. For navigation systems this is information is not available on EU level. For these reasons, the effects found in the FOT are not scaled to EU level.

For ***FEA***, due to the very limited information on driving conditions that result in the found fuel reduction on FOT level and the related uncertainty, scaling up the effect to EU-27 level is not reasonable.

For the ***safety warning systems*** the direct traffic effects and environmental effects were not assessed and (significant) safety effects were not found on FOT level. Therefore no translation to EU-27 level effects could be made.

Usage

In the graph below, results on system usage (proportion of time that the system was active) in the FOT are shown. For the safety warning systems LDW, CS, BLIS and IW the usage is not known. For the vehicles equipped with ACC and FCW, the usage of ACC is measured. FEA could not be deactivated, so this system has a 100% usage and is not included in the picture. SL and CC are together in one bundle, and they cannot be both active at the same time.

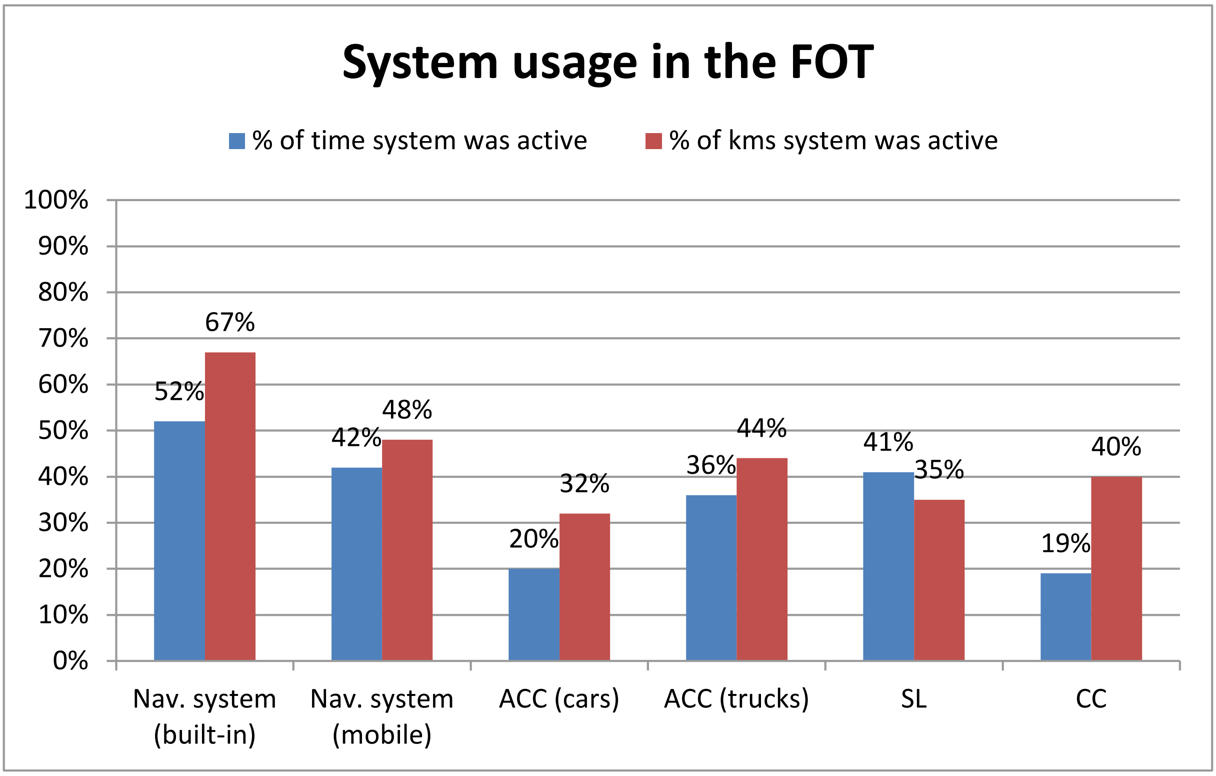

Figure 1: System usage in the FOT

The use of ***navigation systems*** increases with trip length. Furthermore, navigation systems are used more often on unfamiliar trips than on familiar trips. For trips longer than 100 km, navigation systems are nearly always used, independent of the familiarity of the trip. The drivers in the FOT used the built-in device more often than the mobile device.

ACC is used most on motorways in free flow situations. In congestion and on urban roads ACC is not used much.

CC is mainly used on motorways in free flow situations and very little on urban roads and during congestion (the system does not work when speed is below 30 km/h). The use of CC grows when the speed limit increases. CC is on average used more on longer trips.

SL is used on all road types; there is not much difference between the usages on different road types. The use of SL decreases somewhat when the speed limit increases.

The results on usage of ***CC and SL*** are influenced by the fact that only one of the two functions can be used at the time.

1 Introduction

This deliverable describes the impacts of euroFOT functions on traffic efficiency and the environment. The euroFOT project is the first large-scale Field Operational Test (FOT) of multiple Advanced Driver Assistance Systems (ADAS) undertaken in Europe. It evaluates, using instrumented vehicles, the impacts of ADAS on traffic and the acceptance of ADAS to ordinary drivers in real traffic. Almost 1000 vehicles (cars and trucks) from different manufacturers and hosting different ADAS took part in the study that started in 2008.

Eight functions were selected for euroFOT. Five of these functions were expected to have direct traffic and/or environmental effects:

- Adaptive Cruise Control (ACC): tested in a bundle with Forward Collision Warning (FCW)
- Forward Collision Warning (FCW): tested in a bundle with Forward Collision Warning (FCW)
- Speed Regulation System (SRS): combination of Speed Limiter (SL) and Cruise Control (CC)
- Navigation Systems (built-in device and mobile device)
- Fuel Efficiency Advisory (FEA) – only environmental effects are assessed because of a limited amount of data.

The safety warning systems Lane Departure Warning (LDW), Curve Speed Warning (CS), Blind Spot Information System (BLIS) and Impairment Warning (IW) are not expected to have direct traffic and environmental effects. Some checks to confirm this as well as the indirect traffic effect (a result of the safety impact) are briefly discussed.

In this report the impacts of the euroFOT functions on traffic efficiency and the environment are given at the FOT level (for equipped vehicles) and on EU-27 level. The EU-27 results provide input for the cost benefit analysis. To get to the effects on EU-27 level, the effects found in the FOT data have been scaled up to both a larger population and geographical scope. This leads to an assessment of the potential effects of the evaluated ADAS were they to be widely deployed in the vehicle fleets in all of Europe.

This introductory chapter contains some more background information: objectives of the deliverable, relations with other work packages and deliverables, and outline of the document and reading instructions.

1.1 Objectives

The goal of this document is to describe the impacts of the euroFOT functions on traffic efficiency and the environment. This document is a result of work package 6400 in euroFOT. This work package has estimated the impacts of the functions in euroFOT on traffic safety, traffic efficiency and the environment, making use of the empirical data that were collected. A translation of the empirical findings in the FOTs has taken place in this work package so that general conclusions about the impact of the functions can be drawn.

In work package 6400 the following type of traffic efficiency and environmental effects are assessed: direct traffic efficiency effects (such as changes in mileage, speed, travel time), indirect traffic efficiency effects (change in congestion due to a change in number of accidents) and direct environmental effects (change in fuel consumption and CO_2 emissions due to changes in mileage and driver behaviour). To calculate these effects FOT results are used, in some cases complemented with (traffic) micro simulation models. In those cases, data gathered about the changes in driver behaviour as well as information about how the function works is implemented and scenarios are simulated.

1.2 Relations with other work packages and deliverables

Interactions with other SPs and WPs of the project are essential for the work carried out in work package 6400. Below the most important connections and interactions are described, with work packages and deliverables.

- The methodology deliverable prior to this deliverable: Deliverable 6.2 (Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment);
- The output of the work carried out in work package 6400 is used as input for WP6500 (Socioeconomic Cost-Benefit Analysis). WP6500 results in Deliverable 6.7 (Overall Cost-Benefit Study);
- The other deliverables with impact assessment results: Deliverable 6.3 (Final results: User acceptance and user-related aspects), Deliverable 6.4 (Final results: Impacts on traffic safety). All assessment results are available in an overall document: Deliverable 6.1 (Final evaluation results);
- SP2 (In-Vehicle Systems for Driving Support) has provided the requirements and specifications of the selected functions in Deliverable 2.1 (Specifications and Requirements for Testing In-vehicle Systems for Driving Support);
- SP3 (Data Management) provides the data specification, data structure and format (database), data storage, and analysis tools. The requirements of SP6 with regard to data to be measured are considered in SP3;
- SP4 (Methodology and Experimental Procedures) has defined the evaluation criteria (experimental procedures) and performance indicators. SP4 and SP6 have very strong relations. Relevant documents are Deliverable 4.1 (Report on specification of performance indicators) and Deliverable 4.2 (Report on specification of experimental procedures); and
- SP5 (Vehicle and Test Management Centre) collects the data from the FOTs that is used for the assessments. This SP also takes care of quality management. A document that is important for SP6 is Deliverable 5.3 (Final delivery of data and answers to questionnaires).

1.3 Outline deliverable and reading instructions

The outline of this deliverable is as follows. Chapter 2 describes the main aspects of the methodology. Chapter 3 contains the traffic efficiency and environmental impacts for Navigation Systems, Chapter 4 for Adaptive Cruise Control (ACC) and Forward Collision Warning (FCW), and Chapter 5 for Speed Regulation System (SRS). Chapter 6 contains the environmental effects of the Fuel Efficiency Advisory (FEA), and Chapter 7 the results of the three safety warning functions Lane Departure Warning (LDW)/Impairment Warning (IW), Curve Speed Warning (CS), Blind Spot Information System (BLIS).

The chapters with function results have the following set-up. First a summary of effects is given. After that the more detailed results follow, in the following order: system usage & mobility behaviour, direct traffic effects, indirect traffic effects, simulation results (if applicable), direct environmental effects, and results of environment simulations (if applicable).

Chapter 8 describes conclusions and lessons learned. In Chapter 9 the references are given. Finally, a list with indicators, details of the tested hypotheses per function and details of the simulation results for ACC+FCW and SRS are given in the annexes.

2 Methodology

In Deliverable 6.2 (Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment) the methodology for the impact assessment and evaluation of user related aspect in euroFOT is described. This methodology is based on the FESTA methodology for conducting FOTs [1]. In this chapter the most important aspects of the methodology are repeated, and the outcomes and implications of choices made during the FOT and data analysis phase are described. For more detailed methodology aspects the reader is referred to Deliverable 6.2.

In section 2.1 the research questions and hypotheses are given. Sections 2.2, 2.3 and 2.4 describe the analysis process, from data collection to hypotheses testing and impact assessment.

2.1 Research questions and hypotheses

In SP2, research questions and hypotheses were derived, for each aspect of the analysis (e.g. safety, traffic efficiency, driver-related aspects, and environment). These research questions and hypotheses were revised and prioritised in SP6. The research questions and hypotheses that are answered and tested in this deliverable are the following:

Research questions:

1. What is the impact of the function on travel time?
2. What is the impact of the function on journey speed?
3. What is the impact of the function on amount of delay?
4. What is the impact of the function on variation in speed?
5. What is the impact of the function on network performance per road category?
6. What is the impact of the function on fuel consumption per kilometre?
7. What is the impact of the function on CO_2 and regulated emissions per kilometre?

Different research questions are answered using different types of results. The results that are used are objective data from hypothesis testing, subjective data from questionnaires, safety impacts, and simulation results.

Also, not all research questions are applicable to all functions, and some research questions could not be answered because the results were not significant. This does not mean that the function cannot have an effect on the indicator, but it means that we could not find a significant effect. Table 4 shows which research questions were answered.

Table 4: Research questions answered

No.	Research question	ACC and FCW	SRS	Navigation	Safety warning systems	FEA
1	Impact on travel time	✓	✓	✓		
2	Average journey speed	✓	✓	✓		
3	Delay	✓	✓	✓	✓	
4	Variation in speed	✓	✓	✓		
5	Network performance	✓	✓	✓		
6	Fuel consumption	✓	✓	✓		✓
7	Emissions	✓	✓			

Travel time

The impact on travel time is a combination of the effect on average journey speed and the effect on trip distance. The effect on average journey speed is influenced by the road types that the driver chooses. Only for navigation system an effect on trip length and road type was expected. For other functions a seasonal effect was expected to disturb the results on trip length, so subjective data on the impact on trip length and road type were collected to test this. If people did not indicate in the questionnaires that their mobility behaviour changed, then no effect on trip length was assumed. Incidental delay is not taken into account and is reported as a separate indicator. The effect on trip distance is determine

Average journey speed

The average speed is directly tested from the FOT data using statistical tests. The effect is the difference between the average speed in the baseline period and the average speed in the treatment period. The treatment period includes driving with the system on and activated and also driving with the system off. This means that the usage as observed in the FOT is taken into account. The average speed is determined per road type or speed limit in chunks of one minute taking into account the variation between drivers. Generally, ANOVA tests were used. The tests are described in the Annex 1.

Delay

Delays are calculated with use of the speed distribution. As a starting point we assume that on motorways trucks driving slower than 80 km/h are delayed, on rural roads the boundary is also 80 km/h and on urban roads the boundary is 50 km/h. Vehicles that drive 5 km/h cause more delay than vehicles that drive 40 km/h. As a measure for delay, vehicle loss hours are used. The indirect effect of a reduction in delays due to a reduction in accidents is determined from the reduction in accidents for crash-avoidance devices. These were only available for the ACC and FCW bundle.

Variation in speed

The variation in speed is analysed using the speed distribution. For a number of functions the expected effect was that people would drive closer to the speed limit. This is analysed in a qualitative way, except for the Navigation systems function which was statistically tested.

Network performance

The network performance is determined in terms of average network speed. The network performance was determined by traffic simulation for the functions ACC and SRS. For these functions the interaction between vehicles was expected to be different for different penetrations of equipped vehicles.

Fuel consumption

The fuel consumption is directly measured from the Controller Area Network (CAN) data in the FOT and tested for significant effect using statistical tests. The effect is the difference between the average fuel consumption per kilometre in the baseline period and the average fuel consumption per kilometre in the treatment period when the function is active. It is then scaled for the usage based on mileage. This means that the usage as observed in the FOT is taken into account. The fuel consumption is determined per road type or speed limit, taking into account the variance between drivers. Generally, ANOVA tests were used. The tests are described in Annex 1.

CO_2 and regulated emissions

Additional to the effect on fuel consumptions, the function for which the highest environmental benefits were expected, being ACC and SRS, an emission model was used to determine the CO2 and the regulated emissions CO, NOx, PM10 and HC. The model used speed-time profiles observed in the FOT to determine the emissions.

Hypotheses:

1. The average speed will decrease
2. The number of trips made will increase
3. The number of vehicle km travelled will increase
    a. Using subjective data
    b. Using objective data
4. The fuel consumption will decrease

The hypotheses are all related to direct traffic and environmental effects. Indirect effects are taken aboard in research question 2 (as well as direct effects); the other research questions only deal with direct traffic effects.

Table 5: Hypothesis used for direct effects

No.	Hypothesis	ACC and FCW	SRS	Navigation	FEA
1	The average speed will decrease	✓	✓	✓	
2	The number of vehicle km travelled will increase	✓	✓	✓	
3	Fuel consumption will decrease	✓	✓	✓	✓
4	Navigation systems increase the number of vehicle km travelled			✓	
5	Navigation systems increase journey efficiency based on surrogate measures			✓	

Most of the hypotheses mentioned are tested by all VMCs for all functions, and the results are tested for statistical significance (details about the used tests can be found in Annex 1). For navigation systems, additional hypotheses were tested because of the expected effects on trip length. For FEA not all of the minimally required hypotheses could be tested because the available data were of insufficient quality.

2.2 Data collection

During the FOT both subjective data (derived from questionnaires and driver interviews) and objective data (derived from the vehicle CAN and video recordings) were gathered. These data were checked with regard to data quality and further processed: the data were enriched with additional attributes from a digital map, and relevant events and situational variables were recognized. The list with data that was planned to be measured can be found in Deliverable 6.2 Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment. However, because it was harder than expected to recruit participants for the FOT, during the execution of the FOT, concessions had to be made to the experimental set-up and data collection. These are described per function in section 2.5.

Table 6: Days of data collection

System	Total number of drivers	Total days for all drivers in baseline	Total days for all drivers in treatment
ACC and FCW (cars)	204	18942	46298
ACC and FCW (trucks)	68	2966	3343
SRS	35	3695	5932
Navigation	99	2708	5657

2.3 Hypotheses testing

After data processing, the relevant performance indicators (PI) and situational variables (SV) were calculated for each VMC separately. The data were then stored in a database, again for each VMC separately. After each step the data quality was checked.

Using the calculated PIs, the hypotheses were tested by the VMCs by making use of parameters that were measured or derived. The VMC specific hypotheses (formulated by the OEMs of a specific VMC) were tested only at the VMC, without result integration. The common hypotheses (as specified in section 2.1) were assessed in all VMCs, provided that the function was tested for the VMC.

Throughout the deliverable a clear distinction is made between the results of hypothesis testing, resulting in hard numbers about the significance of the effects, and the interpretation of those results. This ensures transparency about how FOT results measured in specific conditions are translated into EU level impacts.

2.4 Impact assessment and scaling up

Based on the results of the hypotheses testing, performance indicators and situational variables, the global assessment (on traffic efficiency, safety and environment) was conducted. The assessment of user related aspects specifically makes use of the subjective data; in the global assessment these data were used as background information and to help explain results.

The traffic efficiency aspects that were assessed are travel time and accident-related congestion. For the environmental assessment, fuel consumption and CO_2 emissions were assessed. Both were assessed at FOT level as well as at EU level (EU-27).

For both the efficiency and environmental impact assessment two approaches were used: a linear approach and a modelling approach. The linear approach used FOT data directly and effects were scaled up to the EU level via situational variables. The modelling approach used FOT data as input for traffic simulations and environmental models, in order to model the interaction between equipped and non-equipped vehicles at higher penetration rates than those in the FOT. The linear approach was applied to all functions. The modelling approach was applied to the ACC + FCW bundle and the SL/CC bundle, because for these functions (the largest) interaction effects were expected.

The results of the impact assessment were scaled up to the EU level to serve as input for the socio-economic cost-benefit analysis. Scaling up of traffic efficiency and environmental effects was based on EU vehicle kilometres.

2.5 Limitations of the study and implications for impact assessment

The most important aspects of the methodology for the impact assessment are given above. Before and during the FOT certain choices with regard to the FOT set-up and data collections were made. Some of the choices have implications for the way the impact assessment was carried out and/or the results. In this section these implications are explained. Some of them are more general issues, others are function-specific.

2.5.1 No separation of functions

The effects of ACC and FCW are presented as a bundle. This is because they were tested together in the same vehicles in the same period, and often used at the same time. The effects can therefore not be assigned to one specific system. For the same reason it was not possible to test the traffic efficiency effects of the lateral warning systems such as LDW, because this system was always present together with ACC and FCW, as the latter two are intended to operate in the longitudinal direction, it has been assumed that any longitudinal effect is due to ACC and FCW, while LDW has no longitudinal effect. To test these systems together was a choice in the design of the FOT. The rationale behind this choice was that either the functions are in practice often bundled when vehicles are commercially sold (because they use the same sensors), and that they were not expected to have effects on traffic efficiency and the environment.

2.5.2 Insufficient data collected

The test setup was changed and the test period shortened for many of the systems. Due to the dropped car sales, the number of participants was less than expected and it took longer to recruit them. For this reason the test setup for all functions was adjusted.

Due to this, some effects were not significant where they might have been with the original test setup. Examples are the average speed result of ACC and FCW on passenger cars on rural roads. Effects that were not significant were assumed to be zero.

In some cases this resulted in less detailed results. For instance, the effect of Navigation systems on travel time could not be determined on a road type level because concessions were made to the experimental set-up, especially the order in which the conditions were planned.

In some cases, it was not possible to test some of the hypothesis because the right type of data was not collected. In the case of the Fuel Efficiency Adviser, the collected data was too much aggregated and crucial performance indicators were missing. For this system it was not possible to determine any traffic efficiency or safety impacts. For the Curve Speed Warning, too few data was collected to obtain significant accident reductions. In the case of the navigation systems the advised route was not logged, so behavioural aspects about compliance to the route advice could not be used as input to the anticipated traffic simulations.

For all the systems, there were not enough data to look at combinations of situational variables, and in some situations even not enough data to look at single situational variables. Situational variables provide insight into the conditions under which drivers use systems, and can be used to explain the results better as well as to extrapolate impacts to national and EU-levels.

2.5.3 Seasonal influences

Due to the difficulties in recruiting participants another concession was made to the test setup. The adapted test setup did not always make it possible to consider seasonal influences.

2.5.4 Differences in test setups between VMCs

The ACC and FCW bundle, as well as the LDW and IW were tested in different VMCs. These VMCs had different test setups. Not only the baseline and treatment periods were different but also the configuration of the systems and the configuration of the sensors were different. Some vehicles were equipped with video data, while others were not. For some vehicles with FCW it was difficult to switch it off, while for others this was easy.

These differences are likely to cause differences in the results. It is however not possible to determine if an observed difference is due to one difference in the setup, or due to another, e.g. cultural differences between the drivers.

Despite the differences, the results from the VMC's had to be combined in order to prevent comparisons among manufacturers' systems.

2.5.5 Navigation Systems (built-in device and mobile device)

Each of the three conditions (without device, with mobile device, and with in-vehicle device; in different orders) endured about one month. This is a rather short period to evaluate the impact of navigation systems. Drivers were able to plan at least some trips in relation to the experimental condition (e.g. I will do this drive to an unfamiliar destination next week because then I will have a navigation system again). Some drivers even asked for a certain order of conditions because they wanted to avoid baseline condition in certain time periods (e.g. holidays planned). Since it was difficult to recruit participants, the order of conditions was changed accordingly to encourage drivers to participate in the FOT, an understandable choice. This influences the results (especially the mileage and distribution of mileage over road types) and therefore the effects are not split for road types.

2.5.6 Adaptive Cruise Control (ACC) and Forward Collision Warning (FCW)

For ACC and FCW the data from different fleets had to be integrated. It was anticipated that it could be a difficult job to explain possible reasons for differences between the fleets. Since the results were rather consistent, the approach proposed in the euroFOT methodology deliverable D6.2 was applied as anticipated. The results were determined per fleet and then weighted by mileage. Fleets for which the results were not significant were included in the overall result as if the effect was zero.

2.5.7 Fuel Efficiency Advisory (FEA)

During the FOT more than 3.6 million kilometres were driven in the baseline and treatment phases (equally distributed over the phases). The quality of this data is poor because data was logged only once every 30 minutes. Because of limited information on driving conditions during the FOT, making a reliable interpretation is very difficult, and for most hypotheses impossible. Influences from shifts in conditions (e.g. higher mileage on urban roads in baseline) or weather effects possibly overweigh the effects of the FEA use. For that reason only the effect on fuel efficiency is assessed.

2.5.8 Safety warning systems

The safety warning functions (Lane Departure Warning, Curve Speed, Warning, Blind Spot Information System, Impairment Warning) were not expected to have direct traffic and environmental effects. Therefore the FOT test was designed in such a way that it is not possible to derive the direct traffic effects of the safety warning functions directly from the data. The reason why the FOT test design did not foresee assessing these direct effects is that the safety warning functions have been tested together with other functions in one vehicle for efficiency reasons, e.g. ACC. In particular, ACC does have a clear direct impact on traffic flow. Any possible small effect from a warning function will be outweighed by a much larger effect on traffic flow by the ACC. It is therefore not possible to determine potential small direct traffic flow effects, if any, from the FOT data directly. Therefore direct traffic effects are not tested in the same way as for the other functions.

3 Navigation systems

Under the label SafeHMI, navigation systems are investigated that provide location and route guidance information to the driver. This includes real-time traffic information, so drivers are guided around traffic jam if that is more efficient. Both a mobile device and an in-vehicle version are tested in euroFOT. Navigation systems are tested in cars from BMW and Daimler.

The experimental set-up is as follows:

- Data are available for 99 drivers; they all drove without device, with mobile device, and with in-vehicle device, but in different orders. Drivers drove the same car during the whole test period.
- Each experimental phase endured about one month. Therefore, each driver participated for three months in the FOT. The duration of each condition is quite short because it had been decided during the planning of the FOT that for experimental power it is better to include more drivers with short measurement periods in the FOT than fewer drivers with a longer measurement period.
- During the FOT, the usage of the navigation system (no navigation system vs. built-in navigation system vs. mobile device) was instructed. The drivers could choose freely when and where to drive and how to use the navigation systems during their trips.
- The familiarity of trips is an important parameter that might influence the usage and the effect of a navigation system. In the Daimler vehicles the drivers were reminded at the beginning of each trip by a beeping sound to rate the familiarity of the oncoming trip by pressing a special button in the vehicle. The BMW drivers were instructed to press a defined button in the vehicle at the beginning of every unfamiliar trip.
- Two different HMI-solutions of the navigation function are compared. It is expected that the HMI-solution of a navigation system influences acceptance, and related to that probably also usage. Because the impact of a function on efficiency is influenced by system usage and also to keep presentation of results harmonized across deliverables, the results are presented separately for both HMI-solutions. It has to be kept in mind that the compared systems do not only differ in HMI-solution. Because they are produced by different manufacturers, they also differ regarding the used routing algorithm and – besides the basic functionality of a navigation system – also in extra functions offered by the system (e.g. the mobile device can store pictures, music, etc.). However, because both systems represent implementation of the same function that first of all differ in HMI-solution and because the analysis evaluates that function, the comparison is believed to be valid.

3.1 Summary of effects

In Table 7 a summary of effects of navigation systems on the FOT vehicles can be found. These effects are changes for the use of navigation systems compared to the baseline condition. ‘-‘ means that there is no significant effect.

Table 7: Summary of effects on FOT level (only cars) of navigation systems ('-' means that there is no significant effect)

	Built-in navigation device	Mobile navigation device
Average change in relative trip length per trip	-6.8 %	-
Average change in relative travel time per trip	-9.4 %	-7.0 %
Change in number of trips	-	-
Change in average speed	-	-
Change in incidental delay	-	-
Change in non-incidental delay (range, depends on road type)[2]	- 6% to 0%	- 10% to - 2%
Change in fuel consumption	-3%	-

What is shown in Table 7 is that there is a decrease in trip length (travel distance) and travel time per trip; these are typically the effects a navigation systems aims for. The effect sizes are larger for built-in navigation devices than for mobile navigation devices. The effects for travel time and travel distance are based on relative values and not on total mileage logged in the three conditions. Associated with these results there is a decrease in fuel consumption for the built-in navigation devices. For the mobile devices the effect on fuel consumption is not significant.

There is no change in number of trips and average speed when driving with navigation systems. There is a decrease in non-incidental delay ('daily' congestion, not congestion caused by incidents). However, this is not tested for significance since this part of the analysis was based on aggregated data (speed bins of 10 km/h). For a t-test to make sense more refined data (bins) would have been needed.

Additionally to the results given above, the analysis shows that the proportion of time spent in congestion does not change with navigation system usage. And the standard deviation of the speed when driving with a navigation system does not differ from the standard deviation of speed in the baseline condition.

3.2 System usage & mobility behaviour

To be able to interpret and explain the effects of the navigation systems, information on the use of the systems is needed, for example: on which type of trips do the drivers use the system(s), and how much of time / kilometres do the drivers use the system(s)? This section handles those questions.

As factors that possibly influence the usage of the navigation system, trip length and familiarity of route are considered. As can be seen in Figure 2, the proportion of trips in which the navigation system is activated rises with the length of the trip. Furthermore, the familiarity of the route has a larger impact on short than on long trips. The graphs show means and standard deviation. That's why the range of the error bars can leave the range of possible values (0-100%)

[2] Not tested for significance

The statistical testing reveals significant main effects on use of the navigation system for condition, familiarity and trip length and two significant two-way interactions (length*condition and length*familiarity). Taking the interactions into account, it can be concluded that the use of navigation systems increases with trip length. There is a difference between the two tested systems: the built-in device is used more often than the mobile device on trips longer than 100km. On shorter trips, usage is in general lower and no difference between the two systems can be found. Furthermore, navigation systems are used more often on unfamiliar trips, but only if the trip is shorter than 100km. For trips longer than 100km, navigation systems are nearly always used, independent of the familiarity of the trip.

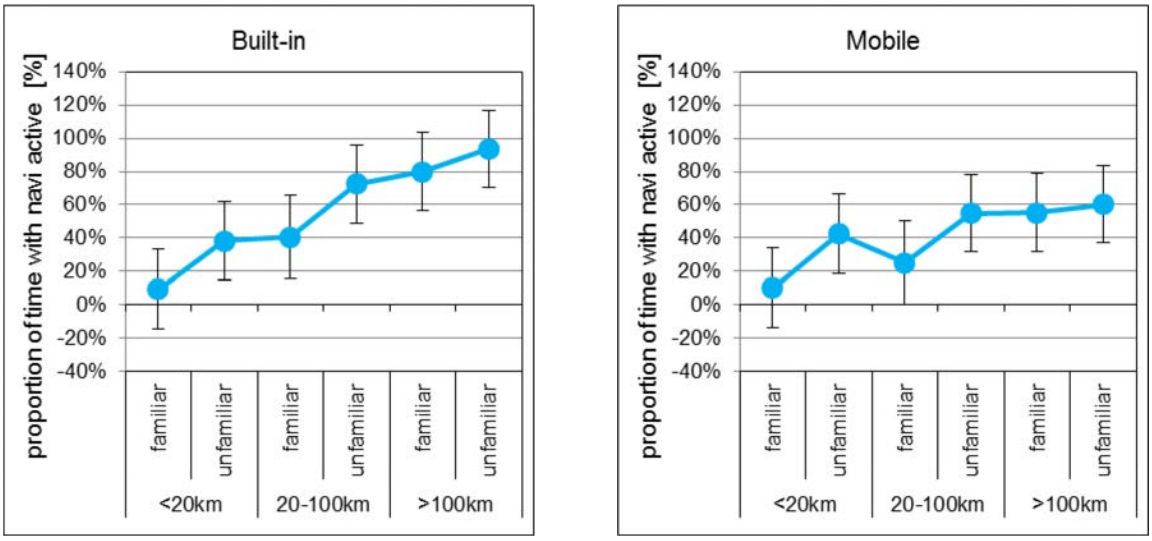

Figure 2: Proportion of trips with active navigation system by familiarity of route and trip length.

For scaling up, the proportion of kilometres with active navigation system is calculated. For the built-in device, the system is active for 49% of all kilometres driven (95%-confidence interval [44.2%-55.0%]); with the mobile device, the proportion of kilometres is 48.7% (95%-confidence interval [43.1%-54.3%]). There is not much difference between the two types of navigation systems with regard to proportion of kilometres that the system is active.

Table 8: Proportion of kilometres with active navigation system by road type and condition

	Built-in device		Mobile device	
	mean	Confidence interval	mean	Confidence interval
Motorway	75.1%	[70.3%; 79.8%]	59.4%	[53.9%; 65.0%]
Rural	47.8%	[43.0%; 52.7%]	46.2%	[40.6%; 51.8%]
Urban	31.8%	[28.0%; 35.5%]	40.2%	[35.0%; 45.5%]

3.3 Direct traffic effects

This section contains the results of the direct route per research question / hypothesis, first on FOT level and then on EU-27 level. Results are split for the built-in and mobile device.

3.3.1 FOT level

Absolute mileage and travel time

Mileage can be presented in different ways. We looked at the average mileage per trip and the distribution of mileage over the different road types. The average mileages and travel times are shown in the table below.

Table 9: Absolute mileage and travel time for the three conditions

	Average mileage per trip	Standard deviation mileage per trip	Change w.r.t. baseline	Average trip duration	Standard deviation trip duration	Change w.r.t. baseline
Baseline	31.5 km	7.9 km		27.9 min	11.4 min	
Treatment built-in device	34.7 km	9.0 km	+ 10.2 %	29.7 min	12.7 min	+ 6.5 %
Treatment mobile device	30.3 km	10.3 km	- 3.8 %	26.8 min	12.0 min	- 3.9%

What can be seen from the table is that with the built-in device, the average mileage per trip increases significantly with 10% compared to the baseline ($F(2,196)=6.12$, $p<0.05$). Since the number of trips per day stays the same, the average mileage per day also increases significantly with 10%. As a result of the 10% increase in average mileage per trip, trip duration is significantly higher in the condition with the built-in device compared to the mobile device ($F(2,196)=6.50$, $p<0.05$). For both parameters, the condition mobile device does not differ from baseline condition.

To evaluate whether there is a change in distribution over road types in the three conditions, the overall proportion of the different road types is calculated per driver and a two-way ANOVA is calculated. There is no effect of condition and no interaction. Therefore, the proportion of the different road types does not change with condition.

To give some more insight in the distribution of mileage over road types (and traffic states), in Figure 3 this information can be found for baseline and treatment periods. About two third of the kilometres driven is driven on motorways, about 17% is driven on rural roads, and 17% on urban roads.

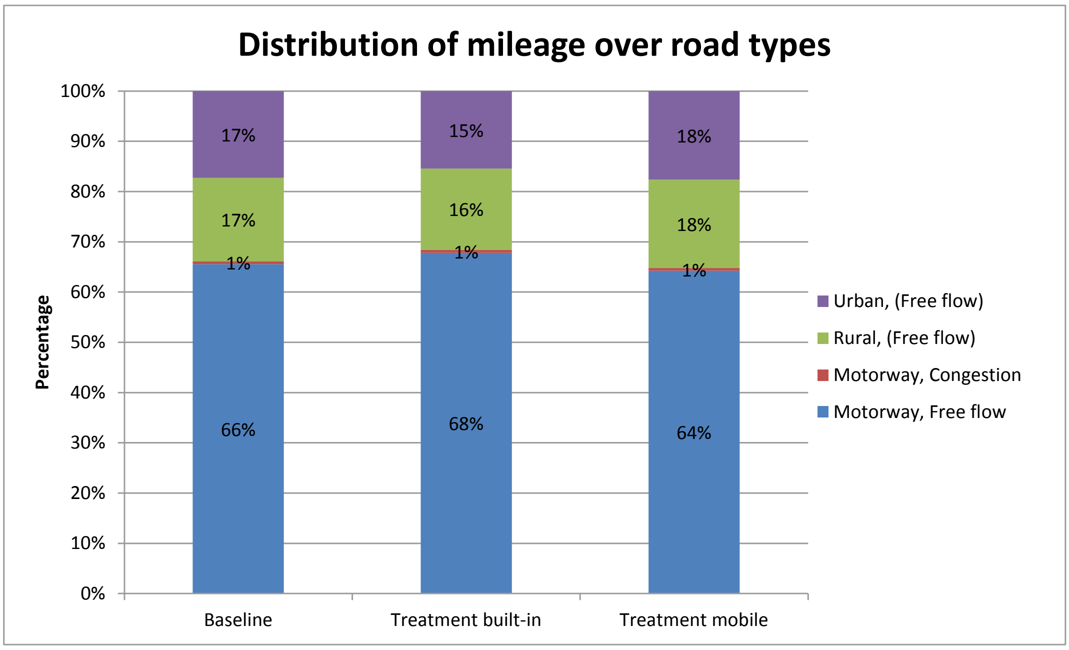

Figure 3: Proportion of FOT mileage on road types.

Relative distance and travel time

It is difficult to evaluate to impact of navigation systems on overall mileage based on the data collected in the FOT. The main reason for this is that the time spent in each condition is only one month and therefore rather short. In addition, drivers were at least partly able to plan their trips (e.g. holidays) in accordance with the FOT conditions. In summary, the reasons why the impact of navigation systems on absolute mileage cannot be evaluated with the FOT data are the following:

- The trips made are not standardized between conditions. Absolute values mainly depend on start and endpoints of a trip made; the variance between trips is large. Compared to that, the influence of a navigation system is expected to be little.
- The duration of one condition was only one month. This means that drivers were able to plan at least some trips in relation to the experimental condition (e.g. I will do this drive to an unfamiliar destination next week because then I will have a navigation system again).
- Some drivers asked for a certain order of conditions because they wanted to avoid baseline condition in certain time periods (e.g. holidays planned). Since it was difficult to recruit participants, the order of conditions was changed accordingly to make drivers participate in the FOT. This influences the results (especially the mileage and distribution of mileage over road types). Therefore the effects are not split for road types.
- Several drivers reported going on holidays in the condition built-in device (one even driving to Thessaloniki). It is not surprising that drives related to holidays influence overall mileage.

Therefore, to analyse the impact on navigation systems on travel time and distance a different approach was used. Travel time and travel distance have to be separated because regarding route choice they are not the same. For instance, if you would like to travel around a town, the shortest way (that is travel distance) would probably lead through the city centre. But because of traffic lights, urban traffic etc. along the way, this is not necessarily also the fastest route (travel time). It is probably faster to stay on the highway that leads around the town. In navigation systems, this difference is reflected in the options that drivers can often choose between fastest and shortest route. To evaluate the influence of a navigation system on trip length and duration, relative values are calculated. To do so, for each trip an estimated route length and trip duration based on start and end GPS-position are derived with a reference route planner. Based on those estimates, the difference between measured route distance and trip duration and the estimated values is calculated. The parameters used describe the difference as a percentage of the estimates. Negative values indicate a decrease in relative travel time or distance and positive values an increase. For the analysis, only the differences between conditions are relevant because it is not the aim of the analysis to evaluate the reference route planning software but to compare the efficiency of route choice in the three conditions.

For the analysis, a trip is considered as driving with navigation system active if the route guiding function has been activated for at least 50% of trip time.

Statistical tests show that for distance the difference between baseline and built-in device is significant and the difference between baseline and mobile device is not significant. For trip duration, the difference between baseline and both treatment conditions is significant. Note that Figure 4 shows means and standard deviations. Because it is tested with a within-subjects design, the error bars do not provide information regarding the significance of statistical testing. This accounts for the standard deviations in Table 10 as well. More information on significance can be found in Annex 1.

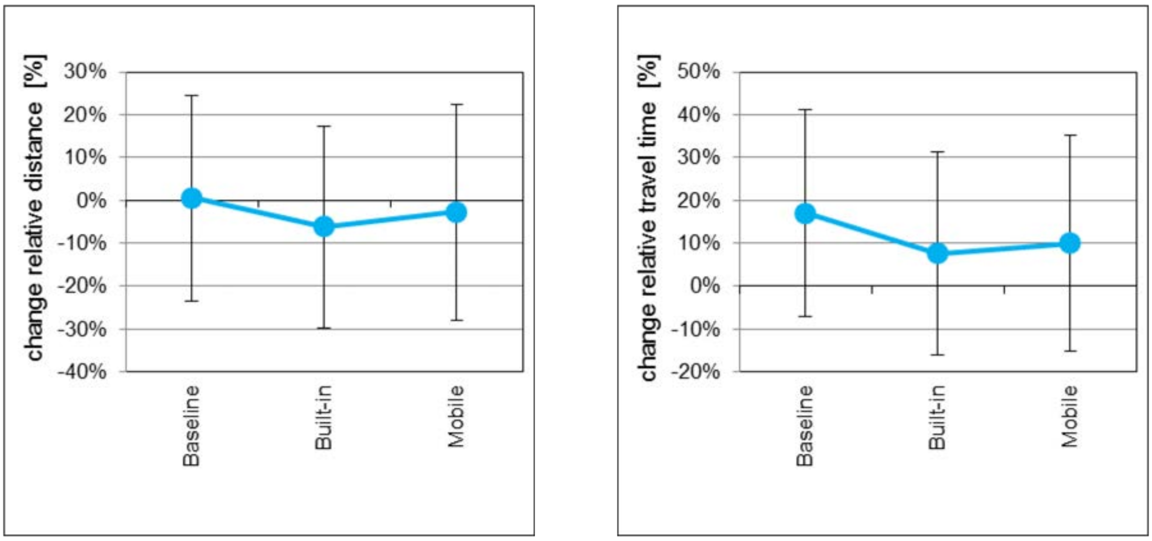

Figure 4: Mean difference between measured and estimated trip distance and trip duration

Table 10: Relative mileage and travel time in the three conditions

	Relative mileage	Standard deviation relative mileage	Change w.r.t. baseline	Relative duration	Standard deviation relative duration	Change w.r.t. baseline
Baseline	+0.6 %	15.4 %		+17.0 %	26.1%	
Treatment built-in device	-6.2 %	21.9 %	-6.8%	+7.6%	34.7%	-9.4%
Treatment mobile device	-2.7%	19.5 %	-3.3%	+10.0%	27.8%	-7%

Hypothesis 3b: The number of vehicle km travelled will decrease (objective data).
We have looked at the trip length. This hypothesis is accepted for the built-in device. The relative trip length is reduced by 6.8 % compared to the baseline. For the mobile device there is a decrease as well but this is not significant.

Hypothesis 6: The travel times will decrease.
This hypothesis is accepted for both the built-in device and the mobile device. The relative trip duration is reduced by 9.4 % with the built-in device and by 7% with the mobile device.

Research question 3: What is the impact of navigation systems on travel times?
With navigation system the relative travel time decreases between 7% with the mobile device and 9.4% with the built-in navigation system.

The effects as reported in this section are effects that could be expected from navigation systems; a decrease in travel time is one of the things navigation systems typically aim for.

In a Dutch literature study from 2008 [8] effects of dynamic navigation systems (in-car navigation systems that give route advice based on real-time traffic information) were researched. Main findings from literature were that with a dynamic navigation system there is a decrease in travel time in the range of 8% to 26% (this last number was only for users not familiar with the area. One study reported a change in mileage, of -16%. The euroFOT results are in this range, however a bit on the lower side.

Number of trips

In all the measurement periods (baseline and treatment), and for both devices (built-in and mobile), around 3.6 trips per day are made on average: 3.55 (standard deviation = 1.54) in the baseline period, 3.61 (standard deviation = 1.51) in treatment built-in period, and 3.62 (standard deviation = 1.43) in treatment mobile period. There is no significant difference between the three conditions in the number of trips made per day.

Hypothesis 2: The average number of trips made will increase. This hypothesis is rejected. The average number of trips made per day does not change.

There is a tendency for a larger proportion of unfamiliar trips to be made in the condition with the built-in navigation system ($F(2,194)=2.98$, $p=0.052$), compared to the mobile system and the baseline, see Figure 5. This means that with the built-in system, relatively more unfamiliar trips are made than with the mobile system and more unfamiliar trips are made than during the baseline period. However, this result is not statistically significant.

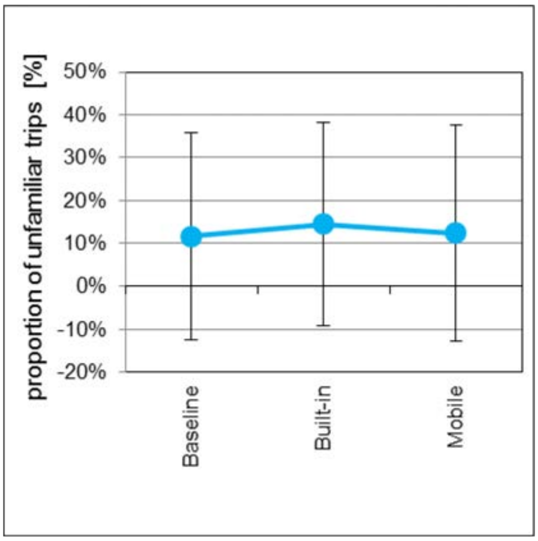

Figure 5: Proportion of unfamiliar trips in the three conditions

The proportion of unfamiliar trips varies between 11.6% (confidence interval [9.0%; 14.3%]) in the baseline condition and 14.5% (confidence interval [11.3%; 17.8%]) in the condition built-in device.

Drivers' rating of driving frequency

After each condition, drivers were asked whether their driving behaviour during the last four weeks differed from their normal driving behaviour. Drivers rated their driving frequency and the frequency of driving on unfamiliar routes on a bipolar scale between -2 = less often than usual and +2 = more often than usual. The results are given in Table 11.

Subjective data indicate that drivers drive more trips than usual in the condition built-in device. In the two other conditions their driving frequency does not differ from their normal driving habits. Furthermore, more unfamiliar trips than usual are made in the condition with the built-in navigation system and fewer unfamiliar trips than usual are made in the baseline condition. With the mobile device, drivers state that the frequency of unfamiliar trips is unchanged. In practice navigation systems are already widely used. Ninety-three per cent of drivers state at the beginning of the FOT that they have a lot of experience with navigation systems. In that sense, driving with a navigation system available can be considered normal driving for a majority of drivers. This could explain the outcome that fewer unfamiliar trips than usual are made in the baseline condition. Also, as discussed previously, some drivers asked for a certain order of conditions because they wanted to avoid baseline condition in certain time periods (e.g. holidays planned). This influences the results, at least the results on the proportion of unfamiliar trips per condition.

Table 11: Subjective rating of driving frequency and frequency of unfamiliar trips

	Frequency of driving					Frequency of unfamiliar trips				
	mean	**Standard deviation**	**N**	**t**	**p**	**mean**	**Standard deviation**	**N**	**t**	**p**
Baseline	-0.06	0.627	107	-0.929		-0.25	0.728	107	-3.585	<0.01
Built	0.16	0.614	108	2.665	<0.01	0.24	0.695	108	3.598	<0.01
Mobile	-0.05	0.523	106	-0.928		-0.06	0.599	106	-0.973	

In a next step, drivers were asked why they changed their driving behaviour. Regarding their general driving frequency, 26% answered that they changed their behaviour because of the navigation system. The other 74% stated that the changes were due to other reasons (e.g. holidays). Regarding the frequency of unfamiliar trips, 63% answered that they avoided those trips because of the lack of a navigation system in the baseline condition and 53% that they had more unfamiliar trips in the condition with the built-in device because of the navigation system.

Hypothesis 3a: The number of vehicle km travelled will decrease (subjective data).
For absolute driving frequency this hypothesis is rejected for both the built-in device and the mobile device. For the mobile device there is no significant result when the drivers are asked about their frequency of driving. For the built-in device there is an increase in vehicle km travelled according to the drivers. However, the majority of the drivers states that this change in behavior was not caused by the FOT condition but by other reasons. In summary, drivers' statements confirm what has been objectively measured based on absolute mileage. But the answers give reason to assume that the observed change is not caused by the navigation system. Therefore, the hypothesis cannot be confirmed and is rejected.

Average speed

In Figure 6 below, average speed is shown for different road types and different conditions. Mean speed is calculated per trip and aggregated per driver. To do so, a mean weighted by travel time is calculated over all trips for each driver.

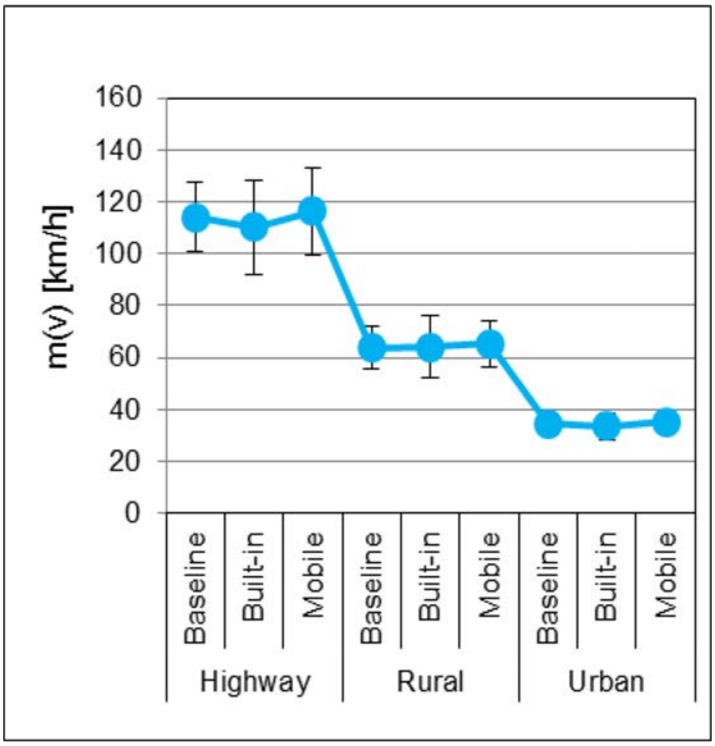

Figure 6: Mean speed for road type and condition

Overall, there is an effect of condition on mean speed. This effect is caused by a higher proportion of motorways in the condition driving with a navigation system active. Separate testing per road type has shown that speed does not change significantly when a navigation system is used.

In Figure 7 below the speed distribution per road type is given for baseline and treatment periods. It is cut off at 160 km/h so for motorways part of the distribution is missing. However, this does not affect the conclusions that we draw.

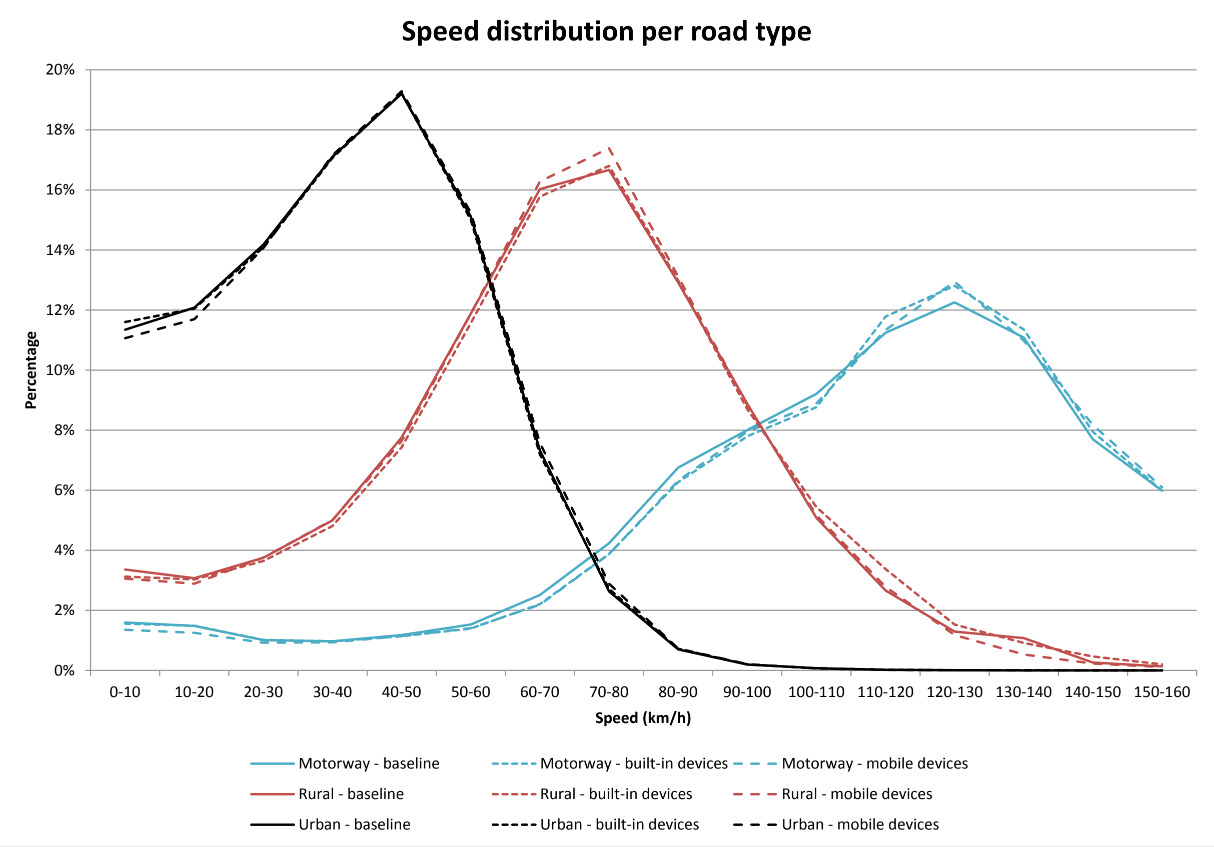

Figure 7: Distribution of speed for different road types.

From the graph above we can conclude that there is not much difference between the speed distributions for the different conditions. For rural roads and motorways it seems that more people drive at relatively higher speeds in the treatment condition compared to the baseline condition. This is confirmed by the cumulative speed distributions given in Figure 8 since there the dotted lines (with navigation systems) are positioned to the right of the baseline line. However, this is a very small effect.

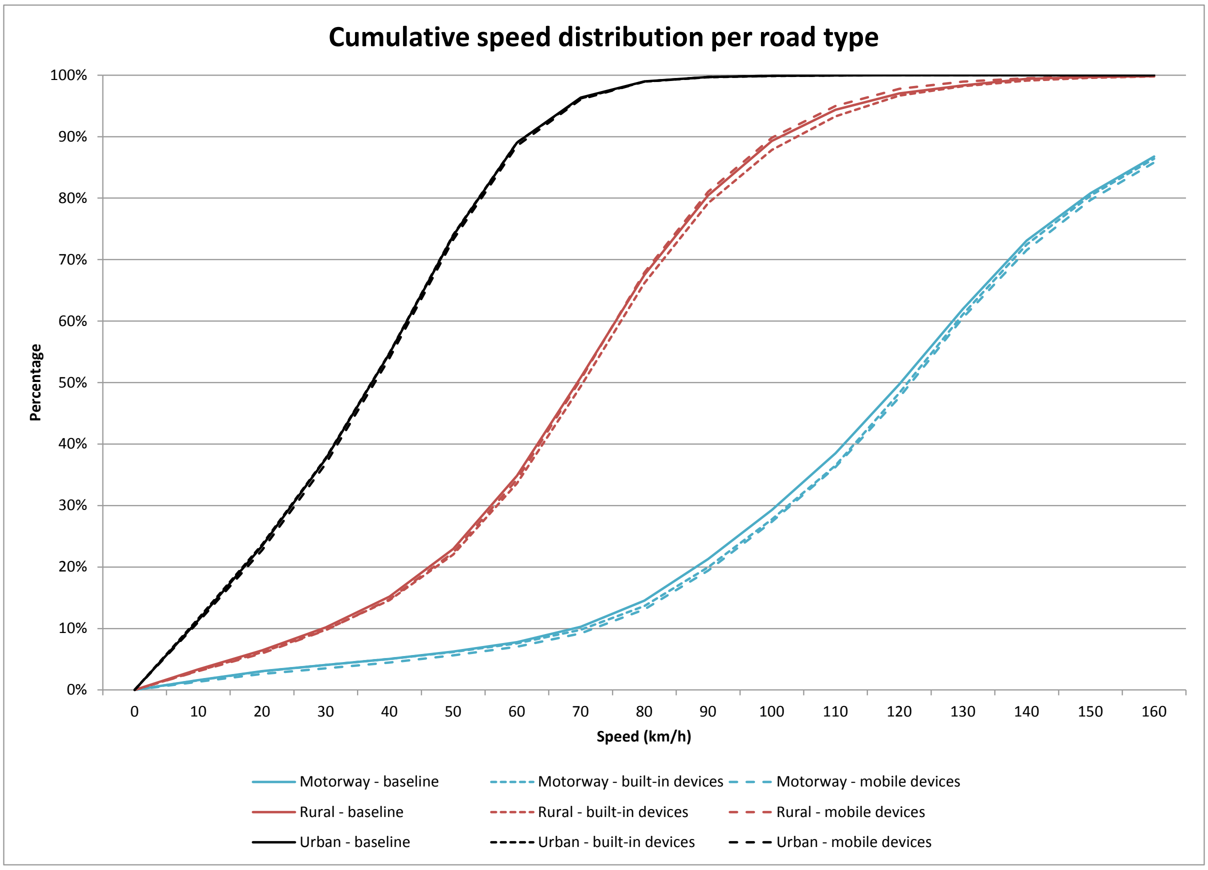

Figure 8: Cumulative distribution of speed split for the different road types

Hypothesis 1: The average speed will decrease. This hypothesis is rejected. The average speed does not change when driving with the navigation system active.

Research question 1: What is the impact of navigation systems on average network or journey speed? The average network speed is not calculated for navigation systems since no simulations were carried out. The average speed is calculated but there is no significant effect of navigation systems on average (journey) speed

Delay & time spent in congestion

All tested navigation systems were equipped with a dynamic routing function which adapts the chosen route dynamically to available traffic information. The goal of this function is to help the driver to avoid traffic jams. Since congestion is only defined for motorways, the analysis on time spent in congestion is restricted to motorway sections. The dynamic routing function is one that is supposed to make driving more efficient independent of the familiarity of the trip. Therefore, the factor familiarity is not included in the analysis. See Figure 9 for the proportion of time spent in congestion for the different conditions.

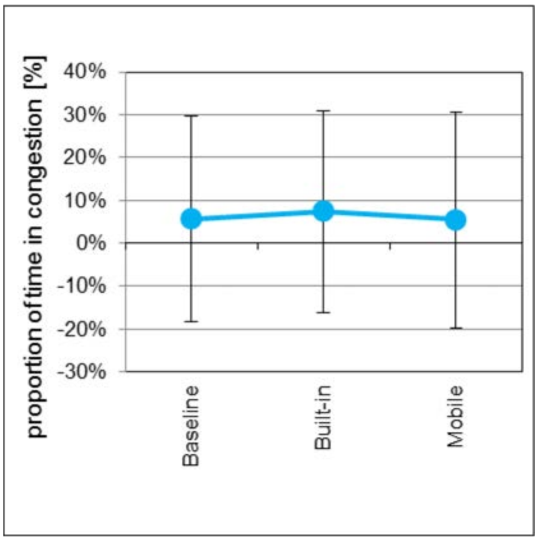

Figure 9: Proportion of time spent in congestion

In Figure 9 it is shown that the proportion of time spent in congestion is around 5% for the baseline period and the built-in device. For the mobile device this proportion is lower, around 3%. Statistical testing shows that there are no significant differences between the conditions regarding the proportion of time spent in congestions.

Delays are calculated with use of the speed distribution. As a starting point we assume that on motorways vehicles driving slower than 100 km/h are delayed, on rural roads the boundary is 80 km/h and on urban roads the boundary is 50 km/h. Vehicles that drive 5 km/h cause more delay than vehicles that drive 40 km/h. As a measure for delay vehicle loss hours are used.

Changes in share of delays (vehicle loss hours compared to the total travel time) are given in the table below, as well as the absolute values. Delays are lower for the treatment periods except for the built-in devices on urban roads. However, the increase in delay on that road type is very small. These results are not tested for significance since they were available only on a higher (aggregated) level. .

Table 12: Delays baseline and treatment period Navigation systems

	Delays		
	Motorways	**Rural roads**	**Urban roads**
Baseline (% time spent in delay compared to total travel time)	8.9%	22.2%	32.8%
Treatment built-in device (% time spent in delay compared to total travel time)	8.5%	21.5%	33.0%
Treatment mobile device (% time spent in delay compared to total travel time)	8.0%	21.8%	32.2%
Change treatment built-in versus baseline period	-4.3%	-3.2%	0.5%
Change treatment mobile versus baseline period	-9.7%	-1.7%	-1.7%

Hypothesis 4: The proportion of time spent in congestion will decrease.
This hypothesis is rejected. The proportion of time spent in congestion does not change significantly with a navigation system.

Research question 2: What is the impact of navigation systems on the amount of delay?
There is less delay in the treatment conditions. However, the absolute amount of delay was small, and the decrease of delay is not tested for significance.

3.3.2 EU-27 level

An important assumption in scaling up is that we assume that the effect found in the FOT will also be found when the navigation system is used by other drivers in other parts of Europe. The FOT showed that there are large differences between the two tested navigations systems. It is therefore difficult to predict the effect of other navigation systems available. A second reason that makes it difficult to scale to an EU level effect is that there are differences between the FOT network (Germany) and the total European network. There are, for example, differences in the density of the network and differences in the possibilities for route change in the network. In Germany two thirds of the kilometres were driven on the motorway, and this is not the case in all of Europe. The effect is likely to be determined by the network topology. Finally, scaling up to EU level requires that the current market penetration and usage rate is known. For navigation systems this is information is not available on EU level. For these reasons, the effects found in the FOT are not scaled to EU level.

3.4 Indirect traffic effects

The safety impacts of navigation systems are that urban intersections are approached in a safer way. But, results of a more detailed analysis that considered familiarity of the trip as a moderating factor, showed effects that a not in-line with a naïve assumption of how navigation systems might support driving safety. Furthermore, mechanisms through which navigation systems might influence driving safety are neither studied nor reported in the literature. Because of that it is unclear how global the observed change in safety indicators is and whether it is caused by the navigation system or by some other uncontrolled factor. , Because of that the results regarding driving safety results cannot be translated into a change in number of accidents. Therefore, indirect traffic effects were not calculated.

Hypothesis 4: The amount of incidental related delay in the network will decrease. This hypothesis could not be tested because no safety effect was calculated.

3.5 Direct environmental effects

To assess effects of a navigation system on the environment the gathered objective FOT data was evaluated regarding fuel consumption. The evaluation was split for the built- in and the mobile device.

3.5.1 FOT level effect

The FOT level effects on environment are split into effects on the fuel consumption and the number of km driven while using the system. Details on the change in km driven can be found in section 3.3 on direct traffic efficiency effects.

Effect on fuel consumption

For the built-in navigation system, a significant decrease of fuel consumption in l/100km can be found in urban and rural areas. The decrease varies between -2.9% and -4.6%. This decrease is strong enough to lead to a significant overall decrease of fuel consumption while the difference in effect between the two road types is not significant. A possible explanation for this reduction is that the routing algorithm encourages the use of larger roads on which the fuel consumption is lower. This hypothesis is investigated below. In summary, the results for the built-in navigation system indicate a significant influence of the function on fuel consumption.

Table 13: Results for change of fuel consumption (in l/100km) for the built-in navigation system

Factor	P-value	Absolute difference [l/100km]	Relative difference [% of baseline]
All	<0.05	-0.29	-3.08
Motorway	>0.05	0.08	0.90
Rural	<0.01	-0.25	-2.93
Urban	<0.001	-0.54	-4.65

Contrary to that, there is no significant influence of the mobile device on fuel consumption. For this, there might be several reasons. First, drivers indicate that they do not trust the mobile device and that the mobile device sometimes gives wrong or inefficient routing advice. It is possible that the expected errors of the mobile device prevent a more anticipating driving style and therefore a reduction of fuel consumption like found for the built-in navigation system.

Table 14: Results for change of fuel consumption for the mobile device

Factor	P-value	Absolute difference [l/100km]	Relative difference [% of baseline]
All	>0.05	-0.14	-1.49
Motorway	>0.05	0.12	1.37
Rural	>0.05	0.01	0.12
Urban	>0.05	-0.2	-1.74

The other option is that the routing algorithm of the mobile device prefers routes on smaller roads and through residential areas and does not advise the driver to stay as much as possible on main roads. Therefore, route choice by the system might prevent a reduction of fuel consumption. To test this possibility, information called functional road class provided by the digital map is used. The road class codes for a certain area whether a road is considered a major or minor road. Road class 1 mostly corresponds to motorways; road class 5 to very small residential roads. The road class does not directly match to road category because for instance in rural areas the local road class 1 might be a larger rural road because no motorway exists.

The differences between the road classes are reflected in average speed on the corresponding roads.

Table 15: Mean speed in km/h on the different road classes

	RC1	RC2	RC3	RC4	RC5
Rural	73.9	67.4	62.9	58.9	43.6
Urban	41.8	40.6	36.1	32.7	26.7

Different navigation algorithms deal differently with the road class information provided by the map. The analysis shows that while driving with the built-in device drivers spent a larger proportion of time on larger roads (that is roads with lower road classes) (rural roads: RC1 $F(2, 170)=21.992$, $p<0.001$; urban areas: RC2 $F(2, 172)=33.914$, $p<0.001$) and a smaller proportion on smaller roads (that is higher road classes) (rural roads: RC3 $F(2, 170)=12.229$, $p<0.001$; urban areas: RC5 $F(2, 172)=58.711$, $p<0.001$).

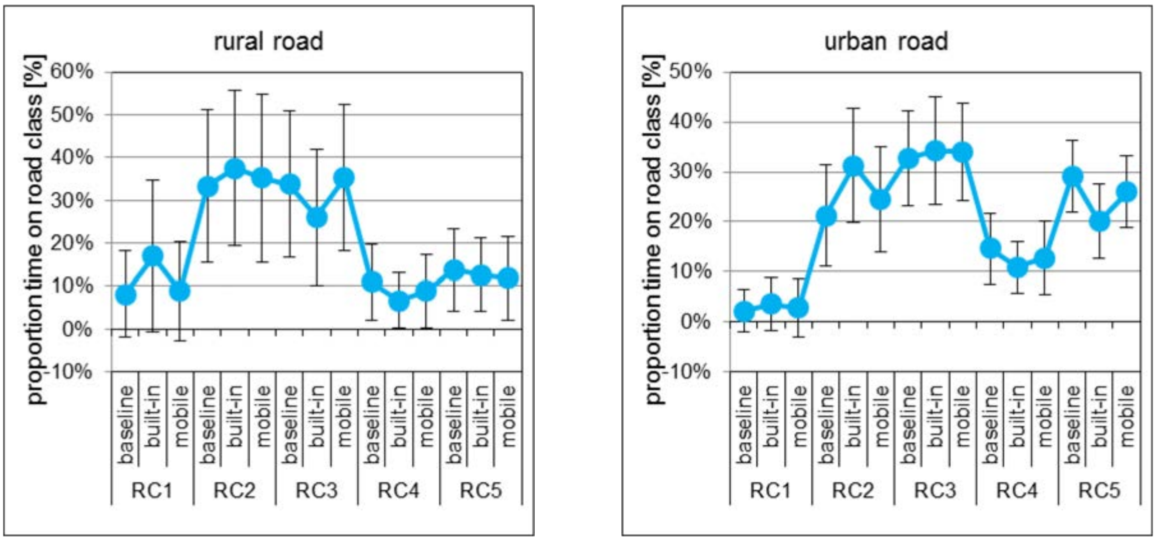

Figure 10: Proportion of time spent on the different road classes

The results indicate that the routing algorithm used by the built-in device prefers staying on main roads to a higher degree than the algorithm used by the mobile device. This is in line with the assumption that the differing effects of the two HMI-solutions might be caused by specific characteristics of the routing algorithms used by the two navigation systems.

In summary, the analysis indicates that navigation systems have the potential to reduce fuel consumption in urban and rural areas. The built-in navigation system supports the driver to stay to a higher degree on larger urban roads on which driving is in general faster and more smooth than on small residential roads and gives therefore a positive effect on fuel consumption. So the results show that the effect is influenced by a change in route choice (and therefore by characteristics of the used routing algorithm) and not by a change in driving style (e.g. more anticipating). Since it is a specific characteristic of the routing algorithm, and both systems under investigation show different fuel consumption reductions, it is not possible to generalise the euroFOT results to other navigation systems.

Hypothesis: Navigation system decreases the fuel consumption.
Navigation systems seem to have the potential to reduce fuel consumption in urban and rural areas. Results indicate that the difference between the two HMI-solutions is based on the used navigation algorithm (and therefore on the functionality of the specific system tested).

Summary of effects of navigation systems on mileage

Besides the absolute reduction of fuel consumption per 100 kilometres, an overall positive effect of navigation systems on the environment exists because both systems reduce travel time. The detailed results on the reduction in driven km can be found in the direct traffic efficiency effects (chapter 3.3). The comparison of route choice by the two navigation system indicated that routing algorithms that support a more pronounced usage for major compared to minor roads do not only reduce travel time but also fuel consumption on the kilometres driven. Furthermore, for both navigation systems, no reduction of time spent in congestion can be found. Therefore, based on the limited FOT-data it cannot be concluded that the dynamic routing function effectively avoids congestion on highways.

3.5.2 EU-27 level effect

Because the significant reduction in fuel consumption with the built-in device is not supported by the mobile device it cannot be decided whether this effect is related to the individual routing algorithm of a specific system or a common effect of navigation systems. Therefore, scaling up this effect to the EU-27 level is not reasonable without further investigation of the effect.

4 Adaptive Cruise Control (ACC) and Forward Collision Warning (FCW)

This chapter contains the results of the ACC and FCW bundle for cars and for trucks. The results for cars are based on three types of cars: Volvo, Ford and Volkswagen. The results for trucks are based on two types of trucks: Volvo and MAN.

The ACC function supports the driver in selecting (and then automatically maintaining) an appropriate speed and distance to the vehicle in front depending on his preferences and the current traffic situation. ACC controls actively the vehicle speed; it detects and tracks if a vehicle is in front and adjusts the speed accordingly. The function is not active below a certain speed. Depending on the system performance the lower limit of the speed is between 0 and 30 km/h.

The FCW function provides alerts to assist drivers in avoiding or reducing the severity of crashes involving the equipped vehicle striking the rear of another vehicle. The function detects and tracks obstacles in front of the vehicle and provides a warning to the driver in case the evaluation of trajectories and relative speed of the subject vehicle and the obstacle show a high probability of a collision. Depending on the system specifications the lower limit of the speed is between 7 and 30 km/h: the system does not provide alerts below this speed.

The experimental set-up is as follows:

- Data are available from 242 drivers and were used to test the average speed effect of ACC and FCW (64 Volvo car drivers, 88 Ford drivers, 26 Volkswagen drivers, 58 Volvo truck drivers, 6 MAN truck drivers).
- Ford and Volkswagen and Volvo car drivers and MAN and Volvo truck drivers all drove without ACC and FCW in the baseline period and with ACC and FCW in the treatment period. In the baseline period, Volvo car and truck drivers had an ordinary non-adaptive Cruise Control system in their car, and the treatment period was the same as for the other vehicles. Drivers drove the same car during the whole test period.
- Each driver participated for at least 6 months in the FOT. For instance, for Volvo cars the duration of the baseline period was 3 month and the treatment period varied between 6 and 9 months for different drivers.

The direct traffic effects on FOT level are split for cars and trucks. The effects on cars are shown on an aggregated level (over the three car types) as much as possible. However, not all baselines are the same. These different baselines resulted in other effects of ACC and FCW when comparing the treatment period to the baseline period. Truck results are also shown on an aggregated level (over the two truck types) as much as possible. As well as for the cars, Volvo truck drivers had a Cruise Control system in their trucks during the baseline period.

The direct traffic effects on EU-27 level are given for cars and trucks together. After this the indirect traffic effects, the simulation results, and the environmental effects are given.

4.1 Summary of effects

In the treatment period (when the vehicles are equipped with ACC and FCW) there is a small reduction in average speed for cars, compared to the baseline. The effect on trucks is minimal. The subjective results show no effect of ACC and FCW on mobility behaviour, route choice and choice of road type.

Traffic simulations show that the effect on network speed is similar in size to the effect found in the FOT and generally linear when more vehicles are equipped. The simulations are based on the driving behaviour and system usage observed in the FOT. The effect scales linear with the penetration of equipped vehicles in most situations. In heavy traffic scenarios when less than 25% of the vehicles are equipped, the average network speed reduction is slightly stronger than the speed reduction measured for the individual FOT vehicles. When the effects are scaled to EU scenario in the CBA, a linear relation is assumed.

For both passenger cars and trucks there is a significant reduction in fuel consumption while driving with ACC and FCW.

ACC and FCW are used more often at higher speed ranges. When ACC and FCW are active (this is not the whole treatment period, but only the times when ACC + FCW is switched on and active), speeds are higher than the average in the baseline period. When ACC and FCW are not active or off, speeds are lower than the average in the baseline period. Overall, including all kilometres driven in treatment both with ACC active and ACC not active, the average speed is slightly reduced, as mentioned above.

In Table 16 a summary of the effects of ACC and FCW on the FOT vehicles can be found. These effects are changes for the use of ACC and FCW compared to the baseline condition. '-' means that there is no significant effect.

Table 16: Summary of effects of ACC and FCW on FOT level

('-' means that there is no significant effect)

		ACC and FCW	
		Cars	**Trucks**
Change in average travel time per trip	**Motorway**	0.3%	0.1%
	Rural road	-	0.02%
	Urban road	0.2%	-
Change in kilometres driven per trip[3]		0%	0%
Change in average speed	**Motorway**	- 0.3%	- 0.1%
	Rural road	-	- 0.02%
	Urban road	- 0.2%	-
Change in incidental delay			
Change in non-incidental delay (range, depends on road type)[4]		0% to 18%	- 26% to + 2%
Change in fuel consumption[5]	**Motorway**	- 2.1%	- 1.9%

What is shown in Table 16 is that there is a small increase in average travel time and a small decrease in average speed. For trucks these effects are marginal. The fuel consumption decreases on motorways.

There is no change in the number of kilometres per trip. There is a tendency towards an increase in non-incidental delay for cars, and a tendency towards a decrease in non-incidental delay for trucks, but this is not tested for significance.

[3] Based on subjective data
[4] Not tested for significance
[5] For car following situations on motorways

Link with EU-27 results and cost benefit analysis

What is important to know for scaling up to EU-27 level and for cost benefit analysis, is what the change caused by ACC and FCW (compared to the baseline condition) is in:

- Number of kilometres driven
- Distribution of kilometres driven over the different road types
- Travel time
- Average speed (per road type)
- Delay (incidental and non-incidental)
- Fuel consumption

From the ACC and FCW results, only the change in average speed, travel time and fuel consumption on motorways plays a role for scaling up and CBA, see Table 17.

Table 17: Summary of effects of ACC and FCW on EU27 level

		EU level
		All
Change in average travel time per trip	**Motorway**	0.7%
	Rural road	0.0%
	Urban road	0.1%
	All	0.2%
Change in fuel consumption	**Motorway**	0.96%

4.2 System use & mobility behaviour

To be able to interpret and explain the effects of ACC and FCW, background information on the use of the system and on mobility behaviour is needed, for example: on which road types do the participants drive, on which road types do the drivers use the system(s), do the drivers change their strategic driving behaviour? These background data are obtained both from subjective data (questionnaires) and objective data.

The following results from the subjective data:

- From the car drivers, about 4% to 15% say their travel pattern changed since driving with the *ACC system*. However, the explanations they give for this mostly do not have to do with travel pattern, but with usage of the system. What is said most often is that they use ACC most on motorways, and do not use it really on urban roads. Some people remark that they drive in a calmer way.
- About 4% of the car drivers say their travel pattern changed since driving with the *ACC system*.
- For both Ford and Volvo cars about 4% say that their travel pattern changed since driving with the *FCW system*.
- For trucks, only 1 of the 31 truck drivers says that their driving pattern has changed. It has become “more consciously”. Of the truck drivers, 97% indicated that ACC did not change their mobility behaviour and 100% indicated that FCW did not change their mobility behaviour.

With respect to the traffic efficiency analyses, we learn the following from the subjective data:

- There is no indication that participants drove more or fewer kilometres with ACC and FCW compared to the baseline.
- There also is no indication that there is a change in distribution of kilometres over different road types with ACC and FCW compared to the baseline.
- ACC is used most on motorways.

The objective data confirm these outcomes, as will be explained in the rest of this section.

Use of ACC and FCW per road type

See Figure 11 for the use of ACC and FCW on different road types for cars, and Figure 12 for trucks. In these figures the share of kilometres in which ACC and FCW were active is shown.

The use of FCW depends strongly on the system configuration. In some vehicles it is very difficult to switch the FCW off, and the FCW is automatically switched on when the vehicle starts. In other vehicles the FCW is switched off much easier and stays off when the vehicle starts for the next trip. Therefore, only the usage of ACC is presented in the figures below.

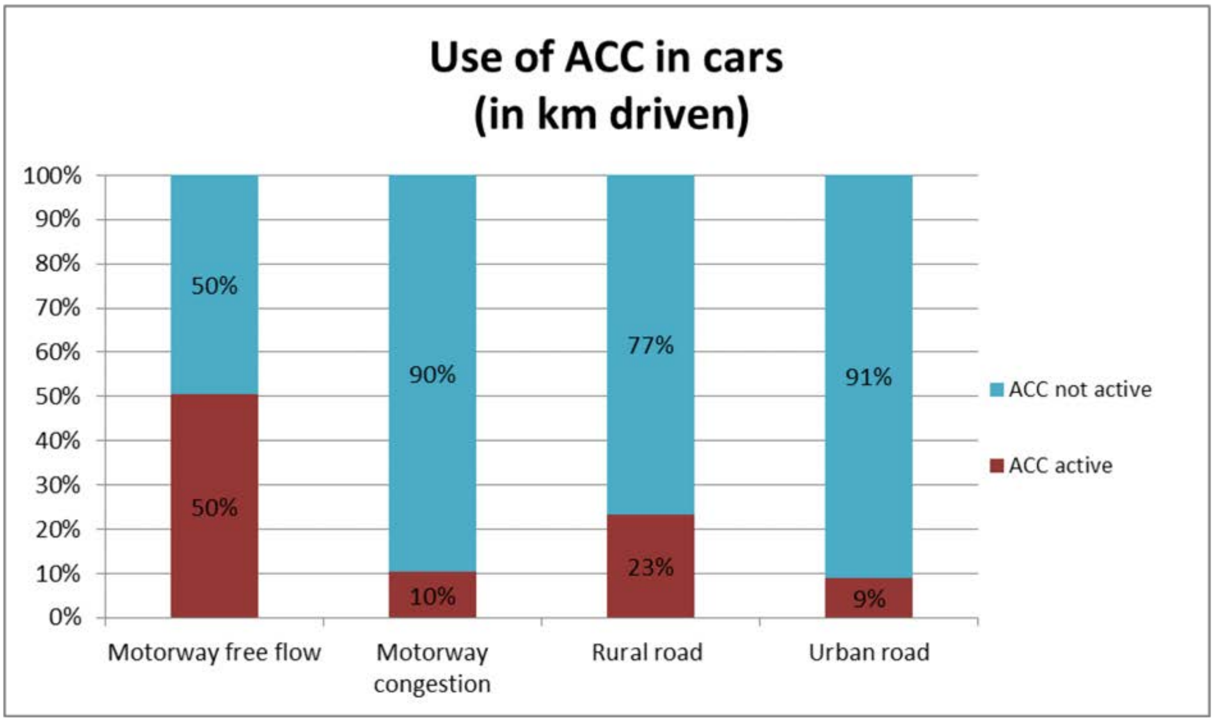

Figure 11: Use of ACC in cars, treatment period

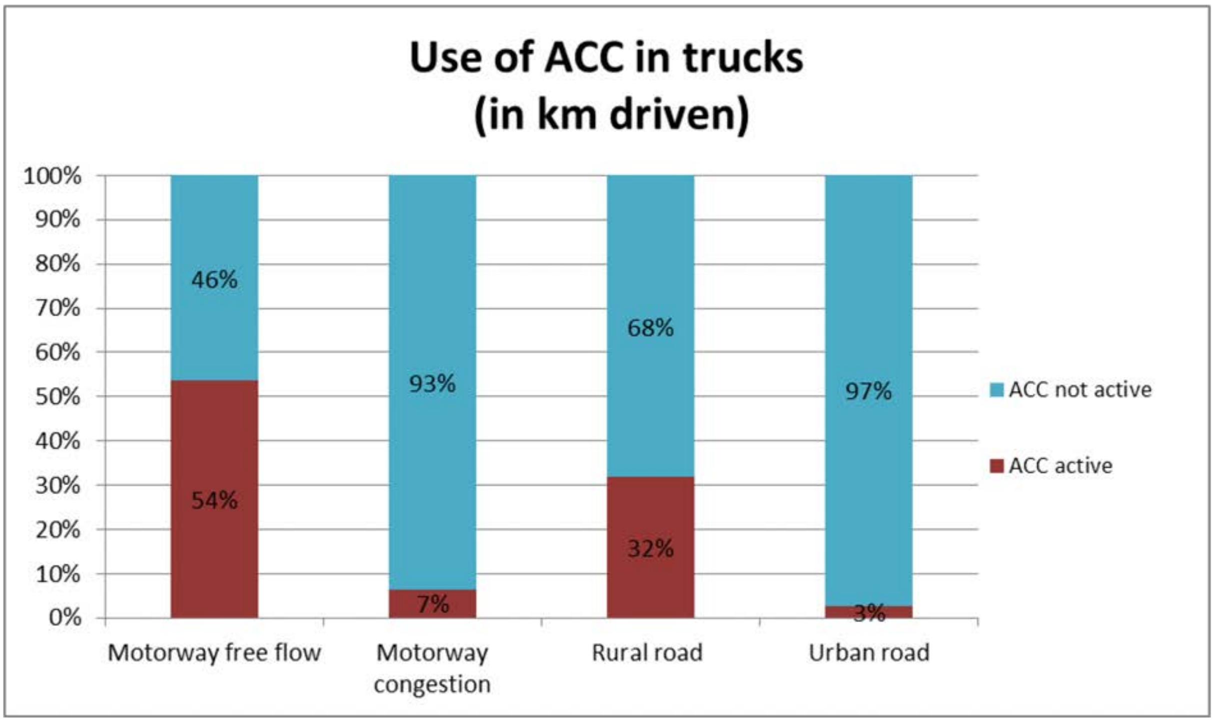

Figure 12: Use of ACC in trucks, treatment period

Figure 11 and Figure 12 show the following:

- ACC and FCW are mainly used on motorways in free flow situations, in 50% and 54% of the kilometres driven for cars and trucks respectively.
- On rural roads ACC and FCW is used less, about 25% and 32% of km driven for cars and trucks respectively.
- On urban roads ACC and FCW are not used much. Trucks almost never use the systems (for only 3% of the kilometres driven), and car drivers use the systems for 9% of the kilometres driven.
- ACC and FCW are not used much on motorways during congestion (10% of kilometres driven by cars, 7% by trucks), but this situation does not occur very often as is shown later.
- Overall (for all road types), ACC and FCW are active 31% of kilometres driven for cars and 40% of kilometres driven for trucks.

These outcomes match with the outcomes of the analyses of the subjective data.

Distribution of kilometres driven over road types

In Figure 13 and Figure 14 the distributions of kilometres driven on the different road types are given for cars and trucks, for the baseline and treatment period.

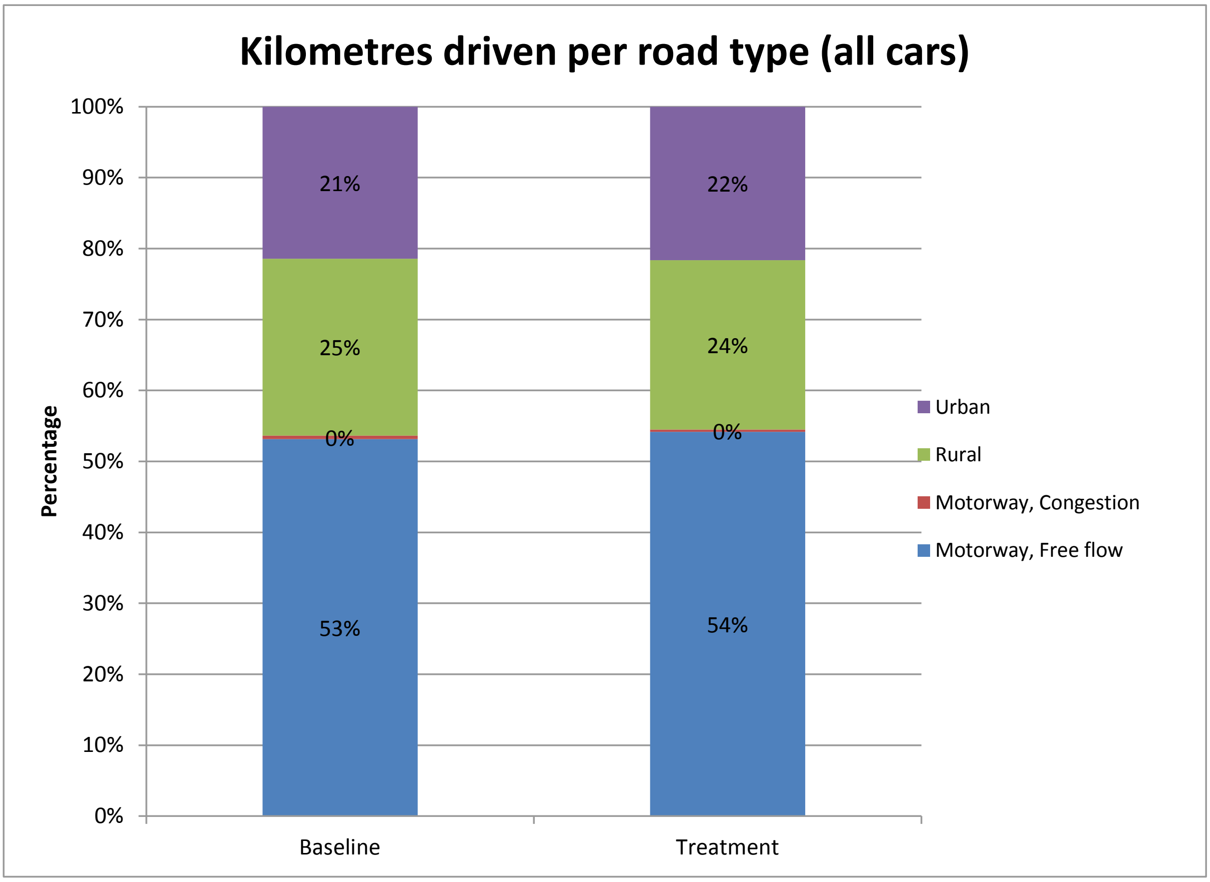

Figure 13: Kilometres driven per road type for cars

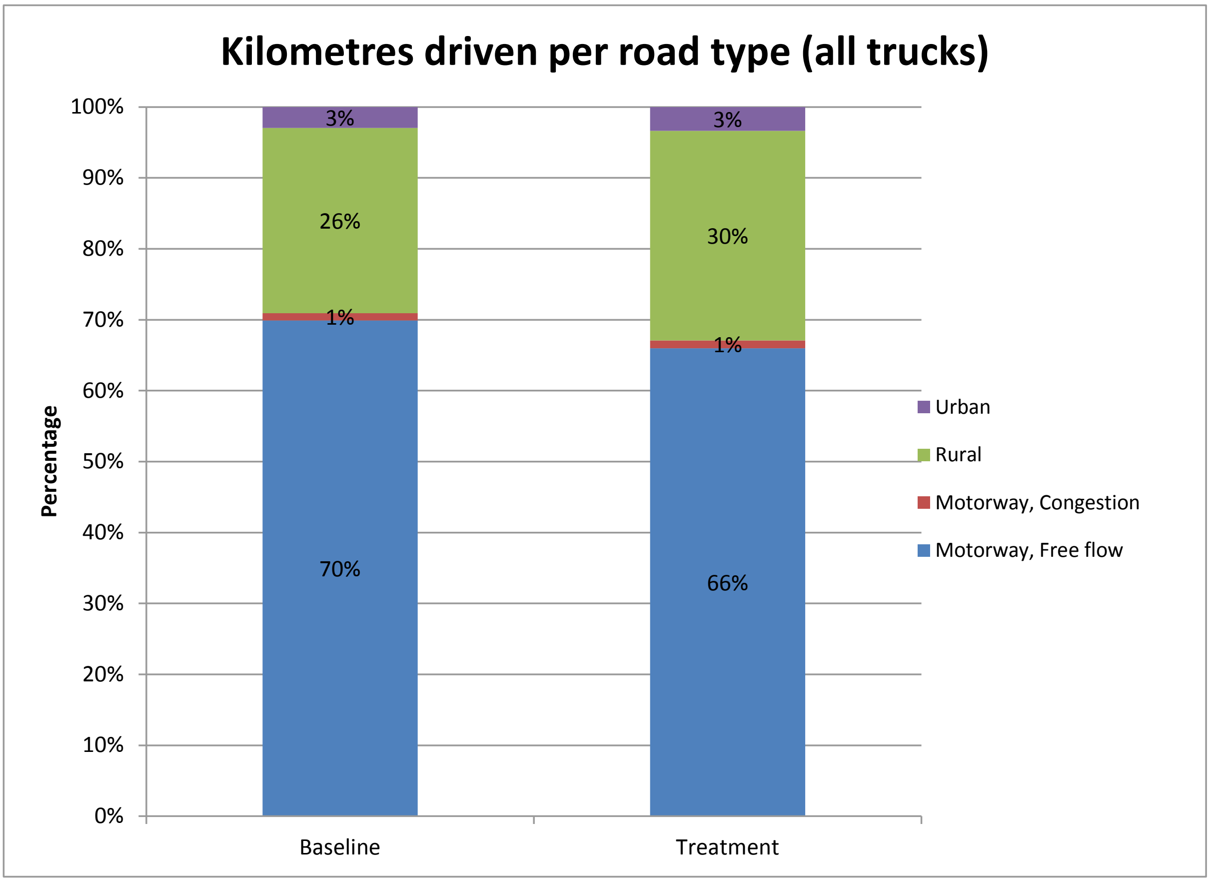

Figure 14: Kilometres driven over different per road type for trucks

Figure 13 and Figure 14 show the following:

- For cars, no change is found in distribution over the road types between the baseline and treatment period.
- For trucks, in the treatment period more kilometres are driven on rural roads and fewer on motorways, compared to the baseline period. An indication for this change was not found in the subjective data, so we have no reason to assume that this is caused by ACC and FCW. The change is possibly caused by seasonal influences.
- There are differences between the fleets when it comes to the distribution over the different road types. These differences in distribution over the road types can be caused, for example, by regional differences. Since FOT results are often depicted per road type and EU results use a weighting over the road types, this is not a problem.

Trips

For cars, the average number of trips per day is 2.4 in the baseline period, and 2.0 in the treatment period. For trucks, the average number of trips per day is 1.9 in the baseline period, and 2.0 in the treatment period. It is not expected that ACC causes people to drive more trips per day. Baseline and treatment were at different times of the year, so it is more likely that these changes are due to seasonal effects. Also, the changes in the number of trips were not found in the subjective data, where people were asked if ACC and FCW caused changes in mobility behaviour. Therefore, we assume that this change is not caused by the system(s), but is a result of other things, for example seasonal influences and is not taken into account in the overall traffic efficiency and environmental effects.

Mileage

The average mileage is evaluated per day and per trip. The distribution of mileage over different road types was already shown in Figure 13 and Figure 14. In Table 18 the mileage numbers are given.

Table 18: Mileage per day and per trip for FOT vehicles

	Average mileage per day (km)		Average mileage per trip (km)	
	Cars	Trucks	Cars	Trucks
Baseline	57	218	24	115
Treatment	45 (-21%)	209 (-4%)	23 (-4%)	107 (-7%)

The average mileage decreases, per day and per trip, for both cars and trucks. With the same reasoning as for the change in the number of trips, we assume that the change in mileage is not caused by the system(s), but is a result of other things.

Hypothesis 3a: The number of vehicle km travelled will increase (subjective data).
The subjective data does not indicate that there is a change in number of kilometres travelled. Therefore this hypothesis is rejected.

Hypothesis 3b: The number of vehicle km travelled will increase (objective data).
The strong effects on the number of km travelled per trip are not likely to be due to the ACC and FCW system.
There are significant differences in the number of kilometres travelled between baseline and treatment. For trucks there is significant increase of 11-42% (for the conditions motorway, motorway free flow, motorway congestion and darkness). For cars there is a significant decrease of 7-12% in the number of kilometres travelled per trip for cars when comparing baseline and treatment for ACC and FCW for all conditions, for motorway, motorway free flow and daylight.
These effects are too large to be explainable by the presence of the ACC and FCW. Additionally, the questionnaires people indicated that they did not change their mobility behaviour due to ACC and FCW. Seasonal influences are a more likely reason.

4.3 Direct traffic effects

This section contains the results of the direct traffic effects per research question / hypothesis, first on FOT level and then on EU-27 level. The results on the FOT level are split into a section for cars and a section for trucks.

4.3.1 Direct traffic effects at FOT level for cars

Travel time
The total average aggregated travel time per kilometre with ACC and FCW in the cars compared to the baseline increases for the different road types by 0.3% (motorways) and by 0.2% on urban roads. On rural roads there is no significant effect, possibly because the effect is small and the variation between drivers is high.

Average speed

In Figure 15 and Figure 16 average speeds are shown for different road types. In Figure 15 the average speeds (over time) are shown for the baseline and treatment period for five categories: motorways during free flow, motorways during congestion, motorway total (free flow and congestion), rural roads and urban roads.

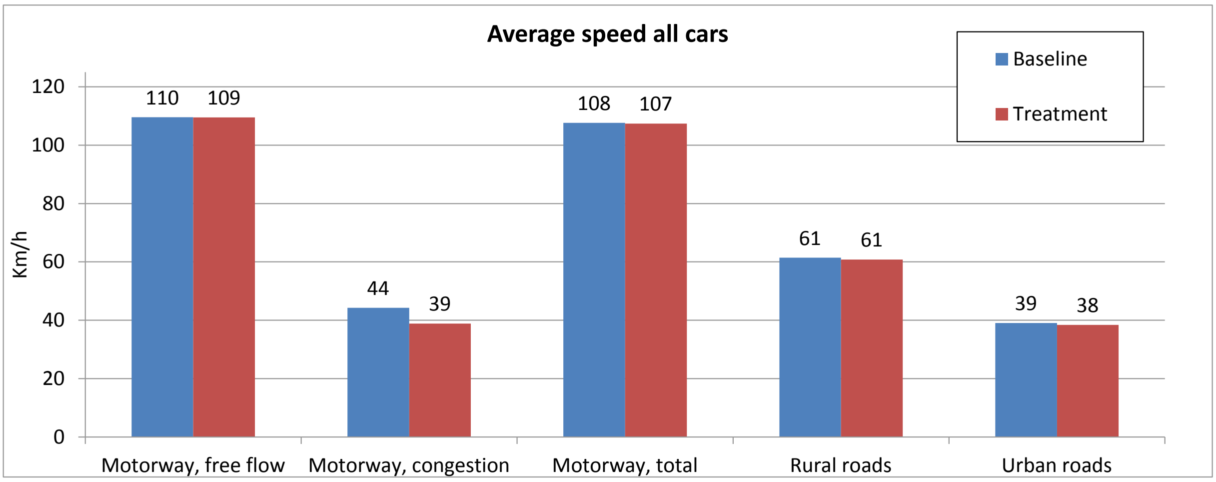

Figure 15: Average speeds per road type for cars comparing baseline and treatment

In Figure 15 it can be seen that on all three road types, the average speed decreases very slightly with ACC+FCW. However, the issue is somewhat more complex than indicated above. In Figure 16 the average speeds (over time) are shown for the same five road categories, but here only for the treatment period, and with data split according to whether

ACC+FCW is active or not. In Figure 16, it can be seen that the average speeds are much higher during the time that ACC+FCW is active, compared to the time that ACC+FCW is not active. This result is independent of road type and congestion level. The usage of ACC+FCW seems to be dependent on traffic conditions.

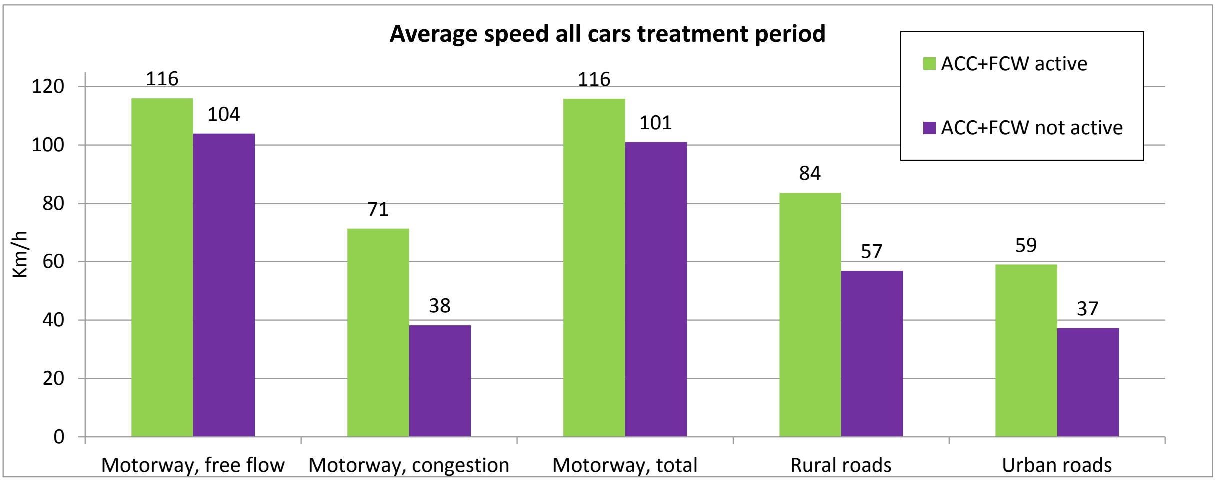

Figure 16: Average speeds for cars per road type for treatment period

Just comparing average speed in baseline and treatment period is therefore not the best way to approach the question of whether ACC+FCW increases average speed. Instead, some type of filtering that focuses on driving when ACC+FCW actually is in use should be applied before making the comparison between baseline and treatment.

An analysis of the usage pattern for ACC+FCW shows that drivers mainly use ACC+FCW on motorways in free flow conditions. Consequently, the hypothesis on whether average speed did increase was re-tested on a data set that reflected these usage conditions, i.e. the hypothesis was tested on all baseline and treatment data where driving speeds were above 50 km/h. This resulted in the following (Table 19):

Table 19: Results on hypothesis testing for average speed of cars

Average speed	Cars
	Hypothesis results
Motorway	-0.7%
Rural	not significant
Urban	-0.7%

In Table 19, we see that under these conditions (i.e. for driving speeds above 50 km/h), the average speed decreases with 0.7% on motorways and on urban roads, but there is no significant effect on rural roads.

This decrease cannot be used straightaway for scaling up the effect of ACC+FCW, because ACC+FCW was not in use 100% of the time when speed was above 50 km/h in the treatment period. Actually, as shown above in Figure 11, the analysis shows that ACC was active about half of that time, and ACC+FCW should be credited in proportion to that, i.e. ACC+FCW can be said to be responsible for 50% of the decrease. In addition, since we the data was not tested for any effects of ACC+FCW at speeds below 50 km/h due to the low usage rate, we assumed that ACC+FCW does not have an impact on all driving that occurs at speeds below 50 km/h.

Table 17 shows the outcome when these factors are taken into account, i.e. it shows what magnitude of average speed change could be expected in a car fleet if all cars in the fleet were equipped with ACC+FCW and used in the same way the euroFOT drivers used the systems.

Table 20: Estimated average speed change in car fleet (100% equipped with ACC+FCW)

Estimated change in average speed	Cars
motorway	-0.3%
rural	not significant
urban	-0.2%

From the above analysis, he following can be concluded:

- In the treatment phase, drivers drive faster when they are using ACC+FCW; this probably has to do with the systems being perceived to be useful under certain traffic conditions and not others by the drivers.
- ACC is used mostly on roads with a high speed limit and free flow situations.
- For the FOT cars, there are small differences between the average speed in the baseline and treatment period. For all road types the average speed is lower in the treatment period than in the baseline period.
- For a general car fleet equipped with ACC+FCW, we have estimated that the average speed will be 0.3% lower on motorways compared to a non-equipped fleet, that there will be no change on rural roads, and an average decrease of 0.2% on urban roads.

Speed distribution

In Figure 17 speed distributions are shown for the different road types and conditions (baseline and treatment).

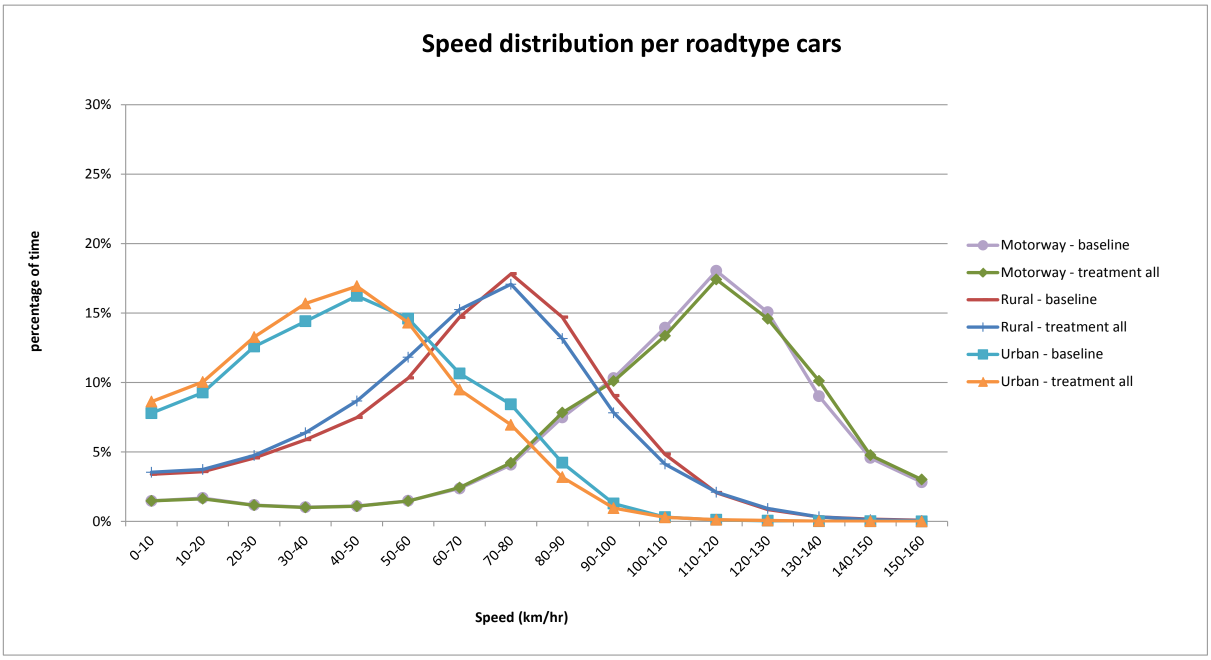

Figure 17: Speed distributions for cars per road type (baseline and treatment period)

From Figure 17 the following can be concluded:

- On motorways there is almost no change in speed distribution.
- On rural roads and urban roads a difference in speed distribution can be seen: in the treatment period, relatively more low speeds and relatively fewer high speeds are driven compared to the baseline period.

Hypothesis 1: The average speed will increase.
This hypothesis is rejected. The overall average speed decreases in the treatment period (when ACC and FCW are available in the vehicle) compared to the baseline period. These differences are significant on motorways and urban roads.

Delay

Delays are calculated with use of the speed distribution. As a starting point we assume that on motorways cars driving slower than 100 km/h are delayed, on rural roads the boundary is 80 km/h and on urban roads the boundary is 50 km/h. Vehicles that drive 5 km/h cause more delay than vehicles that drive 40 km/h. As a measure for delay vehicle loss hours are used. Changes in share of delays (vehicle loss hours compared to the total travel time) are given in the table below, as well as the absolute values.
On motorways the amount of delay is about the same in the two periods. On rural and urban roads there are more delays in the treatment period: 7-8% more than in the baseline period. These results are not tested for significance since they were available only on a higher (aggregated) level: speed bins of 10 km/h.

Table 21: Delays in baseline and treatment period ACC+FCW cars

	Delays		
	Motorways	**Rural roads**	**Urban roads**
Baseline (% time spent in delay compared to total travel time)	7.5%	20.9%	25.8%
Treatment (% time spent in delay compared to total travel time)	7.5%	22.3%	27.8%
Change treatment versus baseline period	-0.5%	+7.2%	+8.1%

Research question 2: What is the impact of ACC AND FCW on the amount of delay?
There is a tendency towards more delay on rural and urban roads. This change in delay is not tested for significance.

4.3.2 Direct traffic effects on FOT level for trucks

Travel time

The change in travel time per kilometre for the different road types (treatment compared to baseline period) is -0.1% on motorways and -0.02% on rural roads. On urban roads there is no significant effect. The effect on rural roads is very small but it is significant.

Hypothesis 6: The travel times will decrease.
This hypothesis is accepted: the average travel time per kilometer decreases on motorways and rural roads.

Average speed

In Figure 18 and Figure 19 average speeds are shown for different road types. In Figure 18 the average speeds (over time) are shown for the baseline and treatment period for five categories: motorways during free flow, motorways during congestion, motorways total (free flow and congestion), rural roads and urban roads.

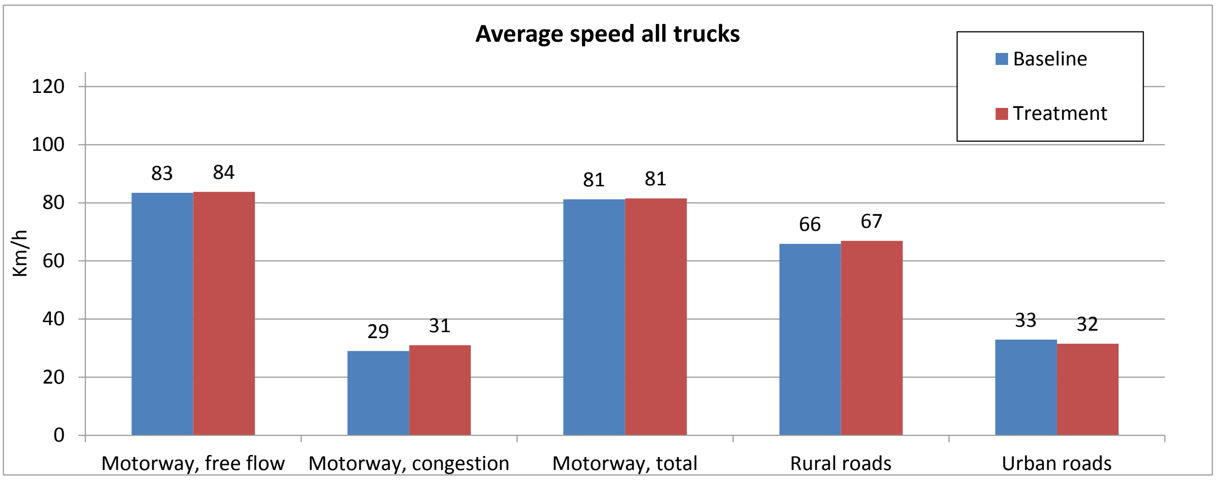

Figure 18: Average speeds for trucks per road type: baseline vs. treatment period

In Figure 18 it can be seen that on motorways and rural roads, the average speed increases slightly with ACC+FCW and on urban roads the average speeds decreases slightly with ACC+FCW. However, in the same way as for cars, the issue is more complex. In Figure 19 the average speeds (over time) are shown for the same five road categories, but here only for the treatment period, and with data split according to whether ACC+FCW is active or not. In Figure 19, it can be seen that the average speeds are (much) higher during the time that ACC+FCW is active, compared to the time that ACC+FCW is not active. This result is independent of road type and congestion level. Only on motorways during free flow situations the effect size is small. The usage of ACC+FCW seems to be dependent on traffic conditions.

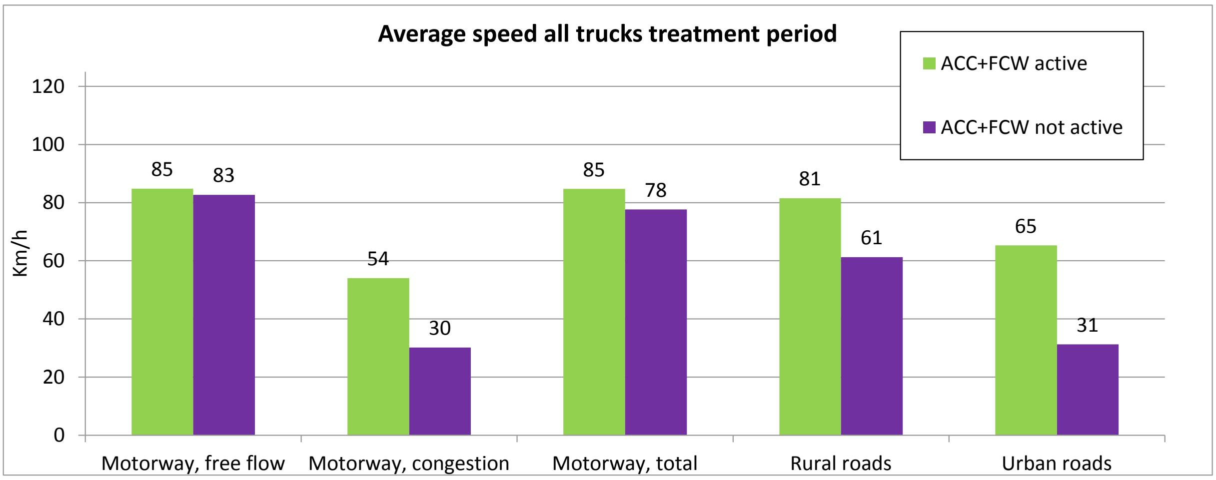

Figure 19: Average speeds for trucks per road type for treatment period

Just comparing average speed in baseline and treatment period is therefore not the best way to approach the question of whether ACC+FCW increases average speed. Instead, some type of filtering that focuses on driving when ACC+FCW actually is in use should be applied before making the comparison between baseline and treatment. Truck drivers mainly use ACC+FCW on motorways in free flow conditions. Consequently, the hypothesis on whether average speed did increase was re-tested on a data set that reflected these usage conditions, i.e. the hypothesis was tested on all baseline and treatment data where driving speeds were above 50 km/h. This resulted in the following (Table 22):

Table 22: Results hypothesis testing average speed trucks

Average speed	Trucks
	Hypothesis results
Motorway	-0.11%
Rural	-0.03%
Urban	Not significant

In Table 22, we see that under these conditions (i.e. for driving speeds above 50 km/h), the average speed decreases with 0.11% on motorways and with 0.03% on rural roads, but there is no significant effect on urban roads.

This decrease cannot be used straightaway for scaling up the effect of ACC+FCW, because ACC+FCW was not in use 100% of the time when speed was above 50 km/h in the treatment period. Actually, as shown above in Figure 12, the analysis shows that ACC was active in 54% of that time, and ACC+FCW should be credited in proportion to that, i.e. ACC+FCW can be said to be responsible for 54% of the decrease. In addition, since we the data was not tested for any effects of ACC+FCW at speeds below 50 km/h due to the low usage rate, we assumed that ACC+FCW does not have an impact on all driving that occurs at speeds below 50 km/h.

Table 23 shows the outcome when these factors are taken into account, i.e. it shows what magnitude of average speed change could be expected in a car fleet if all trucks in the fleet were equipped with ACC+FCW and used in the same way the euroFOT truck drivers used the systems.

Table 23: Estimated average speed change in truck fleet (100% equipped with ACC+FCW)

Estimated change in average speed	Trucks
Motorway	-0.1%
Rural	-0.02%
Urban	not significant

From the above analysis, he following can be concluded:

- In the treatment phase, drivers drive faster when they are using ACC+FCW; this probably has to do with the systems being perceived to be useful under certain traffic conditions and not others by the drivers.
- ACC is used mostly on roads with a high speed limit and free flow situations.
- For a general car fleet equipped with ACC+FCW, we have estimated that the average speed will be marginally lower, only 0.1% lower on motorways compared to a non-equipped fleet, 0.02% lower on rural roads, and that there will be no change on urban roads.

Speed distribution

In Figure 20 the speed distributions for trucks on the different road types can be found.

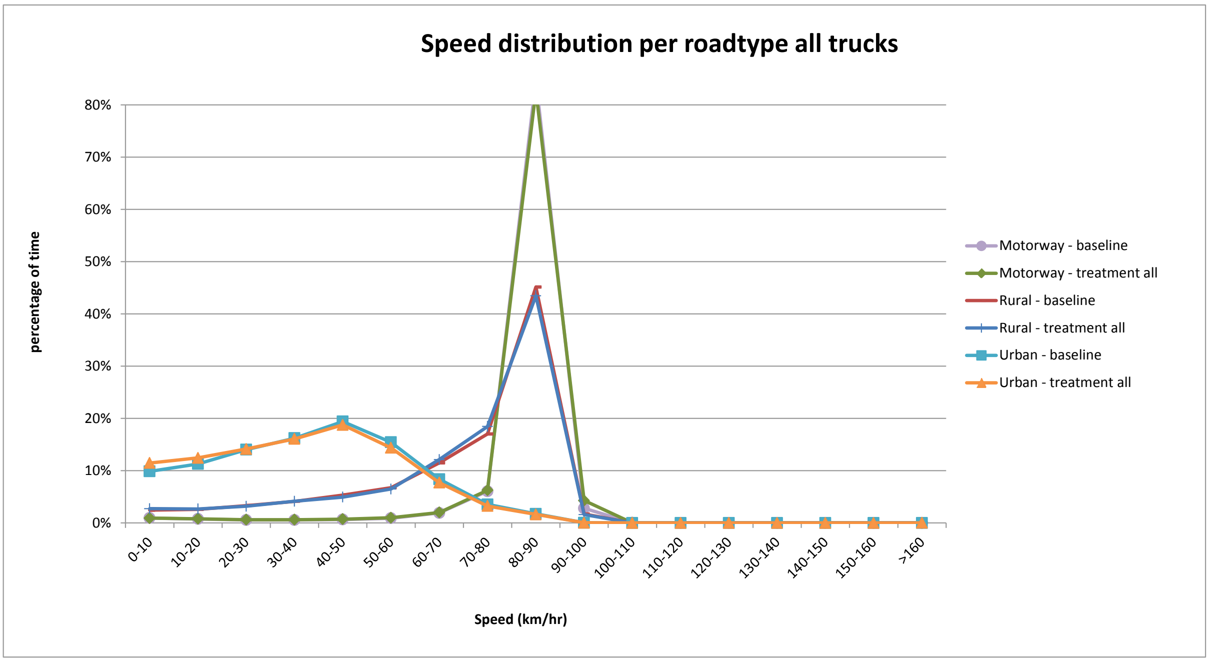

Figure 20:Speed distributions for trucks per road type (motorway baseline is behind motorway treatment)

Figure 20 shows that there is almost no difference in speed distribution for the treatment period compared to the baseline period.

> *Hypothesis 1: The average speed will increase.*
> This hypothesis is rejected. There is very little change in speed distribution. For motorways the average speed is reduced by 0.31% and for urban roads 0.02%.

Delay

Changes in share of delays (vehicle loss hours compared to the total travel time) are given in the table below. A truck has delay when driving slower than 50 km/h on urban roads and slower than 80 km/h on rural roads and motorways. Trucks driving with 5 km/h cause more delay than trucks driving with 40 km/h. This definition of delay is arbitrary, especially on urban roads; since urban networks usually contain many traffic lights and crossings, driving slower than 50 km/h is quite usual. Also on rural roads the speed can regularly be lower than 80 km/h.

There are fewer delays in the treatment period on motorways and rural roads; on urban roads the amount of delay is higher. These results are not tested for significance since they were available only on a higher (aggregated) level.

Table 24:Delays baseline and treatment period ACC+FCW trucks

	Delays		
	Motorways	**Rural roads**	**Urban roads**
Baseline (% time spent in delay compared to total travel time)	8.8%	30.6%	32.9%
Treatment (% time spent in delay compared to total travel time)	7.5%	24.3%	35.7%
Change treatment versus baseline period	-14.9%	-20.7%	+8.4%

Research question 2: What is the impact of ACC AND FCW on the amount of delay?
There is a tendency towards less delay on motorways and rural roads, and more delay on urban roads. These changes in delay were not tested for significance.

4.3.3 EU-27 level

As explained in this chapter, the result from the FOT that we have to take into account in scaling up and the cost benefit analysis is that there is a change in average speed and in travel time. This change varies over the road types, and is different for cars and trucks.

A very important assumption in scaling up is that we assume that the effect found in the FOT will also be found when ACC and FCW are used by other drivers in other parts of Europe. However, there are differences between the FOT network (Germany, Sweden) and the total European network. There are for example differences in the density of the network, and differences in driving styles.

In the FOT, when driving with ACC and FCW in the vehicle the mileage does not change significantly, nor does the distribution of kilometres driven over road types. The distribution of mileage over the different road types is very different for EU-27 compared to the FOT data. In Figure 21 and Figure 22 the distributions of mileage over road types for cars and trucks for EU-27 and for the FOT (baseline period) can be found. In EU-27, the share of kilometres driven on rural and urban roads is much higher than for the FOT, and the share of kilometres driven on motorways is much lower. The share of kilometres driven in congestion on motorways is also higher in EU-27 than in the FOT.

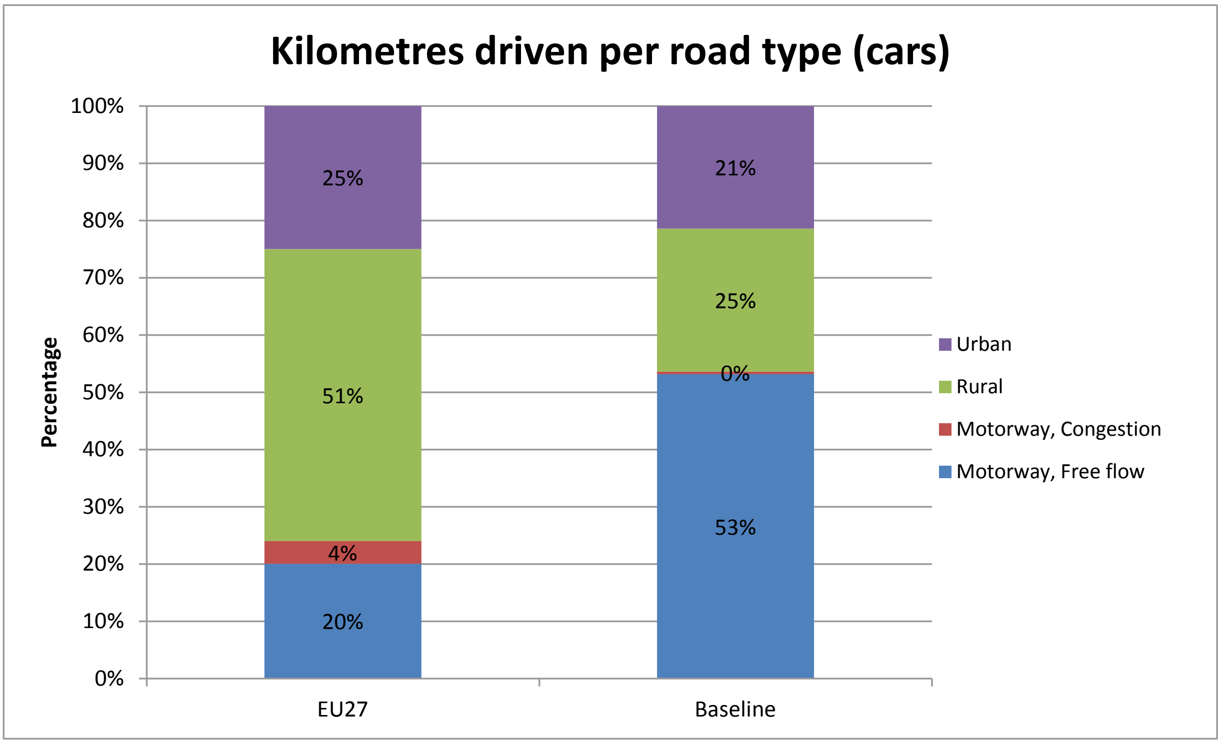

Figure 21:Mileage distribution over road types cars comparing baseline and EU27

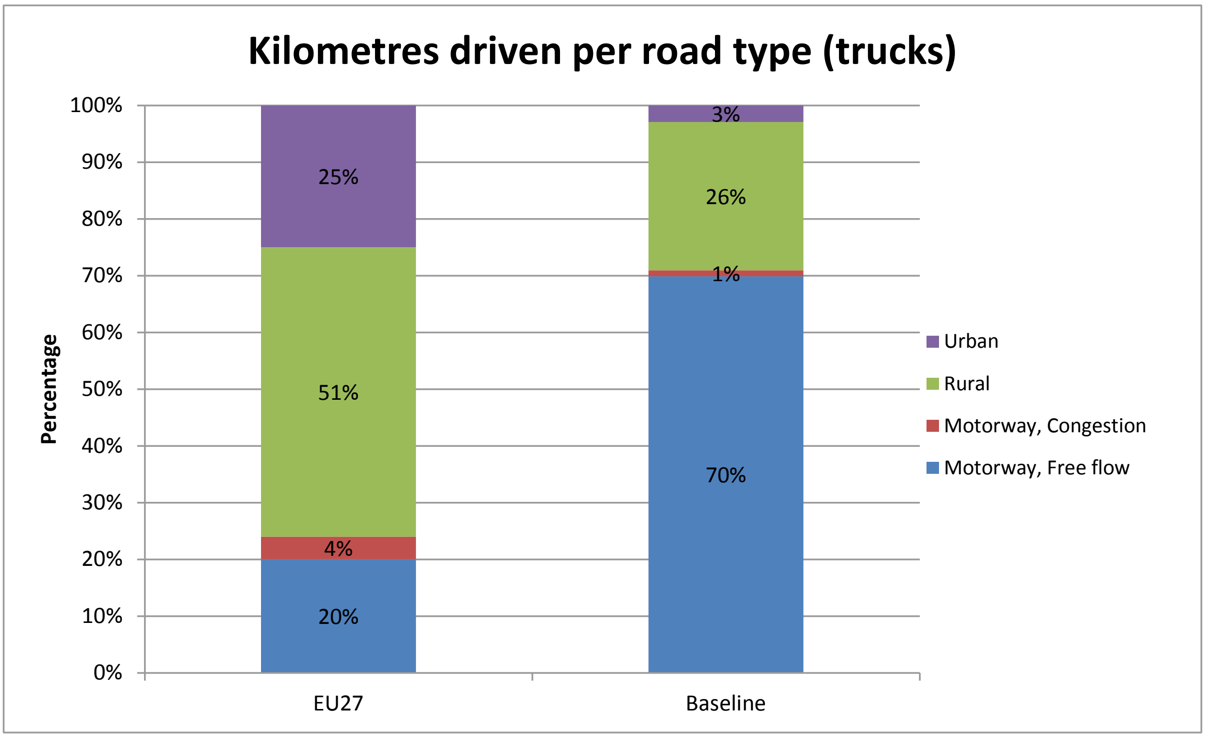

Figure 22: Mileage distribution over road types trucks comparing baseline and EU27

This difference in distribution has implications for scaling up (effects have to be weighted for the different road types). For EU27, change in speed and change in total travel time are calculated.

Total travel time EU-27

We assume that every car and truck is equipped with ACC and FCW, and that results on rural roads for cars and urban roads for trucks are zero (because they are not significant). Taking into account the distribution of kilometres driven on the different road types, the overall change in total travel time is then an increase of 0.2%, see table below for calculations. This means that when all vehicles are equipped with ACC and FCW, there is a very small increase in travel time, so vehicles are underway a little bit longer. Because the change is very small, this will in principle not be noticeable for individual drivers; a trip that lasted 1 hour will then last 1 hour and 7 seconds.

Table 25: Total travel time EU-27

Travel time	Cars	Trucks	Share of km driven EU-27 level	All
	FOT level	FOT level		EU level
Motorways	0.3%	0.1%	24%	0.2%
Rural roads	not significant	0.0%	51.0%	0.0%
Urban roads	0.2%	not significant	25.0%	0.2%
All road types			100.0%	0.1%

Average speed EU-27

The same assumptions hold as for travel time. The changes in average speed are the inverse of the changes in average travel time. To give an example, if the travel time for cars on motorways increases with 0.9% at FOT level, then the average speed for cars on motorways decreases with 0.9% at FOT level.

Possible effects of changes in average speed and travel time on the amount of congestion are not calculated. However, we do not expect this to be a large effect given the direct traffic efficiency effect sizes.

In Table 26 a summary of effects of ACC and FCW on EU-27 level can be found. These results are the input for the cost benefit analysis (WP6500). From the simulation results we concluded that these effects are almost linear with the market penetration. In the CBA a 100% scenario is used and the EU level effect is used as the 100% effect.

Table 26: Summary of effects on EU-27 level of ACC and FCW

	ACC AND FCW
Change in total travel time	+0.2%
Change in km driven	No effect
Change in average speed	-0.2%

4.4 Indirect traffic effects

Next to the direct effect of ACC and FCW on speed, there is an indirect traffic efficiency effect. The safety impact in terms of a reduction in the number of accidents leads to a reduction in congestion. ACC and FCW can reduce the incidental delay due to accidents by about 3 million (3.052.511 from Table 29) lost vehicle hours. This reduction in incidental delay is show in Table 27 for injury accidents, Table 28 for fatal accidents and Table 29 for the two accident types together.

The indirect effects are determined following these steps:

- Number of rear-end accidents from euroFOT safety impact assessment for the EU 27 level
- Distribution of the rear-end accidents over the periods of the day from GIDAS

  The distribution of rear-end accidents over the day according to GIDAS was applied to the euroFOT reduction of rear-end accidents as determined in the safety impact assessment [10]. This assumes that the impact is the same for all periods of the day. Ideally, the effect per period of the day would be determined from the FOT data, but this level of detail was not possible.
- Estimate of the delay per accident type and period of the day according to eImpact (eImpact Deliverable 4 [11])

  Using eImpact, the delay per accident is determined. The calculation is based on a number of assumptions about the traffic conditions and capacity reduction depending on the severity of the accident (see Table 31). This effect is scaled per road type and accident types are scaled with the total delay due to rear-end accidents.

Table 27: Reduction in lost vehicle hours due to reduction in fatal accidents (EU27 level results)

	motorway (range)		rural road (range)		urban road (range)		Total average
	low	high	low	high	low	high	
morning peak	30258	77406	4919	6917	232	232	59982
evening peak	31634	80925	3477	4890	205	205	60668
night	9628	24629	373	525	19	19	17596
rest of the day	79084	202311	10911	15344	545	545	154371
total	150604	385271	19680	27675	1002	1002	**292617**

Table 28: Reduction in lost vehicle hours due to reduction in injury accidents (EU27 level results)

	motorway (range)		rural road (range)		urban road (range)		Total average
	low	high	low	high	low	high	
morning peak	249356	637895	96815	136146	19891	19891	579998
evening peak	260691	666891	68438	96241	17578	17578	563709
night	79341	202967	7345	10328	1628	1628	151618
rest of the day	651727	1667227	214774	302025	46693	46693	1464569
total	1241114	3174979	387371	544741	85791	85791	**2759894**

Table 29: Reduction in lost vehicle hours due to reduction in all accident types (EU27 level results)

	motorway (range)		rural road (range)		urban road (range)		Total average
	low	high	low	high	low	high	
morning peak	279615	715301	101734	143063	20123	20123	639980
evening peak	292324	747815	71915	101131	17783	17783	624376
night	88968	227596	7718	10853	1647	1647	169215
rest of the day	730811	1869538	225685	317370	47238	47238	1618940
total	1391718	3560250	407052	572416	86792	86792	**3052511**

These vehicle loss hours are based on the following accident reductions per time of day in Table 30.

Table 30: Accident reductions per time of day and road type (distribution from GIDAS)

		Fatal accidents cars		Injury acc. cars		Fatal acc. trucks		Injury acc. trucks	
Nr of accidents	Target group population	ACC+FCW EU		ACC+FCW EU		ACC+FCW EU		ACC+FCW EU	
		#	%	#	%	#	%	#	%
Urban	morning peak	10	17.7%	2243	17.7%	0	17.7%	0	17.7%
	evening peak	9	15.7%	1982	15.7%	0	15.7%	0	15.7%
	night	4	7.2%	918	7.2%	0	7.2%	0	7.2%
	rest of the day	23	41.3%	5227	41.3%	0	41.3%	0	41.3%
	weekend	10	18.1%	2295	18.1%	0	18.1%	0	18.1%
Rural	morning peak	20	17.8%	2149	17.8%	20	17.8%	284	17.8%
	evening peak	14	12.6%	1519	12.6%	14	12.6%	201	12.6%
	night	12	10.2%	1223	10.2%	12	10.2%	161	10.2%
	rest of the day	42	36.3%	4372	36.3%	42	36.3%	577	36.3%
	weekend	26	23.1%	2779	23.1%	26	23.1%	367	23.1%
Motorway	morning peak	19	11.3%	875	11.3%	14	11.3%	235	11.3%
	evening peak	20	11.8%	915	11.8%	15	11.8%	246	11.8%
	night	30	17.9%	1392	17.9%	23	17.9%	375	17.9%
	rest of the day	59	35.4%	2745	35.4%	45	35.4%	739	35.4%
	weekend	39	23.6%	1830	23.6%	30	23.6%	492	23.6%
All road types	morning peak	57	17.0%	5523	17.0%	41	17.0%	626	17.0%
	evening peak	49	14.6%	4755	14.6%	35	14.6%	539	14.6%
	night	30	9.0%	2921	9.0%	22	9.0%	331	9.0%
	rest of the day	133	39.7%	12881	39.7%	96	39.7%	1459	39.7%
	weekend	66	19.7%	6384	19.7%	47	19.7%	723	19.7%

Table 31: Lost vehicle hours per accident by road type and period of the day (eImpact)

	Fatal accident			Injury accident		
	motorway	rural road	urban road	motorway	rural road	urban road
Lost hours morning peak (h):	3000	750	500	1000	375	250
Lost hours evening peak (h):	3000	750	500	1000	375	250
Lost hours night (h):	600	100	100	200	50	50
Lost hours rest of the day (h):	1500	500	350	500	250	175

Hypothesis 5: The amount of incidental delay in the network will decrease.
ACC and FCW can reduce the incidental delay due to less accidents with about 3 million (3.052.511 from Table 22) lost vehicle hours

4.5 Simulation results

To gain a deeper understanding of the effects/impacts of the ACC+FCW system on traffic efficiency, traffic flow simulations have been conducted in addition to the collection of field data. The goal of these simulations is to determine the size of the interaction effects of ACC+FCW, i.e., the impact of the system on the traffic flow apart from the impact on the individual equipped vehicle. This impact on traffic flow can be characterized by parameters such as traffic flow, density and average network speed. While the impact on the individual equipped vehicle can be obtained from the FOT data directly, further changes in the traffic flow due to interaction effects such as imitation or coercion can be obtained from simulations. These simulations offer the possibility to consider different penetration rates of the investigated vehicle fleet and to vary the traffic demand (free flow, heavy traffic, etc.) by adjusting the flow of entering vehicles in its mass and its ratio of passenger vehicles to trucks.

The simulations described in the following were conducted with the simulation tool PELOPS which is described in D6.2[9] To keep the simulation results comparable to the FOT data, the scenarios should be as realistic as possible. Therefore, the driver behaviour was derived from the data collected in the FOT by deducing parameters like the desired speed of the driver, his compliance with the speed limit, and car following behaviour.

4.5.1 Scenarios

In all scenarios, the network, the simulation duration and the ACC functionality are kept constant while penetration rate, traffic demand and speed limit are varied. The FOT collected data from two different geographic regions, namely in Sweden and in Germany. A major difference between these two regions is that Swedish motorways always have a speed limit, while German motorways sometimes have no limit. Therefore, the speed limit parameter was included to distinguish these two geographic regions. The speed limit will influence the behaviour of the drivers, and thus the driver behaviour was modelled separately for these two speed limit conditions, based on the FOT data. Apart from these differences the two regions are modelled the same way. That is, they use the same network, the same demand and the same models for the vehicles and the controller. The ACC controller that was used in the simulation is described in D6.2.

Geographic region

The main effect of ACC is expected on motorways, and hence a motorway network is modelled. The network is a segment of the German motorway A3 between Leverkusen and Köln including two motorway junctions (Leverkusen and Köln-Mühlheim). This segment was chosen because of the availability of accurate traffic demand measurements which allow rebuilding the traffic flow on this segment. In reality this network has no speed limit, but in the simulation the same network will also be used for the region with speed limit. The data from eight measuring loops was used to calculate the number of vehicles entering the segment as well as the in- and outflow at the two junctions.

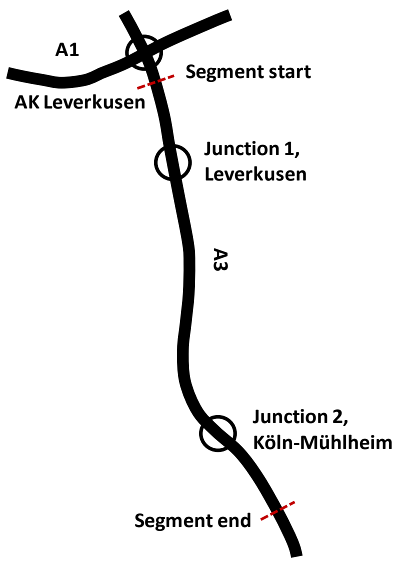

Figure 23: Schematic overview of the motorway segment in the simulations

Traffic demand and time period

With the measurements from the measuring loops, the traffic demand was set up for two variations of the scenarios: The first one represents free flow that was measured between 22:00 and 23:00. For rebuilding heavy traffic, the traffic demand during rush-hour time (between 15:00 and 16:00) was chosen. Notice that the number of vehicles entering at a junction is defined by an absolute value and the number of vehicles leaving by a percentage of the vehicles passing the junction.

In each case the simulation is run for 40 minutes and with starting conditions (positions and velocities of the vehicles in the network) which were obtained by a pre-run of the baseline scenario. Additionally, the first minute of the simulation is not considered in the evaluation. The traffic demand , the number of vehicles entering the network, during the simulated hour was set up according to real world measurements from the measurement loops in the network. The traffic demand that was recorded in a situation with no speed limit is used for both scenarios (with and without speed limit). Comparing the number of vehicles leaving the network (over the full duration of the simulation period) between real world measurement and simulation of the baseline/free flow scenario shows a congruence of 95%. Thus, the simulation can be considered as a good approximation to the real traffic situation.

Table 32: The set traffic demand on the route deduced from traffic flow measurements

	Time of day	Vehicle/h entrance segment	Vehicle/h entrance junction 1	Vehicle/h departure junction 1	Vehicle/h entrance junction 2	Vehicle/h departure junction 2
Free flow	**22:00 - 23:00**	1506 (23.6% trucks)	62 (8.1% trucks)	5.4%	115 (7% trucks)	5.4%
Heavy traffic	**15:00 - 16:00**	1985 (22.9% trucks)	1440 (10.6% trucks)	5.1%	960 (2.4% trucks)	5.4%

The table shows that the biggest difference between the free flow and heavy traffic scenarios is the number of vehicles entering the motorway at the two junctions, and not the number of vehicles entering the segment at its starting point.

Speed limit

The speed limit was chosen as an additional variation parameter for the simulations, in order to be able to simulate the traffic flow for two different vehicle fleets from two different countries. Possible speed limit settings are 120 km/h and no speed limit. The driving behaviour for two conditions was derived from FOT driving in situations with the respective speed limits meaning that the driver behaviour in the simulation with a speed limit of 120 km/h was deduced from situations where there was a speed limit of 120 km/h, and the behaviour in the simulation without speed limit was deduced from situations where there was no speed limit.

Implementation of the FOT driving behaviour

In a first step, the driving behaviour for the baseline was implemented. This is done in PELOPS by assigning values for desired speed, the compliance with the speed limit and the so-called “Need for Safety” parameter (NFS) individually to each driver.

The desired speed was calculated to be the mean speed, calculated over all FOT data where the speed is over 95 km/h and the vehicle is in free flow condition, on a motorway with no speed limit. The speed range below 95 km/h was not considered to exclude acceleration phases. Only free flow conditions were considered in order to exclude any influences from predecessor vehicles.

The “compliance with the speed limit” parameter is only relevant for situations where there is a speed limit. This parameter is calculated as the ratio between the mean speed and speed limit, for FOT data where the speed is at least equal to the current speed limit minus 5 km/h, and the vehicle is in free flow condition (for the same reason as above).

The NFS determines the ("safe") distance headway that a driver tries to maintain. It is calculated backwards from the measured distance headway in the FOT with the help of the formula in PELOPS that relates the NFS to the distance headway, thus reproducing the following behaviour of the driver within the simulations. Since the THW in the FOT for ACC+FW is increased, a reduced throughput might be expected with higher penetrations in dense traffic.

The driver selects the ACC speed setting as follows. If no speed limit is present the driver adjusts the speed setting to his desired speed. In network segments where there is a speed limit the driver sets the speed equal to the permissible speed multiplied by the compliance with the speed limit meaning that a driver with a compliance factor of 1.1 chooses a speed of 132 km/h in areas of a speed limit of 120 km/h.

For driving with ACC the following rules for activation and deactivation are adopted. These are based not on the FOT data but rather on the functional limitations of the ACC and hence can be regarded as reflecting the potential of the system. Generally, the driver switches the system on if possible ($v > 35$ km/h) and deactivates the system if the speed drops under 30 km/h. In addition, the driver takes over control (and switches the system off) if the distance to the front vehicle decreases below a minimum distance d_{min}, given by

$$d_{min} = v_{rel}^2/(1.5 * a_{min,Controller}) + 0.7\ \text{sec} * v_{front\ veh}$$

The meaning of this formula is that the ACC will switch off when the ACC vehicle is driving faster than its predecessor and the ACC controller is not able to brake sufficiently fast to maintain a safe distance. In the real world the system would indicate that to the driver by an acoustic sound and the driver would take over control.

Penetration rates

As mentioned in the traffic demand paragraph, the vehicle flow consists of cars as well as trucks. Since the driving behaviour could only be deduced for passenger cars in the FOT the penetration rates refer to the equipment of those vehicles, while trucks are always unequipped. In total, the simulations were conducted with six different ACC penetrations rates (0%, 5%, 10%, 25%, 50% and 100%) in each vehicle fleet. The penetration rate of 0% was considered to be the baseline. Each scenario was run once since there are no stochastic elements in the simulation. Rerunning a scenario would only cause slight differences (e.g. in the sensor measurement noise) when using another compiler.

4.5.2 Results

The goal of the conducted simulations is the evaluation of the potential of ACC to improve traffic efficiency. In these simulations only the direct effects of the control system can be assessed. Effects that result from fewer accidents due to improved safety in driving with ACC are not part of these simulation results. In the following the effects on throughput are presented for the simulated scenarios. The effect calculations compare the treatment scenarios with the baseline scenario. The shown evaluation considers the first 40 minutes of the simulation time due to an erroneously lowered traffic demand within the last 20 minutes. Three parameters were chosen to measure the change in traffic efficiency in terms of throughput of vehicles in the analysed motorway segment, namely traffic flow, traffic density and speed. All parameters are averaged for road segments of 100 meters and time segments of 60 seconds (over the complete network and simulation duration).

The traffic flow describes how many vehicles pass a road segment in a predefined time period (vehicles/min). In the conducted simulations the number of vehicles per minute was analysed and averaged. The change for the two traffic demands and the two speed limits (shown in Table 33) does not exceed 2.4%. It can be seen in the speed distributions (Figure 75 to Figure 78 in the Annex 0) that there is some congestion at the two junctions

(Distance$_{junction,1}$ = 1200m and Distance$_{junction,2}$ = 7000m) at the beginning of each simulation with heavy traffic. The congestion increases over time due to the high number of vehicles entering at the junctions. This effect is smaller for the scenario without speed limit.

Table 33: Change in traffic flow of the simulated treatment scenarios, compared to the baseline (40 min)

Speed limit	Traffic demand	Penetration rate				
		5%	10%	25%	50%	100%
None	Free flow	0.1%	1.0%	0.0%	-0.2%	-0.5%
	Heavy traffic	0.1%	0.8%	0.1%	-1.6%	-2.4%
120 km/h	Free flow	0.8%	1.3%	1.9%	1.5%	1.2%
	Heavy traffic	-0.9%	-0.2%	-1.1%	-0.9%	-0.1%

As a second indicator for changes in traffic efficiency the traffic density was evaluated. The traffic density is the number of vehicles per road segment (vehicles/km). It can be seen from Table 34 that in every scenario the traffic density with ACC equipped vehicles is higher than in the baseline scenario. The highest increase with more than 15% is found for a high traffic demand (heavy traffic) and no speed limit.

Table 34: Change in traffic density of the simulated treatment scenarios, compared to the baseline (40 min)

Speed limit	Traffic demand	Penetration rate				
		5%	10%	25%	50%	100%
None	Free flow	1.7%	2.0%	2.6%	0.7%	2.7%
	Heavy traffic	3.6%	4.4%	5.4%	8.0%	15.1%
120 km/h	Free flow	1.9%	2.1%	2.4%	4.3%	5.1%
	Heavy traffic	4.7%	5.4%	3.7%	4.9%	7.1%

The third indicator is the average network speed. For every simulation scenario except the last one the average speed with ACC equipped vehicles has decreased in comparison to the baseline scenario (compare Table 35). Speed distributions can be found in Figure 75 to Figure 78 in Annex 3. Just as for the traffic density, the highest change is found for the heavy traffic scenario without speed limit (-18.5%).

Table 35: Change in average network speed of the simulated treatment scenarios, compared to the baseline

Speed limit	Traffic demand	Penetration rate				
		5%	10%	25%	50%	100%
None	Free flow	-1.5%	-1.2%	-2.6%	-1.0%	-3.2%
	Heavy traffic	-2.4%	-3.0%	-3.8%	-7.9%	-18.5%
120 km/h	Free flow	-1.4%	-0.9%	-0.8%	-2.7%	-3.9%
	Heavy traffic	-3.7%	-2.5%	-1.4%	-4.0%	-11.1%

In general, one can say that an increase in average traffic density comes with a decrease in average speed. This can also be seen in Figure 24, where the results from Table 33, Table 34 and Table 35 are visualised. The figure shows that for all scenarios the effect on *traffic flow* is close to zero at all penetration rates. The evaluation of the simulation results show that the influence of ACC on traffic is highly depending on the settings of the ACC (see also [12] and [13]).A further investigation of these effects is needed.

- The heavy traffic, no speed limit scenario shows a roughly linear relation between the penetration rate and the effect for density and speed. The results show a non-linearity for penetration rates below 25%. This could be an interaction effect where the equipped vehicles also influence the unequipped vehicles, but this single indicator is somewhat limited to fully support such a conclusion without further analysis.
- The free flow, no speed limit scenario shows relatively small effects, at most about 3% for all indicators. It does not show a clear relationship between penetration rate and effect size for any indicator.
- The free flow, 120 km/h scenario shows relatively small effects, at most about 5% for all indicators. The relation between the penetration rate and the effect for density and speed looks roughly linear.

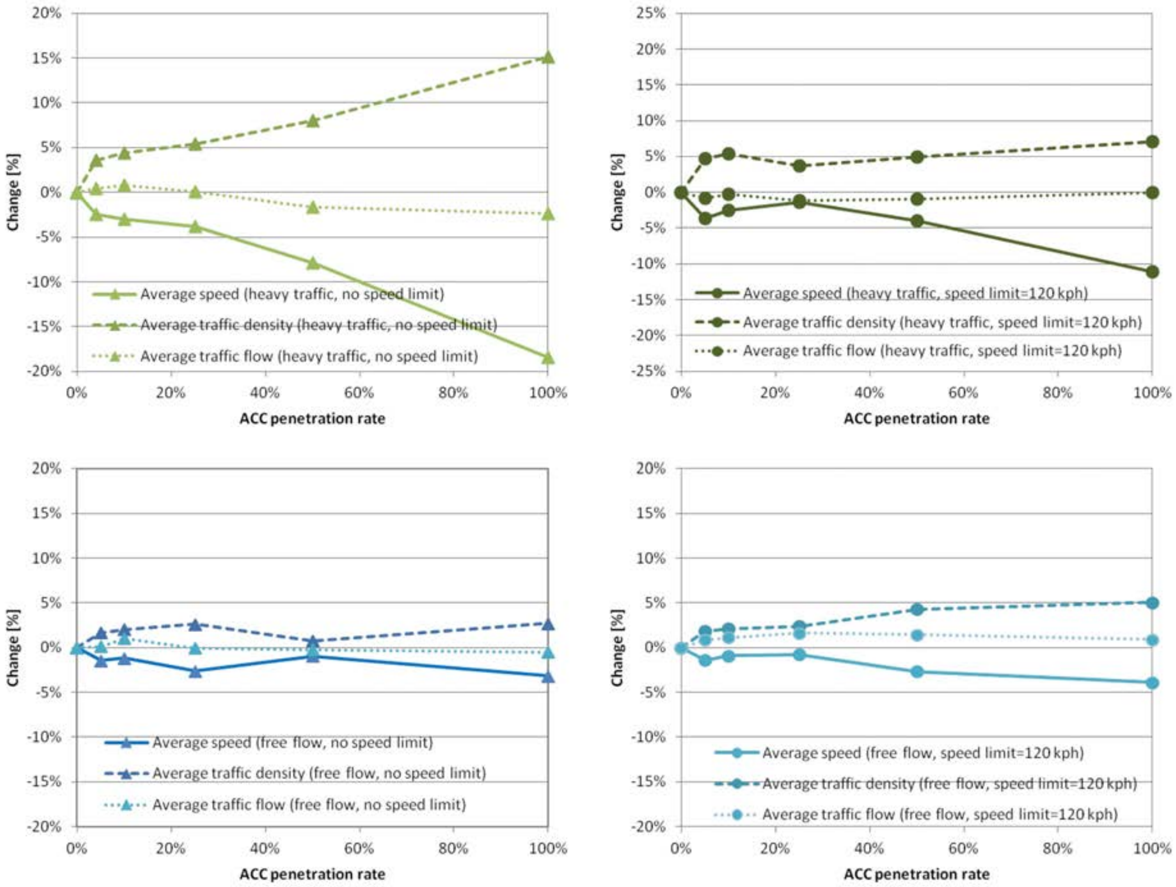

Figure 24: Change in average traffic flow, traffic density and speed compared to the baseline, as a function of the ACC penetration rate

In sum, these main insights can be seen deduced from the simulation results:

1) The simulations affirm the hypothesis "ACC decreases the average speed". In all conducted simulations with ACC usage the average traffic density is increased and the network speed is decreased compared to the baseline scenario.
2) Without speed limit, the effect of ACC equipment is higher in heavy traffic conditions than in free flow conditions. With a speed limit of 120 km/h, this effect is not clear. While the effect of the ACC on flow, density or speed is at most about 5% in free flow conditions, independent on the speed limit, it reaches 15% density change and 18% speed change in heavy traffic without speed limit.

3) The simulation shows that the increased demand from the junctions causes the traffic density to increase and some stop-and-go traffic to appear at the junctions. Because of the low speeds near the junctions the activation of the ACC is relatively low in these areas.

4) The results on density and speed show roughly a linear relation between effect size and penetration rate in the heavy traffic, no speed limit scenario.

5) There is no large effect on flow in any scenario.

6) It is therefore not possible to determine a clear dependency between higher ACC penetration rates and improved traffic efficiency. Since the THW in the FOT, which is reproduced in the simulation, is increased, a reduced density and throughput might be expected with higher penetrations in dense traffic. This was not clearly observed in the simulation results. It has been shown in the literature ([12], [13]) that the effects of ACC on traffic behaviour strongly depend on the systems settings and boundary conditions such as the selected time headway and the maximum deceleration and acceleration. Therefore, further investigation of these parameters is suggested.

7) To compare these results to the FOT data, it should be noted that

   a. ACC usage in the simulations is much higher than in the FOT, ACC being used whenever technically possible in the simulations, and in the FOT only when the driver chooses to do so;

   b. In reality, the vast amount of travel takes place under conditions similar to the free flow conditions of the simulations. Hence the more dramatic effects in the heavy traffic scenario will not have a large influence on the overall outcome.

Research question 1: What is the impact of ACC on average network or journey speed?
The average network speed has decreased with ACC, compared to without ACC, in all conducted simulation scenarios. For heavy traffic scenarios there is a reduction in average speed up to 18.5% while the effect is smaller for free flow conditions (up to 3.9% reduction). There is no clear relation between the speed and the ACC penetration rate, except for the heavy traffic, no speed limit scenario where this relation is roughly linear.

Research question 4: What is the impact of ACC on network performance per road category?
The changes in network performance on motorways are ambiguous. The traffic flow with ACC varies within 2.4% from that without ACC, with no clear tendency of increase or decrease. However, the traffic density increases with ACC compared to without ACC, while the average speed decreases in the simulations. For the heavy traffic, no speed limit scenario these changes are roughly linear in the penetration rate, but for other scenarios no clear relation with penetration rate can be seen.

Research question 5: What is the impact of ACC on section performance?
See results of research question 4.

Hypothesis 4: The average speed will decrease.
This is shown in Figure 25. In all of the conducted simulations with ACC use the average speed was lower than in the related baseline scenario. The highest reductions are achieved in the scenarios with a high traffic demand (-18.5% and -4.0% for 100% ACC).

4.6 Direct environmental effects

To assess the effects of driving with ACC on the environment the gathered data from the FOT was evaluated with regard to fuel consumption. In this section, the evaluation focuses on effects that are directly related to the change in tactical driving behaviour (e.g. speed and acceleration) and does not consider effects like reduction of traffic jams or accidents that result from improved traffic efficiency or/and safety. With the help of the numeric results from the detailed analysis of the fuel consumption it is possible to test the hypothesis related to the change in fuel consumption.

After the presentation of the results from the direct route for passenger cars and trucks the results are scaled up to the EU-27 level via the situational variable road type. Since the questionnaires do not indicate a significant change in exposure (e.g. in the total number of kilometres driven or a shift in circumstances under which these kilometres are driven) a change in exposure does not have to be considered. The data used for scaling up is the same as in the traffic efficiency and the safety impact assessment. Based on the change in fuel consumption on the EU-27 level the reduction in CO_2 emission can be calculated. More details on the methodology of the environmental impact assessment can be found in D6.2 [1].

4.6.1 FOT level effects for passenger cars

The euroFOT data allows detailed assessment of environmental effects, because it includes detailed information on speed, acceleration and fuel consumption. Also, the data can be linked to various situational variables. Since the ACC was designed for the use on motorways and the highest mileage with active ACC during the FOT was driven on motorways, the analysis will focus on that road type.

Comparing driving on motorways with activated ACC to the baseline reveals a significant average fuel consumption reduction of 2.77%. This number consists of FOT results from two different passenger vehicle fleets. Within the considered fleets the reduction in fuel consumption varies between 2.06% and 3.01%. All reductions are within the significance limit of $p < 0.05$. The average was weighted with the kilometres driven in these fleets (and under the same specified conditions). The usage rate on motorways was about 50%.

Table 36: Results for change of fuel consumption for the ACC system in passenger cars

Factor	Average fuel consumption [l/100km] Baseline / Treatment	P-value	Absolute difference [l/100km]	Relative difference [% of baseline]
Motorway	7.30 / 7.1	< 0.05	-0.16	-2.77

In general, one can say that a general tendency for a reduction in fuel consumption could be found within the three different passenger vehicle fleets.

4.6.2 FOT level effects for trucks

In addition to the evaluation of the environmental effects of driving with ACC in passenger cars the fuel saving potential is also analysed for trucks. The traffic and driving situations trucks are exposed to differ from those of passenger cars in various aspects (absolute speed and variation in speed, number of overtaking manoeuvres, travel time, etc.). It is therefore expected that the influence of the ACC is slightly different for trucks than for passenger cars.

Like for the passenger car fleet, the assessment of environmental effects of ACC usage focuses on motorways. During the FOT in two geographic regions and in two vehicle fleets a reduction in fuel consumption of 1.85% was evaluated when driving with the system. The effect is therefore somewhat lower than for passenger cars. A possible reason might be the generally high proportion of driving with only little variation in speed on motorways (also in Baseline). The often monotonous driving pattern on motorways leads additionally to a higher usage rate (57.03%) in comparison with passenger cars.

The results for trucks seem more reliable than the results for cars since the driving patterns (speed and deviation in speed) that are compared in baseline and treatment are very similar because of the general traffic and driving situation (little speed variation).

Table 37: Results for change of fuel consumption for the ACC system in trucks

Factor	Average fuel consumption [l/100km] Baseline / Treatment	P-value	Absolute difference [l/100km]	Relative difference [% of baseline]
Motorway	24.65 / 24.19	< 0.05	-0.46	-1.85

Hypothesis 4: Driving with ACC decreases the fuel consumption.
On motorways the fuel consumption is decreased by 2.77% when comparing baseline to ACC active time (Baseline → Treatment active) for passenger cars. The reduction for trucks is somewhat lower with about 1.85%. For these conditions the hypothesis is confirmed.

4.6.3 EU-27 level effects

In addition to the evaluation of the FOT results the impact of the changes on the EU-27 level should be estimated. To see the potential of the ACC in saving fuel it is assumed for scaling up that all vehicles in the European fleet are equipped with ACC. Since no data on kilometres driven with active ACC is available on EU-27 level the km-based usage rate is deduced from the FOT data. The effects are calculated for driving on motorways based on statistical data on mileage in the EU-27 in 2010. In the EU-27 countries 694.34 billion kilometres per year were driven on motorway with passenger cars and 40.26 billion kilometres with trucks [11].

As mentioned before the system was evaluated in different geographic regions which cause the results to vary within a certain range. The usage rate was defined by the ratio of the sum of kilometres driven with active ACC in both geographic regions and the sum of all kilometres driving within the treatment phase. In sum, about 50% of the kilometres driven with passenger cars on the motorway were covered with active ACC (during the FOT). The combination of the usage rate and the reduction in fuel consumption when driving with ACC could result in achieving a fuel savings of 1.37% in the European passenger car fleet. Assuming an average fuel consumption of 7.3 l/100km (as found in the FOT data, see Figure 25) this would sum up to absolute savings of 693.9 million litres of fuel per year. The results for the potential in fuel saving are shown in Figure 25. Notice that these savings only consider driving on motorways.

From the fuel saving potential it is also possible to derive the savings in CO_2 emission. The CO_2 emissions are calculated based on the average conversion factor for petrol and diesel engines (petrol: 2.32 kg CO_2/l, diesel: 2.62 kg CO_2/l based on [2]). Assuming 61.8% petrol- and 35.3% diesel-powered passenger cars in the European vehicle fleet [3] the estimated fuel savings represent savings in CO_2 emissions of about 1.7 million tons for passenger cars.

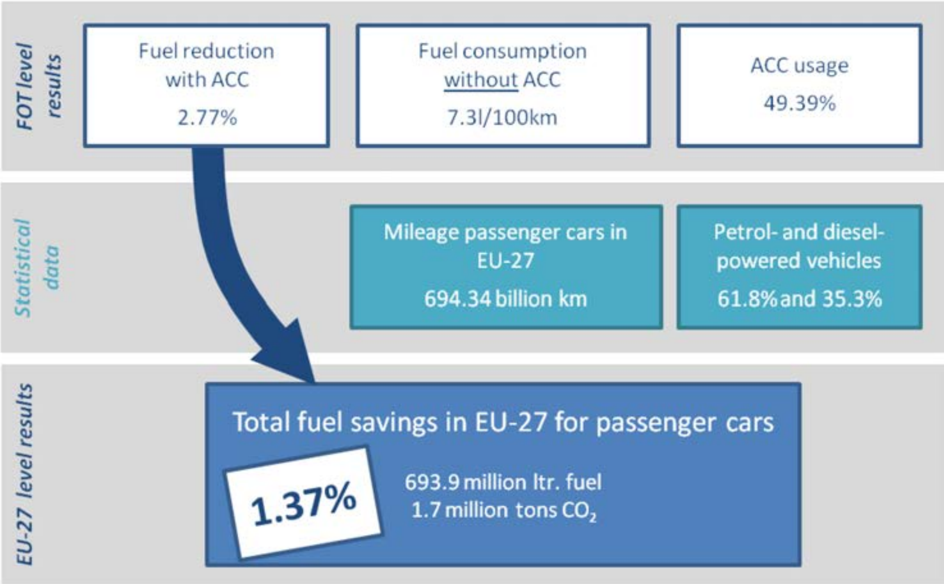

Figure 25: Potential in fuel saving with ACC equipped passenger cars for EU-27

For trucks a usage rate of 57% was recorded during the FOT. Together with a fuel reduction of 1.85% in phases of active ACC, this results in an overall estimated benefit of 1.05%. Assuming an average fuel consumption of 24.65 l/100km (as found in the FOT) one can calculate the total annual fuel savings for driving on motorways with ACC equipped trucks to be 104.6 million litres. With about 98% diesel-powered trucks in the European fleet the fuel savings represent 237.9 thousand tons less CO_2 per year for trucks (see Figure 26).

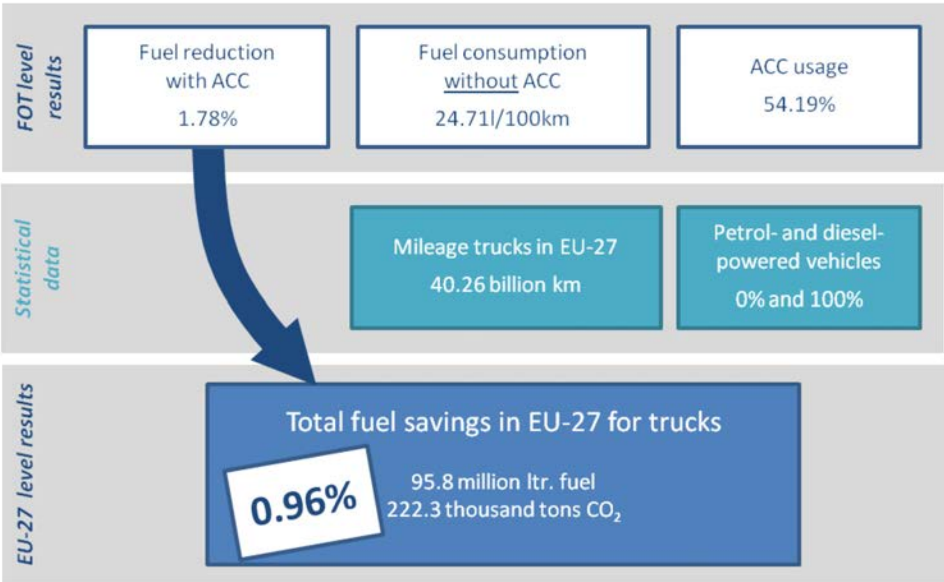

Figure 26: Potential in fuel saving with ACC equipped trucks for EU-27

It has to be considered for both cars and trucks that the proportion of mileage on motorways during the FOT is overrepresented in comparison to the European average. See the comparison between the share of kilometres driven on different road types in the FOT and on EU-27 level in Figure 21 and Figure 22.

4.7 Results of environment simulations

To broaden the insights into environmental effects of ACC usage, the simulation tool Versit+ is used. While the FOT data is focused on fuel consumption based on CAN data, Versit+ is used to calculate effects on the pollutant emission like CO, NO_x and HC. The emission modelling is based on speed profiles gathered from FOT data. The simulations focus on function-related changes in driving behaviour and do not try to assess the changes due to interactions of equipped and unequipped vehicles.

Therefore, Versit+ requires speed profiles with a frequency of ten Hz in different driving situations.

4.7.1 Versit+ simulation

Versit+ is a statistical tool that models “regulated emissions” (CO, NO_x, PM10, HC) as well as CO_2, based on a database of driving patterns and associated measured emissions for 3200 light duty vehicles (20000 tests on 200 driving cycles) and 500 heavy duty vehicles.

The Versit+ model can predict real world emissions per second, based on driving behaviour, which is characterized by speed and acceleration as a function of time and the specific characteristics of the vehicle(s) in question. The characteristics of the vehicle are summarized in a Versit+ vehicle class which is based, amongst others, on the vehicle type (i.e. passenger vehicle, delivery van, etc.), fuel type (i.e. gasoline or diesel) and the Euro class determined by the date of admission. The Versit+ type of the vehicles used in this analysis is the LPADEUR5, meaning: a light-weight Euro-5 passenger vehicle with a diesel engine. This designation best matches the properties of the vehicles used in the euroFOT. For more information on Versit+, see D6.2.

4.7.2 Input

Speed profiles with a frequency of 10 Hz have been used to calculate the effect on emissions. Representative samples of the complete data set have been selected to which the Versit+ model will be applied. Data samples of about 50 minutes per driver for nine different drivers per situation and twelve situations are used. These are listed in Table 40 below. To account for the variation in conditions, the data has been ‘chunked’ into pieces of driving with length of a few kilometres. The length of the chunks are five kilometres for motorway free flow driving and rural driving conditions and two kilometres for driving on congested motorways and 1.5 kilometres for urban driving.

Two random halves of the data set has a similar characteristic which indicates that the data is representative for the complete data set. The table below shows that this results in about 100 hours of driving. The other situational variables are kept the same (vehicle type: car, weather: no rain, lighting: daylight).

Table 38: Used data samples for the Versit+ analysis

Function state	Road type	Traffic state	Minutes driven by all drivers	Number of drivers
Baseline CC not active	Motorway	Free flow	494	9
		Congestion	103	7
	Rural road	-	501	9
	Urban road	-	464	9
Baseline CC active	Motorway	Free flow	497	9
		Congestion	3	2
	Rural road	-	502	9
	Urban road	-	209	8
Treatment ACC not active	Motorway	Free flow	395	9
		Congestion	132	9
	Rural road	-	470	9
	Urban road	-	477	9
Treatment ACC active	Motorway	Free flow	533	9
		Congestion	12	5
	Rural road	-	519	9
	Urban road	-	394	9
Total			**5705**	**9**

The data sample has data from nine different drivers, driving two different models. Both models are 2.4 liter diesel passenger cars from 2010 with the following characteristics.

Table 39: Characteristics of vehicle models used in the Versit+ simulations

Tyre pressure	Engine power	CO_2 rating	Gross weight	Emission class	Engine	Model year
2.2 bar	175 hp	179	1692	2005 PM	2.4l diesel	2010

4.7.3 Output

This section presents the environmental impacts for ACC not active versus ACC active. This definition of baseline and treatment was chosen such that the driving with cruise control, which accounts for about 45% of the driven kilometres in the baseline period, was not included in the baseline. The impacts on the indicators CO_2, CO, NO_x, HC and PM are shown as a percentage of reduction. Additionally the table shows whether this gain is significant (yes/no) within one sigma (68%).

Table 40: Effect on CO2, CO, NOx, HC and PM, including significance (yes/no) per condition

Road type	Reduction in CO_2 [%]	Reduction in CO [%]	Reduction in NO_x [%]	Reduction in HC [%]	Reduction in PM [%]
Motorway (free flow)	1.9 / no	11,4 / yes	15,1 / yes	3,4 / yes*	-0.3 / no
Rural road	1.8 / no	6.4 / no	11.0 / yes	4.7 / yes*	1.1 / no
Urban road	6.5 / yes	12.7 / no	17.5 / yes	51.4 / yes	7.2 / yes

This effect is calculated over a speed range for which data is available, based on the curves fitted through the data points. It is the surface below the graphs in Figure 2. The speed ranges are 40 -70 km/h for urban roads and 90-120 km/h for rural roads and motorways.
The HC result for urban roads is very high. The results marked with an * are significant only for a part of the speed range. The high reduction in HC of 51.4% is in absolute numbers not that high. This is because the EF data point for lower speeds are close to zero, and therefore the fitted curve is also close to zero.

Figure 27 shows the CO_2 emission factor (EF) resulting from the simulations versus the mean speed. The EF is the average emission in grams per driven kilometre. The data points represent the chunks of 1.5, 2.5 and 5 kilometres of driving, depending on the road type. E.g. a data point on urban roads at 80 km/h means that a driver drove an average speed of 80 km/h for 1.5 kilometres.

Figure 27 shows that

- The effect on CO_2 on motorways (free flow) and rural roads are very limited. The confidence intervals (dotted lines) overlap, so the effects are not significant.
- On urban roads, ACC is used mainly at higher speeds than driving without ACC. This is partly because ACC works only at speeds higher than 30 km/h. It might also be because it is less comfortable to use ACC in busy traffic where speeds dive below 30 km/h regularly. The range of the effect is therefore limited to 40 - 100 (see red curve for urban roads in Figure 27)
- The data on congested motorways is too sparse to determine an effect. ACC is hardly used in congestion. The effect is therefore not included in Table 40.

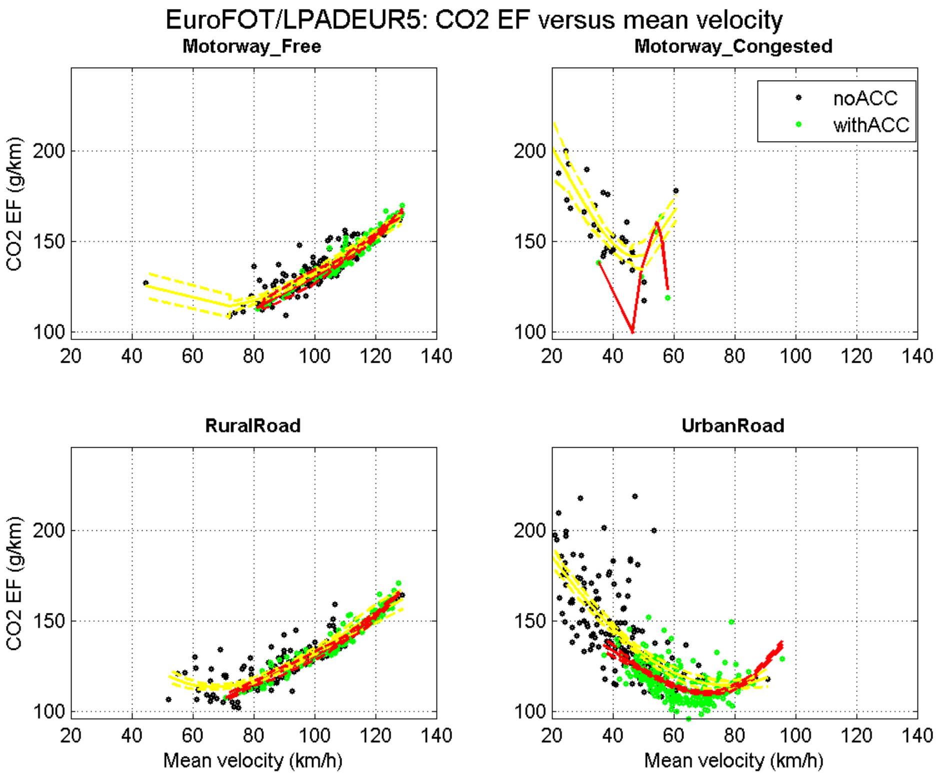

Figure 27: CO2 emission factor (EF) versus mean velocity

(fit ACC= red line, fit No ACC= yellow line, one sigma confidence interval= dotted lines)

Figure 28 shows the gain in emission factors versus speed. The curves are the difference between the fits as shown in Figure 27 for CO_2. They are to be trusted only for the speed ranges for which data in both baseline and treatment are available. These are the ranges are used for calculation the effects, which are mentioned above.

Figure 28 shows that

- The effects on CO_2 are very small.
- For urban roads, the effects in the lower speed ranges (e.g. for HC) is based on little data so the fit may not be correct.

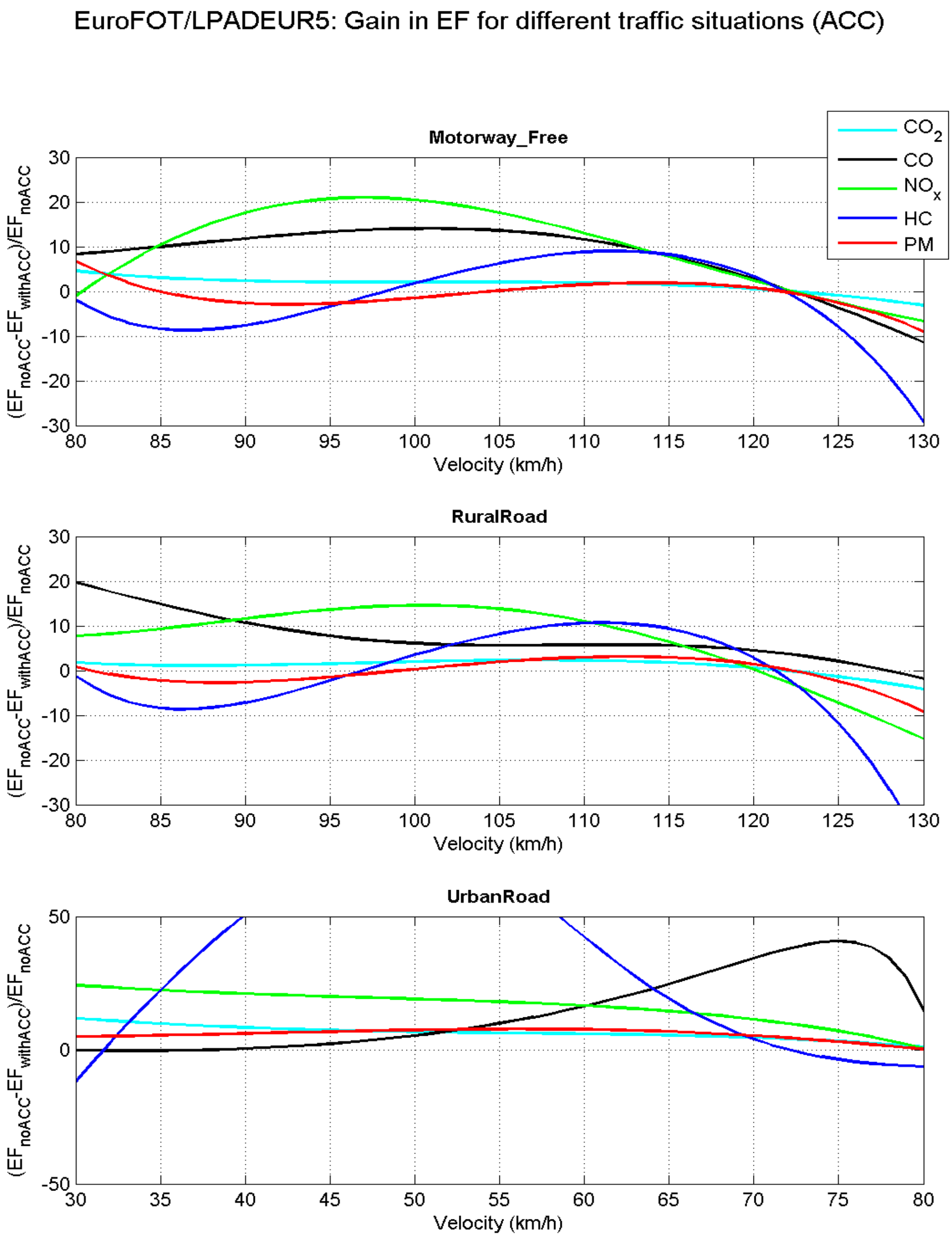

Figure 28: Gain in emission factor (EF) for different traffic situations

(positive values mean reductions of the emission)

The effects presented above are the effects per road type between driving with and without ACC. This does not include the usage of the ACC, e.g. the percentage of time and the speeds for which it was switched on. Table 41 below shows the effects of the FOT including usage. To include the usage, the effect is scaled to the distribution of speeds measured in the FOT. Speed bins of 10 km/h are used for the ranges for which the effects are determined, which are mentioned above. The effects are determined per road type as indicated in Table 41.

When usage is included the effects are as shown in Table 41. Obviously the effects are smaller than the results for the individual system states ACC active, and ACC off, since they compensate each other.

Table 41: Effects including usage (positive numbers indicate a reduction)

Road type	Reduction in CO_2 [%]	Reduction in CO [%]	Reduction in NO_x [%]	Reduction in HC [%]	Reduction in PM [%]
Motorway (free flow)	0.4	2.9	2.3	0.9	0.0
Rural roads	0.2	0.3	2.3	-0.2	-0.2
Urban roads	0.2	0.2	0.8	0.7	0.2

The effects are weighted against the speed distribution between baseline and treatment. Since Versit+ uses speed profiles the effect is known for the different speeds (see figure 2). These effects for different speeds were scaled to how often these speeds were driven in the FOT. The speed distribution from the FOT was used to multiply the km driven in each 10 km speed bin with the effect for each system state in middle of the bin. The speed intervals for which the effect could be determined (listed above) are applied as well here.

5 Speed Regulation System (SRS)

The Speed Regulation System (SRS) helps the driver to manage the speed. This system consists of two functions, namely a Speed Limiter (SL) and a Cruise Control (CC). The Speed Limiter limits the speed of the car in order to prevent the driver from exceeding a programmed speed limit value. This speed limit value is pre-set by the driver during the system activation, and the minimum value of this speed limit is 30 km/h. The Cruise Control function maintains a constant speed without any manual control by the driver. This speed is programmed by the driver. The system can only be activated when the speed is above 30 km/h. The two functions can both be OFF or ON, and they cannot be used simultaneously. When a function is ON, it can be active or inactive. When it is OFF, it is always inactive. Both functions can be temporarily overridden. Results are presented as a comparison between baseline and treatment period. Sometimes the treatment results are categorised in three states, being ‘SL active’, ‘CC active’ and ‘no function active’. Here ‘SL active’ means that the speed is limited by the SL function and is not overridden by the driver (with accelerator kick down), and ‘CC active’ means that the CC function is regulating the speed and is not overridden by the driver (with the accelerator or brake pedal). When for example CC is on but not active, if falls in the category ‘no system active’.

The experimental set-up was as follows. For each driver, the FOT lasted for about 13.5 months, starting with 3 months baseline followed by 11.5 months of driving with the SRS. More information about the experimental set-up can be found in euroFOT deliverable D4.2 [7].

5.1 Summary of effects

The impacts of SRS were analysed and the results can be found in this chapter. The most important results are summarized in this section. For details the reader is referred to the remainder of this chapter.

The SRS slightly increases average speed. The traffic efficiency effect is determined by the change in average speed, since the analyses show that SRS does not affect mobility behaviour, route choice or choice of road type.

The traffic efficiency effect of the sub functions Cruise Control and Speed Limiter cannot be determined because of the experimental set-up: the systems were not tested separately. The systems were both in the vehicle at the same time, and could not be used simultaneously. Because the analyses show that CC is used at higher speeds, the average speed when CC is active is higher than the average speed. When SL is active, speeds are about the same as the average speed. When SL and CC are off, speeds are lower than the average speed. These results are caused by the fact that CC and SL are active under certain conditions that are not representative for the whole data set (selection effect).

In Table 42 a summary of effects of SRS on the FOT vehicles can be found. This is the effect of having the system in the vehicle (treatment period), versus not having it (baseline period). It is not the effect of an active system versus an inactive one. ‘-‘ means that there is no significant effect. The results show that, on average, SRS-equipped vehicles record higher speeds than unequipped vehicles on all road types. There is no effect on the average length of a trip, which suggests that mobility patterns (trip choice, modal choice and route choice) are not affected by the function. These effects on speed and mobility translate into lower average travel times and less delay.

Table 42: Summary of effects on FOT level (only cars) of Speed Limiter and Cruise Control (‘-‘ means that there is no significant effect)

	SRS
Change in average travel time per trip	Urban -1.4% Rural -0.8% Motorway -2.4%
Change in mobility (kilometres driven per trip)	0%
Change in average speed	Urban +1.4% Rural +0.8% Motorway +2.4%
Change in delay (range, depends on road type)	Incidental delay - Recurrent delay -5.5% to -3.5%

Table 42 shows the results that were obtained directly from the FOT data. Additionally, microscopic traffic simulations have been performed for SRS to determine the interaction effects with higher penetration rates of SRS equipped vehicles.

Additionally to the results given above, the main results from the simulations are:

- The use of SRS makes the speed distribution narrower, so the variation in speeds is reduced. This is even more so for the CC function.
- Most of the speed increase takes place on rural roads and urban roads.
- Cruise control is mainly used on motorways in free flow situations. Speed limiter is used on all road types, but most on urban roads and rural roads (around half of the kilometres driven). CC is used on longer trips.

The simulation results show that the average speed increases linearly with the penetration of equipped vehicles. There are no interaction effects on the traffic efficiency indicators average network speed and average delay. Interaction effects are visible for safety indicators, such as small time headways and short times to collision. For the scaling up of the traffic efficiency effects, the effects found in the FOT will be used and the effect will be considered linear for higher penetrations.

For all road types a significant influence of the use of CC on fuel consumption was found during the analysis. The reductions vary between 1% for motorways and 36.3% for urban roads. The high influence on urban roads might be caused by the selection of driving situations when the system is used. This inherent bias in the FOT data on CC leads to precaution in the interpretation of the results as they do overestimate the benefits. The low usage rate of 2.69% is an additional indicator that the system is only used under certain driving situations. The speed limiter has also significant (positive) influence onto fuel consumption on all considered road types with reductions between 1.55% and 5.19%. The reduction can be attributed to a more constant speed while using SL and is like the reduction found for CC influenced by the driver’s choice when to use the system.

5.2 System use & mobility behaviour

To explain the traffic efficiency results, the system use and mobility behaviour results are important. The percentage of the time the system is used is shown in this paragraph.

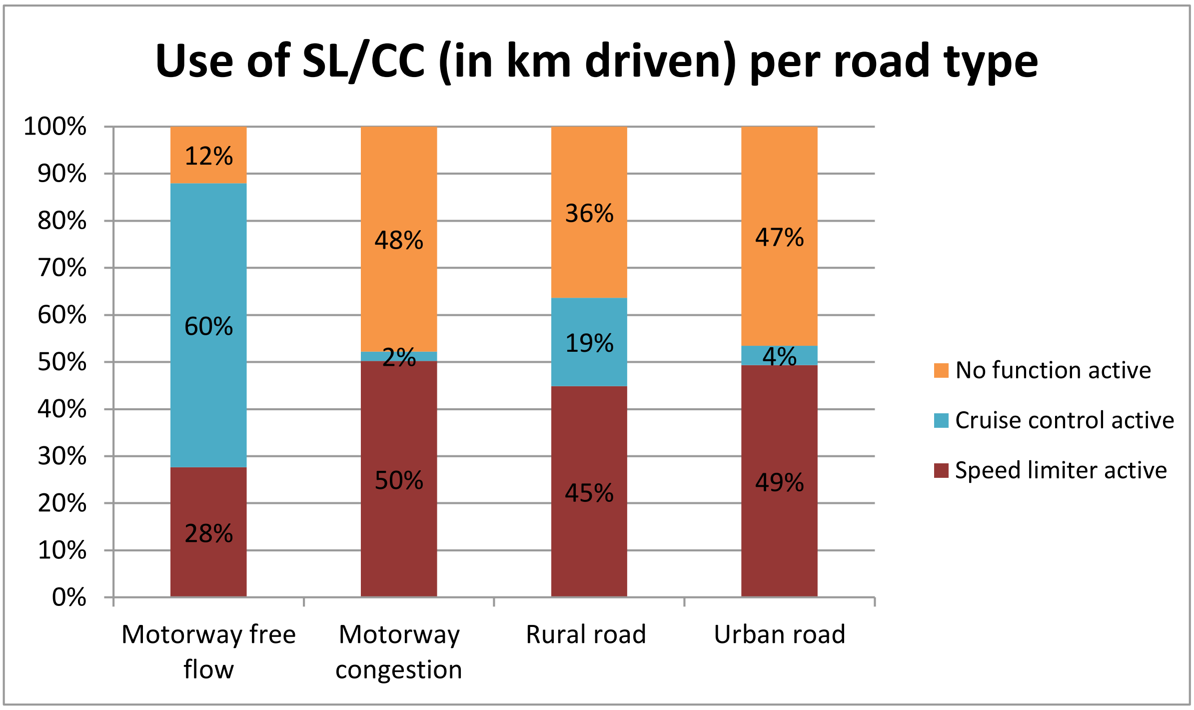

Figure 29: Use of SL/CC per road type

As Figure 29 shows, the cruise control is mainly used on motorways in free flow situations (60% of the km driven), and to a lesser extent on rural roads (19% of km driven). Cruise control is used very little on urban roads and during congestion (it does not work when speed is below 30 km/h).

Speed limiter is used on all road types, although mostly on motorways during congestion (50% of km driven) and on urban roads (49% of km driven). On rural roads it is used on 45% of km driven and motorways during free flow 28% of km driven. When the speed limiter is active on motorways during congestions, it is probably only running but not doing anything.

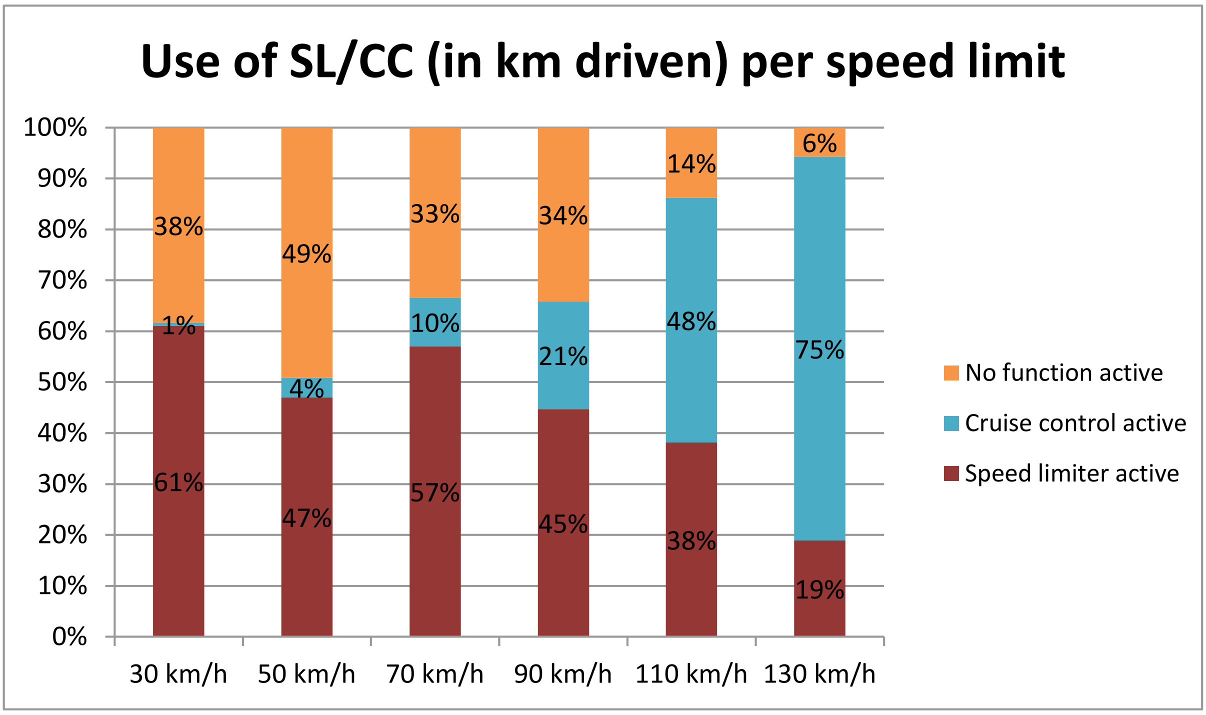

Figure 30: Use of SL/CC per speed limit

Figure 30 shows the same type of usage as Figure 29. The use of Cruise Control grows when the speed limit increases. The use of Speed Limiter generally shrinks when the speed limit increases. CC is on average used more on longer trips. Therefore, the trips where both systems are not used are on average shorter. These results are consistent with the assumption that the Cruise Control function is used in free flow conditions and conditions with very little traffic. These are often the higher speed ranges. Since only one of the functions can be used at the time, it also suggests that the use of SL is replaced by the use of CC in the higher speed ranges.
During and after the FOT, participants have filled in questionnaires at several moments. The following results on mobility behaviour come out of these subjective data. 0% to 12% of the participants said their travel pattern changed since driving with CC. These participants indicated that they drove more relaxed, especially on motorways. 6% to 12% of the participants said their travel pattern changed since driving with SL. These participants indicated that they more often used roads with constant speed (not necessarily other road types), used roads with fewer traffic lights (also not necessarily other road types), accelerated more slowly, and looked at the speedometer less often.
The following conclusions can be drawn with regard to the traffic efficiency analyses. There is no indication that participants drove more or fewer kilometres with the systems than without the systems. We do not expect a significant change in distribution of kilometres over different road types. A couple of participants indicated that they changed their travel pattern, but this has more to do with the way of driving (more relaxed) than with driving on different road types. There might be a small change to relatively more driving on motorways.

5.3 Direct traffic effects

This section contains the results of the direct route per research question / hypothesis, first on the FOT level and then on the EU-27 level.

5.3.1 FOT level

Average speed

In the graph below, average speeds are shown for different speed limits. The average speed for the SRS is slightly higher in treatment than in baseline period. The average speed when using CC is clearly higher than in the baseline (similar to ACC). This is again consistent with the earlier conclusion that CC is used on roads and in traffic conditions where higher speeds are possible due to road characteristics and traffic conditions. Especially on motorways there is a lower average speed when driving with SL.

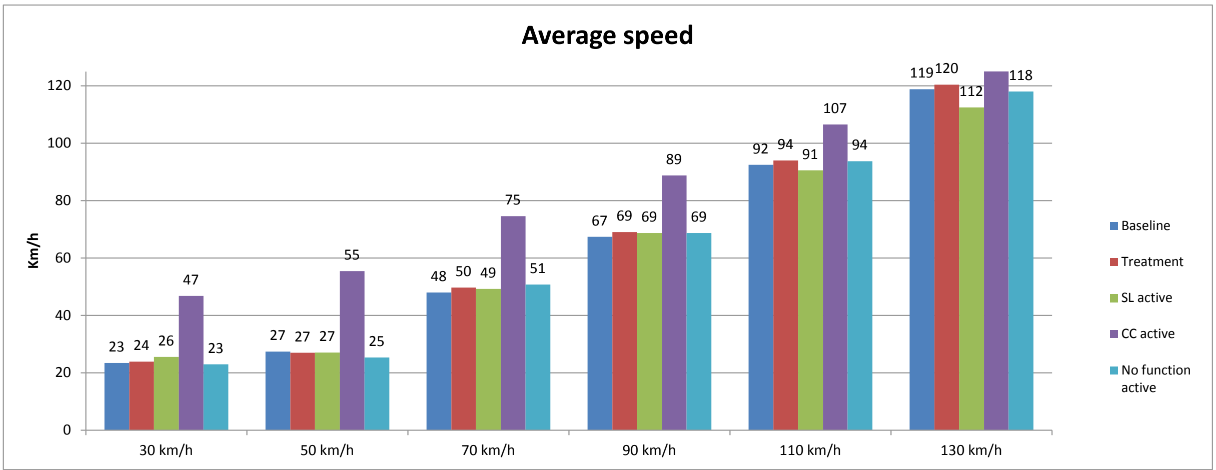

Figure 31: Average speed over speed limit

The average speed results can be found in Table 43. There is a significant increase in average speed on most road types (classified by speed limit), which varies from 0.6% to 2.4%, depending on the speed limit. The overall increase in average speed is larger than the increase for the different road types. This is due to a change in another variable that determines average speed, e.g. traffic density.

The effect on average speed for roads with speed limits 50, 90 and 130 are used as an effect for respectively urban roads, rural roads and motorways for scaling up.

Table 43: Hypothesis testing results for average speed with SRS

(* only 70km/h speed limit is not significant)

Speed limits	Road type	Baseline	Treatment	Effect	Range (95% confidence interval?)
30 km/h		28.6	29.25	2.3%	1.1% to 3.5%
50 km/h	**urban**	**31.82**	**32.27**	**1.4%**	1% to 1.8%
70 km/h*		54.91	55.22	0.6%	0.1% to 1.3%
90 km/h	**rural**	**69.75**	**70.31**	**0.8%**	0.4% to 1.2%
110 km/h		94.74	96.63	2.0%	1.6% to 2.4%
130 km/h	**motorway**	**118.83**	**121.7**	**2.4%**	2.2% to 2.6%
All conditions		62.37	65.43	4.9%	4.6% to 5.2%

See annex 2 for a more detailed description of the tests and results. These numbers in Figure 31 do not exactly match the averages speed numbers from the hypothesis testing table because the filter of data for applied for the hypothesis testing and the differences in used data set. The method used for the statistical testing is the “Generalized Linear Mixed Model” (GLMM) which means that the averages are in fact the Least squares estimation for average speed.

Hypothesis 1: The average speed will increase.
This hypothesis is accepted. There is a significant increase of average speed for all speed limits except 70 km/h.

Travel time

Travel times per kilometre for the different categories change inversely to speed. The average travel time per km decreases with 0.8% to 2.4% (depending on the road type) with SRS compared to the baseline.
The effect on travel time is determined by adding the effect on speed and the effect on number of kilometres driven. The delay, either due to incidental or regular congestion, is not included in this result. Since the number of kilometres driven has neither changed by the SRS, nor the choice of road type or route, only the impact on average speed determines the travel time.

Speed distribution

Figure 32 to Figure 34 show the speed distribution for roads with speed limits of 50, 90 and 130 km/h. Use of CC makes the speed distribution narrower, so the variation in speeds has reduced as expected. CC has its peak around the speed limit. CC is hardly used on 50 km/h roads. This is the same behaviour as Intelligent Speed Adaptation (ISA) systems except that with ISA the speed limit is strictly equal to the official one [2],[6].

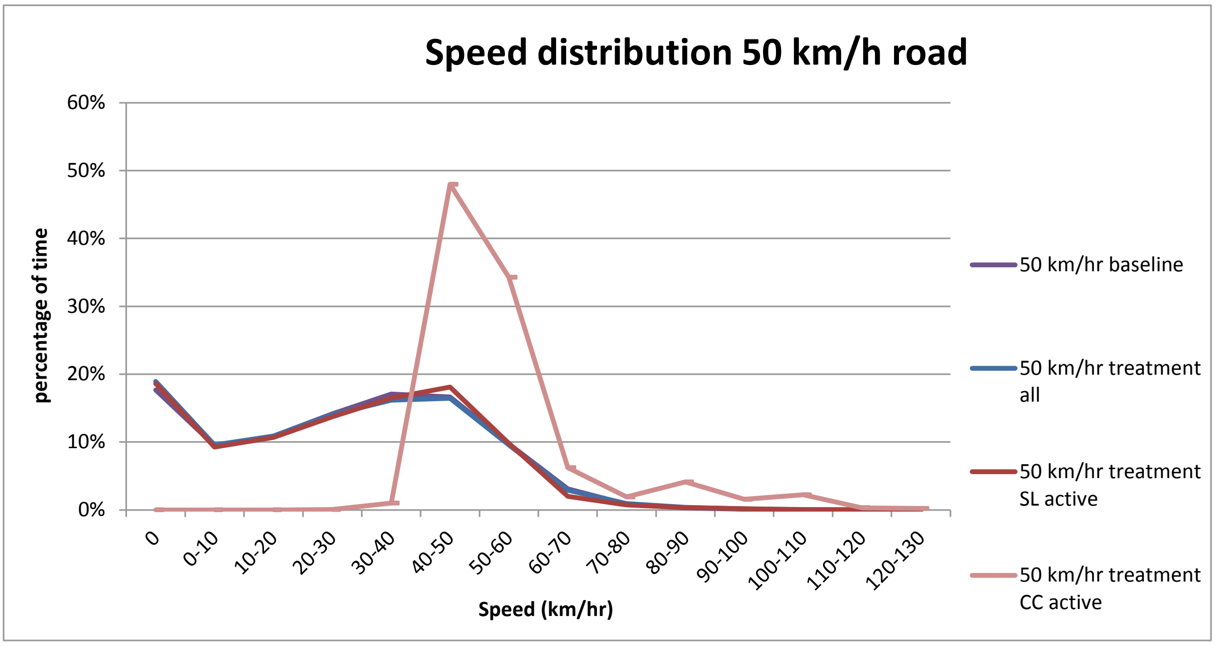

Figure 32: Speed distribution 50 km/h roads

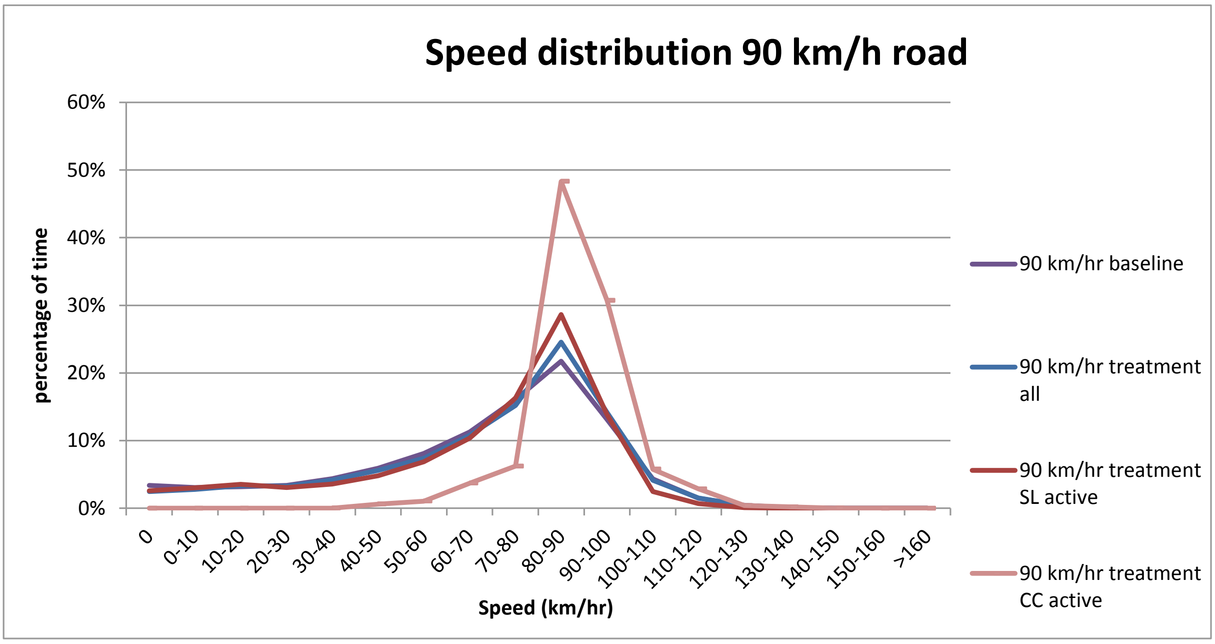

Figure 33: Speed distribution 90 km/h roads

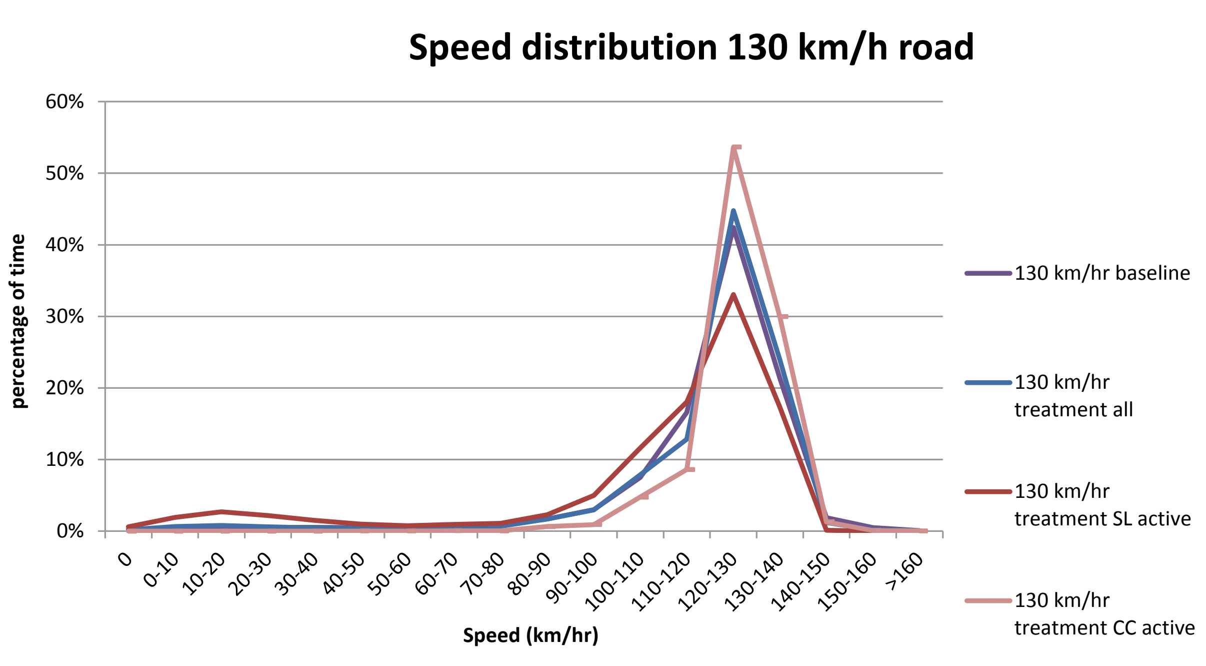

Figure 34: Speed distribution 130 km/h roads

Research question 3: What is the impact of SRS on variation in speed?
Use of SRS makes speed distribution narrower, so the variation of speeds has reduced. This is even more so for the CC function.

Trips

The average number of trips per day is 3.0 in the baseline period, and 3.2 in the treatment period. This is an increase of 7%. The presence of SRS is not likely to be the reason for this increase. This is confirmed by the questionnaires in which people were asked whether their mobility behaviour was changed due to the use of SRS and how. These results are shown in section 4.2 System use & mobility behaviour.

Mileage

The average mileage per day increased with 7%. Because the average number of trips per day increased by 7% as well, the average mileage per trip stayed the same. As Figure 35 shows, there is no change in the distribution of km driven on different road types. Even though some drivers have indicated that driving on motorways becomes more comfortable with SRS, we assume that this does not result in a change in route and therefore a change in road type.

Table 44: Average mileage baseline and treatment period SRS

	Average mileage per day	Change w.r.t. baseline	Average mileage per trip	Change w.r.t. baseline
Baseline	44.1 km		14.8 km	
Treatment (all)	47.4 km	+ 7.4%	14.8 km	0.0%

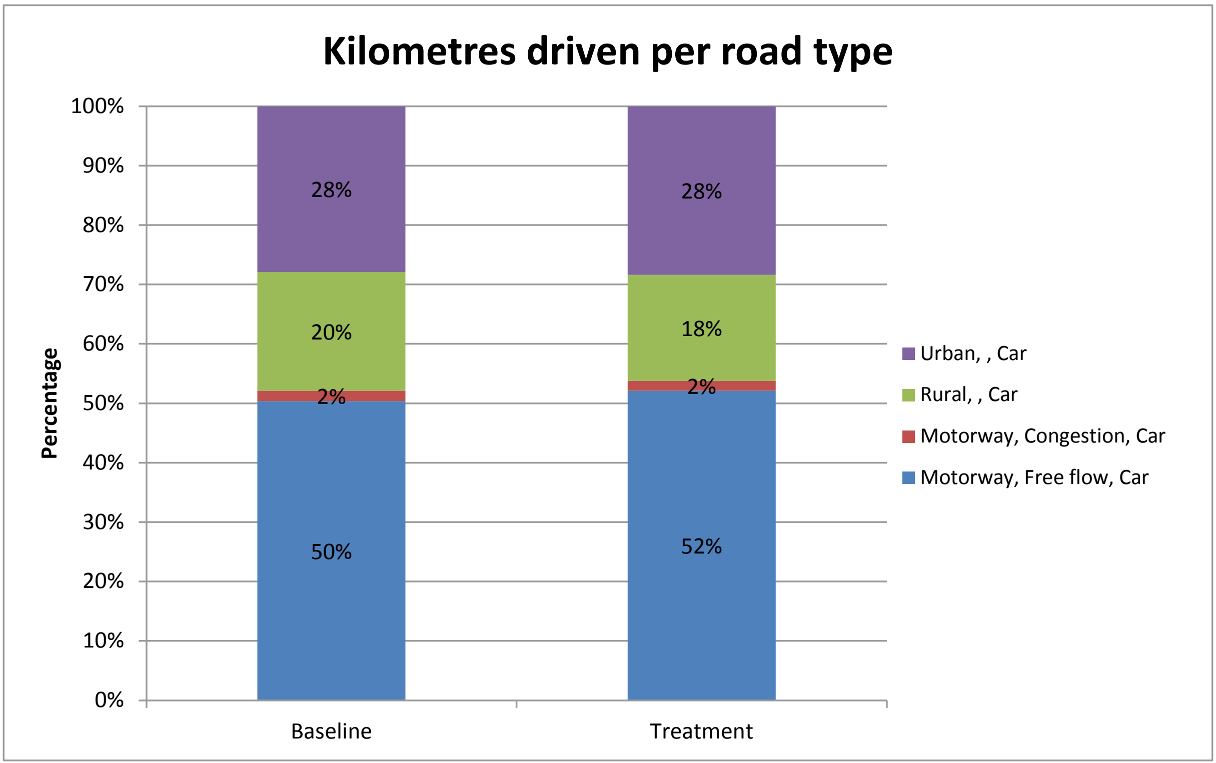

Figure 35: Kilometres driven per road type comparing baseline and treatment

Hypothesis 3b: The number of vehicle km travelled per trip will increase (objective data).
The hypothesis is rejected. SRS does not have a significant effect on the trip length.

Delay

Delays are calculated with use of the speed distribution. As a starting point we assume that on motorways vehicles driving slower than 100 km/h are delayed, on rural roads the boundary is 80 km/h and on urban roads the boundary is 50 km/h. Vehicles that drive 5 km/h cause more delay than vehicles that drive 40 km/h. As a measure for delay vehicle loss hours are used. Note that for this calculation the urban roads are the ones classified as 50, 90 or 130 km/h, rather than urban, rural or motorway km/h.
The share of delays (vehicle loss hours compared to the total travel time) is given in the table below. For 130 km/h roads and 90 km/h roads delays are lower in the treatment period. On 50 km/h roads there is a very small increase. These results were not tested on significance since they were available on a higher (aggregated) level.

Table 45: Delays baseline and treatment period SRS

	Delays		
	130 km/h roads	90 km/h roads	50 km/h roads
Baseline (% time spent in delay compared to total travel time)	3.1%	19.1%	36.5%
Treatment (% time spent in delay compared to total travel time)	2.6%	18.1%	36.7%
Change treatment versus baseline period	-17.0%	-5.3%	+0.6%

Research question 2: What is the impact of SRS on the amount of delay?
With SRS the drivers experience less delay on 130 km/h roads and 90 km/h roads, up to 17% less on 130 km/h roads. On 50 km/h roads there is a very small increase. These numbers are not tested on significance.

One could expect that when the system is off, the average speed would be the same as in baseline. However the FOT data shows that the average speed is lower when the system is off. Since the CC is comfortable to use in conditions when constant speeds can be maintained, a probable explanation is that people use the SRS when the road and traffic conditions allow for fast driving. That means that when the system is off, they are more often in condition with heavy traffic, congestion or traffic lights. Therefore the average speed hypothesis was tested comparing all treatment conditions, so CC active, SL active and both not active, with the baseline data.

5.3.2 EU-27 level

In the FOT, when driving with SRS the mileage does not change significantly, nor does the distribution over roads types.
The distribution of mileage over the different road types is very different for EU-27 compared to the FOT data. See below the graph where the distribution of mileage for cars over road types is given for EU-27 and for the FOT (baseline period). In the FOT, half of the kilometres are driven on motorways. In EU-27, the share of kilometres driven on rural roads is higher. The share of kilometres on urban roads is about the same. The share of kilometres driven in congestion on motorways is higher in EU-27 than in the FOT baseline.

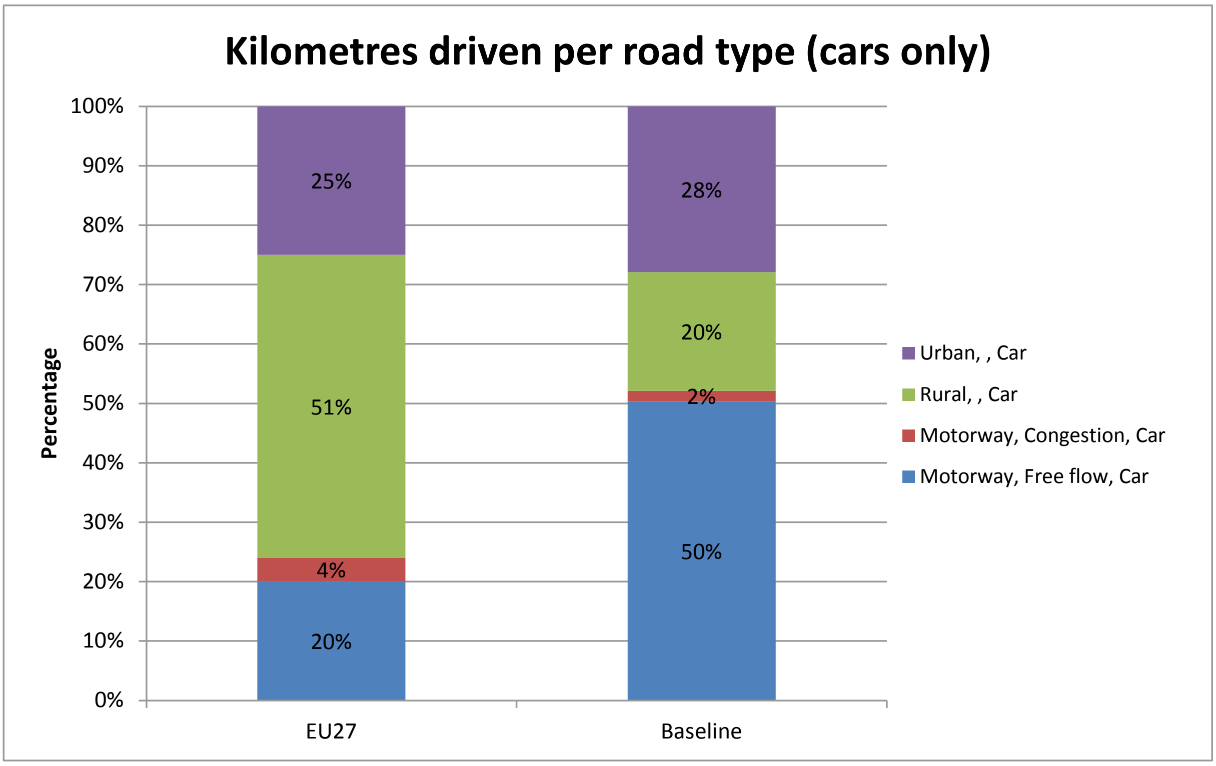

Figure 36: Kilometres driven per road type comparing baseline and EU27

This difference in distribution has implications for scaling up (effects have to be weighed to the different road types). For EU27, change in speed and change in total travel time are calculated.

Total travel time EU-27

Assuming that every car has SRS, total travel time for cars would decrease by 1.2%. With a lower penetration rate, the total travel time on a network level changes in a linear way (so with a penetration rate of 50%, total travel time decreases by 0.6%).
In EU-27, 94.5% of kilometres are driven by cars and 5.5% is driven by trucks. We only know the change in behaviour of car drivers. For now we assume that the effect on trucks is zero. Therefore, the overall change in total travel time on EU-27 level will be a bit smaller:

Table 46: Effect SRS on travel time on EU level

Speed limits	Road type	FOT effect	EU effect
50 km/h	Urban	-1.4%	-1.1%
90 km/h	Rural	-0.8%	-0.8%
130 km/h	Motorway	-2.4%	-2.2%
	All roads		-1.2%

5.4 Indirect traffic effects

For SRS safety impacts were calculated, but it was not possible to translate this into a change in number of accidents. Both SL and CC are mainly expected to have an effect on speed; therefore, models which attempt to quantify the relationship between instances of overspeeding and accidents (Taylor et. al. 2000) were explored. However, we found that these models, which are based on measurements taken from select road locations rather than from continuous vehicle data, fail to capture several important aspects of the underlying safety mechanism. Because of these limitations, a straightforward application of the models on the FOT data would lead to erratic results.

Given these results and the limitations of the investigated models, our conclusion is that a trustworthy up scaling of SL/CC is not feasible. Therefore, indirect effects could not be calculated.

Hypothesis 4: The amount of incidental related delay in the network will decrease.
This hypothesis could not be tested because no safety effect (e.g. change in number of accidents) was calculated.

5.5 Simulation results

The SRS system has been simulated in a microscopic simulation tool. This allows for an analysis at higher penetration rates than can be achieved in the FOT. It also allows us to study the effects of equipped vehicles on the surrounding traffic. This is useful because SRS is expected to influence the traffic around it and hence its effects are possibly not limited to those measured in the FOT (which only concern the equipped vehicle itself). Also, due to interaction effects between equipped and unequipped vehicles, effects may scale nonlinearly with the penetration rate.

The reader is referred to Chapter 5 and Annex 4 in euroFOT deliverable 6.2 [9] for details on the experimental setup, the implemented functionality of SRS and the simulation tool ITS Modeller, which has been used to run the simulations. In order to apply the simulation tool, it is necessary to calibrate the driver models on the FOT data. Annex 2 of this document describes how this is done. This section describes the scenarios that have been analysed and the results that have been obtained.

5.5.1 Scenarios

The functionality of the device, the geographic region, the demand and the time span were kept constant in all scenarios. The penetration rate was varied.

Geographic region

The Utrecht-Amersfoort region was chosen as the geographic region for simulation. This network was chosen because it contains many different road types (with various speed limits matching that in the FOT). Most of the results are presented per road type, since the total network performance may not be representative for EU27.

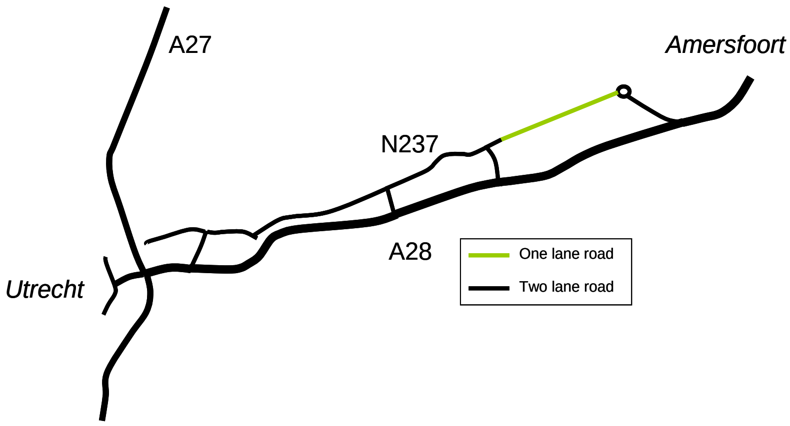

Figure 37: Schematic overview Utrecht – Amersfoort network used for simulation

Time span
Total time span for which the effect of the SRS device is estimated is a whole year. The demand pattern of an afternoon peak is used, but it is downscaled to match the FOT conditions (speeds).

Traffic demand

A 'real' network is chosen, so traffic demand is estimated using information about intensities on the network. This traffic demand is obtained from the ITS Test Beds project [5].

The traffic demand consists of passenger cars, vans and trucks. The addition of vans and trucks makes the road situation more realistic. However, since there is no data available to evaluate the usage of the SRS device for these vehicles, they do not add to the study effect of the SRS device. It was observed that adding trucks and vans to the network significantly influences the average speed. This is shown in Figure 38. The average velocity for cars on a network without trucks equals 119 km/h, where with the presence of trucks this velocity is reduced to 102 km/h. Since the amount of trucks and vans and the number of lanes significantly influence the effect of their presence, it was decided to replace these vehicles in the simulation by passenger cars.

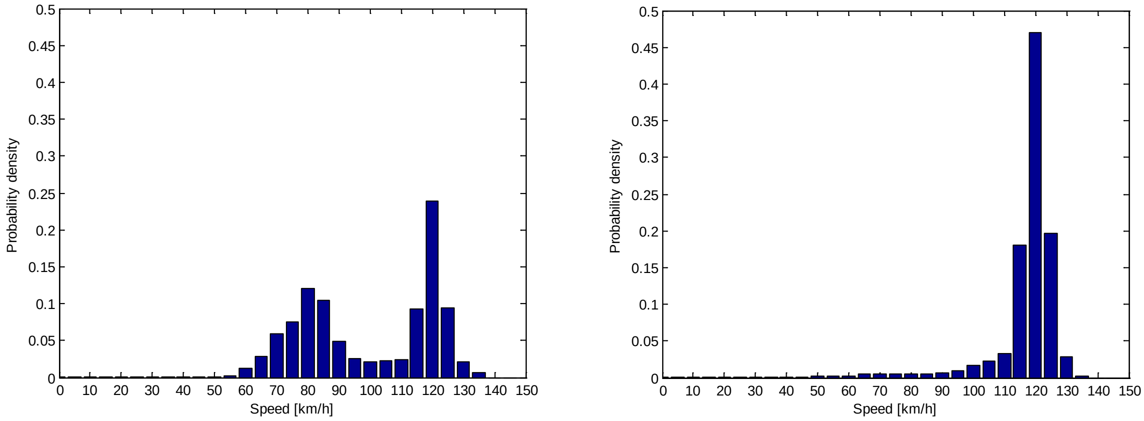

Figure 38: Probability density function of the average speed for normal cars, with trucks and vans (left) and without trucks and vans (right) on the network

The traffic demand has a large influence on the speeds that vehicles realize on the network, and hence – indirectly – also on the usage of the CC and SL functions. Therefore, the demand was calibrated on the FOT data, and was chosen equal to half that of the peak demand of the original network.

Implementation FOT driving behaviour with SRS

To model the effect of SRS with higher penetrations, the behaviour of driving with SRS is implemented according to the FOT data. This includes a model for driving without SRS (baseline driving) and one for driving with SRS. The fitting of the baseline model can be found in annex 3.

To implement the usage of SRS, SL activation and deactivation rules are implemented as follows. For each driver, it is determined whether he wants to use the SL function (per road type) according to the % of usage in the FOT. The SL is switched on when a driver enters a rural road section. So if 40% of the drivers in the FOT use the SL on rural roads, in the simulation 40% of the drivers will switch SL on when they enter a rural road section. SL is only switched off when the car is at rest.

For activating and deactivating the CC, the time-to-collision (TTC) is used as a measure. The TTCs for activation and deactivation are different for each driver and are drawn for a distribution based on the FOT data. For deactivation this is a lognormal distribution, with mu (average) 2.4, sigma (standard deviation) 1.45 and a translation of -3. For activation the FOT shows data two types of drivers. Some drivers activate the CC when the TTC is larger than 50 seconds. This is 74% of the drivers. For the other 26% of the drivers, the TTC for activation fits a normal distribution with mu=22 and sigma=13 with a maximum of 0.26. (See also Figure 70 and Figure 71 in annex 2 for the fits with the real data).

Using these activation and deactivation rules, the usage of the SRS matches the euroFOT results for rural roads and motorways. For urban roads the use of SL (about 10%) is less than in the FOT (about 40%). The comparison can be found in Figure 68 in Annex 2.

Penetration rates

The effect of ITS applications on traffic is not always proportional to its penetration rate. Therefore these rates must be chosen carefully to obtain insight in the effect of the SRS device. We chose to simulate at least one scenario in which all drivers have a SRS device and one scenario at which all drivers use the cruise control function on highways. The goal for these scenarios is to view the potential effect. Next to these potential studies, another goal is to view the effect of SRS at lower penetration rates, to gain insight into the number of cars that need to be equipped minimally to get a positive effect on traffic.

The following scenarios are chosen. Since not all drivers (76%) use the SRS, the scenarios are selected in such a way that the % of users of the CC function is as follows.

Table 47: Scenarios SRS and corresponding penetration rate CC

Scenario	Penetration CC
Baseline: 0% equipped	0%
Treatment: 13% equipped	10%
Treatment: 26% equipped	20%
Treatment: 100% equipped	76%
Treatment: 100% equipped + 100% use	100%

5.5.2 Output

The goal of this simulation is to show the potential effects of the SRS device that combines the functionality from Speed Limiter and Cruise Control. It is expected that this device will influence the throughput, safety and environment on a network scale. This paragraph describes the results from the simulations on throughput.

The measures for the effect on throughput are the (average) speed and the total delay in hours for all vehicles. The latter is mostly referred to as 'lost vehicle hours', and is measured as the difference between the realized travel time and the free flow travel time[6]. The lost vehicle hours per scenario will be compared to those of the reference scenario. The result is the percentage decrease or increase in lost vehicle hours per road type for the simulated penetration rates.
The results in the tables below show a slight increase in average speed. At 100% CC usage the increase is 0.7-4.0%, depending on the road type. The delays decrease by a large amount, which is consistent with the speed result in a qualitative sense.

Table 48: Effect of SRS device on the average network speed

Average Speed	10% CC usage scenario	20% CC usage scenario	76% CC usage scenario	100% CC usage scenario
Urban	0.1%	0.3%	0.8%	0.7%
Rural	0.1%	0.2%	1.0%	1.2%
Motorway 110 km/h	0.3%	0.4%	2.3%	4.0%
Motorway 130 km/h	0.2%	0.3%	1.8%	3.0%

Table 49: Effect of SRS device on delay

Effect on delay	10% CC usage scenario	20% CC usage scenario	76% CC usage scenario	100% CC usage scenario
Urban	-0.2%	-0.7%	-2.1%	-2.1%
Rural	-0.3%	-0.8%	-4.8%	-5.5%
Motorway 110 km/h	-1.9%	-4.8%	-18.8%	-34.6%
Motorway 130 km/h	-1.1%	-2.0%	-10.2%	-17.2%

The speed and delay indicators scale linearly with the CC usage rate (which in turn scales linearly with the SRS penetration rate). This means that for traffic efficiency there are no

[6] The free flow travel time is determined from the speed limit. This means that vehicles exceeding the speed limit may realize negative delays. In this study, negative delays are not included in the estimate, that is, they are set to zero.

interaction effects, and hence the FOT data will also be used also for higher penetration rates by linear scaling.

It is remarkable that for some safety indicators, namely the fraction of vehicles with short TTC or time headway, there are interaction effects. Indeed, for both indicators the effect becomes much stronger or even changes direction for higher penetration rates. A possible explanation is that mixed traffic leads to inhomogeneous flow and hence to lesser safety.

Table 50: Number of kilometres driven per road type in Europe.

(eIMPACT estimate for EU27 2010 (D3 Table 6, based on ProgTrans 2004 + own calculations (using growth rate ProgTrans)

Road type	Speed limit (km/h)	Distance driven (10^9 km)	Share (%)
Urban	50	723.28	25
Rural	80	1475.48	51
Motorway free flow	100-130	580.47	20
Motorway congested	100-130	113.87	4
Total		**2893.10**	**100%**

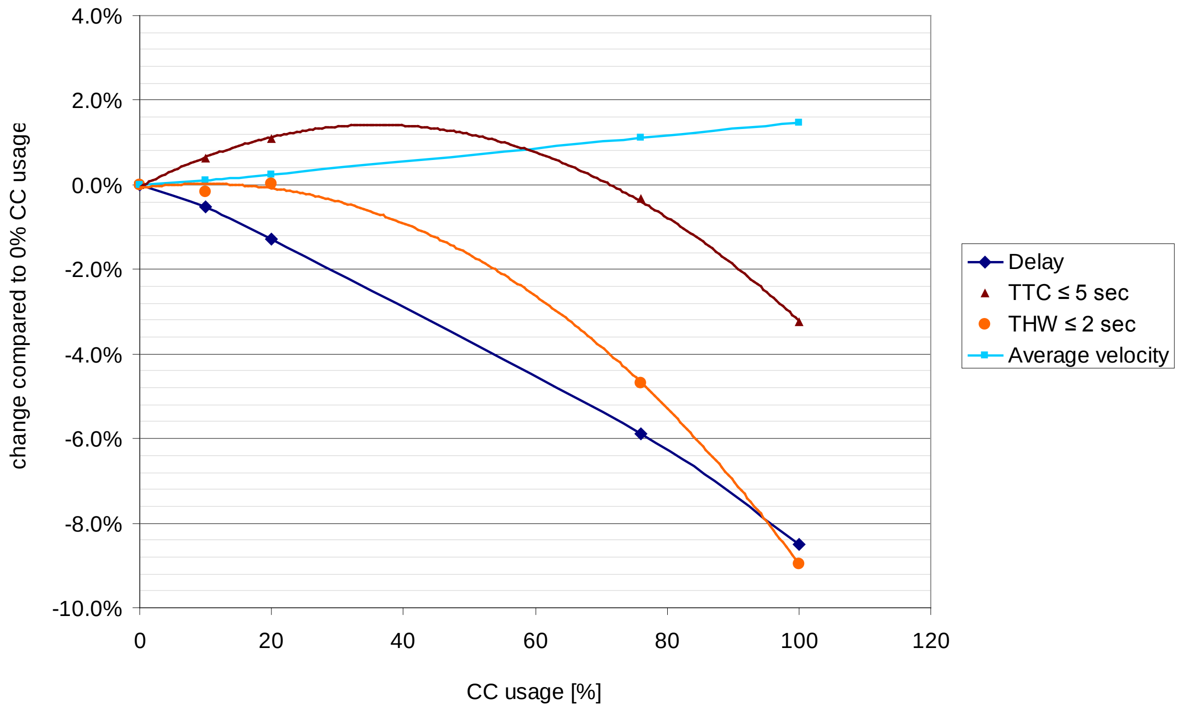

Figure 39: Impact of CC usage on several network level performance indicators in simulation.

The horizontal axis shows the percentage of vehicle kilometres driven in the 'CC active' state in the simulation experiments. The vertical axis shows the relative change in the performance indicators compared to the baseline where all vehicles are unequipped.

The speed distributions as observed in the simulation on roads with a speed limit of 110 km/h and 130 km/h are shown in Figure 40 and Figure 41. The graphs show that when all vehicles use cruise control, the speed distribution is more densely concentrated around the speed limit. However, when the usage is decreased to 76% of all vehicles, it can already be seen that a large proportion of the vehicles is decreasing its speed which causes the standard deviation of the expected speed to increase. At low Cruise control usage rate, the effect compared to the Baseline scenario is small.

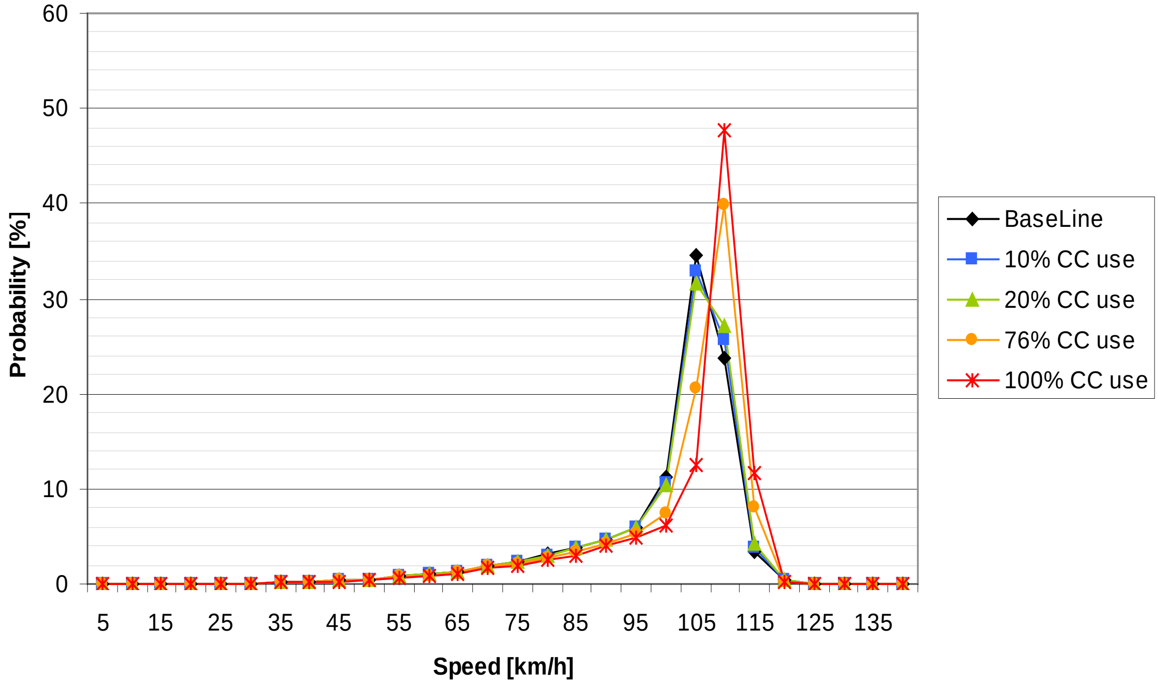

Figure 40: Speed distribution in the simulation for all scenarios with a speed of limit 110 km/h

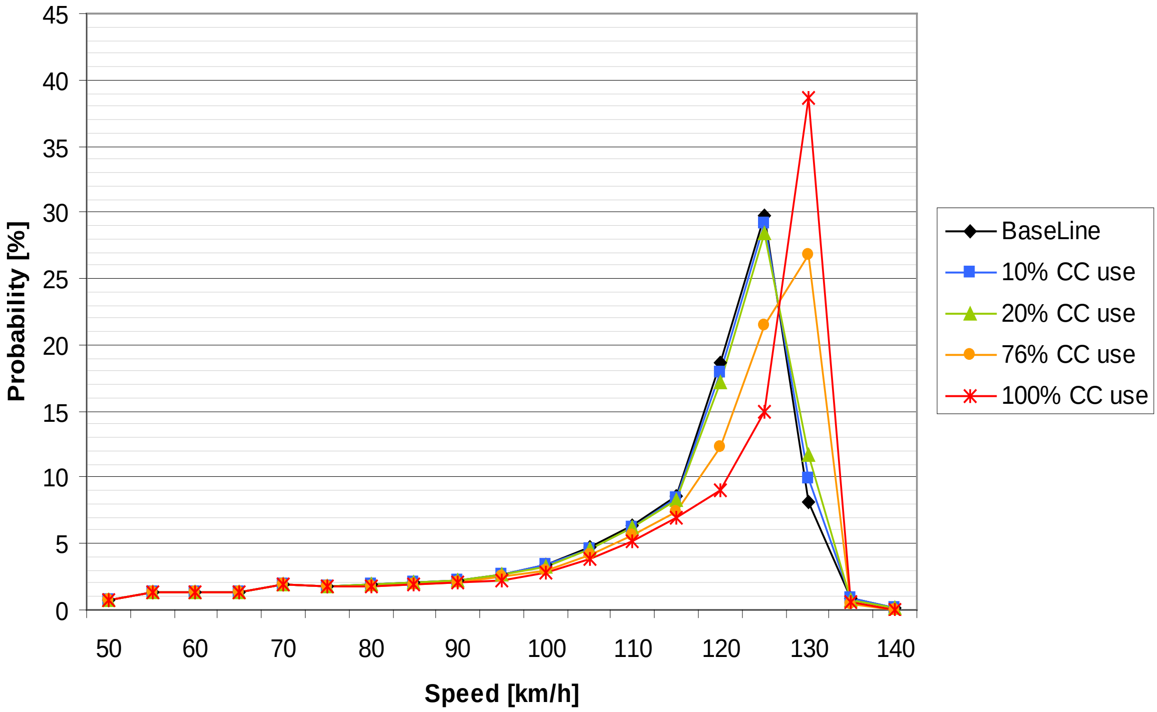

Figure 41: Speed distribution in the simulation for all scenarios with a speed limit of 130 km/h

Research question 1: What is the impact of SRS on the average network speed or journey speed?
This is shown in Table 44. At 100% CC usage the increase is 0.7-4.0%, depending on the road type

Hypothesis 4: The amount of recurrent delay in the network will decrease.
This is shown in Table 45. At 100% CC usage the total delay decreases by 2-35%, depending on the road type. All delay in the simulation can be considered as recurrent delay in the sense that there are no incidents.

5.6 Direct environment effects

5.6.1 Cruise control

Assessment of the environmental effects of the cruise control function is achieved with objective FOT data considering different road types. Similar to the adaptive cruise control, it is expected that the ordinary cruise control (CC) also has a positive effect on fuel consumption by homogenising the speed profile.

5.6.1.1 FOT level effect

For all road types, a significant reduction in average fuel consumption can be found when using the CC. The analysis was divided into speed limits to identify similar driving conditions (urban: 50km/h, rural: 90 km/h and motorway: 130 km/h). The high reductions on urban (36.1%) and rural (13.2%) roads might be caused by the selection of the driver when to turn the system on. If the driver activates the system mostly in situations where it is possible to maintain a constant speed, the comparison between those situations and the general driving in urban (and rural) areas with more traffic and acceleration phases can lead to high differences in the fuel consumption. A more detailed analysis can eliminate the selection effect, and for this reason we selected data according to similar road types (based on speed limits, 50km/h being urban, 90km/h being rural, and 130km/h being motorways). This is not sufficient but most of the factors that might help refining the data selection were not available or not trusted enough to help us. For example, traffic conditions are not known except on motorways, and weather did not provide enough data for efficient comparisons. Further analysis will be done in the future to try using off peak hours instead of free flow conditions. Speed distribution analysis show that slow travel speeds are much more present in baseline than while the system is active. On motorways where this influence is lower the reduction is about 1%. A more stable speed reduces fuel consumption and the results below are in line with that fact. The effect on fuel consumption is high for urban and rural areas, but lower on motorways. This is mainly the reflect of smooth speed profiles on motorways under usual driving conditions, while when CC is used on these roads it has proven to be for speeding purposes, leading to compensate the gains by adopting a higher and less efficient speed.

This inherent bias in the FOT data on CC leads to precaution in the interpretation of the results as they do overestimate the benefits. The low usage rate of 2.69% is an additional indicator that the system is only used under certain driving situations where the driving pattern might be different from the rest of urban driving.

Table 51: Results for change of fuel consumption for the CC

Factor	Average fuel consumption (litres/100km) Baseline / Treatment	Type III fixed effects P-value	Increase (litres/100km)	Percentage (%)
Urban roads	8.33 / 5.32	<.0001	-3.01	-36.1
Rural roads	5.90 / 5.12	<.0001	-0.78	-13.22
Motorways	6.53 / 6.46	<.0001	-0.07	-1.07

Hypothesis 4: Cruise control use decreases the fuel consumption.
The objective data shows a significant influence of CC usage to the fuel consumption on all road types. On rural and urban roads the reduction is higher than on motorways but might also be more influenced by the driver selected driving situations in which the system is used.

5.6.1.2 EU-27 level effect

In addition to the FOT level results, the fuel saving potential of the changes on the EU-27 level is also estimated. For scaling up it is assumed that all vehicles in the European fleet are equipped with CC and have the same average fuel consumption as the vehicles that were used for evaluating the CC function, and that the system is used as often as during the FOT. The effects are calculated for driving on motorways based on statistical data on mileage in the EU-27 in 2010.

The usage rate was defined by the ratio of the sum of kilometres driven with active CC in both speed limit conditions on motorways and the sum of all kilometres driving within the treatment phase. The usage rate is quite high on motorways (66.62%). Combining usage rate and reduction in fuel consumption a fuel saving of 0.71% could be achieved in the European passenger vehicle fleet. Assuming average fuel consumption of 6.5l/100km, this would sum up to savings of 323.8 million litres fuel per year. The results for the potential in fuel saving are shown in Figure 42.

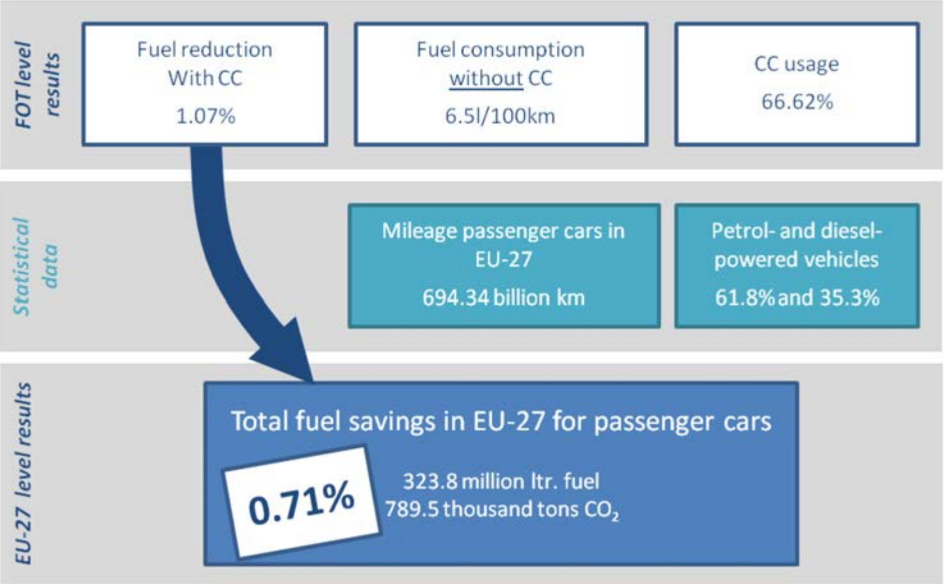

Figure 42: Potential in fuel saving with CC equipped passenger cars for EU-27

From the fuel saving potential it is also possible to derive the savings in CO_2 emission. The CO_2 emissions are calculated based on the average conversion factor for petrol and diesel engines (petrol: 2.32 kg CO_2/l, diesel: 2.62 kg CO_2/l). Assuming 61.8% petrol- and 35.3% diesel-powered vehicles in the European passenger car vehicle fleet the found fuel savings represent savings in CO_2 emissions of 789.5 thousand tons.

5.6.2 Speed Limiter (SL)

As a function associated with longitudinal vehicle control, the speed limiter (SL) has an impact on environmental effects. To evaluate this effect, the fuel consumption of the vehicles equipped with the speed limiter was analysed in phases without using the system compared to those where the system is active. The direct assessment of this analysis is presented as the FOT level results in the following.

5.6.2.1 FOT level effect

The speed limiter was evaluated regarding three road type categories. Because of the presence of various speed limits within the road type categories, the speed limit was chosen as an additional parameter to identify similar driving situations as for the analysis of the CC. All situations reveal a significant influence of SL on fuel consumption and show a reduction when using the system. The highest benefit is found on urban and rural roads (3.75% and 5.19%). On motorways the benefit is lower (1.55%). In general, one can say that the influence of the SL on the fuel consumption decreases with higher speed limits.

Like before, these results might be influenced by the driver’s choice of when to use the system. The higher influence of the SL at lower vehicle speeds is due to thermal engine fuel consumption which is lower for high speeds until 90 km/h. For higher speeds the fuel consumption increases again. The reduction can be attributed to a more constant speed while using SL.

Table 52: Results for change of fuel consumption for the SL

Factor	Average fuel consumption (litres/100km) Baseline / Treatment	Type III fixed effects P-value	Increase (Litres/100km)	Percentage (%)
Urban roads	8,67 / 8,22	<.0001	-0,45	-5.19
Rural roads	5,87 / 5,65	<.0001	-0,22	-3.75
Motorways	6,45 / 6,35	<.0001	-0,10	-1.55

Hypothesis 4: Speed limiter use decreases the fuel consumption.
The objective data shows a significant influence of SL usage to the fuel consumption on all road types. The reduction varies between 1.55% on motorways and 5.19% on urban roads.

5.6.2.2 EU-27 level effect

The fuel reductions that were evaluated during the FOT can be scaled up to the EU-27 level with the help of the driven kilometres. As for the other functions where the fuel savings potential is calculated for all EU-27 member states, it is assumed that all passenger cars in the European fleet are equipped with the system and that the average fuel consumption of these vehicles is the same as of those of the FOT. The effects are projected for driving on motorways. As said before, it is assumed that the usage rate derived from the FOT data can be transferred to the whole EU-27.

Combining the usage rate with the reduction in fuel consumption a fuel saving of 0.26% could be achieved in the European passenger vehicle fleet. With average fuel consumption of 6.5 litre/100km this reductions adds up to a 117.1 million litres per year. This total fuel saving potential represents a reduction of the annual CO_2 emission of 285.5 thousand tons. The results are summarized in Figure 43.

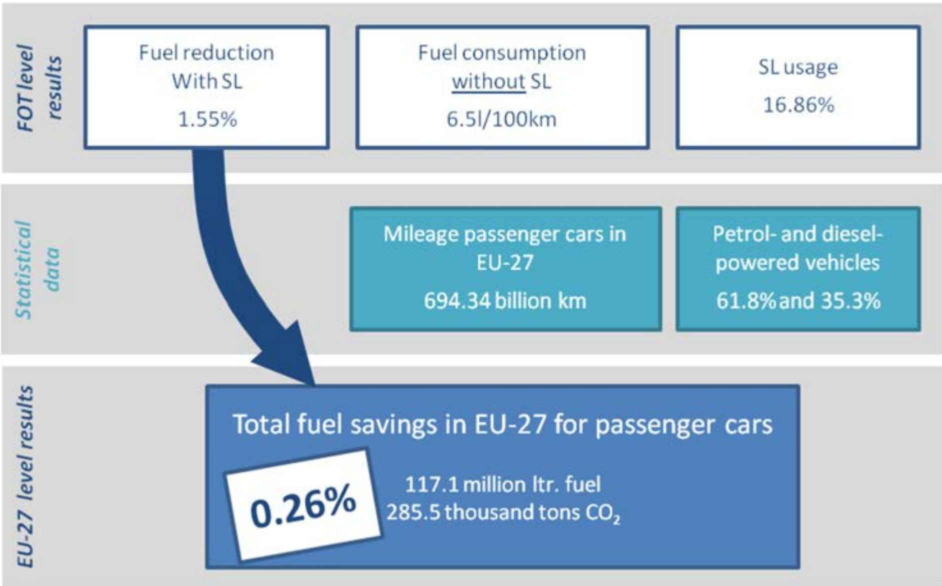

Figure 43: Potential in fuel saving with SL equipped passenger cars for EU-27

6 Fuel Efficiency Advisor (FEA)

The Fuel Efficiency Advisor (FEA) is a system that provides in real time the current location of the vehicle, its fuel consumption, messages, driver times, service intervals and much more to support fuel-efficient driving, or eco-driving. The system consists of on-board functions for the driver as well as follow-up reports in the back-office system. It is the only system in the euroFOT project that directly aims to reduce fuel consumption. Since the system only gives advice and does not intervene, the effectiveness is depending on the willingness of the driver to follow the system instructions. Hence, it is difficult to distinguish between the fuel saving potential of the system and the influences that originate from the way of driving of the system user.

Only the environmental effects of the FEA are assessed because only a limited amount of information on the data gathered during the FOT is given. During the FOT more than 3.6 million kilometres were driven in the baseline and treatment phases (equally distributed over the phases). However, the quality of this data is poor because data was logged only once every 30 minutes. Because of limited information on driving conditions during the FOT, making a reliable interpretation is very difficult, and for most hypotheses impossible. Influences from shifts in conditions (e.g. higher mileage on urban roads in baseline) or weather effects possibly overweigh the effects of the FEA use. For that reason only the effect on fuel efficiency is assessed.

6.1 Direct environmental effects

6.1.1 Direct environmental effects on FOT level

Unlike the other functions tested within euroFOT, the FEA cannot be deactivated by the driver, which implies a usage rate of 100% within the treatment phase. Also, it cannot be evaluated whether the driver acts according to the system instructions or which driver is currently using the vehicle.

During the FOT more than 3.6 million kilometres were driven in the baseline and treatment phases (equally distributed over the phases). Limited information about the conditions under which the data were collected makes the results of the analysis difficult to interpret. Influences from shifts in conditions (e.g. higher mileage on urban roads in baseline) or weather effects possibly overweigh the effects of the FEA use. The treatment phase showed a reduction in fuel consumption of 1.89%, but this effect is not significant. See Table 53 for the results. The high mileage and the equal distribution over the two phases make it reasonable that the distribution over the different road types is equally spread too. However, the limited information on the data and the fact that the trucks were used by different drivers show that further interpretation of the data is not possible with the applied experimental set up.

Table 53: Results for change in fuel consumption for the Fuel Efficiency Advisor

Average fuel consumption (l/100 km)		P-value	Absolute difference (l/100 km)	Relative difference (% of baseline)
Baseline	Treatment			
37.09	36.39	> 0.05	-0.7	-1.89

6.1.2 Direct environmental effects on EU-27 level

Due to the very limited information on driving conditions that result in the evaluated fuel reduction and the related uncertainty ($p > 0.05$) (can the found fuel reduction be associated with the use of the FEA?) scaling up the effect to EU-27 level is not reasonable.

7 Safety warning functions

This chapter explains the absence of traffic efficiency effects for the safety warning functions Lane Departure Warning (LDW), Curve Speed Warning (CS), Blind Spot Information System (BLIS) and Impairment Warning (IW).

Like for all functions, direct and indirect traffic efficiency effects are distinguished. For these functions only indirect traffic effects were expected. The expected indirect traffic efficiency effect is a reduction in accident related congestion, due to the reduction of accidents. The safety warning functions were not expected to have direct traffic and environmental effects. This was even embedded in the test setup. Due to the euroFOT test setup, it was possible to derive the direct traffic effects of the safety warning functions directly from the data. The reason why the FOT test design did not foresee assessing these direct effects is that the safety warning functions have been tested together with other functions in one vehicle for efficiency reasons, e.g. ACC. ACC has a clear direct impact on traffic flow. Any possible small effect from a warning function will be outweighed by a much larger effect on traffic flow from the ACC. It is therefore not possible to determine the potential small direct traffic flow effects of the warning systems, if any, from the FOT data directly. Therefore direct traffic effects are not tested in the same way as for the other functions.

In this chapter first the reasoning behind this assumption is explained, and after this the results on system use and mobility behaviour are described. Finally a short explanation about the absence of the indirect traffic effects is given in Section 7.2.

A possible reduction in accidents by these functions is likely to have an effect on traffic efficiency. These indirect effects on congestion are taken into account

7.1 System use & mobility behaviour

In the traffic efficiency analyses, the direct effects on traffic efficiency of the four safety warning systems are assumed to be zero. The reason for this is that, since these are systems that aim at improving safety (and not traffic efficiency) and give warnings only occasionally, there is no expectation that there are significant effects on traffic efficiency. This section explains the rationale behind this assumption, based on the frequency of warnings, system use and mobility behaviour.

The warnings were expected to occur only occasionally, and the drivers’ response will not have much impact on the traffic flow. This is because responses are very short, e.g. aborting a lane change manoeuvre or temporarily slowing down for a curve, and their effect on traffic flow is minimal. To check the assumption that the warnings functions have only a marginal effect on traffic efficiency, the average distance between warnings is determined. This number varies per function and road type, see Table 54. A specification per road type is not available for all functions. The functions that issue the most warnings are LDW and BLIS. Below the table an analysis of the data can be found.

Table 54: Average distance (in km) between two warnings in treatment period

		Motorway	Rural roads	Urban roads	Not classified	All
LDW	Car	n/a	n/a	n/a	n/a	22
	Truck	27	17	26	21	22
IW	Car	n/a	n/a	n/a	n/a	2705
BLIS	Car	n/a	n/a	n/a	n/a	1
FCW	Car	328	117	43	86	190
	Truck	369	156	35	226	205

For each function the assumption that there are no direct traffic efficiency effects is checked.

For LDW the average distance between two warnings is 22 kilometres. During heavy traffic a response by the driver to these warnings could in some cases cause or prevent shockwaves or ripples. The conditions under which a driver response could cause shockwaves are when there is another vehicle (in its own lane or in the target lane) that has to adjust its speed (brake) abruptly for the vehicle that got the warning. Because of the low frequency of the warning and the conditions in which this could cause a problem (heavy traffic and a vehicle adjusting its speed abruptly) it is expected that the traffic efficiency effect is minimal. To determine the effect of LDW on the number of shock waves would require a detailed analysis of behavioural response to the warnings from surrounding vehicles, as well as a breakdown of the situations in which the warnings were observed. Therefore this was not investigated further.

Impairment warnings occur on average only every 3000 kilometres. Since this is likely to happen on quiet roads, the probability that other traffic will notice any direct effects is very small. Therefore no direct traffic efficiency effect is expected.

The BLIS warning does occur very often, on average every kilometre. This is not a good indicator for direct traffic effects since it is not an actual warning. The system shows a symbol in the side mirror every time another vehicle is the blind spot. Most of the time the driver does not intend to change lanes and does not even notice the symbol, let alone respond to it. The frequency of one warning per kilometre is not a good estimation for the frequency of dangerous situations.

The frequency of forward collision warnings is limited; on average there is one warning every 200 kilometres. The effect on the average speed of the vehicle equipped with ACC and FCW is included in the traffic efficiency impacts described in Chapter 4. If the warning does cause a strong response by the driver then shockwaves may occur if there is a vehicle behind and there is heavy traffic. Because this effect depends largely on the behavioural response of the surrounding drivers, which could not be determined from the FOT, this effect is not included in simulation. Also for this warning there is only a direct traffic efficiency effect on shockwaves when the followers' response is different than without the warning. All in all, the direct traffic efficiency effect of FCW is expected to be very limited.

7.2 Indirect traffic effects

As is described in Deliverable 6.4 [10], the four safety warning functions have no significant impact on traffic safety. Therefore these functions also have no indirect traffic efficiency effects.

8 Conclusions and lessons learned

8.1 Conclusions

The euroFOT functions for which a significant effect on traffic efficiency and/or the environment was found are the Navigation System, Adaptive Cruise Control (ACC) combined with Forward Collision Warning (FCW) and the Speed Regulation System. These functions have both a direct effect (an effect on speed in non-incident situations) and an indirect effect (an effect through a change in the number of accidents that cause congestion).

Contrary to the expectation, due to the experimental setup, in which only fuel consumption recorded in low frequency, no significant effect was found for the Fuel Efficiency Advisor.

No significant indirect effects on traffic efficiency were found for the safety warning systems Lane Departure Warning, Curve Speed Warning, Blind Spot Information System, and Impairment Warning. Small effects and unclear mechanisms linking system use and driver behaviour to safety impacts led to the lack of significant results for safety impacts. Although the FOT data indicates a safety benefit, a statistically significant accident reduction could not be found. Thus, no indirect traffic and environmental effects due to a reduction in accidents could be determined.

8.1.1 Navigation system

Efficiency

The main effects of the two types of navigation systems are a decrease in travel distance and travel time. Travel time and travel distance have to be separated because regarding route choice they are not the same. For instance, if you would like to travel around a town, the shortest way (that is travel distance) would probably lead through the city centre. But because of traffic lights, urban traffic etc. along the way, this is not necessarily also the fastest route (travel time). It is probably faster to stay on the highway that leads around the town. In navigation systems, this difference is reflected in the options that drivers can often choose between fastest and shortest route. For the built-in device the effect sizes are about 7% for travel distance and about 9% for travel time. For the mobile device the effect sizes are about 3% for travel distance and about 7% for travel time.

The effects that were found are effects that could be expected from navigation systems; a decrease in travel time is one of the benefits navigation systems typically aim to achieve. Or in other words, results show that the tested navigation systems reach their purpose and reduce travel time significantly.

More detailed results for mileage and distribution of mileage over road types are not available. Because not enough drivers could be found to participate in the FOT, concessions were made to the experimental set-up, especially the order in which the conditions were planned. This resulted in drivers having a navigation system in the month that they had planned their holiday for example. This reduced the representativeness of the data, especially for the mileage and distribution of mileage over road types, and therefore the effects could not be differentiated for road types.

Environment

For the built-in device a significant effect was found on fuel consumption per driven kilometre on rural and urban roads of respectively -4.7% and -2.9%. For mobile devices no significant effect was found.

There can be several reasons for the difference between built-in and mobile devices. First, drivers indicate that they do not trust the mobile device and that the mobile device sometimes gives wrong or inefficient routing advice. As a consequence, the mobile device is used less often than the built-in device. It is thinkable that the expected errors of the mobile device prevent a more anticipatory driving style and therefore a reduction of fuel consumption like that found for the built-in navigation system. The other option is that the routing algorithm of the mobile device prefers routes on smaller roads / through residential areas and does not advise the driver to stay as much as possible on main roads. Therefore, route choice by the system might also prevent a reduction of fuel consumption.

Besides the reduction of fuel consumption per driven kilometre, an overall positive effect of navigation systems on the environment exists because both systems reduce travel distance. The comparison of route choice by the two navigation system indicated that routing algorithms that support a more pronounced usage for major compared to minor roads do not only reduce travel time but also fuel consumption.

8.1.2 Adaptive Cruise Control and Forward Collision Warning

Traffic efficiency

The FOT data shows that having an ACC and FCW slightly reduces the average speed for cars with 0.4% taking into account when and how the drivers used the systems. The speed reduction for trucks is only 0.1%, and though the difference is statistically significant this is very minimal. When looking only at conditions when ACC is activated the average speed is higher than in baseline.

As expected, ACC and FCW do not affect mobility behaviour, route choice or choice of road type. Traffic simulations show that the effect on average network speed when more vehicles are equipped is similar in size to the effect found in the FOT. Small interaction effects between vehicles are found. The effect scales linearly with the penetration of equipped vehicles when more than 25% of the vehicles are equipped. When fewer vehicles are equipped, the effect is slightly stronger. The simulations are based on the driving behaviour and system usage observed in the FOT.

Environmental effects

For both vehicle types (passenger cars and trucks) there is a significant reduction in fuel consumption while driving with ACC and FCW of -2.1% and -1.85%, respectively. However, the results for trucks seem more reliable since the driving patterns that are compared in baseline and treatment are very similar because of the general traffic and driving situation (car following situations with little speed variation).

8.1.3 Speed Regulation System

Traffic efficiency

The Speed Regulation System (SRS) slightly increases average speed. The effect on urban roads, rural roads and motorways is 1.4%, 0.8% and 2.4%, respectively. The traffic efficiency effect is fully ascribed to a change in average speed, since SRS does not affect mobility behaviour, route choice or choice of road type. The average speed effect is an individual effect and does not depend on the percentage of equipped vehicles.

The traffic efficiency effect of the sub functions Cruise Control (CC) and Speed Limiter (SL) cannot be determined because usage is not independent from speed. Because the CC is used at higher speeds, the average speed when CC is active is higher than average. When SL is active, speeds are average. When SL and CC are off speeds are lower than average.

Environment

The environmental impacts are presented for the SL and CC sub functions separately. All situations reveal a significant influence of SL on the fuel consumption and show a reduction when using the system. The highest benefit is found on urban and rural roads (3.75% and 5.19%). On motorways the benefit is lower (1.55%). In general, one can say that the influence of the SL on the fuel consumption decreases with higher speed limits, but is still positive.

For all road types a significant reduction in average fuel consumption can be found when using the CC. The high reductions on urban (36.1%) and rural (13.2%) roads might be caused by the choice of the driver when to turn the system on. If the driver activates the system mostly in situations where it is possible to maintain a constant speed the comparison between those situations and the general driving in urban (and rural) areas with more traffic and acceleration phases can lead to high differences in the fuel consumption. Speed distribution analysis show that slow travel speeds are much more present in baseline than while the system is active. On motorways where this influence is lower the reduction is about 1%.

8.1.4 Fuel Efficiency Advisor

Limited information about the conditions under which the data were collected makes the results of the analysis difficult to interpret. Therefore only the environmental impact could be determined. The treatment phase showed a reduction in fuel consumption of 1.89%, but this effect is not significant. Because road types and weather conditions were not known, and also, the trucks were driven by various drivers, there is a lot of unexplained variance in the data. Results should be treated with caution.

8.1.5 Remarkable results

- Vehicles equipped with ACC and FCW have a lower average speed than unequipped vehicles, when the whole treatment and baseline data sets are considered, not taking into account whether the ACC is used or not. When usage is accounted for, the data shows that vehicles with ACC active have a higher average speed than unequipped vehicles. ACC is used more in higher speed ranges, which suggests that people activate the ACC when the road and traffic conditions allow them to drive faster than the average speed. Also the ACC is not active in conditions where the driver cannot drive fast, e.g. in heavy traffic. Therefore the average speed when the system is off or standby is lower than in the baseline.
- The same principle applies to the SRS, but now there are three conditions, being CC active, SL active and no function active. Overall the average speed of the SRS treatment phase is slightly higher than in the baseline. One could expect that the driver behaviour in situations where no function is active is the same as in the baseline. This would mean that the average speed when no function is active is the same as in the baseline. However the FOT data shows that the average speed is lower when no function is active compared to the baseline. Since the CC is comfortable to use in conditions when constant speeds can be maintained, but not in highly dynamic traffic conditions, a probable explanation is that people use the SRS when the road and traffic conditions allow for fast driving. This means that when the system is off, they are more often in a traffic condition with heavy traffic, congestion or traffic lights.
- A remarkable result is that the ACC and FCW bundles causes the average speed to go slightly down, while the SRS cause the average speed to go slightly up. The reason for this difference is difficult to determine. The effects depend on the usage. Especially for the SRS system, where the SL functions shows a reduced average speed and the CC shows an increased average speed. A possible

reason is that the SL system is used by people to drive closer to the speed limit in the speed ranges below the speed limit, and use the CC in the speed ranges above the speed limit. The analysis did however not distinguish the results for speeds ranges in sufficient level of detail to determine this possible effect.

- A surprising result from the simulation is that the homogeneity of the traffic flow is independent of the penetration of SRS equipped vehicles. This means that the traffic efficiency and environmental effects can be considered linear with the penetration.

8.2 Recommendations for future FOTs

These are recommendations for future FOTs that result in an easier and better impact assessment. They address both the traffic efficiency and environmental impact assessment but also for the design phase and the test phase.

- Do a pre-FOT impact assessment based on literature. It allows for well thought through selection of hypothesis, a better power analysis and a context in which to interpret and analyse the results.
- Obtain the traffic state from non-FOT data sources and take it into account as confounding variable. Traffic state seems to be the confounding variable that determines many of the unexplained traffic efficiency and environmental effects. Since it turned out to be unfeasible to estimate it from the FOT data (from indicators like time headway, speed and acceleration), it is recommended to obtain it from other data sources, such loop detection data or floating car data from larger fleet. This is an extensive exercise that should be accommodated in the project plan.
- Do not test different functions that have similar effects in one vehicle. It is not possible to determine whether a measured effect is caused by one system or the other.
- When the test setup is adjusted, for example because of a reduced number of participants, make sure that the implications of these adjustments on each hypothesis are estimated. Simplifications of the test design such as removing the control period make it hard or impossible to consider seasonal influences.
- Ensure that the test design serves the goals of the analysis. This means that one has to reason backwards from research questions to hypotheses, to measures, to FOT design (including topics like sensors, data loggers, data bases, questionnaires and experimental setup). If the FOT design imposes restrictions, then the consequences of these restrictions on the measures, hypotheses and research questions need to be investigated and taken into account.

9 References

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Annex 1 Hypotheses testing

Table 55: Hypothesis on objective data for efficiency and environmental impact calculation.

No.	Hypothesis	ACC and FCW	SRS	Navigation	FEA
1	The average speed will decrease	✓	✓	✓	
2	The number of vehicle km travelled will increase	✓	✓	✓	
3	Fuel consumption will decrease	✓	✓	✓	✓
4	Navigation systems increase the number of vehicle km travelled			✓	
5	Navigation systems increase journey efficiency based on surrogate measures			✓	

Hypotheses tested for Navigation systems

Hypothesis: Navigation systems decrease average speed

Comparison situations

1. Baseline – Treatment built in
2. Baseline – Treatment nomadic

Filtering criteria

1. Trip length > 1 km

Considered situations

All situations

1. Road type (rural, urban, motorway)

Performance indicators (PIs)

1. Average speed in km/h.

Chunking

None.

Data

Full Daimler and BMW data set from in German 2 VMC

Statistical Methods

Paired t-test was conducted for each PI between comparison situations in which Driver ID was used to pair the analysis. Factors were fixed one at a time during each t-test.

Results

Significant results ($p<0.0125$) are displayed in the table below.

Table 56: Significant results on navigation systems 1

Built-in navigation system								
Hypo-thesis	Factors	df	t	p	M (baseline)	SD (baseline)	M (treatment)	SD (treatment)
1.1	all	98	-2.60	0.0107[B]	66.13	16.50	69.47	15.83

All other combinations were not significant ($p>0.0125$).

9.1 Hypothesis: Navigation systems increase the number of trips

Comparison situations

1. Baseline – Treatment built in
2. Baseline – Treatment nomadic

Filtering criteria

1. trip length > 1 km

Considered situations

All situations

Performance indicators (PIs)

1. Average number of trips per day in which the condition was true.

Chunking

None.

Data

Full Daimler and BMW data set from in German 2 VMC

Statistical Methods

Paired t-test was conducted for each PI between comparison situations in which Driver ID was used to pair the analysis.

Results

For both conditions, there is no significant difference between the number of trips per day in baseline and in treatment conditions. Therefore, results are not displayed in detail.

Hypothesis: Navigation systems increase the number of vehicle km travelled

Comparison situations

1. Baseline – Treatment built in
2. Baseline – Treatment nomadic

Filtering criteria

1. trip length > 1 km

Considered situations

All situations

1. Road type (rural, urban, motorway)

Performance indicators (PIs)

1. Average number of km per trip.

Chunking

None.

Data

Full Daimler and BMW data set from in German 2 VMC.

Statistical Methods

Paired t-test was conducted for each PI between comparison situations in which Driver ID was used to pair the analysis. Factors were fixed one at a time during each t-test.

Results

Significant results ($p<0.0125$) are displayed in the table below. Conditions with a ^{B} would pass the Bon Ferroni criterion ($p<0.0125$).

Table 57: Significant results on navigation systems 2

Built-in navigation system								
Hypo-thesis	**Factors**	**df**	**t**	**p**	**M (baseline)**	**SD (baseline)**	**M (treat-ment)**	**SD (treat-ment)**
1.1	all	98	-2.86	0.0051^{B}	30.79	16.83	34.57	17.67
1.2	Road = Motorway	98	-2.79	0.0063^{B}	20.78	15.74	24.20	16.7498

All other combinations were not significant ($p>0.0125$).

Conclusions

In line with the results reported in the main part of the document, mileage in the condition built-in navigation system is higher than mileage in the baseline condition. Taking the situational variables into account, this is based on more kilometres driven on highways. The higher proportion of highway leads to an increase in overall speed with the built-in navigation systems. For the built-in device, the significant effects for speed are not caused by changes in speed choice but by a higher proportion if highway kilometres.

For the mobile device, no change in mileage or number of trips can be found.

Navigation systems increase journey efficiency based on surrogate measures

Comparison situations

Baseline: All baseline trips

Treatment – built-in: All trips in condition built-in navigation system with routing function active

Treatment – mobile: All trips in condition mobile navigation system with routing function active

Performance indicators (PIs)

1. Relative trip length: Based on start- and end-GPS-position, estimated trip length is derived from Google Maps. The difference between the measured trip length and the estimated trip length is calculated in percentage of the estimated length. The relative trip length is averaged across all of a driver's trips.
2. Relative trip duration: Based on start- and end-GPS-position, estimated trip duration is derived from Google Maps. The difference between the measured trip duration and the estimated trip duration is calculated in percentage of the estimated length. The relative trip duration is averaged across all of a driver's trips.
3. Proportion of time spent in congestion on highways.

Filtering criteria

Overall:

1. Trip length > 1km

For PI 1 and 2:

2. Absolut difference between estimated and measured trip length is < 100%. Trips where one of the two values is twice as long as the other one are considered being errors (e.g. driver going on a round course).

For PI 3:

3. Road type is highway

Factors

None.

Chunking

None.

Data

All of the available data in DB divided *per driver*.

Statistical Methods

PI1, PI2 & PI3: Repeated measures ANOVA with within factor condition. For post-hoc-testing, Bonferroni tests are used.

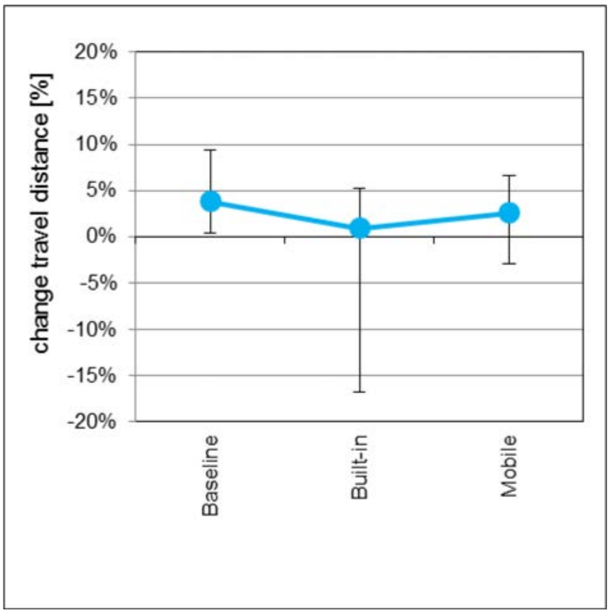
Results

Table 58: Results of the indicators trip length, trip duration and time spent in congestion

PI	Effect	df	Error df	F	p
Relative trip length	Condition	2	168	6.02	<0.01
Relative trip duration	Condition	2	168	5.56	<0.01
Time spent in congestion	Condition	2	168	1.24	n.s.

Table 59: Means and standard deviations for relative trip length and duration and for time spent in congestion.

PI	Baseline		Built-in		Mobile	
	m	sd	m	sd	m	sd
Relative trip length	0.0060	0.1542	-0.0618	0.2192	-0.0273	0.1947
Relative trip duration	0.1704	0.2608	0.0763	0.3472	0.1001	0.2777
Time spent in congestion	0.057	0.040	0.074	0.082	0.055	0.069



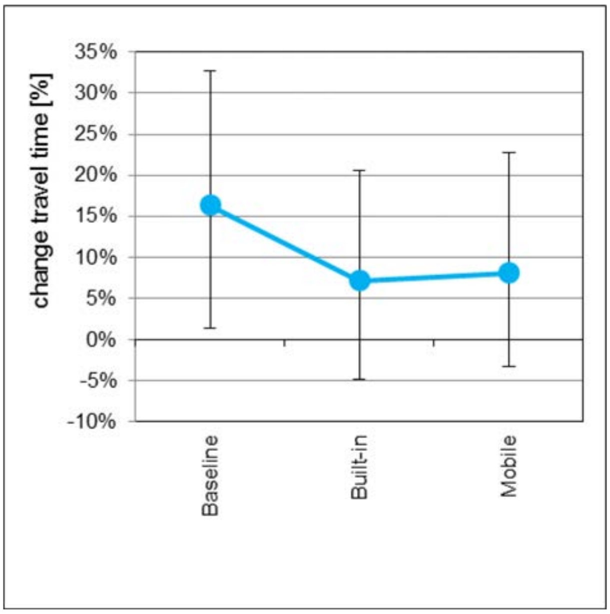


Figure 44: Influence of condition on relative travel distance (left) and relative travel time (right). Graphs show median and interquartiles.

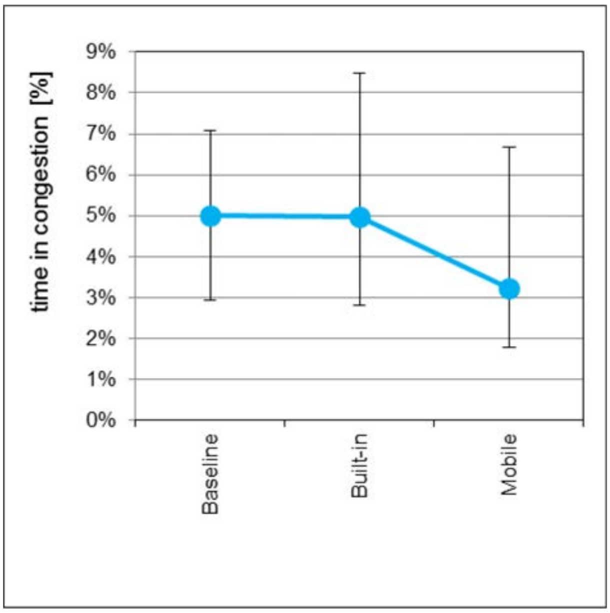


Figure 45: Time spent in congestion on highways in the different conditions. Graphs show median and interquartiles.

Conclusions

Navigation systems reduce relative travel time. For the built-in device, also a decrease in relative travel distance can be found. Since this is mainly a function of the used navigation algorithm, the difference between the HMI-solutions cannot be attributed to the used HMI-concept. The proportion of time spent in congestion on highways is not influenced by the usage of a navigation system.

Navigation systems decrease fuel consumption

Comparison situations

Baseline: All baseline trips

Treatment – built-in: All trips in condition built-in navigation system with routing function active

Treatment – mobile: All trips in condition mobile navigation system with routing function active

Performance indicators (PIs)

1. Mean fuel consumption [l/100 km]

Filtering criteria

1. Trip length > 1km
2. Engine on

Factors

Road type (highway, rural, urban)

Chunking

None.

Data

All of the available data in DB divided *per driver*.

Statistical Methods

Repeated measures ANOVA with within factor condition. For post-hoc-testing, Bonferroni tests are used.

Results

Post hoc tests show that on urban roads fuel consumption while driving with the built-in navigation system is reduced compared to baseline and compared to driving with the mobile device.

Table 60: Results on the interdependence of navigation systems and fuel consumption

Road type	Effect	df	Error df	F	p
Rural	Condition	2	170	2.69	0.071
Urban	Condition	2	172	10.66	<0.001

Table 61: Means and standard deviations of fuel consumption in the different conditions separate for road type.

Road type	Baseline		Built-in		Mobile	
	m	sd	m	sd	m	sd
Highway	8.8	1.3	8.9	1.4	8.9	1.5
Rural	8.5	1.3	8.3	1.2	8.4	1.6
Urban	11.6	1.6	11.1	1.8	11.3	1.8

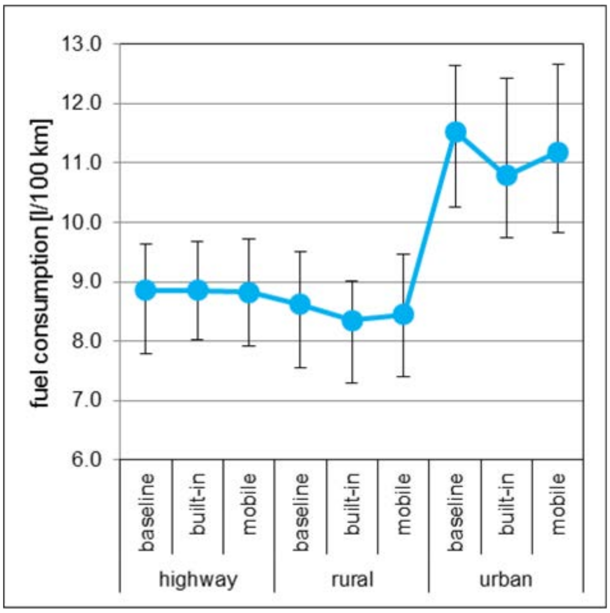


Figure 46: Mean fuel consumption in the different conditions separate for road type.

Conclusions

On urban roads, fuel consumption is reduced by 4.4% while driving with the built-in navigation system. Furthermore, there is a tendency for a similar effect on rural roads.

The type of the navigation system affects interaction with the system

Comparison situations

Built-in navigation system

Mobile device

Performance indicators (PIs)

1. Usage of the system measured as proportion of time with active route guiding function.

Filtering criteria

Trip length > 1 km

Factors

1. Familiarity of the route (familiar vs. unfamiliar)
2. Length of the trip (<20km, 20-100km, >100km)

Chunking

None.

Data

All of the available data in DB divided *per driver*.

Statistical Methods

For PI1, multifactorial ANOVA, Bonferonni-test for post-hoc testing.

Results

Table 62: Results of ANOVA for system usage.

Factor	df	Error df	F	p
Condition	1	19	8.26	<0.01
Familiarity	1	19	79.71	<0.001
Trip length	2	38	62.15	<0.001
Trip length*condition	2	38	21.46	<0.001
Length*familiarity	2	38	14.68	<0.001

Table 63: Means and standard deviation for proportion of trips driving with active navigation system.

Familiarity	Trip length	Built-in		Mobile	
		m	sd	m	sd
Familiar	**< 20 km**	9.3%	12.4%	10.2%	12.9%
	20-100 km	40.6%	29.4%	25.3%	24.2%
	> 100 km	79.8%	32.4%	55.1%	38.4%
Unfamiliar	**< 20 km**	38.4%	34.9%	42.6%	37.0%
	20-100 km	72.4%	32.6%	54.9%	38.7%
	> 100 km	93.6%	17.4%	60.3%	40.3%

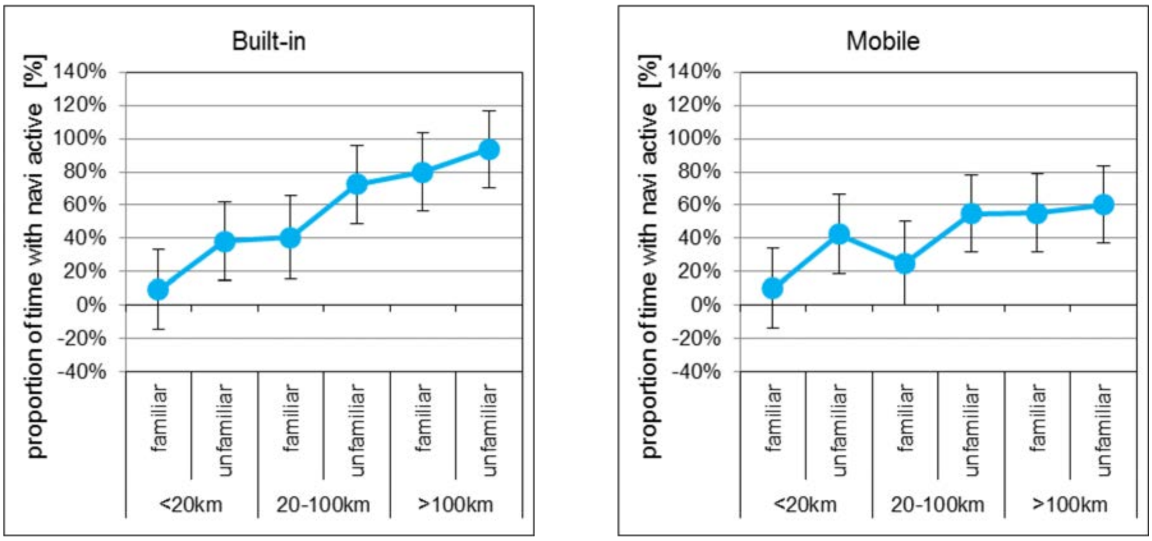


Figure 47: Proportion of trips with active navigation system for familiarity of route and trip length.

Conclusions

The mobile device is used less often than the built-in device. This is because for the built-in navigation system the usage rate rises with trip length. Compared to that, the usage rate for mobile device does not differ between long and medium trips. As a consequence, the built-in system is used more often than the mobile device on long trips. Furthermore, navigation systems are used more often on unfamiliar compared to familiar trips. For familiar trips, usage rises with trip length. For unfamiliar trips, usage does not differ between medium and long trips.

Hypotheses tested for ACC and FCW

Having ACC AND FCW decreases average speed

Comparison situations

1. Baseline
2. Treatment

Filtering criteria

- with vehicle speed above 50km/h
- and expected speed > 60 km/h (trucks NL 95 km/h, UK 110 km/h)

The reason for these filtering criteria is to reduce variation in the tested sample and therefore have an improved significance.

Factors

Road type (motorway, rural and urban roads.)

Performance indicators (PIs)

Chunked Average Speed.

Chunking

1 minute chunks.

Data

Volvo trucks

Data from 58 drivers, total 1 386 733 km.

MAN trucks

6 drivers, who have sufficient number of accumulated kilometres (>100 km) in Baseline and Treatment werewas used for the analyses. About 106.000 km distance driven in the selected sample for this test.

Ford cars

88 drivers, which have sufficient number of accumulated kilometres (>100 km) in Baseline and Treatment was used for the analyses. Unknown Roads are not included in the analyses, About 954.000 km distance driven in the selected sample for this test.

VW cars

26 drivers, which have sufficient number of accumulated kilometres (>100 km) in Baseline and Treatment was used for the analyses.

Volvo cars

64 drivers, which have sufficient number of accumulated kilometres (>100 km) in Baseline and Treatment was used for the analyses. Unknown Roads are not included in the analyses,

Statistical Methods

ANOVA repeated measures-test was conducted between comparison situations in which Driver ID was used as a random effect.

Analyse tool: SAS (repeated mixed ANOVA).

The linear mixed model Proc MIXED was used. Unstructured (UN) matrix was judged to give the best estimation of the variance and covariance parameters.

Results

The table shows the integrated results of the three car fleets and the two truck fleets present in the FOT.

Hypotheses are tested per fleet using the same statistical method and approach as described in this section. The test results were then combined in the following way:

- The effect is the average for all fleets
- It is weighted over km driven (total for baseline and treatment)
- Non-significant effects are assumed zero, so the distance driven by vehicles for which no effect was found is included in the weighted average.

Note that the average speeds are not available for rural and urban roads because the mileage for this selection is not available for one of the fleets.

Table 64: Results average speed effect ACC and FCW integrated for all FOT vehicles

Average speed	Cars	Trucks
Motorway	-0.7%	-0.11%
Rural	not significant	-0.03%
Urban	-0.7%	not significant

Conclusions

The bundle of ACC and FCW <u>decreases</u> the average speed.

Hypothesis: ACC+FCW in trucks increases the number of vehicle km travelled

Comparison situations

1.Baseline – Treatment

Filtering criteria

1. None

Considered situations

1. All situations
2. Road type (rural, urban, motorway)
3. Traffic state (congested, not congested)
4. Lighting (light, dark)

Performance indicators (PIs)

2.Average number of km per trip.

Chunking

None.

Data

44 drivers, one fleet, 1.200.000 km driven.

Statistical Methods

Paired t-test was conducted for each PI between comparison situations in which Driver ID was used to pair the analysis. Factors were fixed one at a time during each t-test.

To eliminate the effect of outliers, trips longer than 600 km were removed.

Results

Four combinations were significant ($p<0.05$). Results are displayed in Table 1. Conditions with a ^{B} would pass the Bon Ferroni criterion ($p<0.00625$). This is only the condition ‘darkness’.

Table 65: Significant results - ACC+FCW in trucks increases the number of vehicle km travelled

Factors	df	t	p	M (baseline)	SD (baseline)	M (treatment)	SD (treatment)
motorway	44	2.45	0.009	96.39	28.48	107.91	29.57
darkness	41	4.99	0.000 [B]	73.15	39.37	103.54	34.41
motorway free flow	44	2.32	0.013	95.64	58.61	106.45	32.63
motorway congestion	39	1.80	0.040	2.25	0.23	2.73	0.22

Conclusions

There is significant increase of 11% to 42% in the number of kilometres travelled per trip for trucks when comparing baseline and treatment for ACC and FCW for the conditions motorway, motorway free flow, motorway congestion and darkness. These effects are too large to be explainable by the presence of the ACC and FCW. Additionally the questionnaires people indicated that they did not change their mobility behaviour due to ACC and FCW. Seasonal influences are a more likely reason.

Hypothesis: ACC+FCW in cars decreases the number of vehicle km travelled

Comparison situations

2.Baseline – Treatment

Filtering criteria

2. None

Considered situations

5. All situations
6. Road type (rural, urban, motorway)
7. Traffic state (congested, not congested)
8. Lighting (light, dark)

Performance indicators (PIs)

3.Average number of km per trip.

Chunking

None.

Data

188 drivers from three fleets (Volvo cars, Ford and VW) driving 139.977 kilometres in baseline and 235.930 kilometres in treatment.

Statistical Methods

Paired t-test was conducted for each PI between comparison situations in which Driver ID was used to pair the analysis. Factors were fixed one at a time during each t-test.

To eliminate the effect of outliers, trips longer than 600 km were removed.

Results

Significant results ($p<0.05$) are displayed in Table 1 and Figure 1. Conditions with a [B] would pass the Bon Ferroni criterion ($p<0.00625$). This applies to none of the conditions.

Table 66: Results - ACC+FCW in cars decreases the number of vehicle km travelled

Factors	df	t	p	M (baseline)	SD (baseline)	M (treatment)	SD (treatment)
all	187	1.98	0.024	23.88	13.43	22.28	12.17
motorway	175	2.00	0.023	38.93	2.19	35.53	1.87
motorway free flow	187	1.70	0.045	9.95	12.04	8.75	9.27
daylight	186	1.96	0.026	22.13	13.16	20.46	11.18

Conclusions

There are significant decrease of 7% to 12% in the number of kilometres travelled per trip for cars when comparing baseline and treatment for ACC and FCW for all conditions, for motorway, motorway free flow and daylight. These effects are too large to be explainable by the presence of the ACC and FCW. Additionally the questionnaires people indicated that they did not change their mobility behaviour due to ACC and FCW. Seasonal influences are a more likely reason.

ACC reduces the average fuel consumption (passenger cars)

Comparison situations

Baseline: All baseline with ACC state off

Treatment: All treatment with ACC state active

Filtering criteria

1. Travelled time with vehicle speed not null > 5 min.
2. Vehicle speed >=50 km/h
3. THW>0 (car following)
4. Expected speed >60 km/h
5. Minimum mileage for each driver in baseline/treatment conditions (100km)

Factors

2. Road type
3. Weather (only motorway)
4. Lighting (only motorway)

Performance indicators (PIs)

2.Average fuel consumption per 100 driven km

Data

All drivers (N), which have sufficient number of accumulated kilometres (>100 km) in Baseline and Treatment, were used for the analyses. N=163 samples for motorway (698695 km), N=53 for rural (30189 km) and urban roads (27944 km), N=80 for lighting conditions (557663 km) and N=77 for weather conditions (555412 km).

Statistical Methods

Repeated measures ANOVA

Results

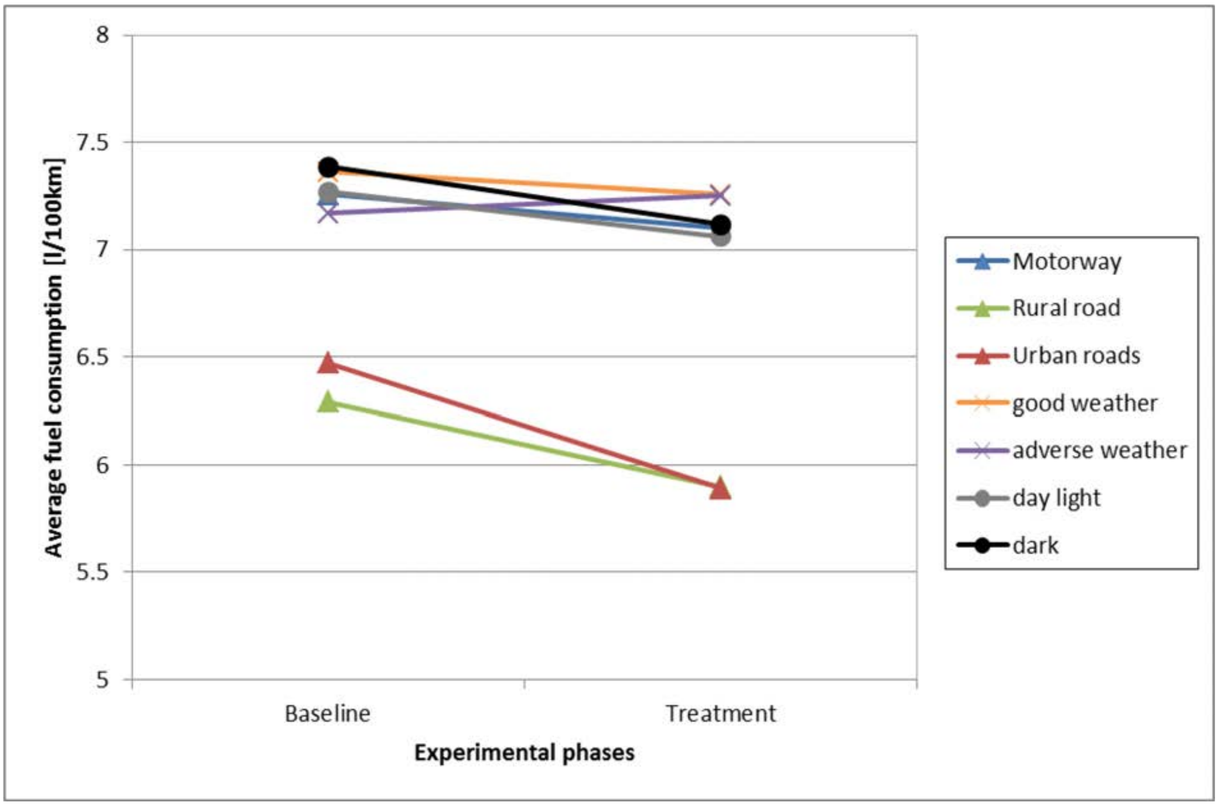


Figure 48: Impact of ACC on average fuel consumption – cars

Table 67: Impact of ACC on average fuel consumption - cars

Conditions	Baseline	Treatment	% Increase/ Reduction	N	Mileage [km]
	Mean	Mean			
Motorway	7.20	7.06	-1.97	163	698695
Rural	6.29*	5.9	-6.2	53	30189
Urban	6.47*	5.89	-8.96	53	27944
Good	7.37	7.26	-1.46	77	489399
Adverse	7.16	7.24	0.11	77	66013
Day light	7.29	7.04	-3.44	80	413223
Dark	7.39	7.11	-3.17	80	144440

* Only diesel-powered vehicles

Conclusions

Using ACC decreases the average fuel consumption by 1.97% while driving on motorway. A higher reduction could be found on rural and urban roads (6.2% and 8.96%). The reduction on rural and urban roads might overestimate the fuel saving potential because of the differences in driving patterns in both experimental phases caused by the driver's choice when to use the system. The evaluation on weather and lighting conditions (while driving on motorways) reveals reductions between 1.46% and 3.44% with an increase of 0.11% during adverse weather conditions.

ACC reduces the average fuel consumption (trucks)

Comparison situations

Baseline: All baseline with ACC state off

Treatment: All treatment with ACC state active

Filtering criteria

1. Travelled time with vehicle speed not null > 5 min.
2. Vehicle speed >=50 km/h
3. THW>0 (car following)
4. Posted speed > 100 km/h
5. Minimum mileage for each driver in baseline/treatment conditions (100km)

Factors

1. Motorway

Performance indicators (PIs)

1. Average fuel consumption per 100 driven km

Data

All drivers (N), which have sufficient number of accumulated kilometres (>100 km) in Baseline and Treatment, were used for the analyses. N=23 driver for motorway (327295 km).

Statistical Methods

Repeated measures ANOVA

Results

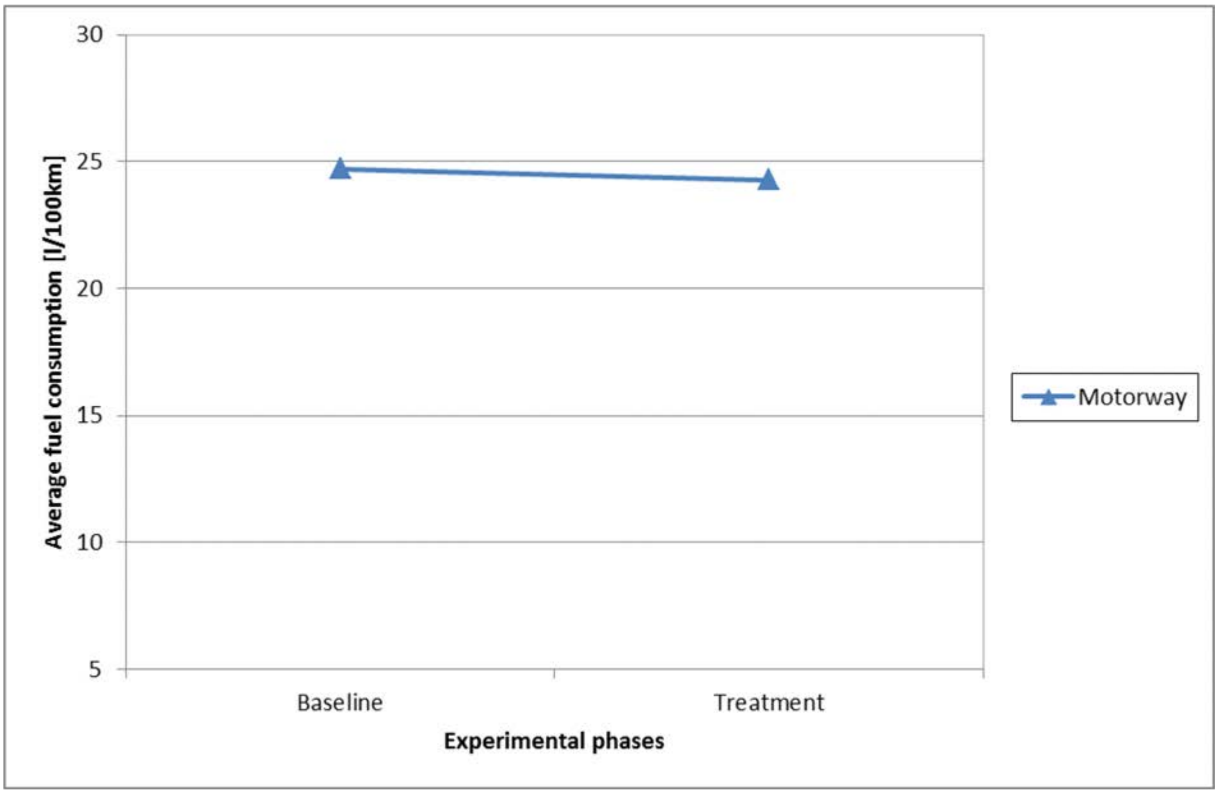


Figure 49: Impact of ACC on average fuel consumption – trucks

Table 68: Impact of ACC on average fuel consumption - trucks

Conditions	Baseline	Treatment	% Increase/ Reduction	N	Mileage [km]
	Mean	Mean			
motorway	24.71	24.28	-1.75	23	327295

Conclusions

Using ACC decreases the average fuel consumption by 1.75% while driving on motorway.

Hypotheses tested for SRS

Having SRS decreases the average speed.

Comparison situations

Driver speed choice is highly dependent on the road design. A high correlation is expected between speed limit, road type, and average measured speed, and there is a need to carefully choose baseline and treatment data for comparison purpose.

3. Baseline: Random sampled chunks according to exposure.
4. Treatment: Random sampled chunks according to exposure.

Filtering criteria

Chunks are filtered before sampling from the baseline according to the following:

- Average speed >5km/h.
- Map speed limit information available

Factors

5. Speed limit (30, 50, 70, 90, 110, 130 km/h)

Performance indicators (PIs)

4.Chunked Average Speed.

Chunking

10 to 30 sec chunks with homogeneous values for: TripID, DriverID, road type, speed limit, weather (dry or rain), and lighting (night or day). The other variables are not constant and treated as PI (percentage of time in a specific situation for example).

Data

35 drivers, which have sufficient number of accumulated kilometres (>5000 km) in Baseline and Treatment werewas used for the analyses. Unknown Roads are not included in the analyses,

Statistical Methods

The suitable method for this kind of analysis is the “Generalized Linear Mixed Model” (GLMM) which allows introducing a random effect specific to each subject. In this case, we include intercept and driver ID as random effects, specified by the compound-symmetry structure, which has constant variance and constant covariance. The compound symmetry structure arises naturally with nested random effects, such as when subsampling error is nested within experimental error. Other appropriate random effects cannot be included for computational purposes as it has proven to lead the statistical models not to converge due to the large amount of data.

A sufficient number of chunks in all the conditions are needed for the model being able to estimate correctly the fixed effects (SL and CC effects). Due to insufficient observations (for example, SL usage on 30km/h roads), some drivers do not contribute to the estimates of effects for some of the speed limits. This may induce different fixed effect estimation for baseline data. Average fixed effects are estimated by the mean of a least square estimation using the estimate of the fixed effects parameter vector. Estimated fixed effect values are generally different than the exact means.

Analyse tool: SAS software (PROC GLIMMIX).

Results

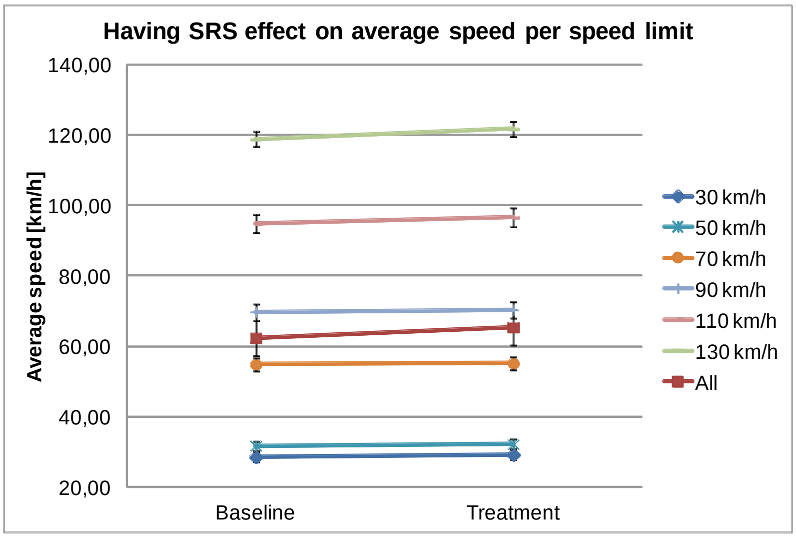


Figure 50: SRS effect on average speed per speed limit

Significant results (p<0.05) are displayed in Table 69.

Table 69: SRS effect on average speed per speed limit

Factor (Speed limits)	Least squares estimation for average speed Baseline / Treatment	Lower bound Baseline / Treatment	Upper bound Baseline / Treatment	Type III fixed effects P-value	Increase Km/h	Lower bound effect	Upper bound effect
30 km/h	28,60 / 29,25	27,1 / 27,8	30,1 / 30,7	0,0002	0,65	0,31	0,99
50 km/h	31,82 / 32,27	30,4 / 30,9	33,2 / 33,7	<.0001	0,45	0,33	0,58
70 km/h	54,91 / 55,22	53,1 / 53,4	56,7 / 57,0	0.1224	0,31	0,08	0,69
90 km/h	69,75 / 70,31	67,4 / 67,9	72,1 / 72,7	<.0001	0,56	0,27	0,85
110 km/h	94,74 / 96,63	92,2 / 94,1	97,3 / 99,2	<.0001	1,89	1,55	2,24
130 km/h	118,83 / 121,70	116,7 / 119,6	121,0 / 123,8	<.0001	2,87	2,64	3,1
All conditions	62,37 / 65,43	57,91 / 60,97	66,83 / 69,89	<.0001	3,06	2,87	3,24

Conclusions

The function SRS increases significantly the average speed in all driving contexts except for 70km/h limited roads which do not provide as much data as other driving context.

Factor analyses show a similar effect for all the situations, with an average speed increase of more than 10 km/h.

Hypothesis: SRS increases the number of vehicle km travelled per trip

Comparison situations

3. Baseline – Treatment built in
4. Baseline – Treatment nomadic

Filtering criteria

None

Considered situations

All situations

1. Driving conditions (car following, free flow)
2. Speed limit (30, 50, 70, 90, 110, 130)
3. Road type (rural, urban, motorway)
4. Traffic state (congested, not congested)
5. Lighting (light, dark)

Performance indicators (PIs)

4. Average number of km per trip.

Chunking

None.

Data

Renault data set from in French VMC available on 07-11-2011. 35 drivers drove 1.601.758.881 km driven in baseline, 2.434.677.839 km driven in treatment. This test was performed earlier and was therefore performed on a part of the final data set. Other analyses are performed on the full data set.

Statistical Methods

Paired t-test was conducted for each PI between comparison situations in which Driver ID was used to pair the analysis. Factors were fixed one at a time during each t-test.

Results

Significant results (p<0.05) are displayed in Table 70. Conditions with a [B] would pass the Bon Ferroni criterion (p<0.00625). This is only the condition 'Speed limit 130 km/hr'.

Table 70: Significant results of SRS effect on number of vehicle km travelled per trip

Hypothesis	Factors	df	t	p	M (baseline)	SD (baseline)	M (treatment)	SD (treatment)
2.b	Speed limit 130 km/h	32	2.89	0.003	16534.09	12161.53	21235.67	11804.41

All other combinations were not significant (p>0.05).

Conclusions

There is no significant effect on average trip length.

The distance driven on road with a 130 km/h speed limit with the SRS is larger that without.

Hypothesis tested for FEA

FEA decreases fuel consumption

Comparison situations

Baseline: FEA unavailable

Treatment: FEA available

Filtering criteria

2.None

Factors

6. None

Performance indicators (PIs)

Average fuel in l/100km.

Chunking

None.

Data

Data from 50 drivers: 25 with FEA available and 25 with FEA unavailable.

Statistical Methods

Independent sample t-test.

Results

The shown results are not significant with regard to the chosen significance level.

Average fuel consumption (l/100 km)		P-value	Absolute difference (l/100 km)	Relative difference (% of baseline)
Baseline	Treatment			
37.09	36.39	> 0.05	-0.7	-1.89

Conclusions

There is no significant change in time in fuel consumption in treatment. It is important to point out that since the data obtained from FEA trucks were extremely limited (no factors could be included in the analysis) and drivers in treatment were different from drivers in baseline, further analysis must be performed in order to better understand the effects of FEA on fuel consumption.

Annex 2 Detailed simulation results for SRS

The main effect of the SRS function is expected to be on the longitudinal driver model. Therefore the calibration effort is limited to this part of the driver model. The two main components of the longitudinal driver model are the free driving model and the car following model. Both are calibrated on the data, in a way described in the following two sections. The section after that shows some results of this implementation. A final section discusses how the usage of the SRS function is modelled.

Free Driving

When driving without a predecessor, it is unlikely that a normal human driver maintains a constant speed. There will most of the time be an accelerating and decelerating behaviour. Examples of this oscillatory behaviour are shown in Figure 51, Figure 52 and Figure 53 for respectively urban, rural and motorways.

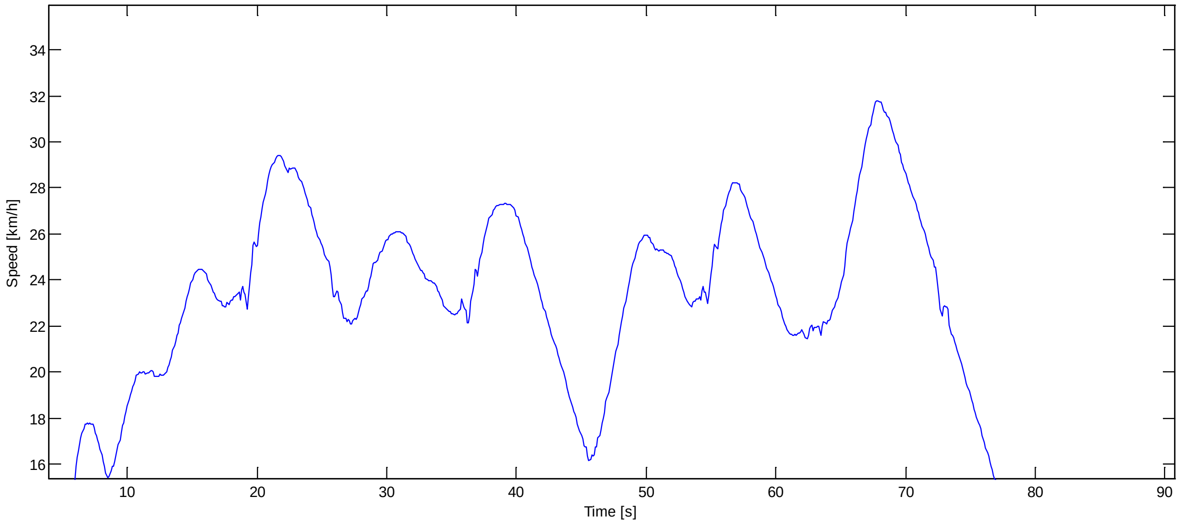


Figure 51: Example from FOT data of speed oscillations on an urban road without predecessor

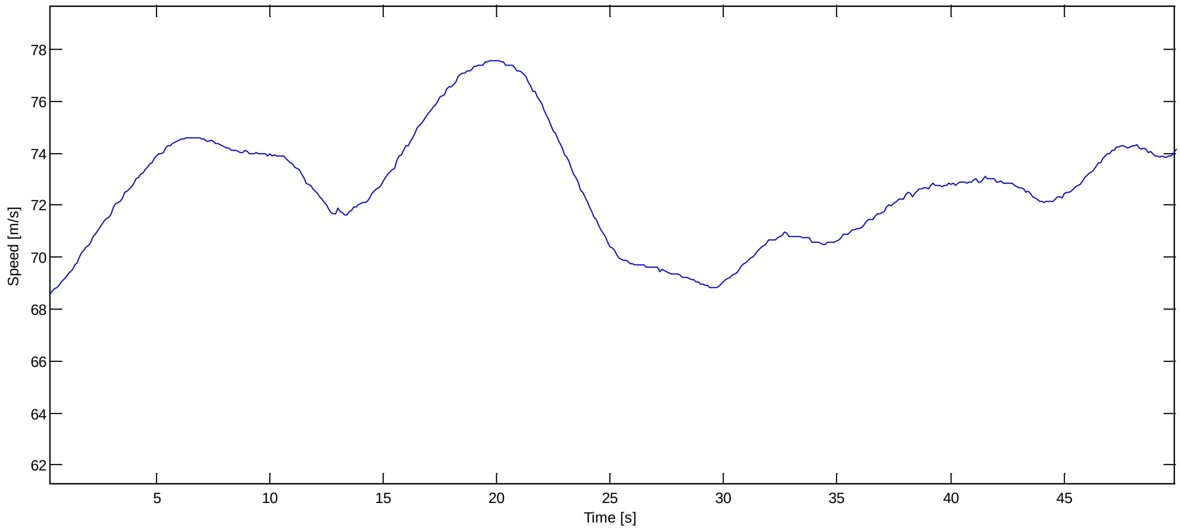


Figure 52: Example from FOT data of speed oscillations on a rural road without predecessor

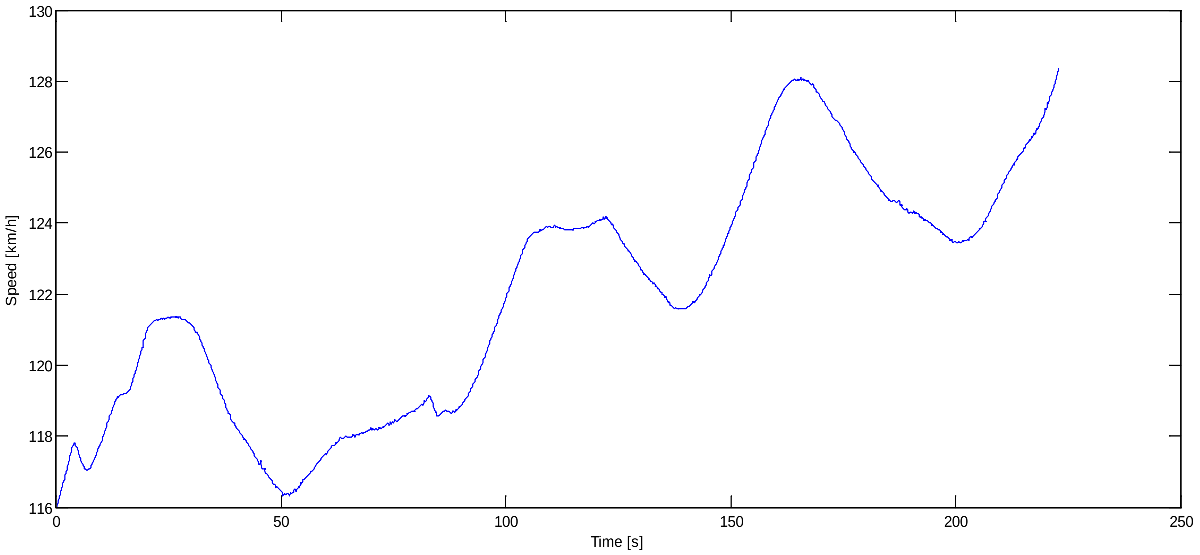


Figure 53: Example from FOT data of speed oscillations on a motorway without predecessor

The average wavelengths and amplitudes of these oscillations can be obtained from the FOT data using Fourier transformations. Three frequency bands have been chosen to group the wavelengths, namely:

1-15 sec

15-30 sec

30-60 sec

The average amplitudes (in km/h) for different road types in these bands are shown in Figure 54.

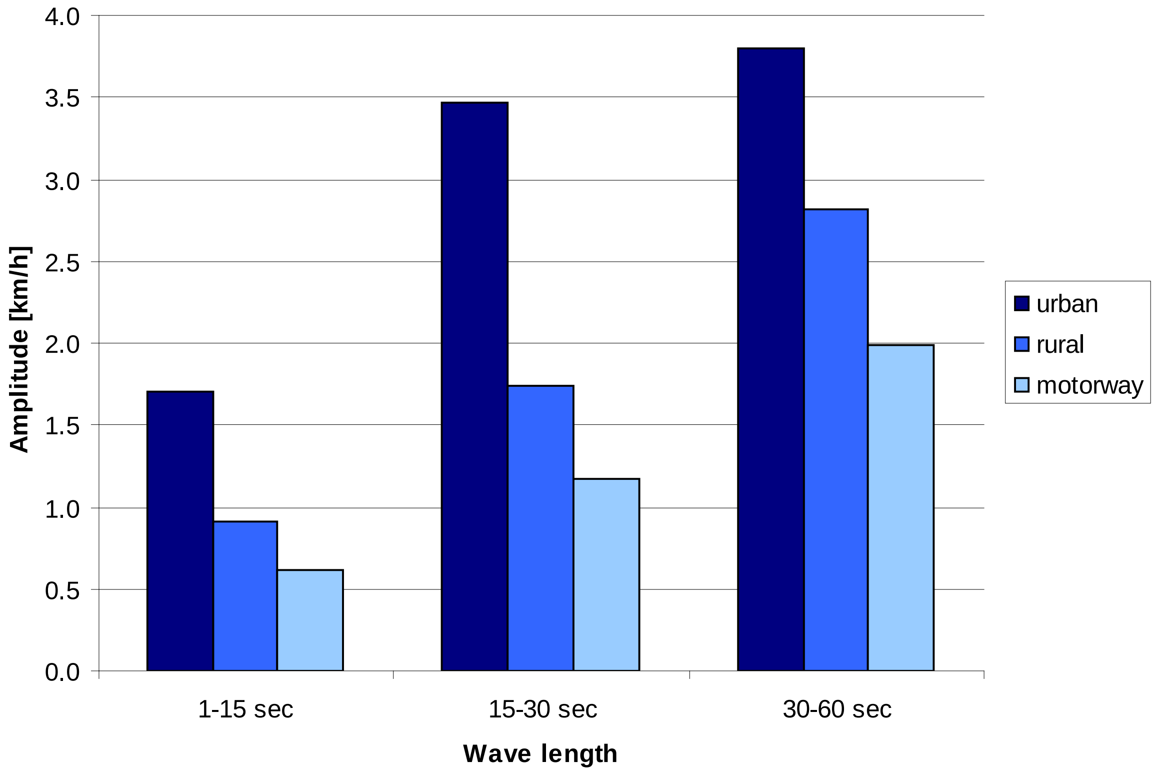


Figure 54: Amplitudes of speed oscillations for different road types in three frequency bands

The wave amplitudes lie between 0.5 and 1.5 times the average amplitude. The free driving behaviour in baseline is now modelled by adding up the three different waves corresponding to the frequency bands and amplitudes shown in Figure 54. They vary per road type and driver in order to personalize the driving behaviour.

Car Following

In the data obtained in the euroFOT project, the presence of a predecessor is detected for all logging vehicles. This makes it possible to create or calibrate a car following model from this data.

Figure 55 shows the distance to the predecessor vehicle plotted against the relative speed, that is, the difference in speed between the ego vehicle and its predecessor. In an ideal errorless situation, the relative speed will be zero for all cases, or approach zero as well as possible. In Figure 55 it can be seen that the actual relative speed deviates quite a lot from zero, and so is not ideal. Human errors cause the vehicle to show random behaviour.

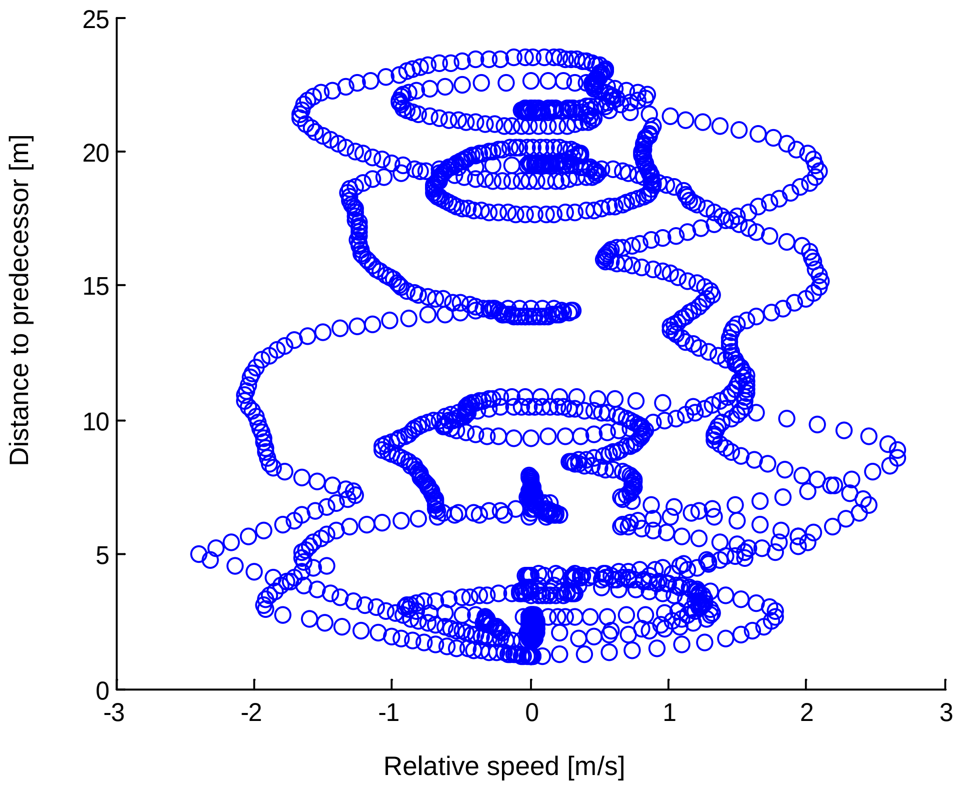


Figure 55: Following behaviour from euroFOT data in baseline

The Psycho Spacing model described by Hoogendoorn [2] and Wiedemann [4] is a model that can fit this type of behaviour. In this model, the driver reacts to the vehicle in front when the distance and relative speed cross certain threshold values, where random perception errors for human mistakes are included for realism. A graphical overview of the working principal of this model is shown in Figure 56. A description of the model can be found in [4].

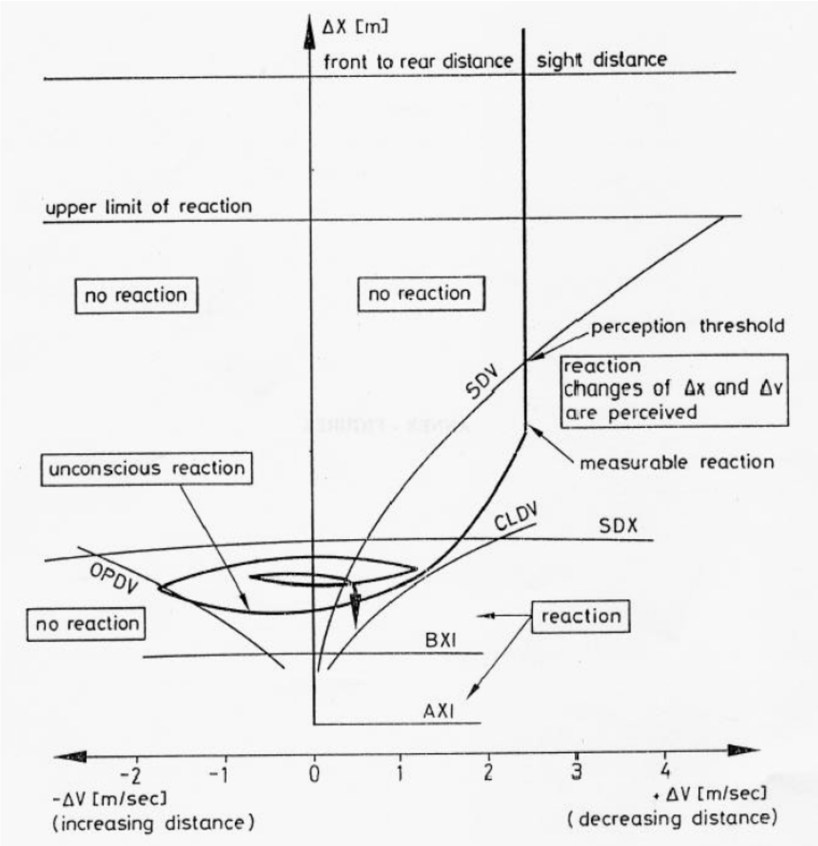


Figure 56: Psycho-Spacing Model (Wiedemann and Reiter, 1974)

In the next paragraphs the derivation from the euroFOT data of all constants necessary for the Psycho spacing model will be described.

Desired distance calculation

The desired distance needed for the psycho spacing model should be in the form:

- ABX (=Min_Desired_distance)= AX + BX*sqrt(v)
- SDX (=Max_Desired_distance) = AX + BX*EX*sqrt(v).

The constants AX, BX and EX are estimated by looking at random trajectories from the euroFOT data.

These trajectories have been filtered to cases where:

- Predecessor within 200 m
- Relative speed = 0 m/s

The output is shown in Figure 57, which shows the distance headway as a function of speed. The assumption is made that this graph contains values for the minimum desired distance and for the maximum desired distance. Therefore this graph has been divided in two areas.

With these values, the constants needed for the psycho spacing model can be estimated, and fitted to a normal distribution (Figure 58, Figure 59 and Figure 60). This is direct input into ITS modeller.

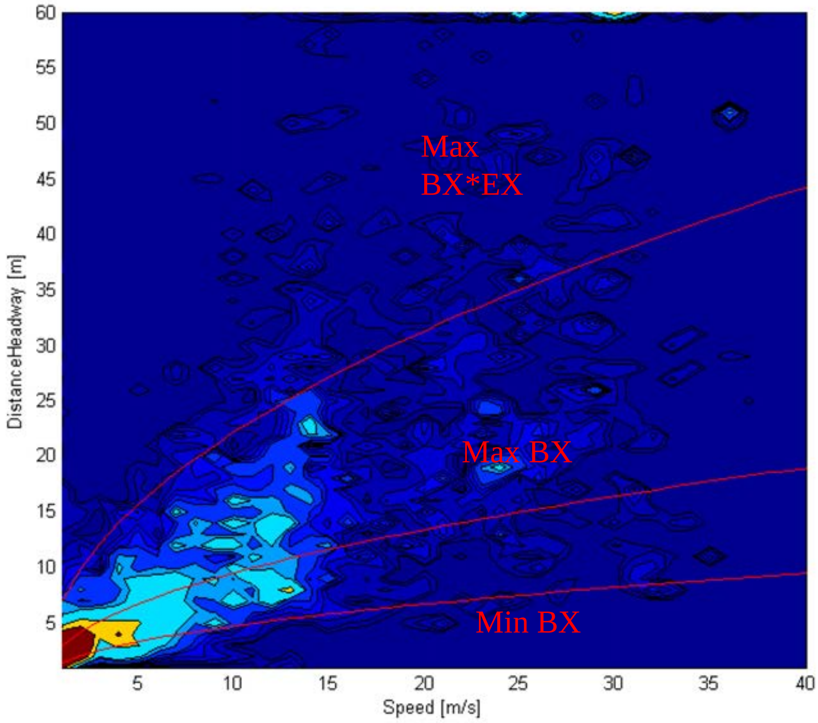


Figure 57: Desired distance headway with minimum and maximum estimation

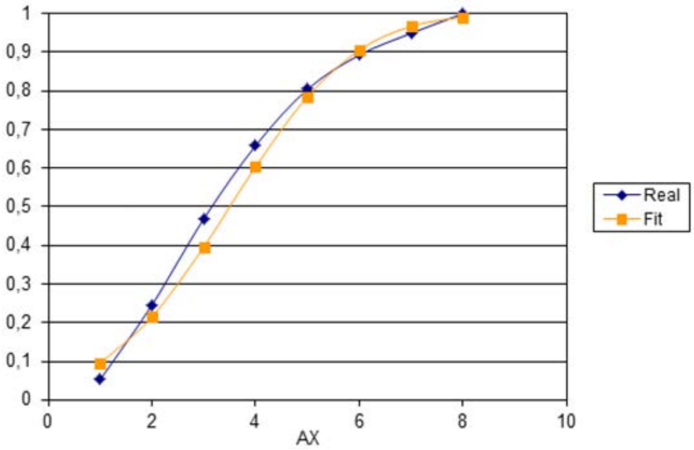


Figure 58: Cumulative distribution of AX, measured and fitted to normal distribution

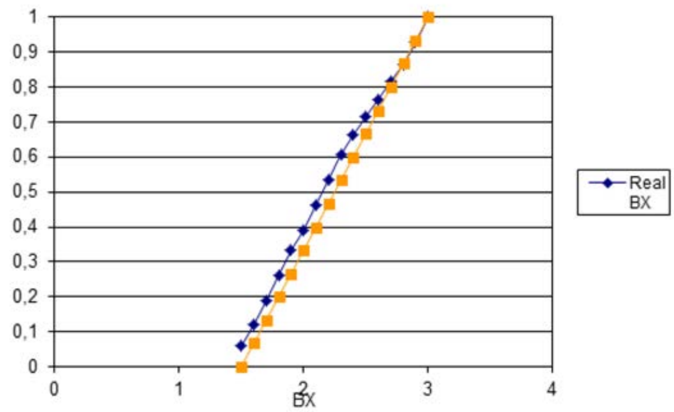


Figure 59: Cumulative distribution of BX, measured and fitted to uniform distribution

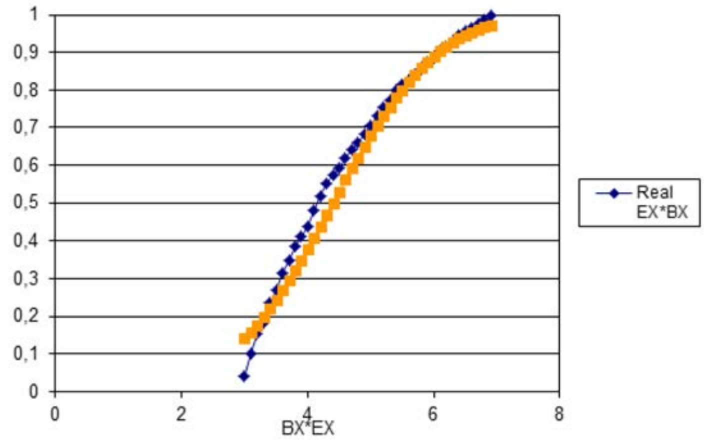


Figure 60: Cumulative distribution of BX*EX, measured and fitted to normal distribution

Threshold speed calculation

With the desired distance available, the next estimation is the threshold speed at which the driver realizes he is closing in on a vehicle. The threshold speed-difference as a function of following distance is described by

$$SDV = \left(\frac{DX - AX}{CX} \right)^2,$$

With AX = distance to predecessor at speed zero, DX=distance to predecessor, CX= random factor between 25 and 75 [4].

AX was already defined above. The relative speed at which the predecessor is noticed can be found by looking at moments in time where the change in relative speed is zero, or when the change in relative speed switches sign. An estimation of CX can be made using this data. The results are shown in Figure 61. CX seems to be log-normally distributed, with mu = 3.4 and sigma = 0.7.

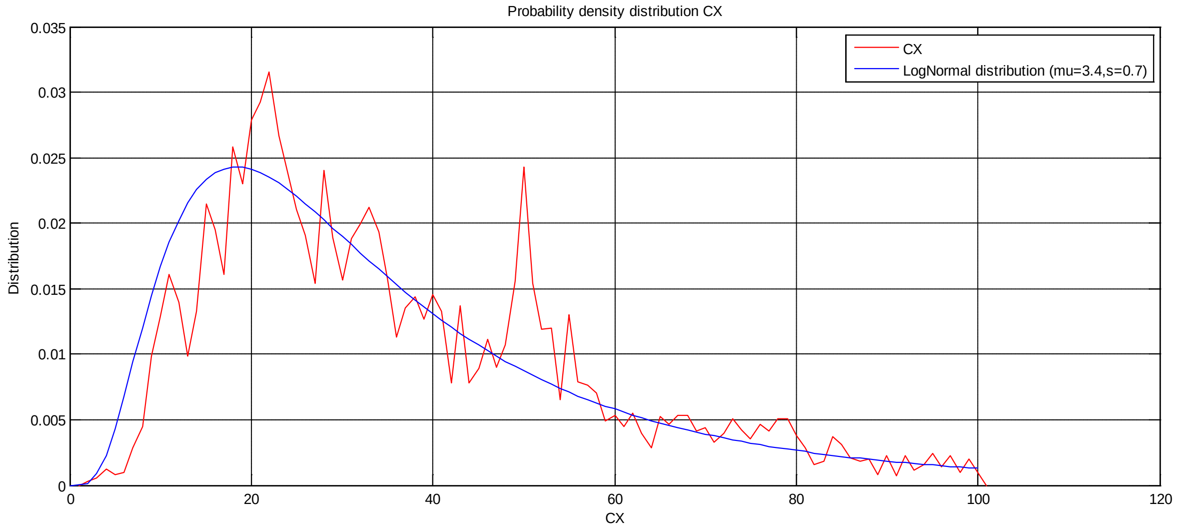


Figure 61: Distribution of CX, measured and fitted to lognormal distribution

The psycho spacing model does not allow for larger values than 75 and smaller values than 25 for CX (see [4]) to make the model stable, so the distribution is cut off at these values.

Now that SDV is known, CLDV can be calculated by dividing SDV by EX.

To determine OPDV, the relation between points at which realization of increasing relative speed and realization of decreasing relative speed is observed. It seems from Figure 62 that there is not a significant difference between those values, and the average relative speed equals to -0.0048. Therefore it is assumed that OPDV equals to –CLDV.

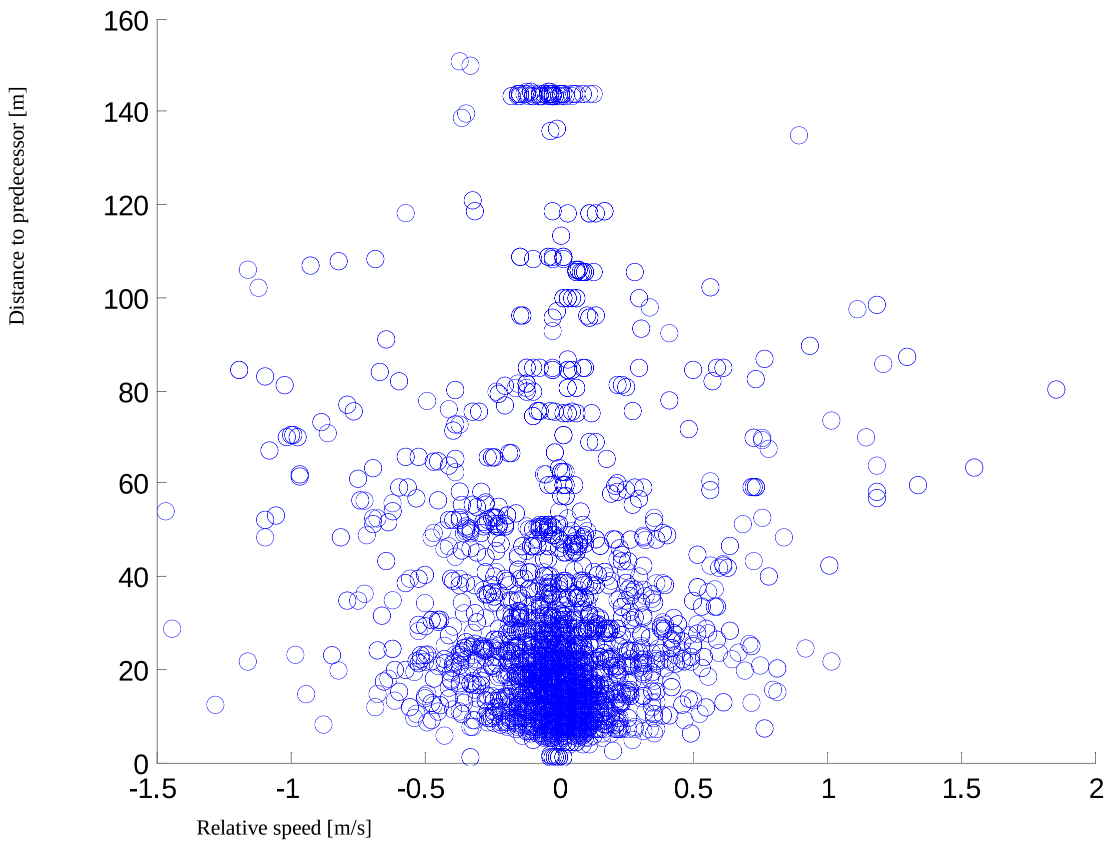


Figure 62: Threshold relative speed to predecessor

ITS Modeller implementation

Examples of the output from the car following behaviour in ITS Modeller are shown in Figure 63 and Figure 64. Figure 65 shows an example of the output from the free driving model. The speed limit at the start here equals 120 km/h, and after 50 seconds the vehicle arrives at a stage where the allowed speed equals to 80 km/h. The small irregularities are caused by a random error.

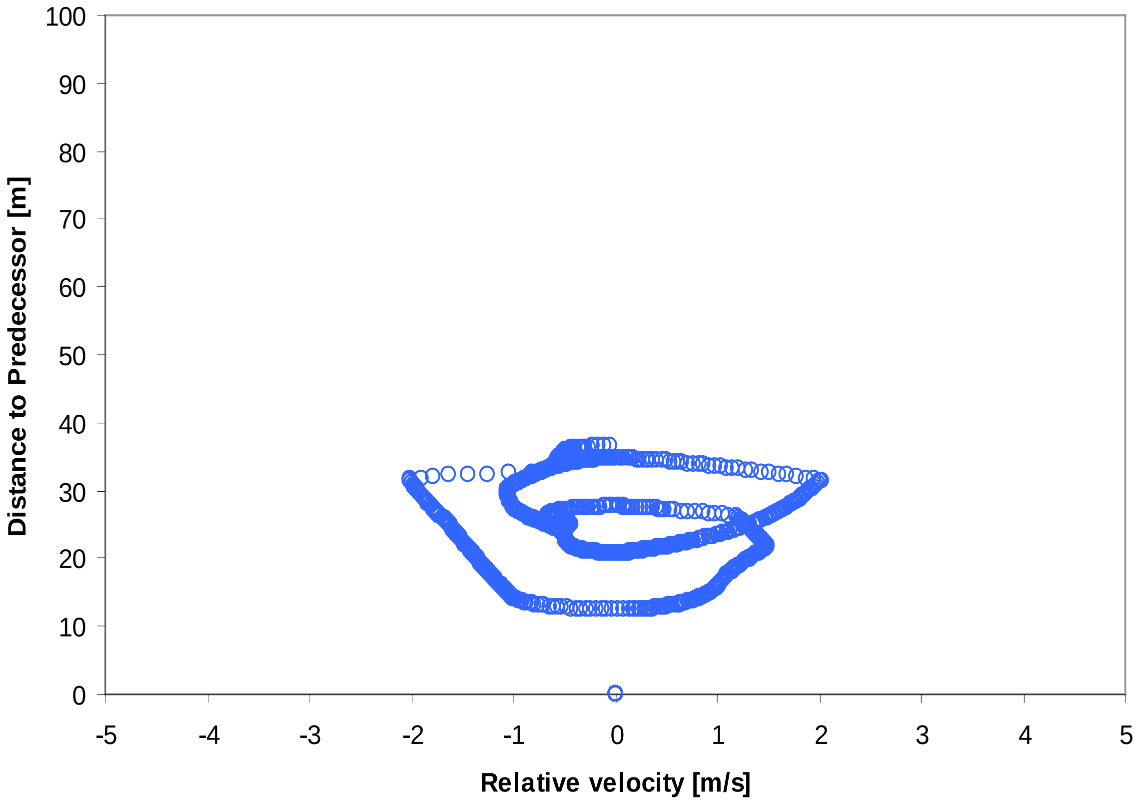


Figure 63: Example of ITS Modeller car following pattern at high throughput

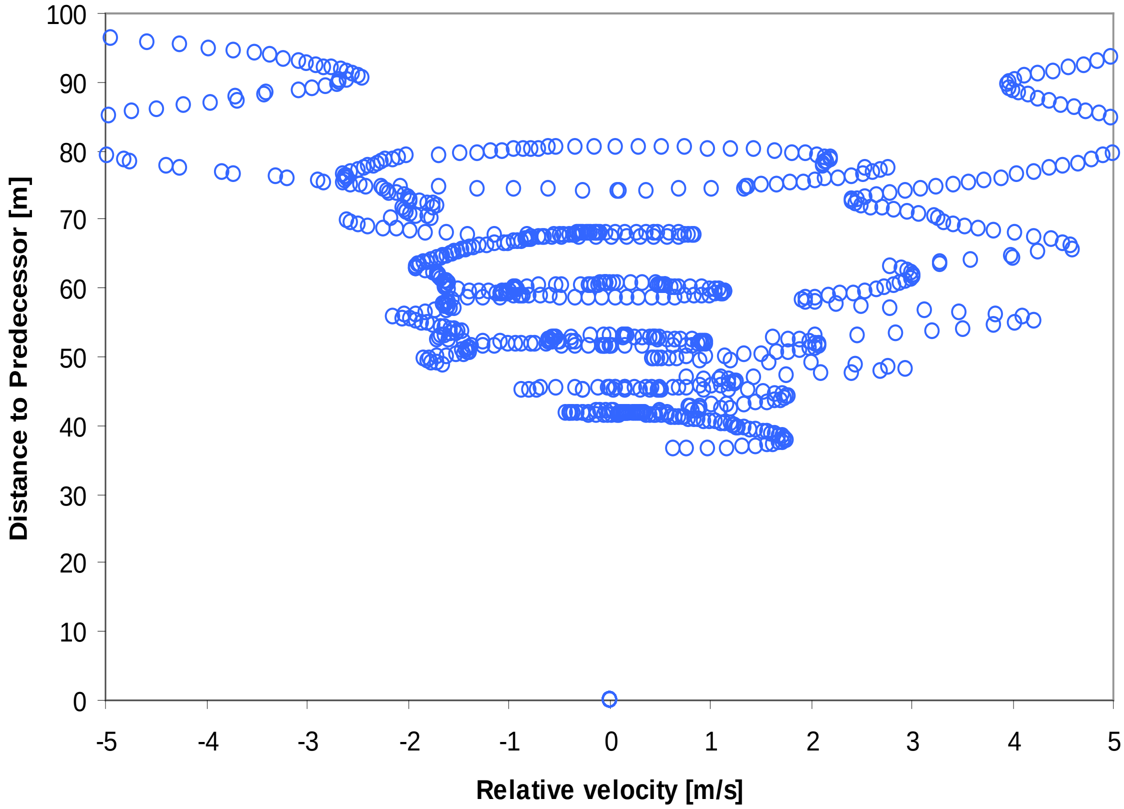


Figure 64: Example of ITS Modeller car following pattern at low throughput

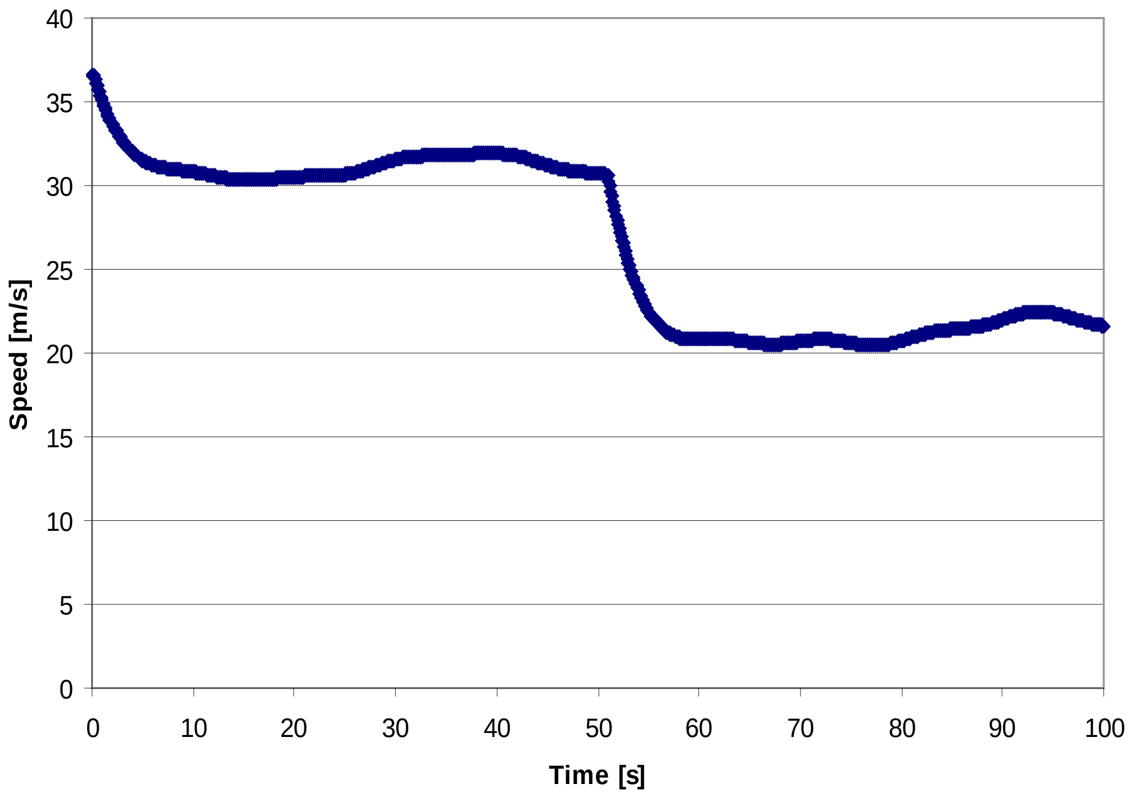


Figure 65: Example of ITS Modeller free driving model output

Speed Limiter and Cruise Control Usage

This section discusses the usage of the SL and CC functions. This concerns both the activation of the functions and their settings.

Usage

With data available from the field test it is possible to calculate the percentage of people using the Speed Limiter application and the Cruise Control. It is not possible to use both applications at the same time. The results are shown in Figure 66, and the FOT results are compared to the simulation results. The comparison shows that the simulation matches the FOT data reasonably well on rural roads and motorways, but on urban roads the SL usage is far too low.

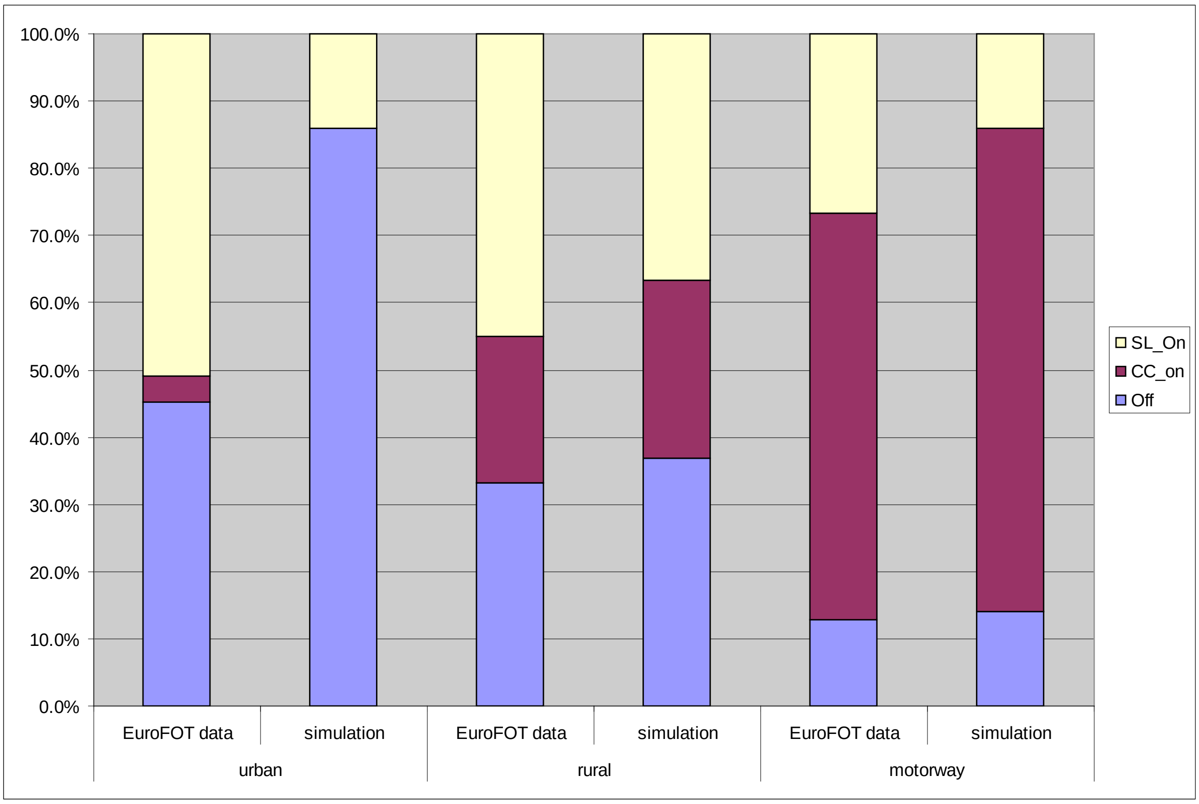


Figure 66: Usage SL and CC in the FOT and in the simulation

The percentages are used in ITS modeller to define the number of vehicles using both applications, when driving without a predecessor.

Activation SL

It is expected that the SL is switched on and off depending on the ratio between actual speed and desired speed. Figure 67 shows the cumulative distribution of this ratio for activating and for deactivating the Speed Limiter application. From this graph a direct relation between speed ratio and activating or deactivating the device cannot be determined (where "in standby" means deactivation). The graph values are the fractions of all activations and deactivations that have occurred before a given speed ratio. The distributions do not deviate enough to come up with a relation.

Therefore activation and deactivation as a function of speed was observed instead (see Figure 68). What can be observed from this graph is that most of the time deactivation occurs when the car is at rest. It is therefore implemented that SL is only switched off when the car is at rest.

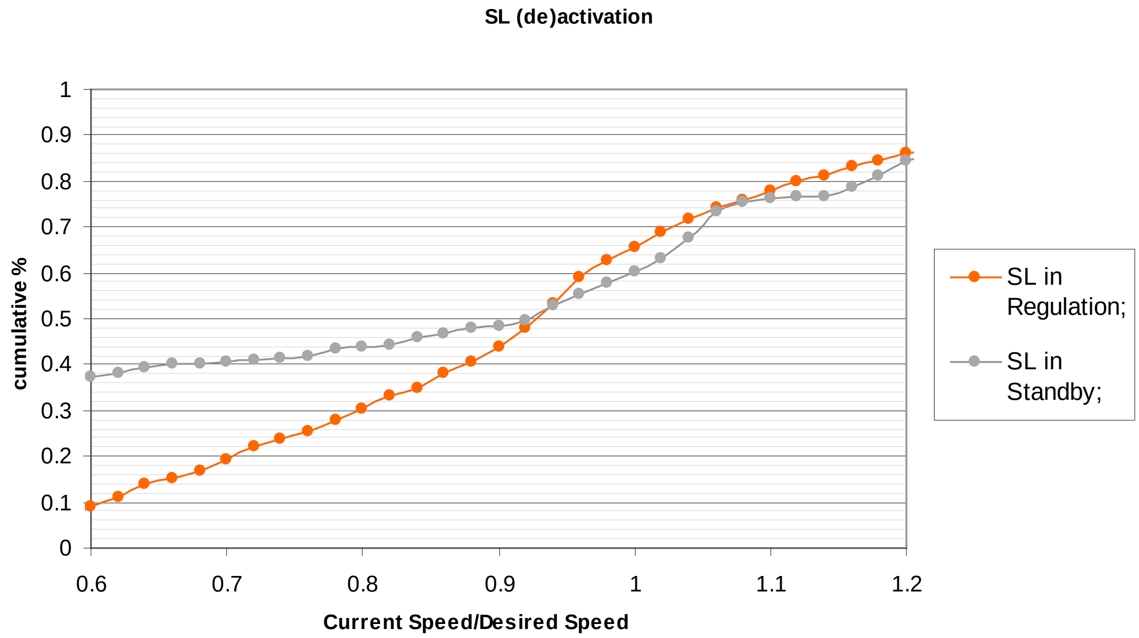


Figure 67: Speed Limit activation and deactivation as a function of speed ratio

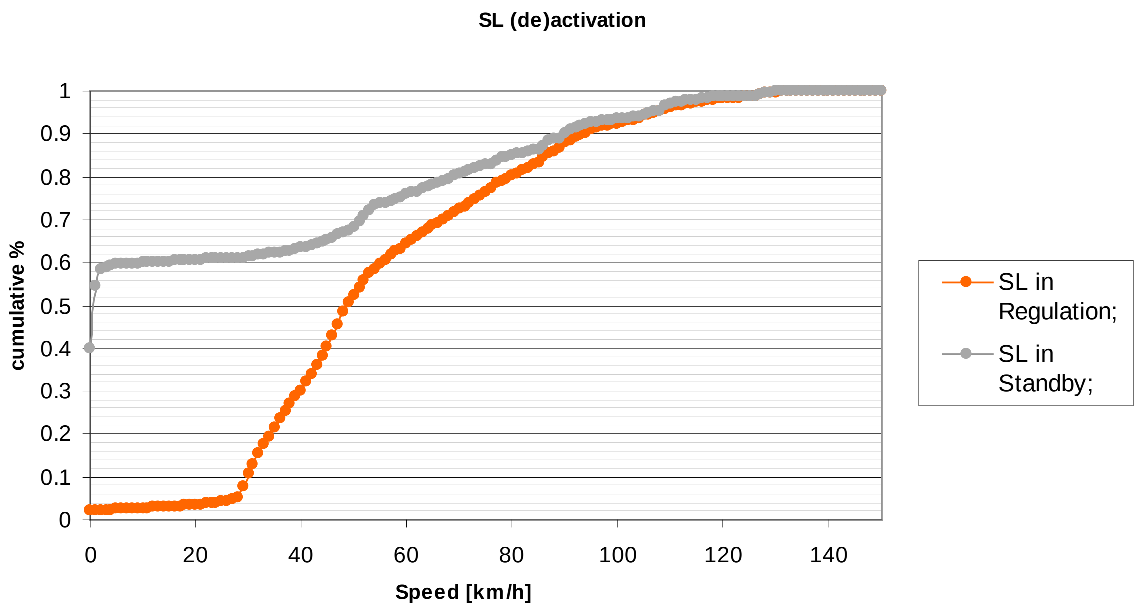


Figure 68: Speed Limit activation and deactivation as a function of speed

Activation CC

When a predecessor is spotted, the driver may choose to switch the cruise control to standby. This behaviour is investigated by looking at the values for the Time to Collision (TTC) at the moment that the status of the cruise control was changed.

Activation of the Cruise Control application is done with infinite TTC values mostly, and deactivation with positive values for the TTC. This can be seen in Figure 69.

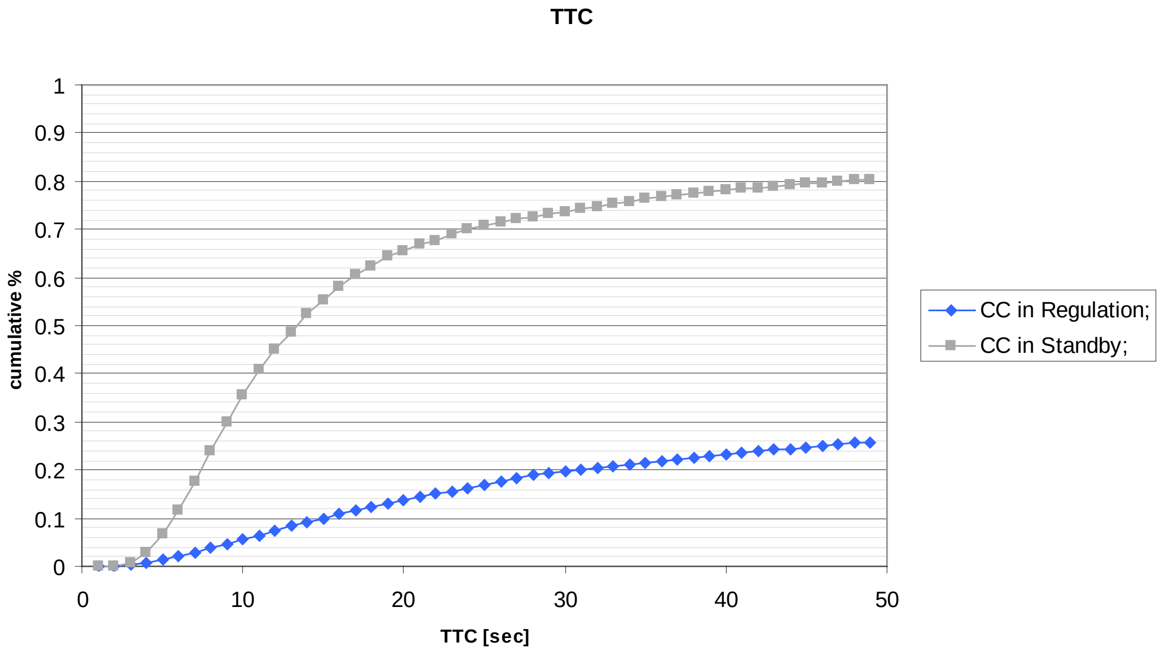


Figure 69: Cumulative distribution of the TTC when activating and deactivating Cruise Control

Figure 69 shows for example that only 20% of all activations occur at TTC's below 30 seconds, while over 70% of deactivations occur for TTC;s below that value

Furthermore, the CC activation and deactivation seems to be independent of the distance to the predecessor and the relative speed to the predecessor on themselves. Therefore the TTC is used as a measure for activating and deactivating the cruise control.

The TTC, at which the cruise control is deactivated, can be fitted quite well with a lognormal distribution, with mu 2.4 and sigma 1.45 and a translation of -3, as can be seen in Figure 70.

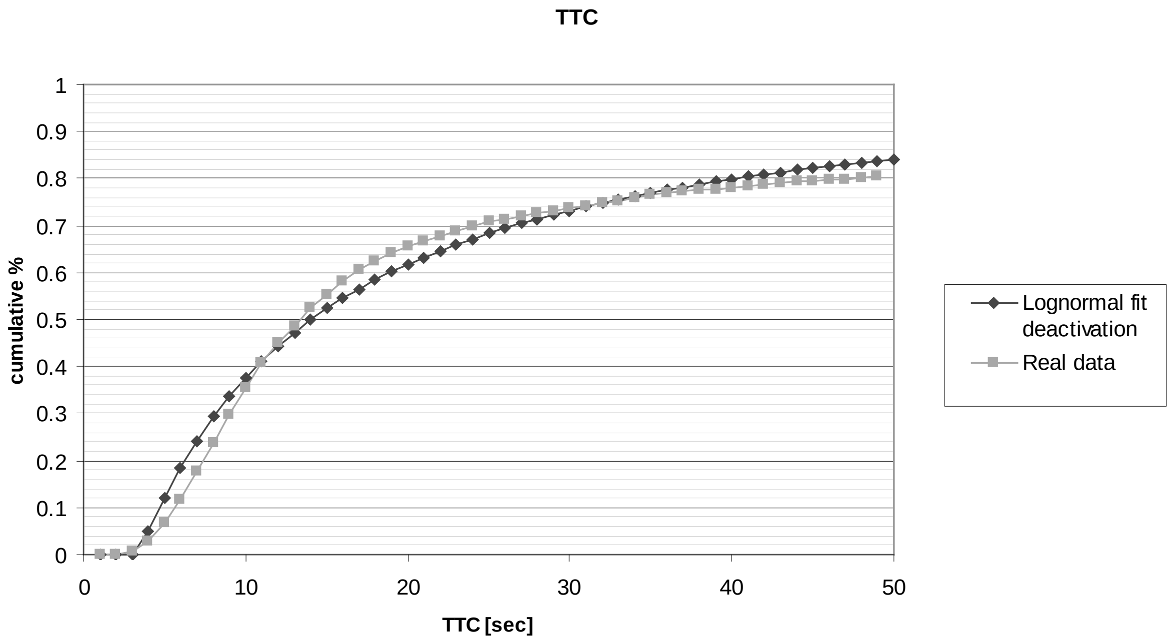


Figure 70: TTC lognormal cumulative distribution for switching off CC

The TTC, at which the cruise control is activated, equals in 74 % of the cases to a TTC larger than 50 seconds (activation rule for TTC here equals to 50 sec). At the other 26% of the cases, the TTC fits a normal distribution with mu=22 and sigma=13 with a maximum of 0.26 (see Figure 71).

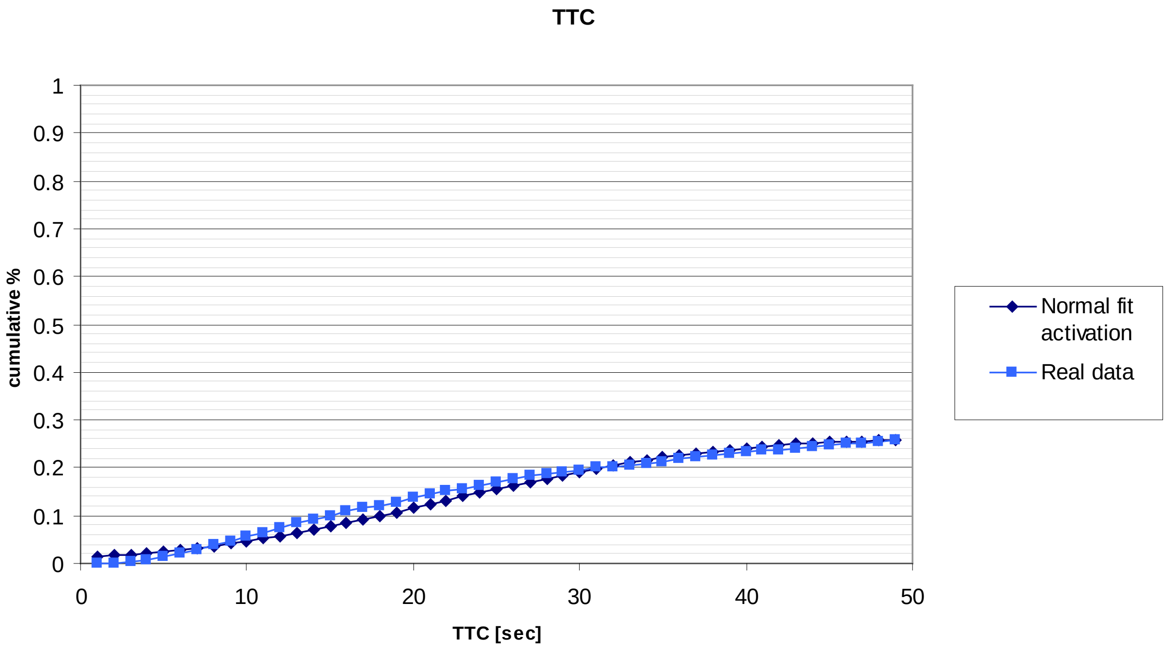


Figure 71: Normal fit activation TTC

Intended speed

The intended speed as a function of the speed limit is shown in the diagrams below. These diagrams are based on data where vehicles have no predecessor. The blue bars show the average speed, the red lines indicate one time the standard deviation above and below the average.

It can immediately be noted from these diagrams that the standard deviation of the speed is low while using CC. For the Speed Limiter application the effect is less obvious. While here too, a lower standard deviation would be expected, this appears to be the case only on 80 km/h roads.

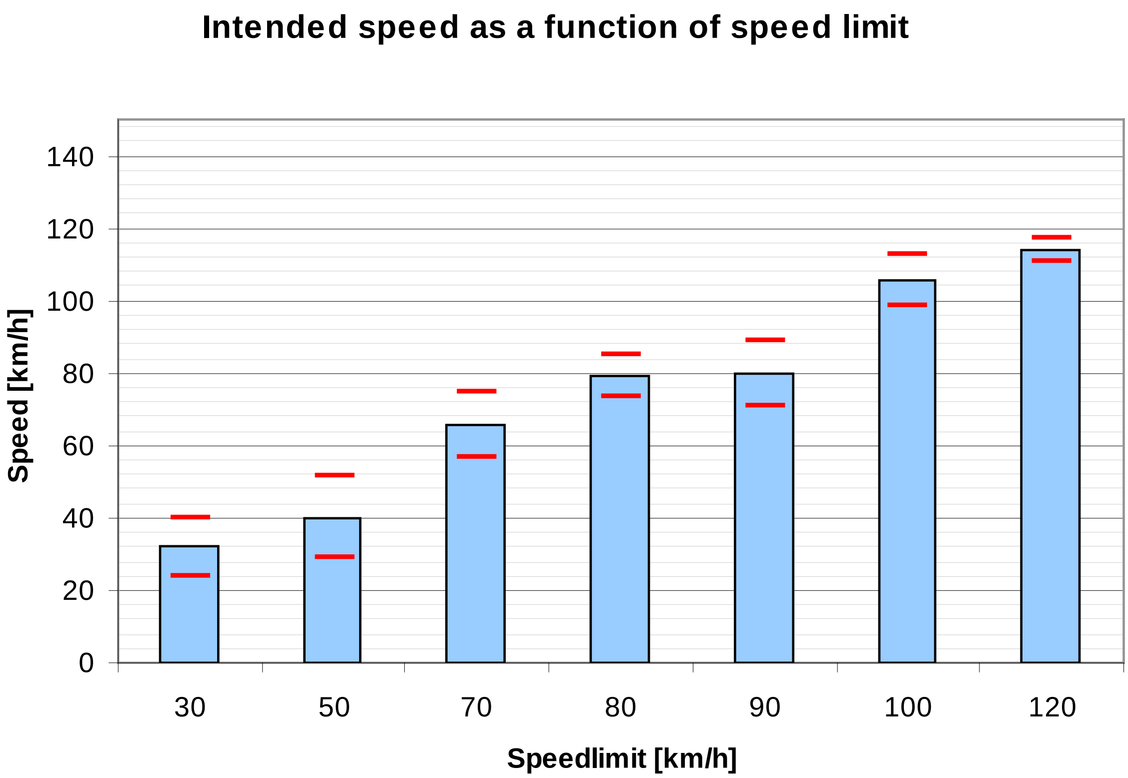


Figure 72: Intended speed 'normal' vehicles

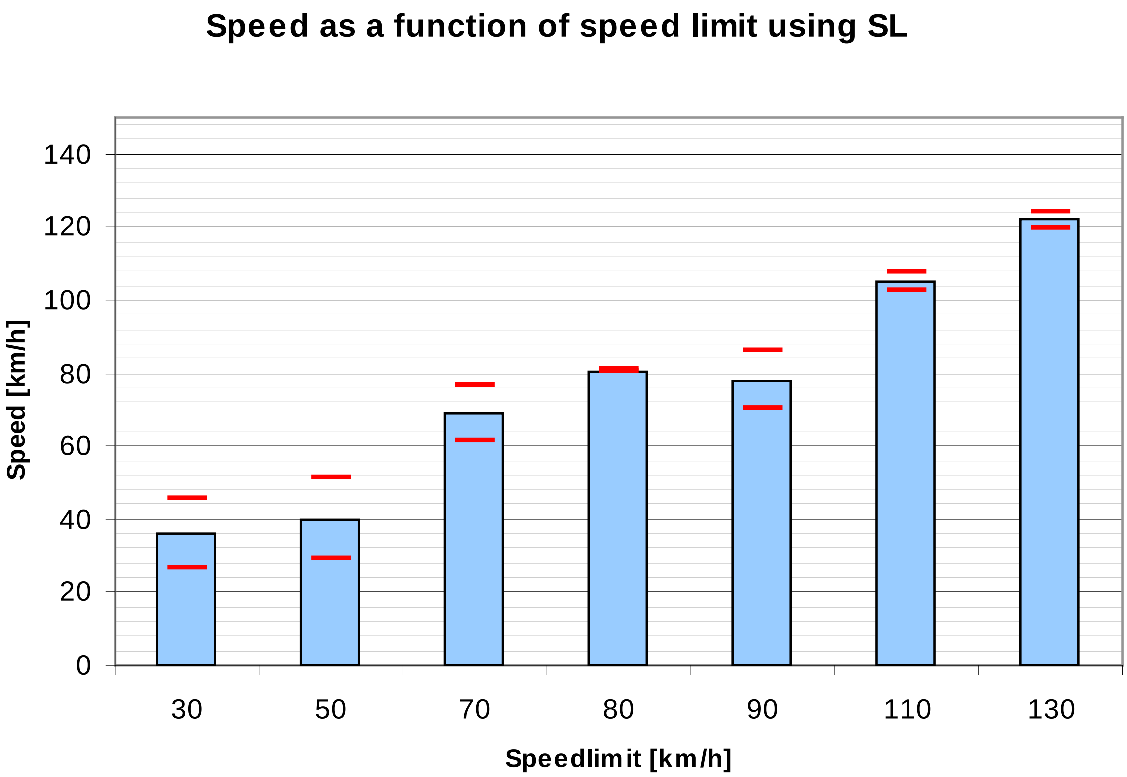


Figure 73: Intended speed vehicles using Speed Limit function

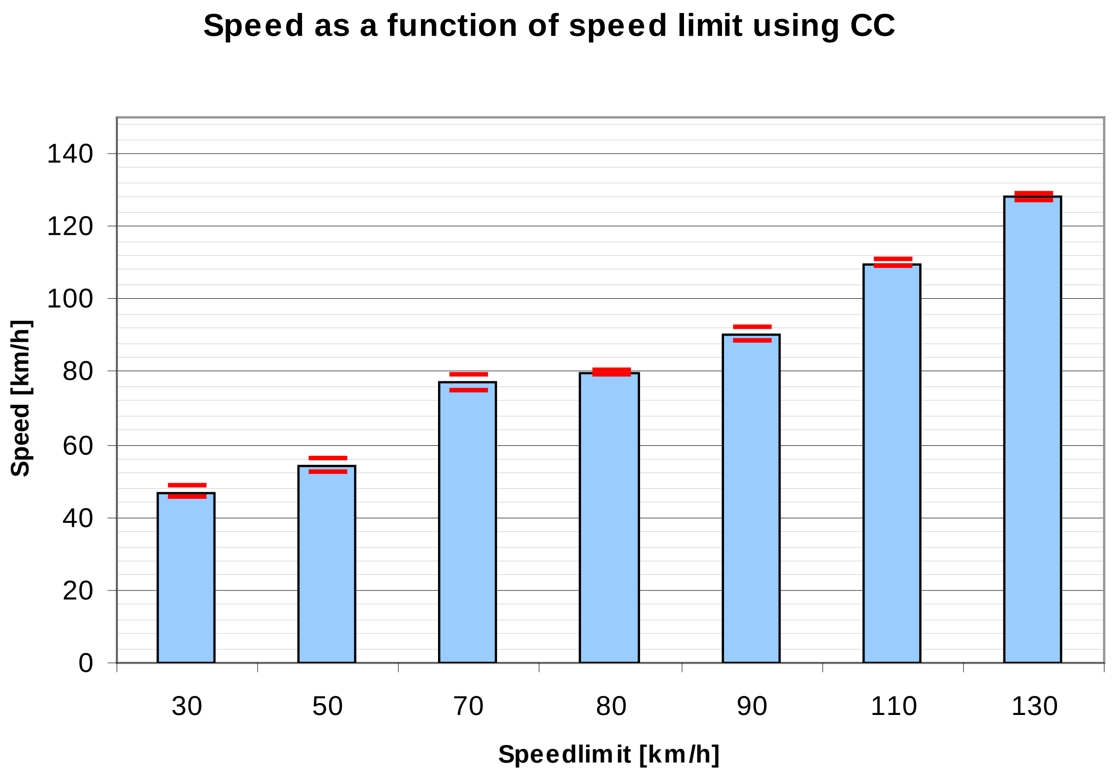


Figure 74: Intended speed vehicles using Cruise control function

Annex 3 Detailed simulation results ACC

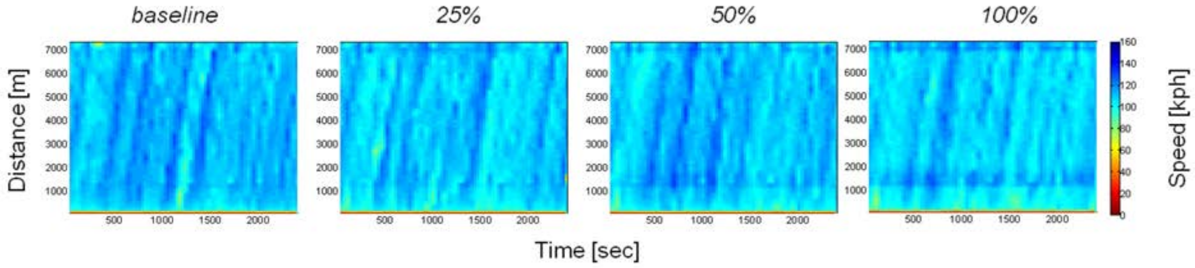


Figure 75: Simulated speed distribution (no speed limit, free flow)

All the scenarios in Figure 75 show free flow traffic. Qualitatively no significant differences can be seen between the scenarios, and this is reflected by the small differences in the indicators shown in Table 33 - Table 35 in the main text.

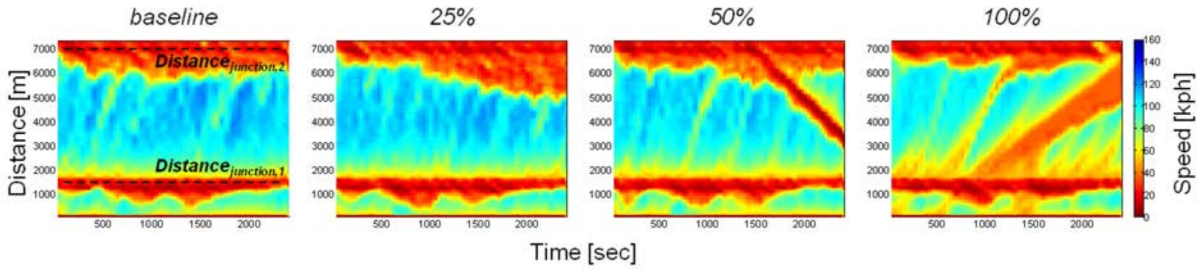


Figure 76: Simulated speed distribution (no speed limit, heavy traffic)

All the scenarios in Figure 76 show congestion at the two junctions. The congestion pattern is typical for a stationary bottleneck.
The 50% scenario shows a congestion wave travelling backwards. Judging from the picture, the wave speed is roughly 4 m/s or 14 km/h, which is in accordance with typical values found in the literature.
The 100% scenario in particular shows shock waves travelling forward. The downstream fronts are called forward forming shock waves, which are not very common. An uncommon feature of this shock wave is that the flow in the congested region has to be higher than in the downstream free flow region. Inside the shock wave regions the speeds are lower, but visual inspection of the simulation suggests that traffic is still in free flow. Possibly these regions are free flow regions with higher flow, higher density and lower speed than the surrounding traffic, and they could have been formed by stochastic variations in the traffic demand or outflow from the upstream junction. The speed of the wave is not the same for all waves and seems to be lower when the vehicle speeds inside the shock waves are lower (which is in accordance with the suggested explanation). Judging from the picture, the wave speed is at most about 10 m/s or 36 km/h.

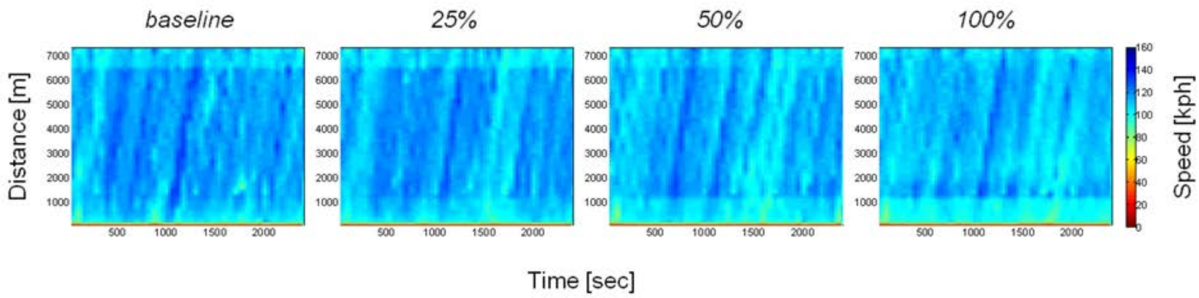


Figure 77: Simulated speed distribution (120 km/h speed limit, free flow)

All the scenarios in Figure 77 show free flow traffic. Qualitatively no significant differences can be seen between the scenarios, and this is reflected by the small differences in the indicators shown in Table 33 - Table 35 in the main text.

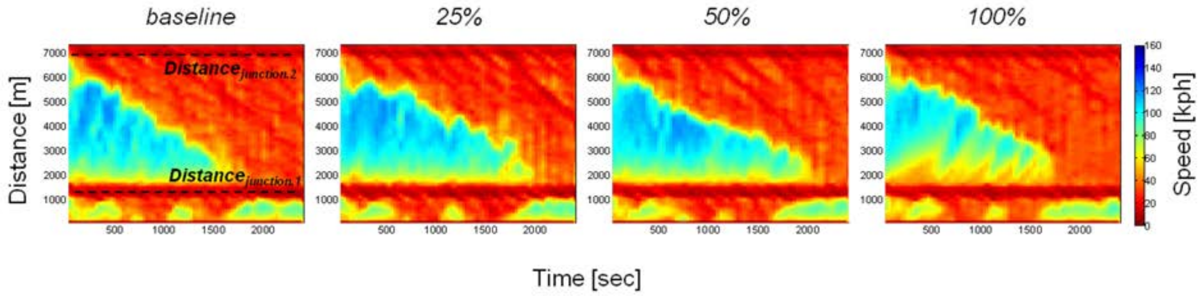


Figure 78: Simulated speed distribution (120 km/h speed limit, heavy traffic)

All the scenarios in Figure 78 show congestion at the two junctions. The congestion is significantly larger than in the heavy traffic, no speed limit scenario, for unknown reasons. In all scenarios there is a big congestion wave travelling backwards, is it with a rather jagged boundary. Judging from the picture, the wave speed is roughly 2.5-3 m/s or 9-11 km/h, which is somewhat low compared to typical values found in the literature.
In the 100% case some light forward moving shock waves can be seen.