Summary:

Advanced driver assistance systems – status and future potential

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For five types of advanced driver assistance systems (ADAS) – automatic cruise control (ACC) with forward collision warning (FCW) and automatic emergency brake (AEB), pedestrian/cyclist warning with AEB, lane departure warning (LDW), intelligent speed adaptation (ISA) and alcohol/drug ignition interlock – scenarios were developed describing the uptake of these systems until 2035. The scenarios are based on the results of a Delphi study among 41 vehicle safety experts from Nordic countries. It is estimated that the number of killed or seriously injured (KSI) in Norway can be reduced by up to 9% during the next 20 years in the most likely scenario and by up to 16% in the most optimistic scenario. In the long run, the effects could be improved most by increasing the uptake of the most restrictive systems, having the largest effects and the lowest predicted uptake. In the short run, the effects could also be increased by accelerating the increased uptake of informative ISA, ACC with FCW and AEB, and LDW.

ADAS and effects on KSI

ADAS included in the study were chosen based on their assumed potential to reduce the number of KSI in Norway (low penetration rates and large assumed effect). Table S.1 gives an overview of the ADAS included in the study and their assumed effects on the number of KSI in the respective target groups. The assumed effects are based on a review of studies that have investigated the effects of the systems on (preferably) crashes or alternatively on speed and driver behavior.

Combined effects of the ADAS are calculated in two variants, the first includes only the basic versions of each of the systems, the second includes additionally the more advanced versions:

Basic
- ACC with FCW and AEB
- Pedestrian warning with AEB
- Lane departure warning (LDW)
- Informative ISA
- Alcohol ignition interlock (alcolock)

Advanced
- ACC with FCW and AEB
- Pedestrian and cyclist warning with AEB and blind spot warning
- Autonomous lane keeping (ALK)
- Mandatory ISA
- Combined alcohol and drug ignition interlock

The “intermediate” versions pedestrian and cyclist warning with AEB (without blind spot detection) and overridable ISA are not included in the calculation of combined effects. Cooperative ACC (CACC) is not included because no effect estimate is available. Combined effects of the advanced versions presume that the deployment of the advanced and basic versions of the ADAS is equal to the deployment of the basic versions in the combined effects of the basic versions only.

TableS.1: ADAS and assumed effects on KSI.

System	Versions	Assumed effect on KSI
Adaptive cruise control with autonomous emergency brake	▪ **ACC with FCW and AEB:** Adaptive Cruise Control (ACC) with Forward Collision Warning (FCW) and Autonomous Emergency Brake (AEB): Warns the driver and brakes in case of imminent collision	**-5,3 %** KSI in passenger cars
	▪ **CACC:** Cooperative ACC, can send and receive information to / from other vehicles	(no effect estimate available)
Vulnerable road user warning with autonomous emergency brake	▪ **Pedestrian warning with AEB:** Warns the driver and can initiate emergency braking in case of imminent collision with pedestrian	**-7,0 %** KSI pedestrians
	▪ **Pedestrian and cyclist warning with AEB:** As above, warns and brakes for cyclists in addition to pedestrians	**-7,0 %** KSI pedestrians and cyclists
	▪ **Pedestrian and cyclist warning with AEB and blind spot detection:** As above, can additionally warn in case of cyclists approaching from behind	**-7,0 %** KSI pedestrians **-8,0 %** KSI cyclists
Lane departure warning / Automatic lane keeping	▪ **Lane departure warning (LDW):** Warns the driver in case of unintentional lane departure	**-6,4 %** KSI in passenger cars
	▪ **Automatic lane keeping (ALK):** Holds the car within the driving lane at speed above 60 km/h in specific situations (e.g. on rural roads with few junctions and continuous lane markings)	**-15,0 %** KSI in passenger cars
Intelligent speed adaptation	▪ **Informative ISA:** Intelligent Speed Adaptation (ISA), shows the current speed limit and warns the driver if the speed limit is exceeded	**Up to -7,5 %** KSI in crashes with passenger cars [1]
	▪ **Overridable ISA:** As above, increases additionally the counterforce of the gas pedal	**Up to -9,3 %** KSI in crashes with passenger cars [1]
	▪ **Mandatory ISA:** Makes it impossible to exceed the speed limit	**Up to -16,2 %** KSI in crashes with passenger cars [1]
Alcohol and drug ignition interlock	▪ **Alcohol ignition interlock (alcolock):** Prevents persons with illegal blood alcohol concentration from starting the engine	**Up to -11,1 %** KSI in crashes with passenger cars [2]
	▪ **Alcohol and drug ignition interlock (alco- and druglock):** As above, prevents additionally persons under the influence of drugs from starting the engine	**Up to -14,6 %** KSI in crashes with passenger cars [2]

[1] It is taken into account that ISA most likely is most effective among those who are the last to voluntarily buy a car with the system (non-linear relationship between deployment and effect).
[2] It is taken into account that the prevalence of drunk and drug driving is higher in older cars than in new cars.

Implementation scenarios: Delphi study

In order to develop scenarios of the future uptake of the five types of ADAS a Delphi study has been conducted among vehicle safety experts from Norway, Sweden, Denmark, and Finland. The Delphi study has been conducted as an online-survey in two rounds with questions about

- The uptake of each of the ADAS in 2015 as well as in five, ten, and fifteen years (providing none of the systems becomes mandatory)
- Whether any of the ADAS will become mandatory and, if so, in how many years.

In the second round information about the results from the first round (average and ± one standard deviation) as well as estimated proportions of all new cars sold with each of the systems in Norway in 2015 was presented along with the questions.

In order to recruit respondents, personal invitations to participate in the study were sent to 112 persons, 57 (51%) of which participated in the first round and 41 (37%) of which participated in both rounds. Additionally, nine persons participated in the second round only (these were recruited on a seminar about ADAS at AstaZero In Sweden where results from the first round were presented).

Return rates were about equal in each of the countries, but lower among persons from car industry (5% in the second round) and from public administration (34%) than among researchers (61%).

The most remarkable change in the results from the first to the second round was a decrease of dispersion for most of the questions. Consensus was still not achieved for many questions, especially those about the uptake of systems with medium uptake and in the more remote future.

Based on the results from the second round of the Delphi study three scenarios were developed that describe the uptake of each of the ADAS in 2015 and in the next 15 years:

- ***Pessimistic:*** 10^{th} percentile (10% of respondents assume lower uptake)
- ***Likely:*** Median (half of all respondents expect higher/lower uptake)
- ***Optimistic:*** 90^{th} percentile (10% of respondents assume larger uptake); if at least one third assumes that a system will become mandatory, the proportion of all new cars that is sold with the system is set to 100% from the year the system is expected to become mandatory on average.

Additionally to scenarios with larger uptake are defined:

- ***Optimistic 2:*** The same as optimistic, but the restrictive systems are assumed to become mandatory in five years (mandatory ISA, alcolock) or in ten years (alco- and druglock)
- ***100%:*** In this scenario it is assumed that all vehicle kilometers travelled are travelled by cars with ADAS. This scenario does not describe an expected (or realistic) development but shows the maximum effect that theoretically can be achieved by increasing the deployment of ADAS.

Figure S.1 shows the proportions of all new cars that are sold with each of the ADAS (only ADAS included in the calculation of combined effects) in the pessimistic, likely, and optimistic scenario.

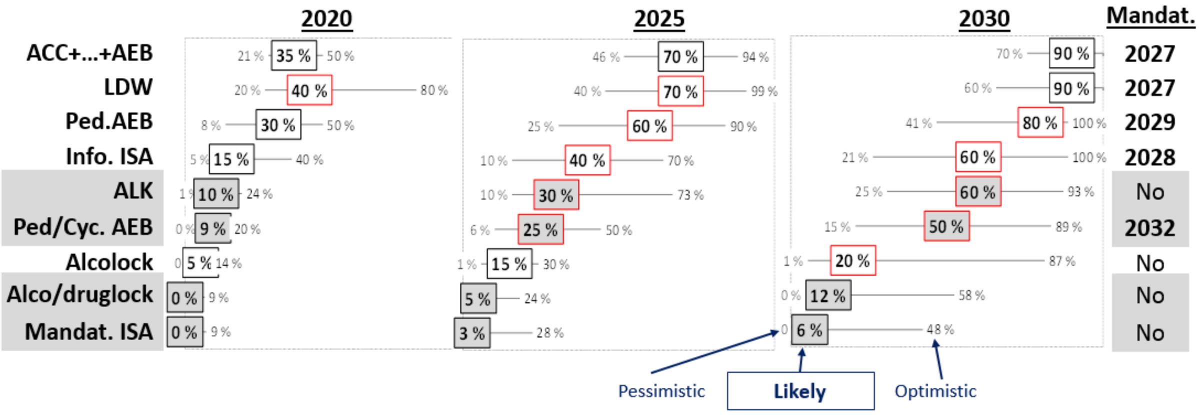

Figure S.1: Proportions of all new cars sold with each of the ADAS in the pessimistic, likely, and optimistic scenario.

The results show that the expected uptake is smaller for the more advanced and the more restrictive ADAS and that the relationship between the assumed effects on KSI and the expected uptake is about inversely proportional (more effective systems – smaller uptake).

Vehicle kilometers travelled with ADAS

The development of the proportion of all vehicle kilometers travelled with each of the ADAS is estimated for each of the three scenarios that describe the future uptake of the systems. Available information about an average passenger cars' life time and annual mileage, as well as decreasing annual mileage over time, are taken into account. Figure S.2 summarizes the proportions of all vehicle kilometers travelled with each of the ADAS in the pessimistic, likely, and optimistic scenario as well as in the scenario optimistic 2 (different from optimistic only for mandatory ISA, alcolock, and alco- and druglock).

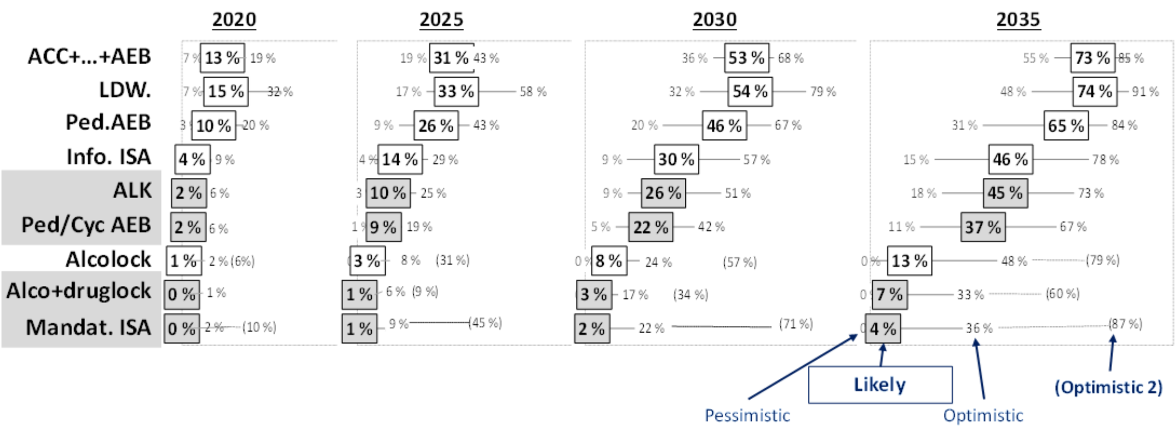

Figure S.2: Proportions of all vehicle kilometers travelled with each of the ADAS in the pessimistic, likely, optimistic, and optimistic 2 scenario.

The results show that deployment is expected to increase most for ACC with FCW and AEB as well as LDW, while the restrictive systems (mandatory ISA, alcolock and druglock) are not expected to achieve considerable deployment.

Effects on KSI

The effects on the development of the number of KSI of the increased uptake of the five types of ADAS are estimated for each of the scenarios that have been developed with the help of the Delphi study. The baseline scenario of the development of the number of KSI is the development from 1990 to 2014. The trend has been adjusted for the theoretically possible reduction of the number of KSI until 2024 (Elvik & Høye, 2015). The number of KSI in the baseline scenario is expected to decrease from 852 in 2015 to 488 in 2035.

Combined effects

Figure S.3 and S.4 show the expected reductions of the number of KSI (absolute and percentage changes, respectively) in the pessimistic, likely, and optimistic scenario as well as in the scenarios optimistic 2 and 100%.

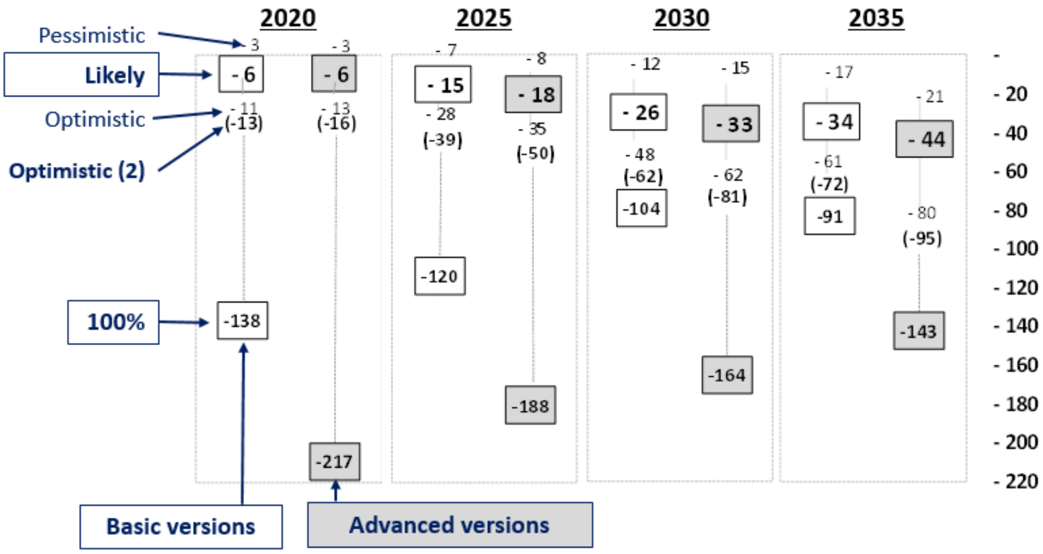

Figure S.3: Reductions of KSI (absolute changes) expected from increased deployment of ADAS (combined effects).

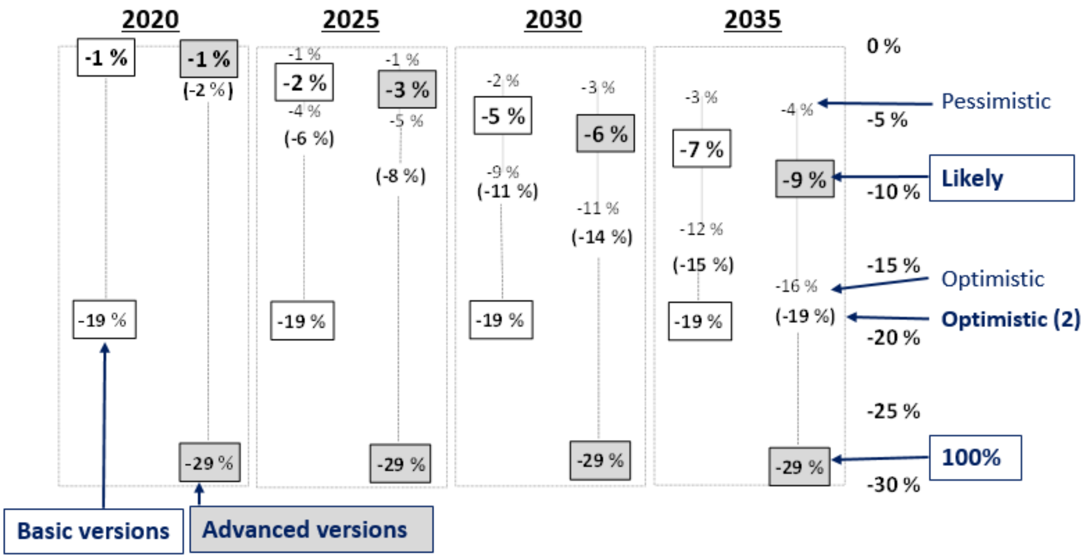

Figure S.4: Reductions of KSI (percentage changes) expected from increased deployment of ADAS (combined effects).

Figure S.3 and S.4 show that even in the scenario optimistic 2 with mandatory alcolock (basic versions) or mandatory ISA, alco- and druglock (advanced versions) the expected reduction of the number of KSI is considerable smaller than in the scenario with 100% deployment. This is partly due to the fact that it takes many years to achieve increasing deployment and partly that the restrictive systems are most effective among the last who start to use them.

Contributions of the individual ADAS

The expected decrease of the number of KSI with each of the ADAS in the likely and optimistic scenario as well as in the scenario optimistic 2 are shown in figure S.5. The pessimistic scenario is not included in figure S.5 because the effects are too small. Figure S.5 shows cumulative numbers, for example LDW is expected to reduce the number of KSI with three in the likely scenario and with additional three in the optimistic scenario (together six in the optimistic scenario).

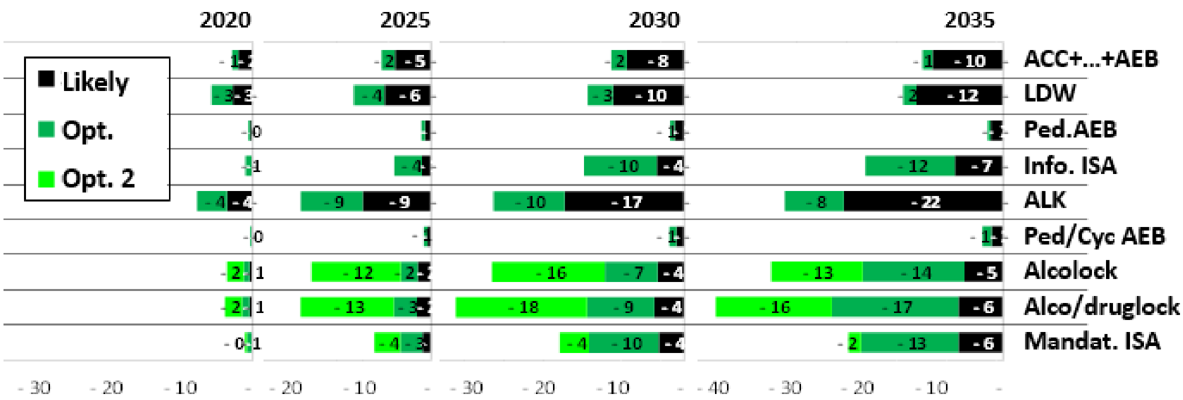

Figure S.5: Expected effects of increased deployment of ADAS on the number of KSI in the likely, optimistic and optimistic 2 scenario.

In the long run, those systems that are expected to bring about the greatest reductions of KSI in the *likely scenario* are (in descending order):

- Autonomous lane keeping (includes effects of increasing deployment of LDW)
- LDW
- ACC with FCW and AEB.

Those systems that are expected to have the greatest effects in the optimistic scenario are alcolock, drug ignition interlock, and ISA. In the pessimistic scenario these systems have no effect (the expected uptake is expect to remain zero, except alcolock wish is expected to be installed in 20% of all new cars in 15 years).

Pedestrian warning with AEB and pedestrian and cyclist warning with AEB and blind spot detection are expected to decrease the number of KSI only by small amounts. This is due to the relatively small effects of these systems on the total number of KSI (KSI pedestrians and cyclists are 12% of all KSI).

Potential benefits of accelerating the increase of the deployment of ADAS

In order to illustrate the potential benefits of accelerating the increase of the deployment of each of the ADAS figure S.6 shows the differences between the optimistic and optimistic 2 scenarios and the hypothetical scenario with 100% deployment. The red bars show the theoretically possible reductions of KSI when the deployment of the ADAS increases from the most optimistic scenario according to the Delphi study to 100%.

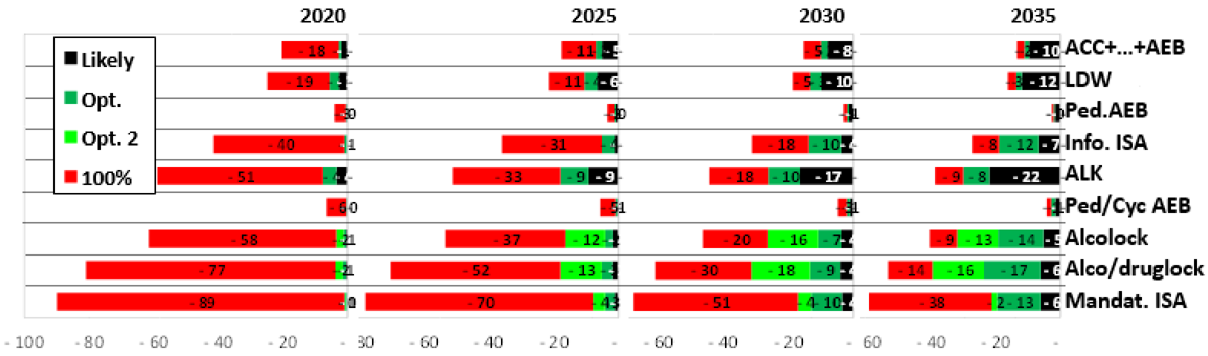

Figure S.6: Expected effects of increased deployment of ADAS on the number of KSI in the likely, optimistic and optimistic 2 scenario as well as at 100% deployment.

Restrictive systems: Increased deployment of mandatory ISA and alco- and druglock above the optimistic scenario would have the greatest effect on the number of KSI. This is due to the low expected deployment in the optimistic scenario and the large effects on KSI. For mandatory ISA it is additionally assumed that the effect will be greatest among the last who buy a car with the system. For alco- and druglock it is taken into account that there is more drunk and drug driving in older cars which delays the achievement of the maximum effect.

For ***alcolock*** one may also expect a relatively large effect of increasing deployment, but as for mandatory ISA the effect will be largest (both in total and per car) at 100% deployment.

Informative ISA and automatic lane keeping: The expected effects of these systems are almost as large as of alcolock. Increasing deployment of ALK will have a more constant effect on KSI and there will probably be less resistance against ALK that against the introduction of mandatory ISA.

Other systems: For the other systems there is less to gain in the long run of accelerating the increase of deployment. This is partly because relatively high deployment rates are expected for the systems and partly because the systems have smaller effects on KSI (especially vulnerable road user warning with AEB).

Reliability of the results

In this report scenarios have been developed that describe developments of cars and road traffic in future years. The scenarios are based on past developments and what is known or assumed now. It is assumed that no large "revolutions" are going to happen such as major changes of technical, organizational, juridical or other developments. Additionally, the calculations are based on a lot of assumptions about the future deployment of ADAS, their effects on the number of KSI and the development of the number of KSI, amongst others. Several of these assumptions and their implications for the results are discussed in the following.

Expected replacement of the car park: It is expected that the replacement of the car park is unchanged during the analysis period. If measures are taken to accelerate the replacement, the deployment of the ADAS will increase faster than assumed.

Assumed effects on KSI: The ADAS included in the study are still relatively new and there are few crash studies that have investigated their safety effects. Most effect estimates are therefore based on indirect measures of crash effects and must be regarded as relatively uncertain.

Baseline scenario: The baseline scenario of the development of the number of KSI is relevant for the expected absolute effects on the number of KSI. The expected percentage changes of KSI are not dependent on the baseline scenario, but the combined effects depend on the assumed proportions of KSI in the different target groups. If for example pedestrian and cyclist volumes, and thus the proportions of KSI pedestrians and cyclists, increase more than expected, vulnerable road user warning will have larger effects than expected.

Respondents in the Delphi study: The results indicate that there are some differences between respondents from different sectors. The results and the scenarios might therefore have been different if the distribution of sectors among the respondents had been different.

Scenario definitions: The scenarios are based on the results from the second round of the Delphi study. The likely scenario had been almost unchanged if the results from the first round had been used (the median values changed only to a small degree). However, had the results from the first round been used, the optimistic scenario would have been far more optimistic and the pessimistic scenario would have been still more pessimistic. This is because the dispersion of the results has decreased considerably in the second round. Whether or not the results have come closer to the "truth" is however unknown.

Moreover, since there were 41 respondents in the second round, the expected uptake of the ADAS in the optimistic and pessimistic scenario is highly dependent on the answers from only eight respondents (the 10% with the highest / lowest expected uptake).

Sources of error in the Delphi study: The aim of a Delphi study is to gather knowledge from experts that is only to a very little degree available from other sources. Even if the results therefore are about the closest one can come to a "best guess", there are several potential sources of error that may have affected the results. The most important ones are:

- ***Desirability bias:*** This is a tendency to regard desired outcomes as more likely than undesired outcomes. Such an effect may have affected the results in both rounds. Additionally the different backgrounds of the respondents are likely to have affected the results.
- ***Influence of the majority:*** The majority tends to influence most individuals, regardless of how "right" the majority is. Several studies show that a majority can influence how individuals answer even if the majority obviously is wrong, and that it can impair memories of own answers if these are not in accordance with the majority. Such effects are likely to have affected changes from the first to the second round. Possible explanations for the influence of the majority are a desire to "fit in", as well as a lack of other sources of information.

Both effects are generally largest in situations with high uncertainty. The influence of the majority does not depend on the majority being physically present. Both effects may therefore have affected the results of the present study. They may have resulted in

- Exaggerated expectations of the future uptake of ADAS
- Artificially low dispersion of the results in the second round, i.e. at least a part of the consensus that has developed may be due to the influence of the majority, instead of professional agreement and answers coming closer to the "truth".

In order to avoid or handle such sources of error future Delphi studies may take the following approaches:

- Respondents may be asked to state the degree of uncertainty (such statements do however not indicate the degree to which answers are represent the "truth").
- Respondents may be asked to state reasons for changes of answers from the first to the second round.
- Ask how important each of the system is rated.