Final report

Accident prevention systems for lorries

The results of a large-scale field operational test aimed at reducing accidents, improving safety and positively affecting traffic circulation




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Foreword

The Ministry of Transport (FileProof) instructed Connekt to undertake a large-scale field operational test of active driver assistance systems, so called accident prevention systems (APS), for lorries.

This very special large-scale study involved more than 2,400 lorries supplied by 123 companies. The study lasted 8 months and over a total of around 77 million kilometres driving behaviour was measured during normal daily driving on Dutch motorways. This fact generated both challenges and limitations as well as learning experiences about tackling such large-scale field operational trials and data processing. Learning experiences for which there is much (international) interest.

It is clear that accident prevention systems fitted perfectly in the daily operation of a haulier. The robust systems contribute positively to the feeling of driving safely and the professionalism with which the driver performs the driving task.

That there are also other effects on driving behaviour, traffic flow and safety than expected in literature or by experts is both surprising and, on the other hand, possibly a key influence on the very heavy traffic in the Netherlands. More reason, therefore, to emphasise the driving task in the future along with the relationship between the surroundings and the driver, of which there appears to be very little knowledge.

Following this field study the number of accident prevention systems in the Dutch market has virtually doubled and more than 120 companies have had experience of them. A significant sep forward.

Almost every participating company has indicated that it will continue to use accident prevention systems after the study. At this moment (September 2009) seven companies have already stated that they will extend the use of accident prevention systems to lorries not currently equipped with them.

Connekt thanks everyone that contributed to this very special field study, this report and the their constructiveness in this study: members of the Core Team, the Scientific Sounding Board, the Advisory Group in which all transport sectors were represented, the SWOV and, of course, all participating companies.

Nico Anten
Managing Director, Connekt/ITS Netherlands

Summary

In 2008 and 2009 on the instructions of the Ministry of Transport (FileProof), Connekt undertook a large-scale field operational test of active driver assistance systems, so called accident prevention systems (APS), for lorries. Over eight months five different accident prevention systems and a registration system were tested on Dutch motorways.

Large-scale field operational test

It is not an easy task to measure directly the effects of an APS on the number of accidents or on traffic flow. Even a large-scale study involving many hundreds or thousands of lorries is inadequate. However, the effects of an APS on driving behaviour for a large number of lorries over an extended period can be measured in a large-scale field operational test. Using generally available knowledge, those effects can then be translated into effects on traffic flow and safety. Before such a large-scale test can be carried out, it is necessary to establish whether the selected systems function as intended.

Since relatively few systems are in operation in the Netherlands, such a test will have significant influence on the experiences with and acceptance of these systems by hauliers and drivers.

Research questions

The study was therefore structured along the following lines:

a. How effective are the systems studied? Do they correctly detect the (hazardous) situation? Do they warn the driver properly and in time? And if active systems intervene, do they do so properly?
b. What is the effect on traffic safety if APS are used by a (large) portion of lorries driving on the Dutch road network?
c. What is the effect on traffic flow if APS are used by a (large) portion of lorries driving on the Dutch road network?
d. Can the government act as stimulator to encourage use of APS?

Accident prevention systems

The accident prevention systems selected for the field study are:

Adaptive Cruise Control (ACC)

- ACC maintains the preset speed and adapts this to maintain a present headway distance if the preceding vehicle is slower or other road user merges with the lane.

Lane Departure Warning Assist (LDWA)

- LDWA warns the driver if he threatens to breach the lane marking (without using his indicator).

Forward Collision Warning/Headway Monitoring & Warning (FCW/HMW)

- FCW warns the driver if frontal collision is imminent; HMW warns the driver in the event of the headway distance being too short. These systems were tested as integrated parts of a single device.

Directional Control/Roll over Control (DC/ROC)

- DC/ROC detects situations in which the steerability of a vehicle is endangered and corrects this by a brake intervention on one of the wheels.

Summary

Black Box Feed Back (BBFB)

- BBFB gives the driver feedback about the driving performance compared with others in terms of:
  - Changes in speed (consistent or inconsistent driving behaviour);
  - Harsh braking (significant delay);
  - Use of cruise control;
  - Fuel consumption.

Inventory

In the autumn of 2007 an inventory was made of the population of APS (excluding BBFB) in the Netherlands at that moment in time. It came to a total of around 1,500 systems, 90% of which were the Directional Control type, an anti-rollover system much used in container lorries transporting hazardous goods. To carry out a representative field operational test of adequate scale, extra hauliers had to be found in order to have a number of different accident prevention systems built in to new lorries. The total number of systems thus increased by around 1,600.

Functional effectiveness of the systems studied

The abovementioned accident prevention systems were firstly tested on a test track to answer the initial question relating to the functional effectiveness of the systems. The conclusion of the test track tests was that the active driver assistance systems (subdivided into intervening, informing and feedback systems) were functionally effective. They do what they have to do: detect reliably, warn the driver and intervene where necessary.

Field operational test

For the Field Operational Test (FOT) around 2,400 lorries were equipped with data registration systems to enable driving behaviour to be monitored and measured, and these systems were divided into different groups, including a reference group, depending on the type of APS. The reference group had a 'silent' system, which means that while the driver was not informed data were measured. The drivers in the reference group knew they were part of the test. The lorries were monitored for eight months on the Dutch motorway network over a total distance of about 77 million kilometres. Around 300 lorries generated no data at one time or another due to various reasons, such as technical problems or stoppages. Not all lorries were monitored for eight months. The systems were not removed after the measurements but remain the property of the participating companies.

Measurements

The field study measurements reveal that driver assistance systems or accident prevention systems have an effect on how the driver performs his driving task. The systems reduce the risks of accidents to a greater or lesser degree, with the key indicators being:

- Longer headway times with the use of ACC and FCW/HMW;
- Lower rollover risks with the use of DC and ROC;
- Driving less close to the preceding vehicle with the use of ACC;
- Fewer unintended lane breaching with the use of LDWA;
- More consistent driving with the use of BBFB.

Driver questionnaires confirm this picture.

Summary

A second result of the measurements is that just five accidents (with just material damage) were registered during the measuring period and all five were in the reference group whereby the driver was not assisted by an APS. That is clearly lower than the 16 - 19 accidents for the entire field operational test (or 6 for the control group) that would on average be expected based on the kilometres driven or the size of the group. This low number of registered accidents is not predicted based on the basis of the measurements of the effects of APS in the field operational test. The fact is that those effects are not significant enough to explain such a difference. In order to gain a better explanation it is recommended that this group is monitored for a longer period in respect of the number of accidents caused.

Effect on traffic safety

The literature contains reports in which quantitative verdicts are made about the increase in traffic safety when APS are applied on a large scale. The quality of the models and causal links, however, fall short and thus the verdicts need to be treated with a certain degree of caution. In other words, the second research question cannot be answered by models and links to literature. A model has thus been developed to enable a prediction to be made about the effect on traffic safety, using data from the field study, despite the limitations. Those estimates indicate that the active intervention systems ACC and DC/ROC can be expected to have more impact than other systems.

Effect on traffic flow

The effect of APS on the traffic flow was predicted using a traffic flow model composed on the basis of literature and expert meetings. The direct effect on traffic flow is minor since hardly any significant deviations of the average speed and headway time could be demonstrated between vehicles containing active accident prevention systems and the reference group. The indirect effect by avoiding accidents will be present, however, but is difficult to quantify. The magnitude will always be limited given the very modest share (approx. 1.6%) of the lost vehicle hours caused by accidents involving lorries.

Driver experiences

Consultation among players in the market and driver questionnaires reveal that these systems are valued by them in practice, provided that they are set up in harmony with practice (prevention of excessive warning). The systems contribute positively to the perception of safe driving and the professionalism of the performance by the driver of his driving task. ACC is particularly experienced as positive and the robustness of all systems considered more than adequate.

Virtually all the participating companies have indicated a desire to continue using these systems after the end of the test. Seven companies have indicated that they will extend use of APS to lorries not currently equipped with the system.

Summary

Conclusions

Indications are strong that people drive very close behind one another on Dutch motorways (0.5 to 1.5 s at 80 km/u). Because maintaining distance to the preceding vehicle in busy traffic is a key component of the driving task, the measurements support the theory that:

- ACC can directly alleviate the task of maintaining a safe distance and FCW/HMW can support this task;
- DC and ROC actively prevent critical limits from being exceeded;
- LDWA helps prevent unintended lane breaches, provided the set-up is such that the attention of the driver is not distracted from his main driving task;
- BBFB ensures a more consistent driving behaviour provided the social embedding of the feedback is properly catered for.

Recommendations

It is recommended that both the group using APS and the reference group are monitored for a longer period and to continue registering the number of accidents to see whether the number of accidents remains as low as measured for a longer period.

It is recommended to continue providing incentives to use APS now that a critical mass has been achieved and positive experience gained. The amount of data collected in the FOT is huge. It is recommended to make the dataset available to third parties for further analysis.

In subsequent research it is recommended to delve deeper into the relationship between engineering systems and behaviour as well as driver reaction. Literature still provides too little insight into how driver support systems can lead to modified behaviour.

1. Introduction

1.1 Background

Freight traffic in 2007 accounted for 15% of all traffic on Dutch motorways and in the same percentage of fatalities on Dutch motorways freight traffic was involved. Freight traffic accidents often have a disruptive effect on traffic flow on the road network and generate long traffic jams [15].

On Dutch motorways in 2007 some 1.1 million vehicle hours were lost due to lorry accidents. This figure amounts to approx. 1.6% of the total number of vehicle hours lost on the Dutch arterial roads.

In a study by DHV [31] a different traffic flow gauge was used, namely the traffic jam severity (time x length); 1.45% of the entire traffic jam severity between 2000 and 2005 was attributable to lorry accidents.

Both the absolute and relative size of freight traffic are expected to continue rising until 2020. As it does so, the Ministry of Transport and the transport sector will face a challenge, namely how to enable efficient road transport, improve safety and boost traffic flow. Use of modern technology, like driver support systems or accident prevention systems (APS) can assist here.

For this reason, the Ministry of Transport instructed Connekt/ITS Netherlands to conduct a broadly structured field operational test to measure the effects of accident prevention systems in practice. The aim of the field operational test was to gain better insight into the extent to which these systems can aid traffic safety and traffic flow on the Dutch road network. To date these systems have only been analysed to a limited degree.

The aim of the field operational test was translated during the operation into four research questions that are considered in chapter 2 ‘Research structure’.

The field operational test would test five separate systems intended to prevent accidents involving lorries. The systems were built into a large number of lorries. A registration system recorded driver behaviour. The effects of these sophisticated systems were measured over an eight-month period.

The ‘Accident prevention systems for lorries’ project is one of more than 60 projects run by ‘Tackling Traffic Jams in the Short Term’ (FileProof) that the Ministry has conducted with a view to reducing the number of traffic jams in the period 2006 - 2009.

In the first quarter of 2006, at the Minister’s request, Ministry staff considered new options for reducing traffic jams using relatively simple means and in the short term. Numerous creative ideas were also proposed by central government, trade and industry, interest groups and knowledge institutes. In total, the feasibility of almost 3,000 ideas was assessed by external experts. This resulted in a Ministry-wide programme involving some 60 projects taking a short-term approach to resolving traffic jams. The project ‘Accident prevention systems for lorries’ was one of these 60 projects. The category to which it belongs is entitled ‘Projects to reduce incidental traffic jams’.

1. Introduction

1.2 Organisation

The client of the APS project was the Ministry of Transport (FileProof), with DG Mobility delegated as customer and supervisor.

FileProof requested Connekt to conduct this project. Connekt is a public-private network consisting of govern-ment bodies, private companies and knowledge institutes. It connects parties, enabling them to work in mutual trust to achieve the enduring improvement of mobility in the Netherlands. The project management was performed by Connekt.

As main contractor appointed by the Ministry of Trans-port (FileProof), Connekt outsourced some of the project performance to two parties selected by the Ministry: TNO and Buck Consultants International (BCI). TNO is a Dutch research institute that applies scientific knowledge with the aim of strengthening the innovative power of industry and govern-ment. BCI is an independent international research and consultancy agency that researches, advises and conducts project management in the fields of economics, space, infrastructure, property and logistics.

Together, representatives of the Ministry of Transport, Connekt, TNO and Buck Consultants International formed the Core Team.

The Dutch national road safety research institute (SWOV) made its traffic safety knowledge available to further sub-stantiate the intrinsic background in this field.

The management of Connekt discussed a progress report each quarter with the FileProof organisation.

In addition to the Core Team, which was responsible for the result, a Scientific Sounding Board group was set up to safeguard the quality of the research. This group consisted of SWOV, the University of Twente, TU Delft, RWS-DVS, FileProof and Askary. Furthermore, a number of coordina-ting organisations were involved in the field operational test in the role of Advisory group (TLN, BOVAG, KNV, EVO, VERN and the RAI Association).

In addition, the market was closely involved in the project, for example:

- Suppliers of driver assistance systems and measuring equipment: Clifford Electronics in cooperation with Octo Telematics and CarrierWeb;
- A team of 75 specialists and dealers able to fit factory-fit and retrofit systems;
- Lorry suppliers in the Netherlands: DAF, Volvo, Scania, MAN, Mercedes, Iveco and Renault (united under the RAI Association);
- Dozens of dealers in a dealer network (united under BOVAG);
- 2,400 vehicles owned by 123 participating tranship-ment companies and hauliers.

2. Research set-up

2.1 General set-up and report structure

The aim of the APS project was to develop understanding of the extent to which accident prevention systems (APS), also known as driver assistance systems, when used on a large scale can contribute to traffic safety and traffic flow on Dutch roads. This was to be achieved by means of a wide-ranging Field Operational Test or FOT.

It was not possible to measure directly the effects of an APS on the number of accidents or the traffic flow. Even a large-scale test involving many hundreds if not thousands of lorries would be too small to achieve this. What a large-scale test does enable, however, is the measurement of the effects of an APS on the driving behaviour of a large number of lorries over a longer period. One would expect it to be possible, with the aid of generally available knowledge, to translate these effects into effects on traffic flow and safety.

In this report, the word 'effectiveness' is a broad concept. For this reason, a subtle distinction has been introduced into this study. The APS that were tested were required to correctly detect the (hazardous) situation, to alert the driver correctly and in time and/or to intervene themselves in the correct manner. The extent to which a system satisfies this requirement is indicative of its functional effectiveness; the system does what it is supposed to do.

For systems that inform, the driver's behaviour (and reaction) following a system alert is of importance. If a driver (hypothetically) ignores a system's reports repeatedly, even a perfectly functionally effective system will not be able to contribute to the traffic safety or traffic flow. We refer to the extent to which the system brings about an adaptation (either momentary or permanent) in the driver's behaviour (and reaction) as the degree of 'behavioural effectiveness'.

The ultimate effectiveness of a system with regard to safety and traffic flow will depend, therefore, on (1) the system's functional effectiveness, (2) the system's behavioural effectiveness, and (3) any other determinants. In this test it was not possible to measure this behavioural effectiveness.

In this test we have limited ourselves to measuring the vehicle behaviour.

The research was structured around the following primary questions.

> Research question 1:
> How effective are the systems studied? Do they detect the (hazardous) situation correctly?
> Do they warn the driver correctly and in time?
> And if the intervening systems are active ones, do they do this in the correct manner?

How the functional operation of the systems was tested on a test circuit is described in chapter 3.

A large number of lorries was equipped with various accident prevention systems. In addition a reference group equipped with a 'silent' system. In the reference group, the drivers were not informed by the system but were measured. Subsequently, the lorries were fitted with data registration systems and tracked over a longer period.

1 Many aspects influence driving behaviour. Therefore it is unclear how the behavioural effectiveness of a warning signal should be monitored.

2. Research set-up

How the groups were compiled and what was measured by the data registration systems is presented in chapter 4.

> Research question 2:
> What is the effect on traffic safety if APS is used by a (large) proportion of the lorries driving on the Dutch road system?

> Research question 3:
> What is the effect on traffic flow if APS is used by a (large) proportion of the lorries driving on the Dutch road system?

With the aid of models taken from the literature, the measured effects of an APS were translated into predictions about the change in traffic safety and traffic flow (presuming large-scale application).

The effects on traffic safety are discussed in chapter 5 and in chapter 6, the effects on traffic flow.

Since relatively few accident prevention systems were operational in the Netherlands at the start of the test in 2008, the FOT will have had considerable influence on the hauliers' and drivers' experience of these systems and their acceptance of them. For this reason, a fourth question was added in consultation with the client.

> Research question 4:
> Can the government adopt a role that encourages the use of APS?

The results of the driver surveys and the interviews with the participating companies are presented in chapter 7.

From the research point of view, a field operational test is by definition not ideal since field conditions are often uncontrollable.

Discussed in chapter 8 are the results and the observed phenomena.

Chapter 9 contains the conclusions.

2.2 Set-up of the Field Operational Test

An earlier study [11] examined which accident prevention systems could be used in a large-scale field operational test. Some of these systems can be incorporated in existing lorries after they have left the factory (retrofit), others can be factory-fitted only. This means the system must be supplied as part of the order for a new lorry submitted to the manufacturer, also known as an Original Equipment Manufacturer (OEMs).

Further aspects of the set-up concerning the size of the random survey and registration methodology are presented in [30]. In order for the measurement data in a field operational test to support statistically sound judgements, it is necessary that each group of accident prevention systems has sufficient lorries. The smaller the possible effect, the larger the group must be to enable reliable judgements.

An ideal size is 400 lorries per group, but some sound judgements can also be made with considerably lower numbers (more than 50).

2. Research set-up

In 2007 a poll was carried out among suppliers of systems that can be retrofitted and manufacturers of systems that can be factory-fitted to establish the then current population of APS (excluding the so-called Black Box Feedback system) in the Netherlands.

The total number of systems was roughly 1,500, of which 90% were of the type Directional Control, an anti-rollover system much used in tankers carrying hazardous goods. According to indications given by the OEMs, the picture for factory-fitted systems is no different in the rest of the EU. A significant motive among tanker hauliers is the requirement in Germany for certain types of tanker transport to carry an APS.

However, that number was too small to provide the basis for a field operational test.

Three issues determined the term of the field operational test:

- The delivery of factory-fitted systems in new lorries, the incorporation and testing of the retrofit systems;
- The construction, testing and operation of the data registration systems on this scale;
- The validation and processing of the measurement data obtained with the systems.

This led to the choice to:

- Test four types of commercially standard and easily obtainable APS in the test, supplemented with a feedback system that may also have an effect on traffic safety and traffic flow.
- Use existing data registration systems.

Together with suppliers, manufacturers and hauliers a population ultimately totalling more than 2,400 lorries was compiled for inclusion in the test. This is approx. 1% of the total population of lorries in the Netherlands.

The APS-test project team made no small demands upon the hauliers and their drivers. For example, the retrofitting in a garage took on average four hours, vehicles were sometimes recalled for repair, the software had to be configured, and the drivers were also tracked and questioned about the use of the systems. To compensate for the disruption to daily business operations, the systems were retrofitted free of charge as part of the test. Following the conclusion of the test, the data registration systems became the property of the haulage companies.

2. Research set-up

The following types of systems were selected for the field operational test:

FCW/HMW (Forward Collision Warning/Headway Monitoring and Warning, see Figure 1).
The system consists of a camera and processing unit, a display and speakers. The warning is issued both as a sound and as an image. It is presented in phases.

FCW issues a warning if the headway time (Time To Collision/TTC) becomes too small. The TTC is defined as the distance to the vehicle in front divided by the difference in speed. The standard setting is 2.7 sec.

HMW issues an alert as soon as the vehicle approaches too closely the vehicle in front. The warnings issued by HMW come in four steps:

- Exceeding 2.5 seconds — grey
- Between 1.1 and 2.5 seconds — green
- Between 0.7 and 1.1 seconds — orange
- Less than 0.7 seconds — red

The system works at any vehicle speed. The settings shown above were used in both the test track tests and the field operational test. In the field operational test the driver could disengage neither system. The system can be retrofitted.

LDWA (Lane Departure Warning Assist, see Figure 2).
This system similarly consists of a camera and processing unit, a display and speakers. LDWA can be an additional functionality of an FCW/HMW system. In this field operational test the Mobileye system produced by Clifford Electronics was chosen as the LDWA system and/or FCW/HMW system to be retrofitted. This system alerts the driver when an unintentional lane departure (without use of the indicator) is imminent.

Figure 1: Forward Collision Warning/Headway Monitoring and Warning - Source: Clifford Electronics

Figure 2: Lane Departure Warning Assist

2. Research set-up

The driver is informed by a 'rumble strip' noise on the side on which the line crossing is imminent as well as by a visual warning. Imminence is established using a Time To Line Crossing criterion that, using a camera, determines how much time remains before a line crossing occurs. A system requirement is that sufficient good line markings are visible on the road.

The retrofit LDWA system produced by Mobileye has the following characteristic settings:

- Becomes active at speeds in excess of 55 km/hr, and becomes inactive once more if the speed drops below 50 km/hr.
- Warning for a Time to Line Crossing (TTLC) of 0.5 seconds.
- After a warning, the next warning will be given only if the vehicle has since returned to its lane and the distance to the road line is more than 0,3 m (to avoid overuse of the alarm).
- No warning if indicators/alarm lights are operational.

Like the other systems, this system could not be disengaged by the driver in this test. The system can be retrofitted.

ACC (Adaptive Cruise Control, see Figure 3).
Like a cruise control system, ACC maintains the vehicle at a speed chosen by the driver. In addition, the system keeps an eye on the vehicle in front using a radar or similar sensor. The headway time to the vehicle in front is maintained automatically at a safe level; the ACC can accommodate this by reducing the speed of its own vehicle.

The system is available factory-fitted only and for this test the settings were not adjusted. In the test the driver was able to adjust the setting as required and to disengage the system.

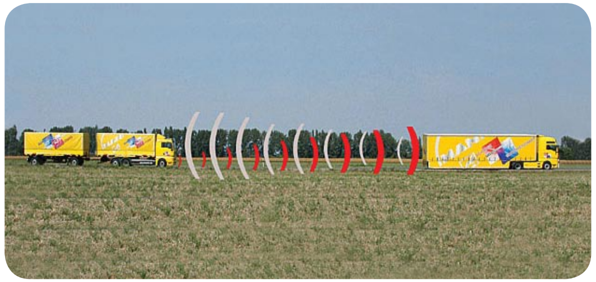

Figure 3: A box lorry with ACC following a preceding vehicle - Source: MAN Trucks

DC/ROC (Directional Control/Roll Over Control, see Figure 4). DC is a system that autonomously takes action if the vehicle no longer responds well to steering movements or starts to slip. Normally this is achieved by applying the brakes selectively to some of the vehicle's wheels, something the driver could never do. DC can be easily combined with Roll Over Control (ROC), which has a similar operating principle and which attempts to prevent the vehicle from rolling over. The system is available factory-fitted only and cannot be switched off.

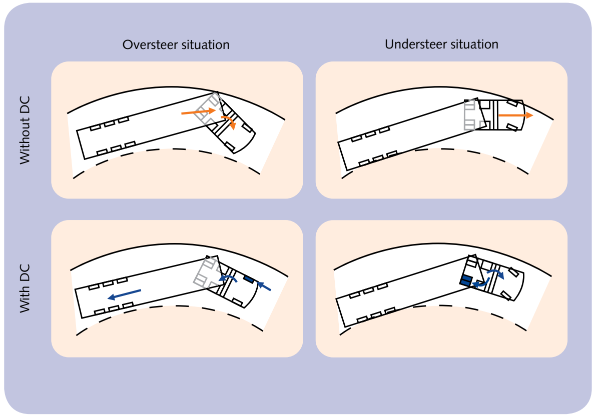

Figure 4: DC brake intervention in oversteer and understeer situations

2. Research set-up

BBFB

The Black Box FeedBack system (BBFB) is a feedback system related to driving behaviour. It is produced by CarrierWeb. Information about the driver's driving behaviour is retrieved from the standard-fit interfaces in lorries by the Motor Management System (Black Box). The information is fed back to the driver and the fleet manager.

Figure 5 shows an example of the information received by the driver from the BBFB system.

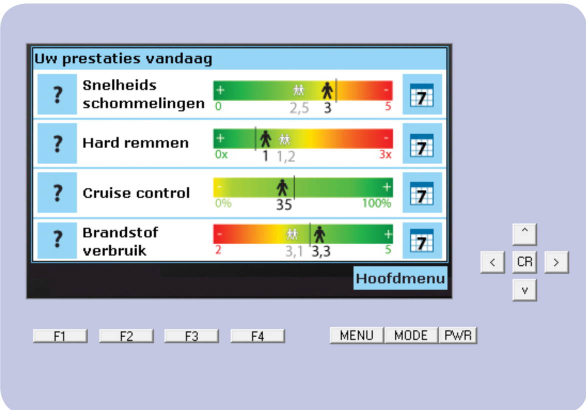

Figure 5: Information in the BBFB screen - Source: CarrierWeb

The information received by the driver includes:

- Changes in speed (constant driving behaviour or not);
- Harsh braking actions (considerable delay);
- Use of the cruise control;
- Fuel consumption.

For each variable the driver receives information about his results for the day and the past weeks. Moreover, the results can be compared with those of the driver's own long-term average and with colleagues' results.

2.3 Effectiveness of the systems studied (research question 1)

The effectiveness of the systems was determined in a two-part process:

The first part involved determining the functional effectiveness of the systems:

Do they detect the (hazardous) situation correctly? Do they warn the driver correctly and in time? And if the systems intervening are active ones, do they do this in the correct manner?

The behaviour of the systems was tested systematically on a closed test circuit with the aid of a refined and accurate measuring system. This measuring system was much more precise and extensive than those that can be used in a large field operational test (FOT) to track lorries. This measurement provided detailed information about the behaviour of the systems.

The second part consisted of the field operational test in which lorries in the FOT were tracked over a longer period of eight months. The behaviour of the systems and the

2. Research set-up

vehicle were measured and collected as part of day-to-day activities (albeit with a less refined measuring method than on the test circuit).

In the test circuit the testing of behavioural effectiveness (does the driver adapt his driving behaviour as a consequence of the systems) was not measured. In the field operational test a derivative of this was measured, namely how the vehicle behaved.

As the effect of DC/ROC in the FOT could be measured only to a limited extent, an extra loan test was set up specifically for this group. A lorry equipped with these APS and with the full range of test circuit measuring instrumentation was loaned over several weeks to various hauliers.

2.4 Effect on traffic safety (research question 2)

The effect on traffic safety of the large-scale use of an APS can be derived from four sub-research studies:

- Literature study of the relationship between APS and traffic safety;
- Analysis of the accidents in the Netherlands involving lorries: on which type of accident would such a system be able to have a preventive effect/or be able to reduce the chance of and extent of the bodily injury?
- Analysis of the measurement results obtained in the FOT;
- Development of a conceptual and quantitative model with which a prediction can be made about the effects on traffic safety, assuming the measurement results obtained in the FOT.

2.5 Effect on traffic flow (research question 3)

The effect on traffic flow of the large-scale use of APS can be derived from four sub-research studies:

- Literature study of the relationship between APS and traffic flow;
- Analysis of the traffic flow effects related to APS in lorries;
- Analysis of the measurement results obtained in the FOT;
- Development of a conceptual and quantitative model with which a prediction can be made about the effects on traffic flow, assuming the measurement results obtained in the FOT.

2.6 Encouraging the use of APS (research question 4)

As an effect of the large field operational test, a large number of drivers and hauliers gained field experience of using APS.

Their experience is determining whether and how the government can continue to encourage the wider use of APS in its role as ‘encouraging party’. In order to collect these experiences and to test the measurement results of the field operational test, driver surveys and company interviews were held at the end of the FOT.

3. Study of the functional effectiveness of the systems examined

3.1 Test track testing

In the period October 2008 - January 2009 five test sessions were carried out at the ATP test site in Papenburg (Germany) and on the test track in Sint Oedenrode (the Netherlands). In all cases, the lorry used was equipped with the full range of measuring instrumentation.

To establish the operation of the selected APS (excluding BBFB), test manoeuvres were performed with a loaded articulated lorry under controlled conditions [6, 7]. For each of the four types of APS, specific tests were conducted to establish the system's operation.

The experiments used were tailored specifically to the APS tested:

- ROC & DC: stationary circle test, spiral test, braking in the bend, lane changing, stepped steering movements, roundabout approach;
- ACC: approaching moving preceding vehicle;
- FCW: approaching moving preceding vehicle, approaching stationary vehicle;
- LDW: crossing lane lines;

The various systems and their results are discussed below.

ROC&DC

ROC is a system mounted on a trailer; DC is a system mounted on the tractor unit. Both systems respond to lateral acceleration and intervene by braking one or more wheels.

In this way, the systems attempt to correct hazardous dynamic behaviour such as (the likelihood of) the vehicle rolling or slipping.

The functionality of ROC & DC was determined by conducting measurements with the test vehicle. In the reference situation the system was not operational. During the relevant measurement, the system was again operational.

Figure 6: Example of test vehicle - Source: TNO

To prevent the vehicle from rolling during the reference test, the trailer was equipped with lateral supports of the type shown in Figure 6.

As an example of a test, a circle test is shown in which the lorry is driven at an increasing speed in a circle with a constant radius. The actual results are shown in Figure 7 and figure 8.

The stationary circle test was performed by slowly increasing the speed while driving in a circle with a radius of 43 metres. The test was performed until the speed at which the DC/ROC active system intervened was approached or in the case without active APS, the rollover limit (point at which vehicle starts to roll). Shown in figures 7 and 8 are the most important variables, the driving speed vx and the lateral acceleration ay for the various configurations.

Figure 7 shows clearly the relationship between driving speed and lateral acceleration. To maintain the intended circle path, lateral acceleration must increase as speed increases.

3. Study of the functional effectiveness of the systems examined

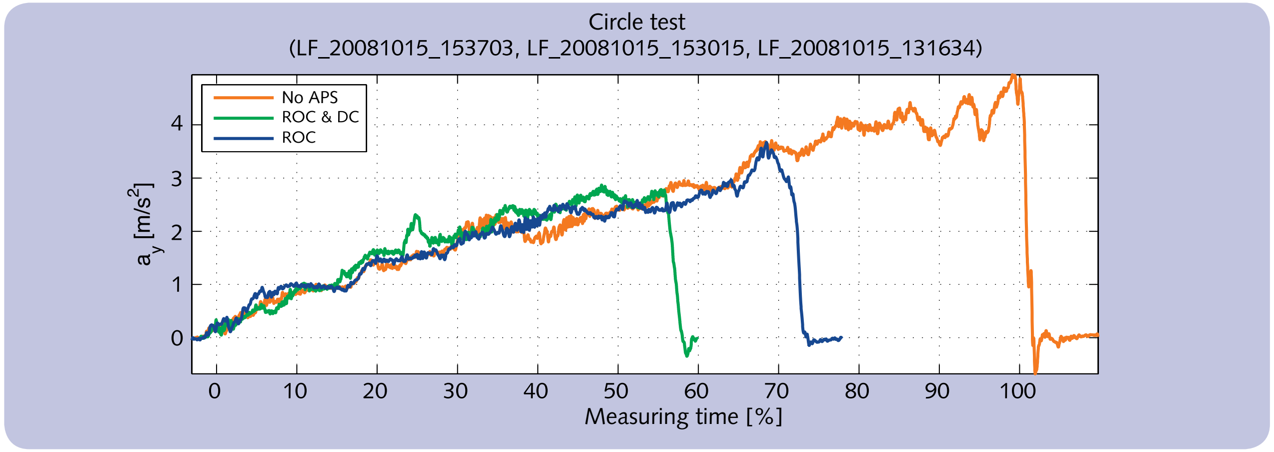

Figure 7: Lateral acceleration in circle test for each type of system

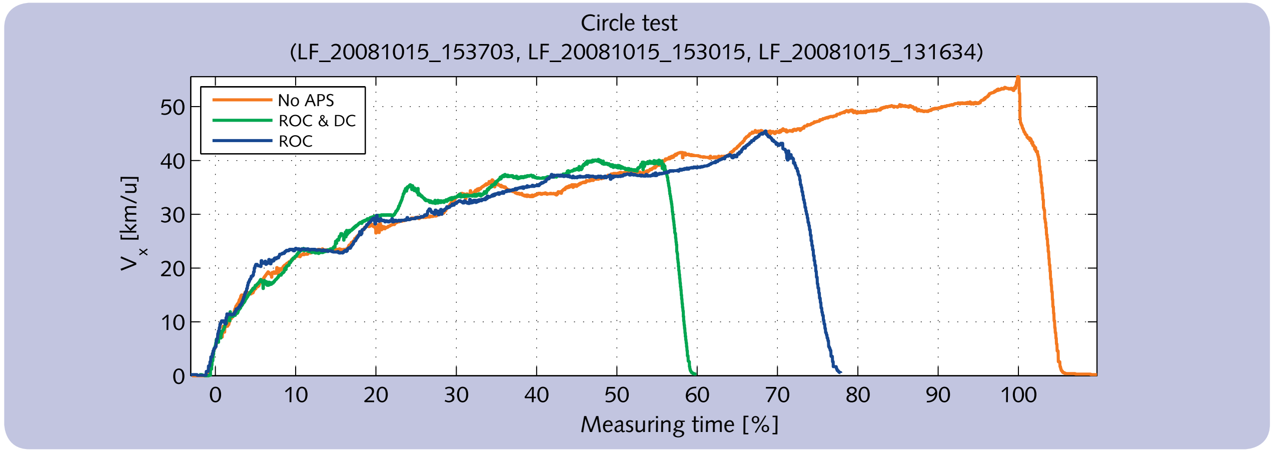

Figure 8: Driving speed in circle test for each type of system

The active system intervenes when the rollover risk becomes too great. In Figure 7 this intervention is clearly evident for all signals. In the Figures 7 and 8 we see at this point that the lateral acceleration suddenly reduces and driving speed decreases simultaneously. At the moment of system intervention, which the driver feels, the driver responds by releasing the accelerator and driving out of the circle.

DC intervened at a lateral acceleration of roughly 3 m/s2 and ROC at a lateral acceleration of roughly 3.5 m/s2. For the test vehicle without ROC & DC, the speed was increased until slipping occurred at a lateral acceleration of roughly 4.7 m/s2.

It is evident from the tests on the circuit track that both the systems tested function effectively in terms of autonomously intervening and preventing hazardous situations such as rolling or slipping. In ample time before a hazardous situation occurs, the systems intervene in a correct manner.

3. Study of the functional effectiveness of the systems examined

ACC

In the field operational tests the drivers can adjust the setting of the ACC. In the test track testing the system's standard setting was used (DAF). The distance at which the ACC intervenes averages 100 metres and is not correlated with the difference in speed. Neither is the distance at minimum TTC correlated with the approach speed and varies from approx. 23 metres to approx. 65 metres.

The approach test, whereby the vehicle with activated ACC approaches a preceding vehicle, is the most appropriate test for an ACC system. The approach occurs on a straight road; of the two vehicles the preceding vehicle is driving more slowly. Shown in Figure 9 is an example of one of the tests. Shown here are the course of the driving speed, the distance to the vehicle in front and the longitudinal acceleration (ax) as a function of the time.

Shown in the upper plot are the preset ACC speed (vx set point), the lorry's speed and the speed of the vehicle in front (a car). At time 7 s the vehicle in front is seen by the ACC system and the speed of the car and the lorries distance from it are measured.

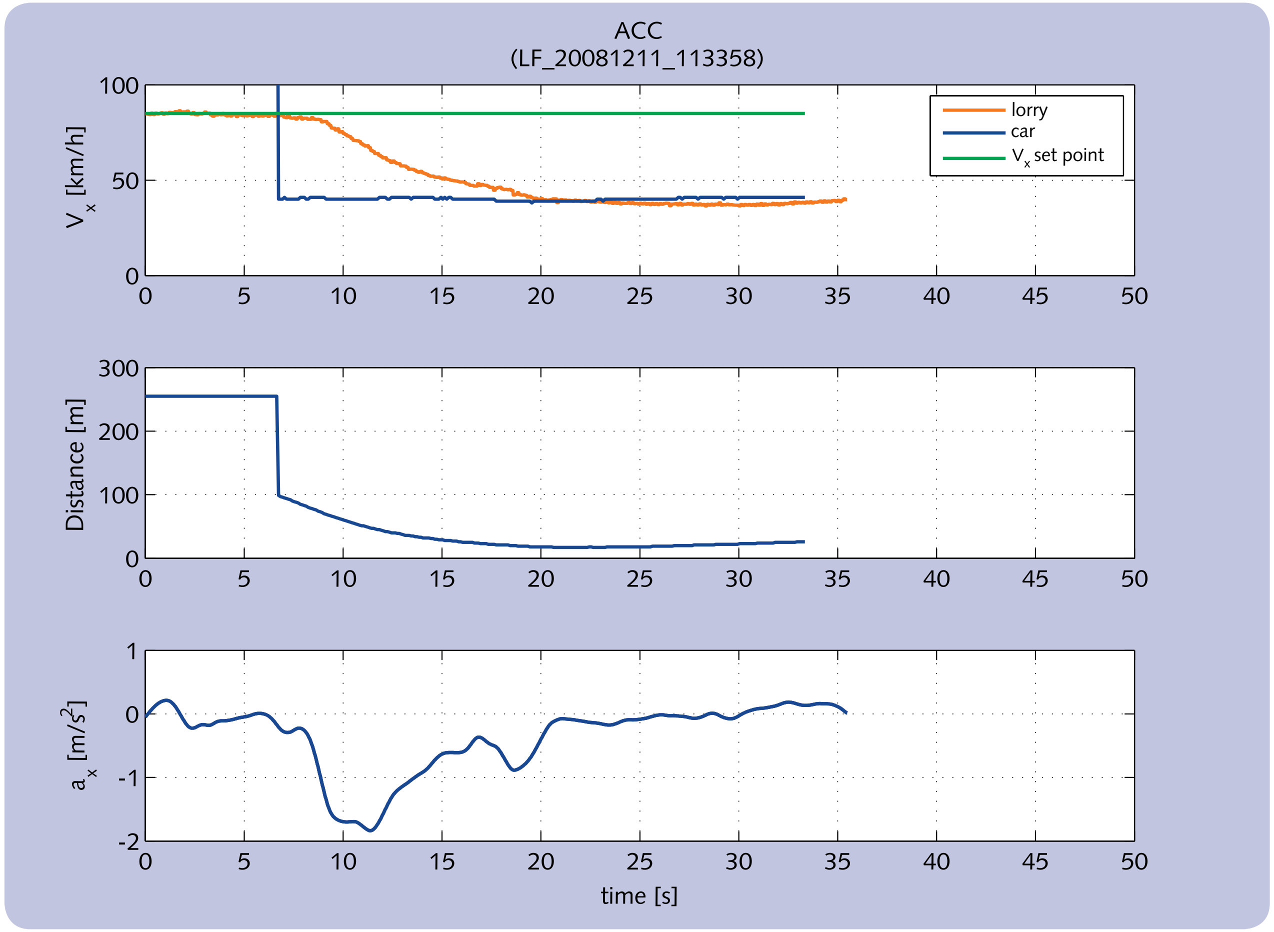

Figure 9: ACC's reaction to approaching the vehicle in front

3. Study of the functional effectiveness of the systems examined

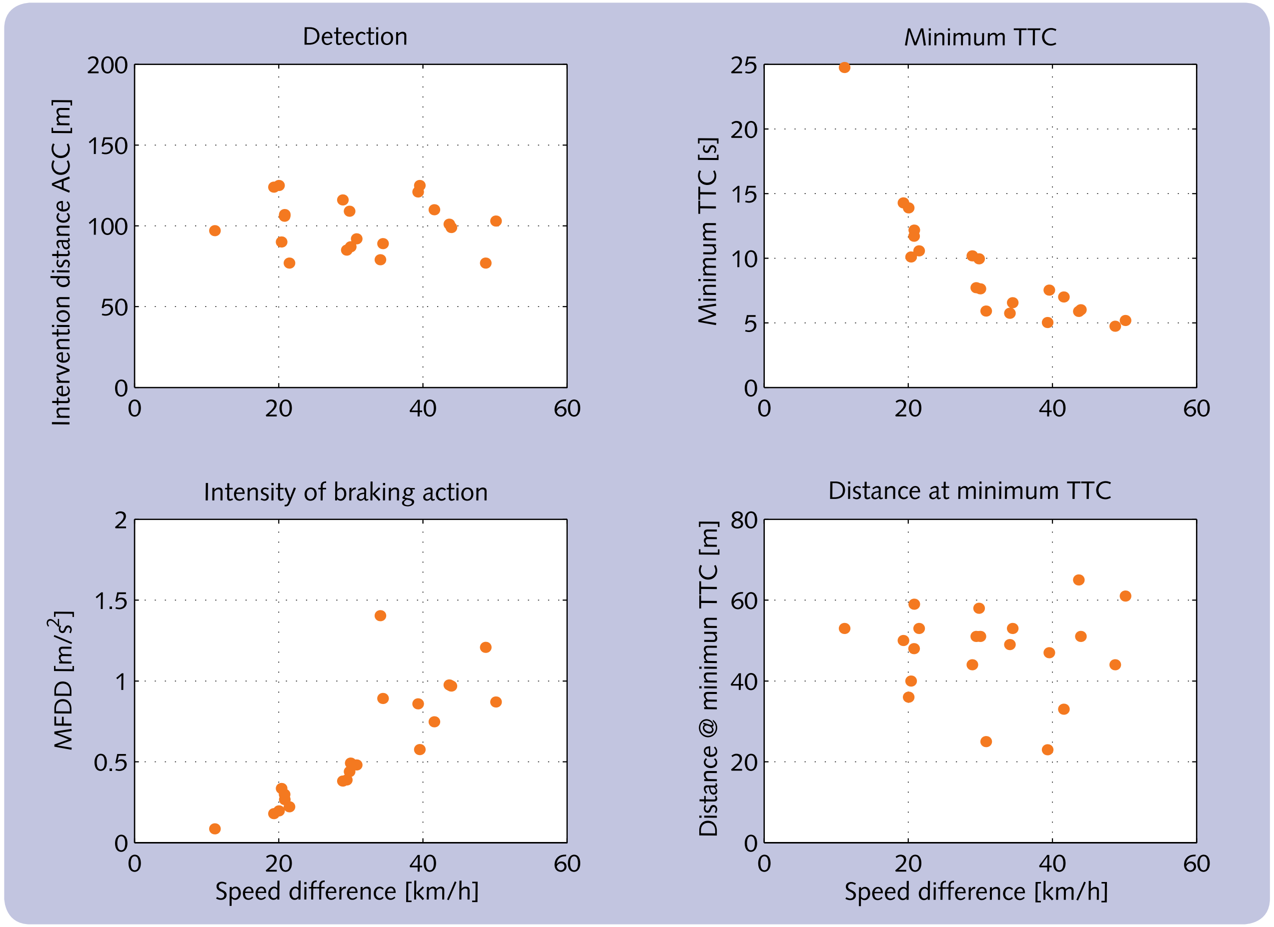

Figure 10: Measured functionality of ACC on approaching the vehicle in front

Almost immediately following the detection of the car, the lorry is subject to automatic braking; a minimum distance of approx. 17 metres to the car is maintained. Temporarily, the lorry's driving speed falls below that of the vehicle in front in order to allow the intervening distance to increase. In approx. 200 metres of road driven, the ACC achieved the speed reduction that was coupled with a maximum braking delay of almost 2 m/s2.

Shown in Figure 10 are several key variables in the approach test measured at various speed differences between the two vehicles, namely:

- Distance intervention ACC - distance to the car in front at the moment that the ACC system intervenes;
- MFDD - Mean Fully Developed Deceleration: the lorry's average braking delay;
- Min TTC - minimum Time To Collision;
- Distance @ min TTC - distance between the two vehicles at minimum Time to Collision.

Of the above key variables only the minimum TTC and average braking delay MFDD depend on the difference in starting speeds of the two vehicles (or rather the approach speed of the ACC vehicle to the vehicle in front). The minimum TTC varies from 25 s to approx. 5 s at the highest approach speed. The average braking delay increases until approx. 1.5 m/s2 at increasing approach speed.

A minimum TTC of 5 s or more is realised by the ACC system. This is a comfortable time since a driver's reaction time is approx. 1 second and, moreover, the driver has been alerted by the ACC system's braking intervention. As such, it can be concluded that under the conditions tested (vehicle in front drives at constant speed and faster than 25 km/h) a safe situation can be achieved with the ACC system.

The ACC system cannot be regarded as a Forward Collision Warning System. This is because it can be disengaged by the driver. Moreover, the maximum braking delay possible is limited to 2.5 m/s2 and the preceding vehicle's minimum speed must be greater than 25 km/h for the system to intervene. Stationary and slowly moving objects are filtered out by the radar system.

If the ACC system is not capable of realising a safe distance by employing the maximum braking delay (2.5 m/s2), an alarm is given. In this case the driver should perform a braking intervention in order to avoid a collision.

It is evident from the tests that ACC functions effectively.

FCW/HMW system

FCW issues a warning when the headway time (Time To Collision/(TTC) becomes too short. The TTC is defined as the distance to the vehicle in front divided by the difference in speed. The standard setting is a warning of at least 2.7 seconds (earlier if possible).

HMW issues a warning as soon as the vehicle approaches too closely the vehicle in front.

The warnings issued by HMW come in four steps:

- Exceeding 2.5 seconds — grey
- Between 1.1 and 2.5 seconds — green
- Between 0.7 and 1.1 seconds — orange
- Less than 0.7 seconds — red

The system works at any vehicle speed. The settings shown above were used in both the test track tests and the field operational test.

In order to test the FCW/HMW system the lorry was driven towards a stationary vehicle and a preceding vehicle moving more slowly than the lorry. The FCW/HMW cannot intervene independently; it warns the driver of the need to reduce vehicle speed. In the tests, the driver brought the vehicle, immediately following a warning, to a halt in the available distance.

From the results it is evident that the FCW issues an alarm at a TTC between 2.5 and 4.2 seconds, depending on the approach speed (10 to 80 km/hr) and the difference in speed between the two vehicles. The distance to the preceding vehicle is then between 20 and 70 m depending on the difference in speed.

3. Study of the functional effectiveness of the systems examined

Shown in Figure 11 are several key variables in the approach test with the FCW/HMW system produced by Clifford Electronics/Mobileye:

- Detection distance - distance to car at the first moment that the FCW/HMW system has detected the car;
- TTC FCW - Time to Collision at the moment that an audio alarm is given;
- MFDD - Mean Fully Developed Deceleration, average braking delay;
- Distance @ TTC FCW - distance to car at Time To Collision.

From the figures, it is evident that the system detects the vehicle in front in most tests at more than 100 metres. In only three cases was the detection distance shorter, namely approx. 70 metres. The driver received warning, except on two occasions, two seconds before a possible collision via an audio alarm (TTC FCW).

During the warning, the distance to the vehicle in front was approx. 10 metres to approx. 70 metres at an approach speed of 10 km/h to 80 km/h respectively.

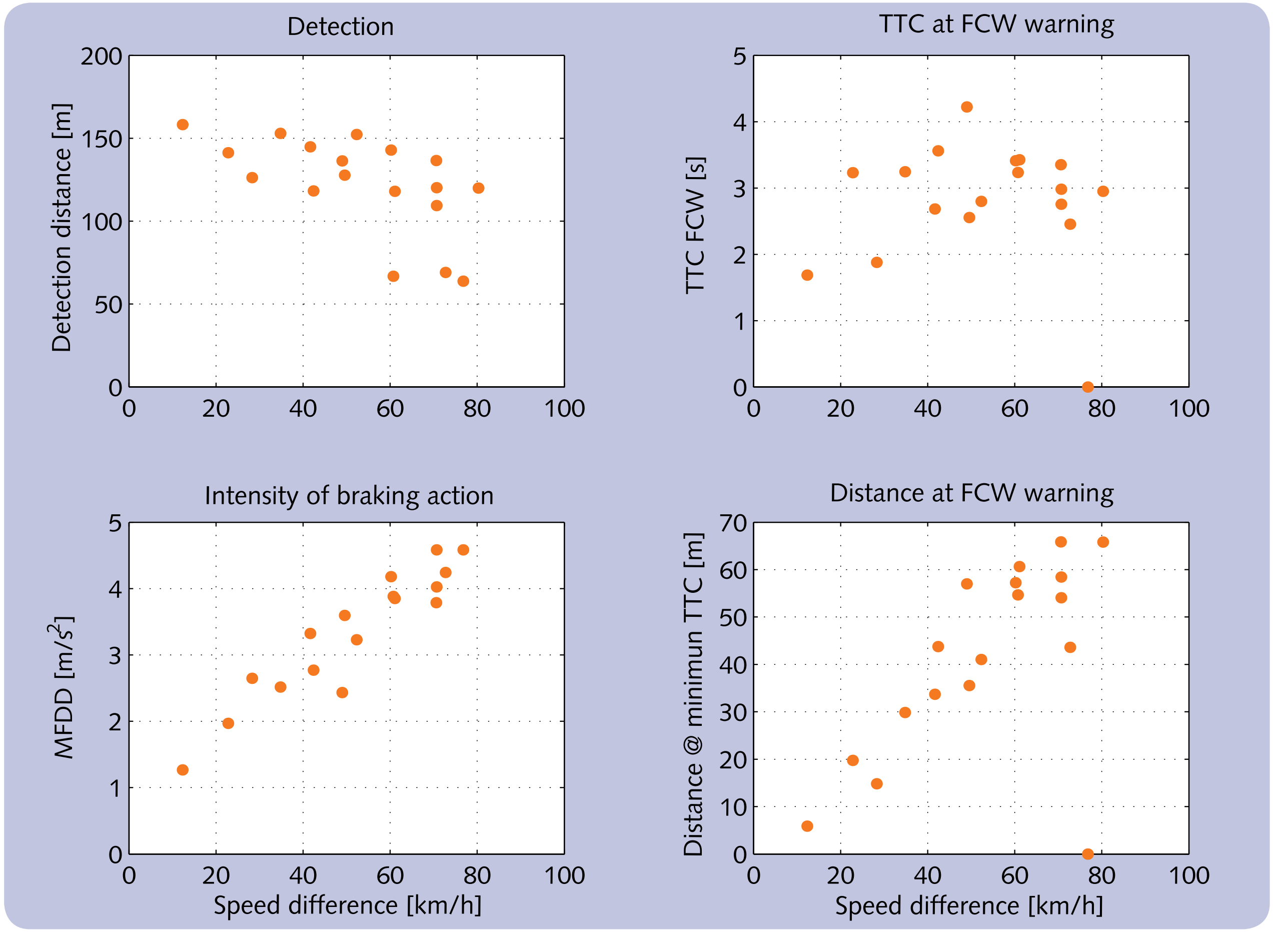

Figure 11: Measured warning times, distances, etc. issued by FCW/HMW upon approaching vehicle in front

3. Study of the functional effectiveness of the systems examined

The test driver was able to avoid a collision in all tests. The braking delays this required (see MFDD in Figure 11) indicate that at the greater speed differences it was necessary to brake firmly to very harshly (maximum braking delay 5 m/s2 = emergency stop). The minimum Time to Collision varies from 1.2 to approx. 3 seconds and the associated minimum distances are approx. 3 to 12 metres.

In no test did the lorry come into contact with the preceding vehicle. The driver's reaction time averaged 0.35 seconds, which can be considered very quick; the test driver was able to react so quickly because he/she knew that a warning would be given. In accident reconstructions a reaction time of 1 second is assumed. Thus, at normal reaction times and with constant braking delays, the lorry would in all probability have come into contact with the preceding vehicle. In that case, the impact of the collision would still have been reduced by the reduced collision speed; and the severity of the consequences would also have been reduced.

It is evident from the tests that FCW/HMW functions effectively.

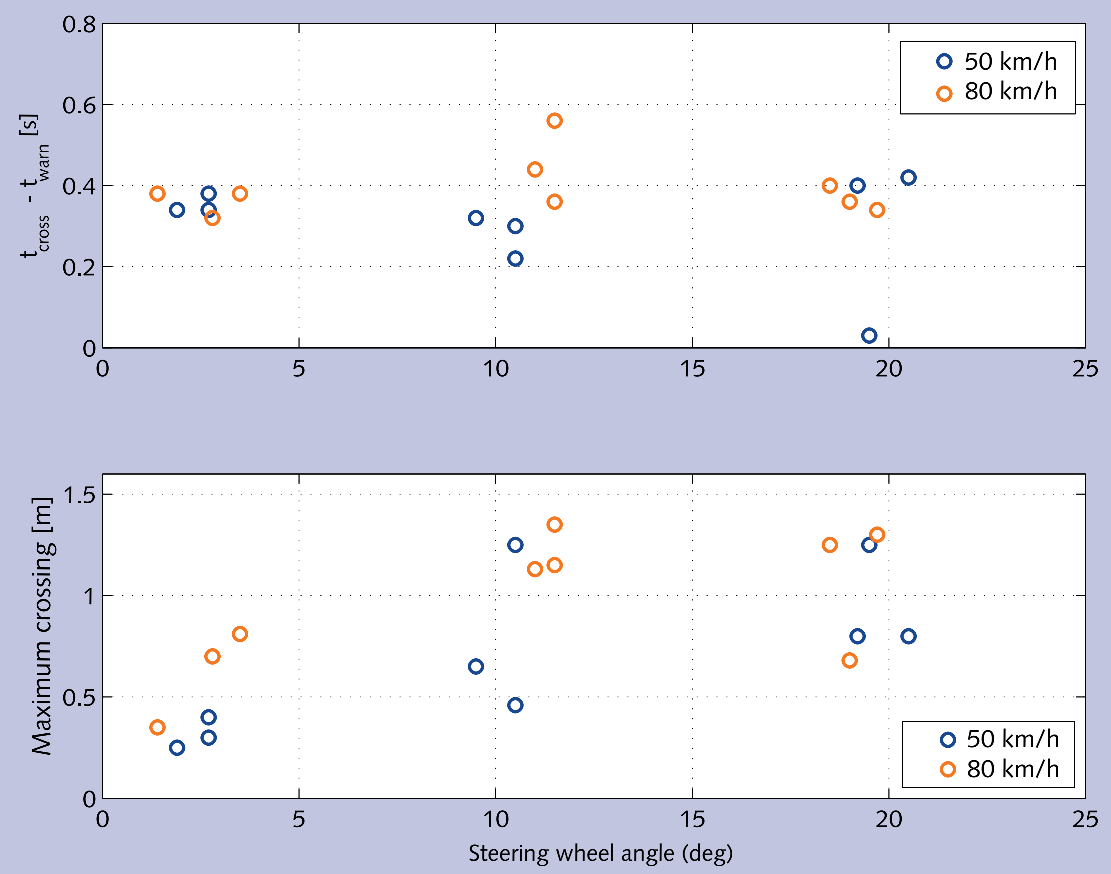

Figure 12: Measured warning times and line crossings for LDWA

3. Study of the functional effectiveness of the systems examined

LDWA system

The retrofit LDWA system produced by Mobileye has the following characteristic settings:

- Becomes active at speeds in excess of 55 km/hr, and becomes inactive once more if the speed drops below 50 km/hr.
- Warning for a Time to Line Crossing (TTLC) of 0.5 seconds.
- After a warning, the next warning will be given only if the vehicle has since returned to its lane and the distance to the road line is more than 0,3 m (to avoid overuse of the alarm).
- No warning if indicators/alarm lights are operational.

The crossing of the lane lines was tested with small steering movements.

In order to determine the speed dependency, the measurements were performed at two speeds: 50 km/hr and 80 km/hr.

Figure 12 illustrates the time between warning and line crossing (tcross-twarn). The lower part of the graph shows the maximum crossings depending on the driving speed and steering wheel angle.

The warning time (time between LDWA alarm and actual crossing) amounted to approx. 0.2 to 0.6 seconds with an average of 0.35 seconds. In many cases the warning time is shorter than the 0.5 s stated in the system specifications. In most cases, the crossing was limited to one tyre crossing the line.

It is evident from the tests that is LDWA functionally effective.

3.2 Loan test

As the data registration systems used in FOT provide only limited insight into the effects of Directional Control (DC) and Rollover Control (ROC), the use profile of a lorry was established in relation to the rollover risk over a five-week period [6, 8] using a vehicle equipped with the full range of measuring instrumentation. During this test, known as the loan test, various haulage firms made a total of 107 trips with a lorry carrying TNO instrumentation. Participating drivers were chosen at random from among the employees of the hauliers. The loan test was limited to the DC/ROC system.

At the start of each trip during the loan test the Roll-over Propensity Assessment System (RPAS) [1] estimation algorithm was used to determine the critical lateral acceleration (= rollover limit). The rollover limit is the lateral acceleration at which the vehicle begins to roll. This is dependent on, among other things, the load, which can vary with each trip.

Using the estimated rollover limit, for every minute that the vehicle drove faster than 15 km/h, the maximum rollover risk that occurred was calculated and logged (in that minute). The rollover risk is defined as the measured lateral acceleration divided by the rollover limit.

3. Study of the functional effectiveness of the systems examined

The histogram in Figure 13 presents a summary of the results for the entire test. It can clearly be seen that the rollover risk more often assumes relevant values for a loaded vehicle (the orange bars). The numbers above the vertical bars in the graph show the numbers of minutes for an empty (i.e. less than approx. 20% loaded, blue) and laden (orange) vehicle respectively.

In total the risk value of 45% was exceeded in 24 minutes (thus 24 times) while the lorry drove for 6,849 minutes (6,849 registered events) (0.35%). While this seems sporadic, it is basically once a day on average. In incidental cases this will lead to an intervention by DC at 55% rollover risk. An intervention by ROC is less common because that system intervenes only at a rollover risk of 70%.

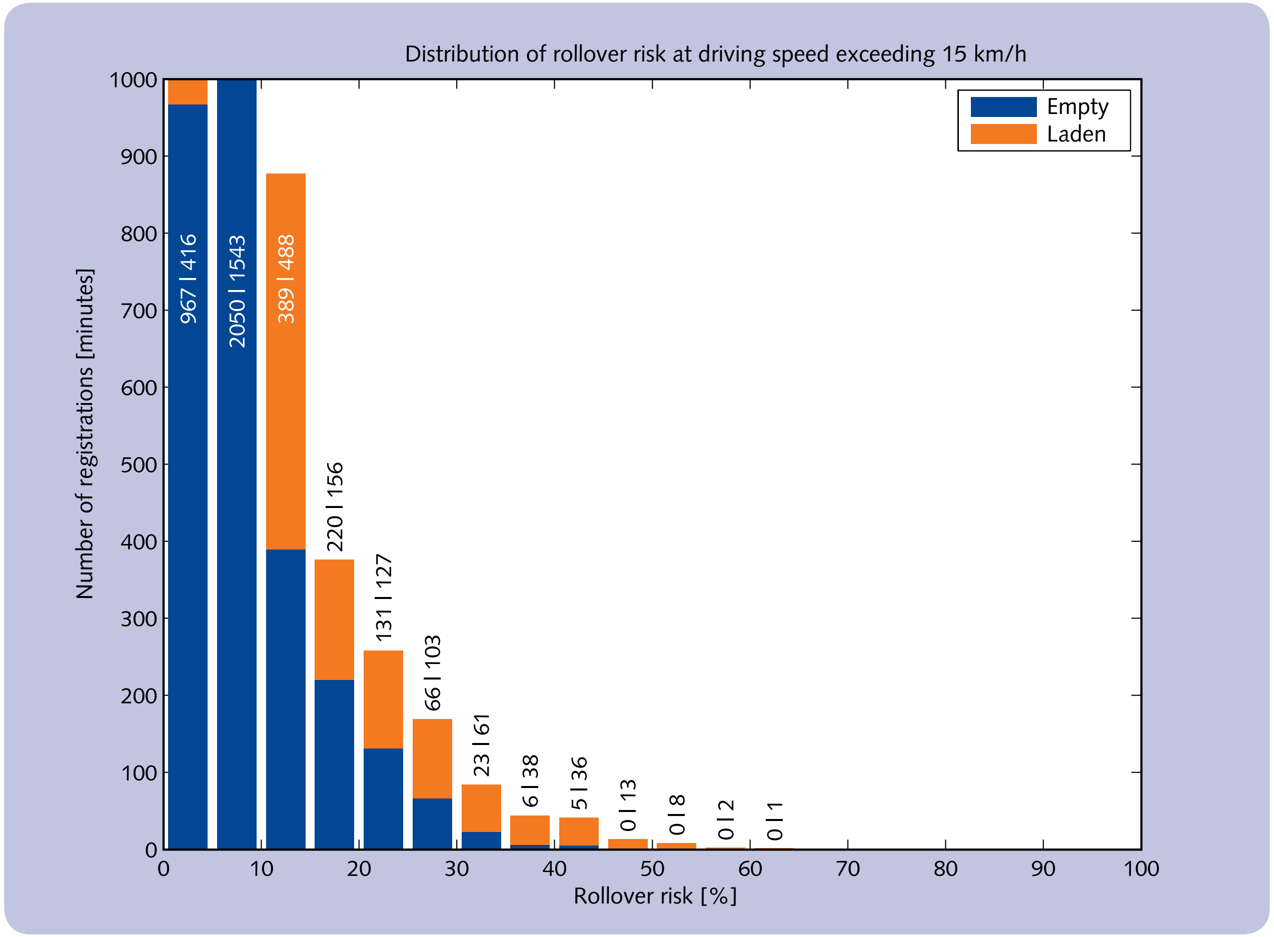

Figure 13: Distribution of measured rollover risks

The influence of loading is shown in Figure 14. For one of the measuring days, the rollover risk measured is shown for various load levels per trip. The load levels are expressed as percentages and shown by different colours. The highest rollover risk occurs on this particular day with a load exceeding 80% (black). After offloading the load to 50% (blue) almost the same maximum rollover risk occurs. It seems that the driver seeks the same level of rollover risk each time.

The analysis shows the following:

- Interventions by DC are rare;
- The DC discussed here was installed on the tractor unit and intervenes earlier than ROC installed on the trailer unit;
- The rollover risk during normal use is considerable less than the ROC trigger level.

Only in the situation with the highest recorded rollover risk did the DC system intervene. The rollover limit for ROC interventions (= 70%) was not exceeded, and correspondingly no ROC interventions were registered during the loan test.

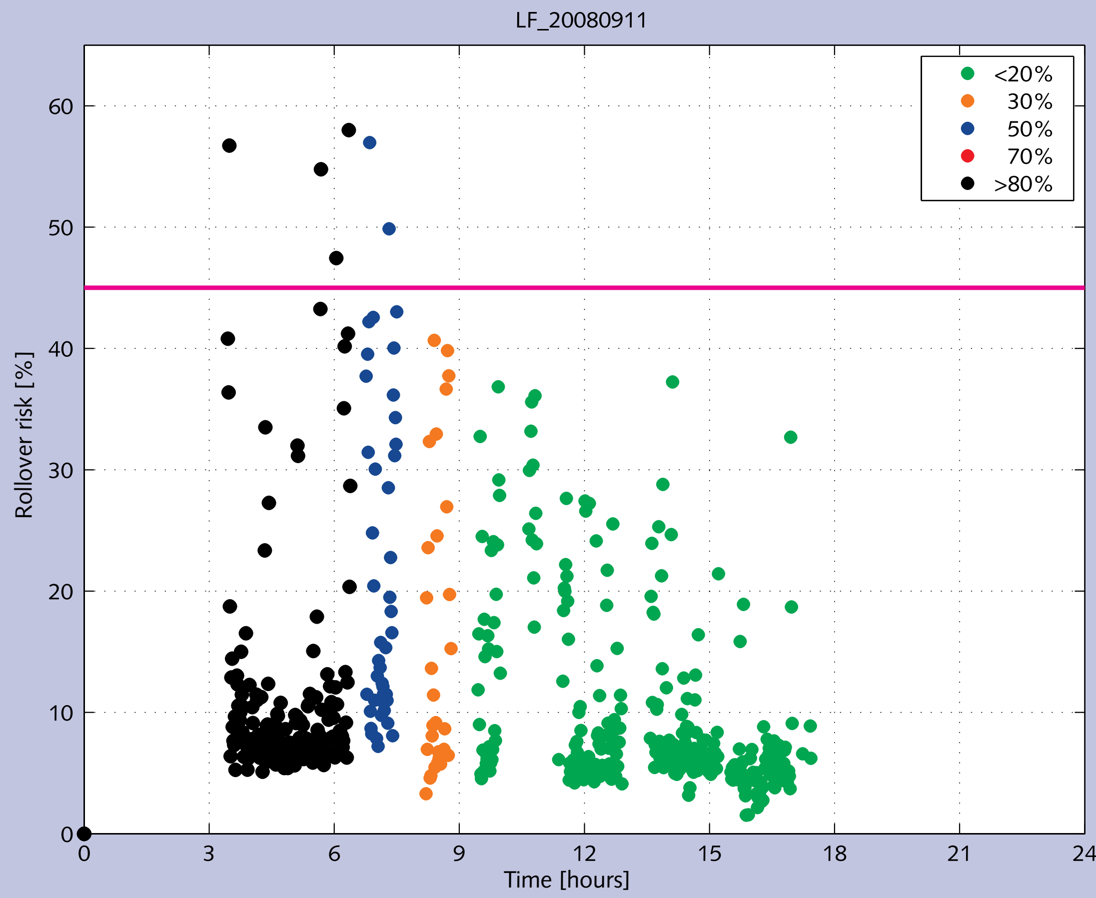

Figure 14: Measured rollover risk depending on the load (one measuring day)

3. Study of the functional effectiveness of the systems examined

The results of the test suggest that drivers have a good sense of the rollover risk at various load levels.

Further analysis of the DC intervention reveals that a high rollover risk occurs primarily on motorway slip roads (both entrances and exits) and on clover-leaf intersections. This is mostly in long bends at the end of the bend, where the driver increases speed in anticipation of the straight road section that follows.

A high rollover risk usually occurs several times within a trip and often during multiple trips on the same day, irrespective of the load.

Figure 15 shows the location and the route driven where the DC system intervened. The route travelled is shown by the cyan line, starting on the left-hand side of the figure. The vehicle drove on the right-hand side of the road.

Figure 15: Route driven - Source: TNO

The rollover risk and other variables are shown in Figure 16. The rollover risk is shown in the bottom two figures by means of the colours green - yellow - red - blue (from low to high risk). During the blue parts, DC intervened.

The ‘s’ indicates the starting point of the measurement. The figure also shows the measured vehicle speed, steering wheel angle, lateral acceleration and lateral and longitudinal positions expressed in the x and y positions.

3. Study of the functional effectiveness of the systems examined

With regard to the occurrence of elevated rollover risk, the following is concluded:

- The infrastructure is an important factor. Situations that appear frequently in the list of elevated rollover risk are: motorway slip roads (entrances and exits), in clover-leaf intersections and connecting roads with straight sections and bends. The highest rollover risk often occurs at the end of the bend where the driver increases speed in anticipation of the straight road section that follows.
- The load level is an important factor. Empty lorries have less chance of rolling than (heavily) loaden lorries.
- In all cases the driver maintained a sufficient margin.

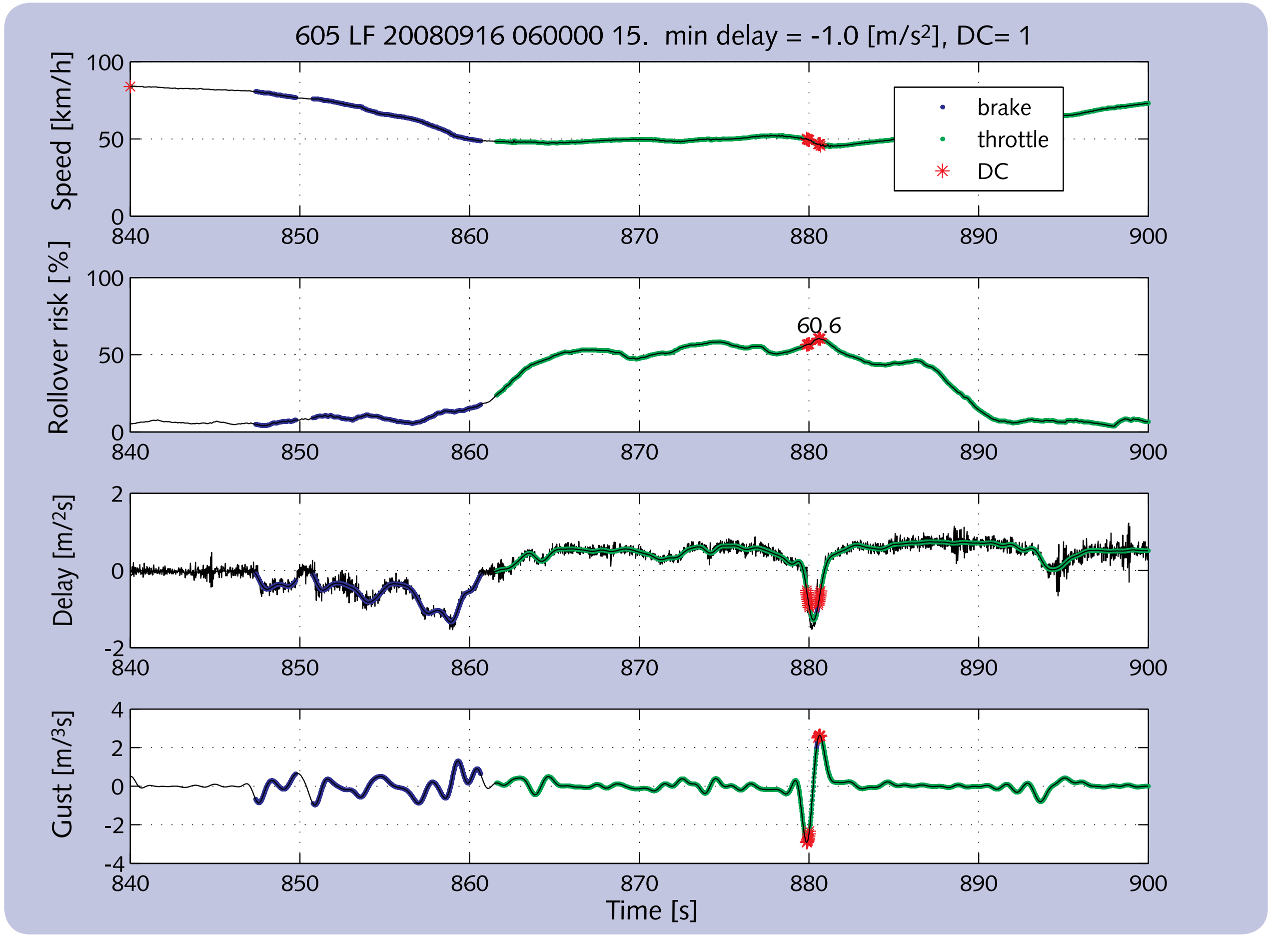

Figure 16: Rollover risk measured during trips by a bend (with DC intervention)

4. Field Operational Test

4.1 Field Operational Test general

In the EU project FESTA [9, 1] a FOT is defined as:

A study undertaken to evaluate a function, or functions, under normal operating conditions in environments typically encountered by the host vehicle(s) using quasi-experimental methods.

The planning, performing and analysis involved in a FOT carried out under ideal circumstances are shown by the FESTA 'V', see Figure 17.

Briefly stated, this methodology involves first studying functionality, in this case the APS. The trick is to subsequently translate the research questions into testable hypotheses. Once it is known what must be measured, (and how often/accurately), measurements and sensors can be chosen and the data registration designed.

Subsequently, the earlier hypothesis can be verified or not using the analysis of the database of measurements. As a result, policy statements can be made.

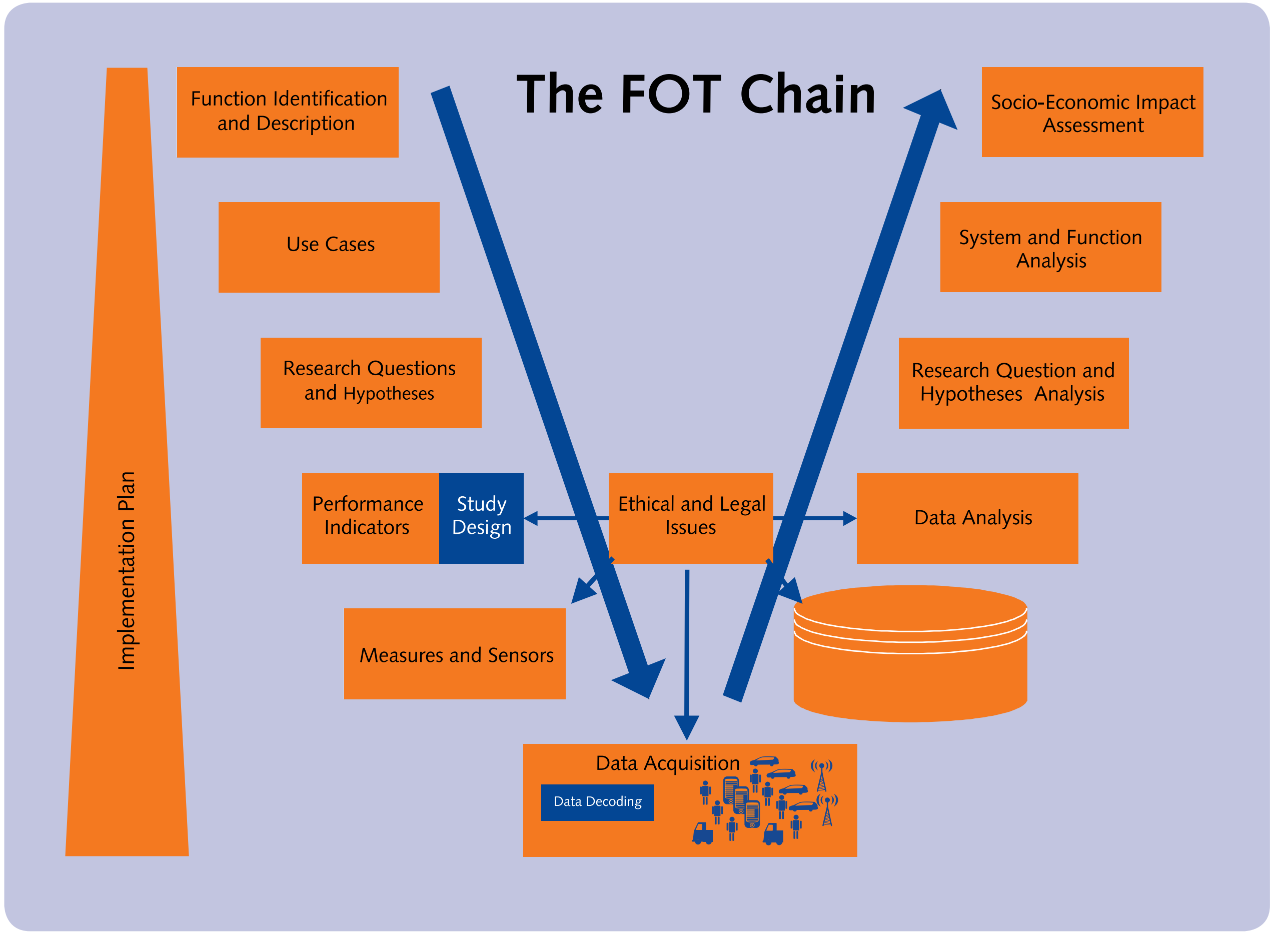

Figure 17: FESTA method

4. Field Operational Test

In practice, compromises sometimes have to be made to be able to realise a workable field operational test. In the case of APS the main challenge was to equip as many lorries as possible with APS and data registration systems, and then to ensure that the data registration functioned.

That resulted in:

- A number of potentially disruptive influences like the weather, traffic jams or road works not being able to be directly measured but only indirectly derived and added;
- Measurements based on events rather than continuity;
- The use of two different data registration systems;
- An inability to select participants randomly;
- An inability to randomly allocate systems to participants;
- The drivers in two sub-groups in subprojects being able to switch off the APS without the possibility of monitoring that;
- A limited time to check the quality of, and subsequently analyse, the data.

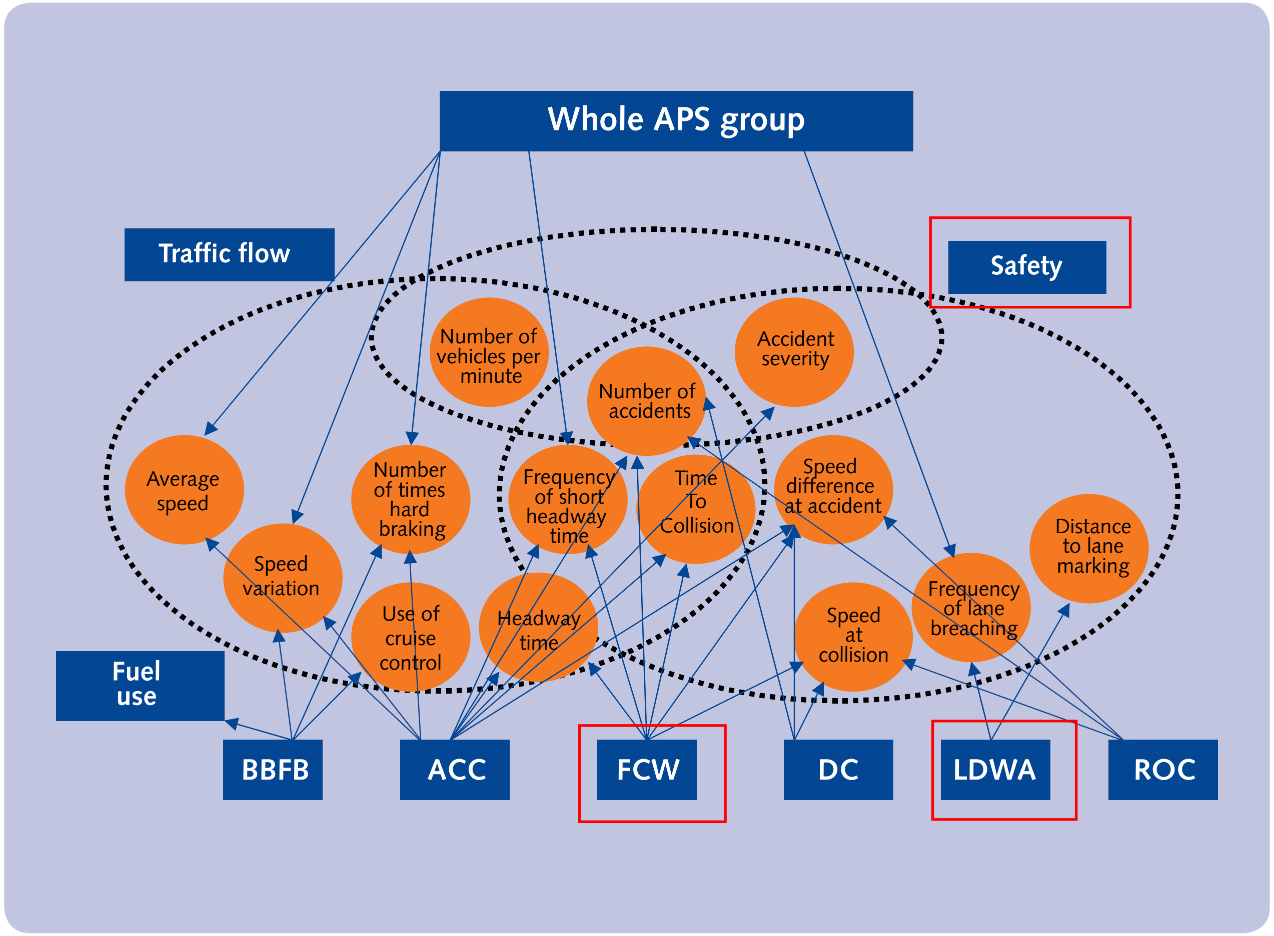

Figure 18: The effect of APS on the indicators

4. Field Operational Test

To determine the effects on traffic safety, indicators were identified that have a relationship with traffic safety and flow.

By virtue of its operation, each of the separate APS has an assumed effect on the indicators of both domains as visualised in Figure 18. It should be stated that other factors also influence these indicators. How such disruptive variables are handled is explained in greater detail in Section 5.3 *The Relationship between APS and safety.*

The possible effects of APS on the indicators ultimately translated into 30 testable hypotheses. A number of hypotheses were tested for all types of APS and a number of hypotheses were tested for each individual APS. All hypotheses (including those that could not be tested) are presented in Appendix 2.

The experimental situation (the vehicles with active APS) was compared with the reference situation (the reference vehicles with what is known as a 'silent APS'). In the reference group, the drivers were not told but were measured. The analysis was performed only for the Dutch motorway system.

For the purposes of testing the hypotheses, the data was divided into:

- The APS groups;
- Light (after sunrise - after sunset, based on date and time);
- Speed limit (80 - 100 - 120 km/hr).

4.2 Selection and distribution of participants in field operational test

In all, 123 hauliers were found to participate in the field operational test (FOT). Their lorries, including their technical specifications, were included in what is known as the zero database. Four OEMs (DAF, VOLVO, MAN, Scania) were found willing to share details of some of the production with the project team to enable the joint assessment of which orders would be eligible for building in ACC or LDWA (factory-fitted).

Based on the specifications and the possibilities, the next step was to examine which lorries were most suited to which group, how the groups could remain as comparable as possible and the 'bias' resulting from the selection could be minimised.

4. Field Operational Test

In addition, the following were taken into consideration:

- National versus regional transport;
- Hauliers with large (> 50 lorries) versus small fleet;
- Average trip length in kilometres;
- Use of lorries during day or at night;
- Type of transport (for example, general cargo or hazardous materials);
- Age of lorry (year of manufacture 2001 or later).

In contrast to earlier recommendations, several types of lorries were chosen rather than one type. With just one type, the field operational test would not have been large enough to enable statistically sound judgements or the number of types of system in the FOT would have had to have been limited.

Lorries with a date of manufacture prior to 2001 were excluded from the selection because the risk of drop-out/ sale during the project could be considered realistic. For the detailed elaboration of the selection method, readers are referred to [10].

The summarised result of the selection is presented in Chart 1 based on the activities of the haulier and the types of lorry. The total is more than 100% because companies were able to give several answers.

The type of lorry is described in Chart 2.

In order to make the testing of BBFB feasible, it was decided to select companies already using the CarrierWeb onboard computer.

	% companies
General cargo	60
Liquid bulk	25
Solid bulk	18
Hazardous cargo	28
Containers	20
Exceptional transport	10
Other	8

Chart 1: Activities of participating companies

Combination	Total	%
Motorised vehicle	332	14%
Motorised vehicle - container	14	1%
Unknown	119	5%
Articulated lorry	1.674	70%
Articulated container chassis lorry	66	3%
Articulated container lorry	197	8%
Sum total	**2.402**	**100%**

Chart 2: Lorry type distribution

4. Field Operational Test

Figure 19 shows the distribution of the systems across various subprojects (SPs) and the numbers of vehicles per SP in which an APS was built in. In total 2,402 vehicles were involved in the project distributed across four subprojects.

The features of the subprojects (SPs) were as follows:

SubProject1 consisted of lorries some of which were equipped with APS retrofit systems. The data registration was carried out using a modified 'Clear Box' system produced by Clifford Electronics/Octo Telematics. The data registration system also measured a number of data items from the APS concerned (Mobileye). The reference group had a 'silent' Mobileye on board. As a result, measurements could be taken but the driver received no alerts. The driver was not able to disengage the system.

SubProject2 consisted of lorries some of which were equipped with a Mobileye (FCW/HMW and LDWA), and some with only a BBFB. The data registration system was provided by CarrierWeb. The driver was able to disengage the Mobileye without this being registered.

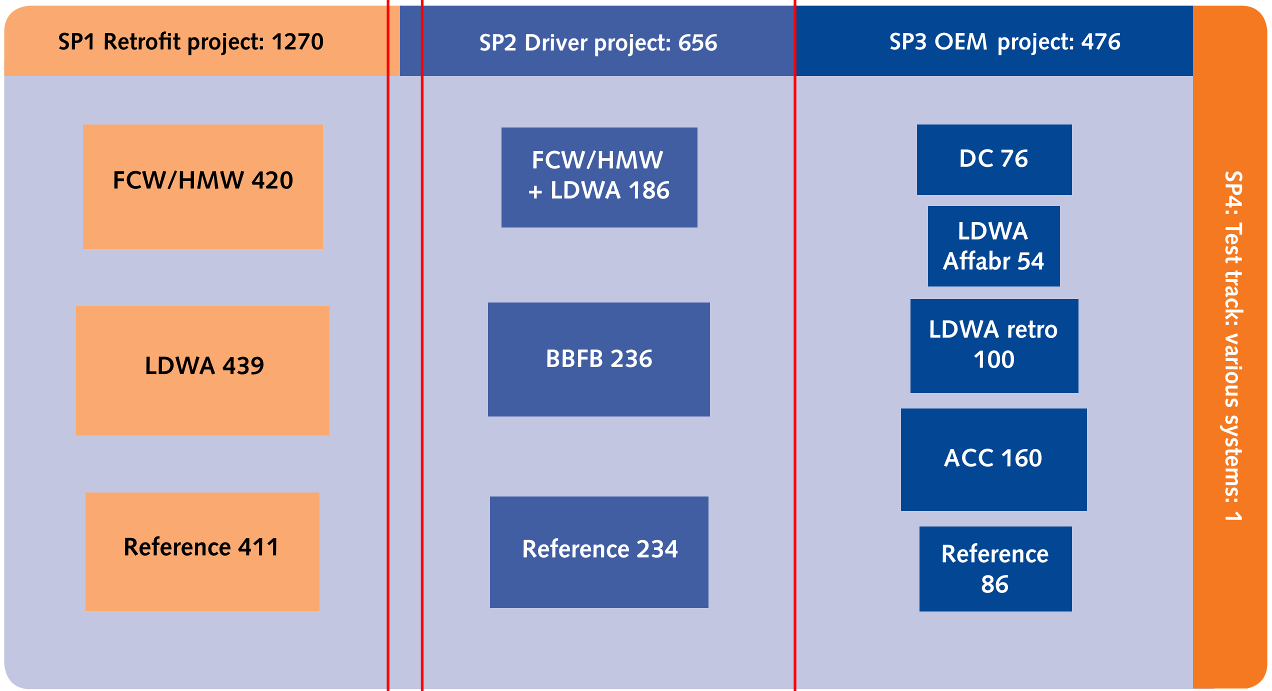

Figure 19: Vehicle distribution across sub-projects

4. Field Operational Test

SubProject3 consisted of lorries with APS, almost all of which were factory-fitted. The data registration was carried out using a modified 'Clear Box' system produced by Clifford Electronics/Octo Telematics and a 'silent' Mobileye. The driver was able to disengage the ACC without this being registered.

SubProject4 consisted of the lorry that was used for the test track experiments.

In total 2,402 lorries were fitted with equipment. However, the number of lorries for which measurement results were saved is lower than this number (2,086 lorries). This is because at the start of the project not all lorries were equipped with APS, while later in the project lorries dropped out due to their sale or lack of use. This was attributable to a range of factors, including the economic crisis.

4.3 Data registration

In SubProject1 and SubProject3 data registration took place using registration units produced by Clifford Electronics/Mobileye and Octo Telematics. These units were based on the 'Clear Box' concept developed by Clifford Electronics [2] and Octo Telematics and a Mobileye.

For a detailed analysis and audit of this data registration and the data shown below the reader is referred to [21].

With the aid of a GPRS connection, a GPS receiver, an acceleration sensor and a CANbus link with the APS (Mobileye: LDWA, FCW/HMW) three types of data were collected (see [2,3] for detailed specifications.

Standard data:

- Start of location (GPS coordinates);
- End of location (GPS coordinates);
- Every two kilometres:
  - Date/time;
  - GPS coordinates/GPS speed;
  - Momentary headway time;
- Crash trigger data:
  - If the acceleration sensor measures too high a value (trigger event, configurable);
  - Speed and acceleration before and after the trigger moment;
- Diagnostic data.

APS event data:

- Event data APS:
  - If the APS measures an event (trigger event, configurable);
  - Type of event, date/time, GPS coordinates/GPS speed.

APS detailed data:

- Triggered by an event;
- Detailed snapshot lasting approx. 6 seconds before the event until 4 seconds after the event of:
  - GPS coordinates/GPS speed;
  - Accelerations as measured by the sensor;
  - Mobileye data.

These data were enhanced by Octo Telematics with GIS data (converted to geo-codes for roads), filtered where necessary, and clustered to form a number of data files. The acquisition system for SP2 differed from all the others because it was generated using the fleet management system produced by CarrierWeb. In this case, 'events' is taken to mean the measured signals issued by the accident prevention systems.

4. Field Operational Test

The frequency with which the data were saved was once every two minutes. No current values were saved but rather indicators, which were calculated immediately, concerning the elapsed period of 2 minutes, for example the average speed and the maximum acceleration/deceleration.

The raw data from the data registration were quality controlled prior to processing and filtered again, if necessary. During sub-analyses subsets were enhanced with variables of importance to the analysis, such as the files of actual data based on the measured GPS positions, road type, number of lanes, applicable speed limits, etc.

Owing to the conversion and the addition of indexation data, the files that were analysed became larger than the original data files.

Data file	Data Space (Mb)
TRIP_SUMMARY	71
TRIP_DETAIL	49.372
APS_SUMMARY	19.678
APS_DETAIL	103.072
CRASH_SUMMARY	11
CRASH_DETAIL	361
Total	**172.860**

Chart 3: Amount of data collected from sub-projects 1 and 3

Chart 3 shows the quantity of raw data collected in SubProject1 and SubProject3. The total is more than 170 GigaBytes.

Chart 4 shows the number of kilometres driven that was logged per month in SubProject1 and SubProject3. The number of lorries was determined each month by a range of factors, including the availability of units and the repair and modification of APS.

Chart 5 shows the quantity of raw data collected in SubProject2. The total is more than 14 GigaBytes.

Year	Month	Total km driven	Total journeys	Average kilometres per day	Number of lorries
2008	10	8.145.428	248.417	345	1.043
2008	11	8.173.006	248.136	333	1.223
2008	12	8.818.063	254.757	333	1.304
2009	1	9.259.496	264.454	328	1.350
2009	2	9.203.939	276.281	322	1.469
2009	3	10.800.269	330.630	323	1.493
2009	4	10.218.884	311.555	326	1.498
2009	5	9.033.672	278.108	310	1.547
Total		**73.652.757**	**2.212.338**		

Chart 4: Kilometres driven and measured in sub-projects 1 and 3

4. Field Operational Test

Data file	Data Space (Mb)
Haulier1_data	400
Haulier1_GPSdata	1.200
Haulier2_data	2.400
Haulier2_GPSdata	10.300
Total	**14.300**

Chart 5: Amount of data collected

Year	Month	Total km driven	Number of lorries
Haulier 1			
	3	101.459	51
	4	227.330	51
	5	253.975	86
Subtotal		**582.764**	
Haulier 2			
2009	2	50.082	71
2009	3	698.452	405
2009	4	800.042	455
2009	5	920.263	453
Subtotal		**2.468.839**	
Total		**3.051.603**	

Chart 6: Kilometres driven and measured in sub-project 2

Chart 6 shows the number of kilometres driven and measured in SubProject2.

The number of lorries was determined each month by a range of factors, including the availability of units delivered factory-fitted and the repair and modification of APS and data registration units.

4.4 Analysis of measurements

Owing to the lengthy measuring period, particularly in SP1 and SP3, all sorts of weather conditions were encountered, from extreme cold in the winter (to -20 °C) to heat in the spring (30 °C), dry weather, wet weather and snow. Data that was influenced by extreme weather, such as the snow in January 2009 that was extreme by Dutch standards, have not been included in the analysis.

The hypotheses presented in Appendix 2 were tested in the data analysis. This involved the use of variance analysis. The analysis was performed on data collected on Dutch motorways and for speeds in excess of 55 km/hr.

The independent variables were:

- APS (with the conditions LDWA, FCW/HMW and reference serving as examples in SP1).
- The speed limit, with 120, 100 and occasionally 80 km/h as possible values. This variable was correlated with the location where the lorry drove. The limit of 100 km/h is found typically near urban areas and a speed limit of 80 km/h applied at a couple of specific locations.
- Half-day, with day and night as possible values. This variable includes the effects of both light conditions and weight of traffic.

Of the hypotheses in Appendix 2 12 turned out to be significant, 18 hypotheses were not significant, and 23 hypotheses could not be tested for a range of reasons, including the lack of sufficient (correct) data specific to the hypothesis in question. The most important findings are shown below. For the details of the analysis, the reader is referred to Appendix 5.

The division into groups analysed and associated APS types and vehicle categories is shown in Chart 7.

4. Field Operational Test

	SP1 Retrofit	SP3 OEM		SP2 Drivers	
		SP3a: Bulk	SP3b: OEM	Tr1	Tr2
APS	LDWA FCW/HMW Reference	DC LDWA (retro) Reference		BBFB Referentie	BBFB LDWA + FCW/ HMW Reference
Vehicles	Articulated lorry Motorised vehicle	Articulated container chassis lorry Articulated lorry	Articulated lorry Articulated container lorry	Articulated lorry (4 x 2 en 6 x 2)	Articulated lorry (4 x 2)
Number	1.230	143	194	78	487
Data	Octo			CarrierWeb	

Chart 7: Classification of APS groups

SubProject1 and SubProject3 are similar in terms of data registration, SP2 differs from them. In order to achieve comparable groups, the analyses in these two groups were performed separately.
Two hauliers with different business models cooperated in SP2 (own drivers versus lease of lorries). These are referred to as Haulier 1 (Tr1) and Haulier 2 (Tr2). Since this fact could be influential, it has been included in the analysis.

The number of lorries in Chart 7 is lower than the total number of lorries followed. A significant cause of this is the removal from the analysis of a number of types of lorries necessitated by there being too few of them to perform a good analysis (for example, some 4-axis lorries).

In addition, it was found that some of the lorries had driven almost exclusively outside the Netherlands, as a result of which they provided no data.

Group 1 (Octo data registration system)

The subgroups SubProject1 and SubProject3 (LDWA, FCW/ HMW, DC, ACC, Octo data registration) were analysed together.

- Various positive, statistically significant effects were found for ACC: higher average headway time higher, % headway times < 1 s lower, fewer FCW/HMW alerts and fewer LDWA alerts. However, whether the ACC was switched on or off could not be measured or indeed what the setting was. Therefore it cannot be demonstrated whether the effect is due to ACC use or ownership. The driver surveys reveal great satisfaction with ACC, which could indicate a high level of ACC use.

- An LDWA reduces the number of warnings per hour. Thus, an LDWA leads to fewer unintentional line crossings or better use of the indicators. The group with an LDWA fitted post-factory shows a decrease of 30%, the 'factory-fitted' group up to 60%. The percentage of shorter headway times (< 1 s) increases, however, as a consequence of an LDWA.

- FCW/HMW has no measurable effect in the percentage of shorter headway times (< 1 s). A subsequent analysis indicated that in the average headway time a measurable positive effect was indeed observed (0.14 s).

4. Field Operational Test

Group 2 (CarrierWeb data registration system)

The second analysis was performed on the data for Sub-Project2 (BBFB, LDWA + FCW/HMW, CarrierWeb data registration). In SubProject2 no ACC was used but it was known whether the cruise control was on or off. This fact has been included in the analysis. In addition, in this group LDWA and FCW/HMW were used only in combination with one another.

For both hauliers a limited and contrary effect of the BBFB was evident on the average speed. The first haulier (own drivers) demonstrated desirable behaviour: 24% less speed variation. The second haulier (leased lorries) demonstrated slightly undesirable behaviour: 5% more speed variation.

LDWA and HMW/FCW appear to have a (small) effect on average speed. Average speed was 0.4 km/h lower compared to the reference group.

The use of a cruise control had only a small measurable effect: for an engaged cruise control there was a marginally higher average speed (2.2 to 2.7 km/hr) and as would be expected with fewer variations in speed.

The BBFB was not seen to have any effect on the use of cruise control. An analysis was performed for the number of times harsh acceleration occurred (> 1.5 m/s2) and the number of times harsh deceleration occurred (< -0.8 m/s2). The measured differences are small but the BBFB group braked harshly less often than the reference group and less often than the group with the Clifford Electronics/Mobileye system (FCW/HMW and LDWA).

4.5 Data validation

Owing to the relative complexity of collecting so much data from this number of participants, Ernst & Young performed an audit of the data registration and processing carried out by the Clifford/Octo system, from lorry to raw data [21]. The conclusion of the audit reads as follows:

The three answers prove that raw data process of collection and export is robust and reliable. Some minor integrations, described in detail in each section of this document, should be performed.

Two validations were performed for subprojects 1 and 3, both at the end of the measuring period. In the first [20] the events in the field were counted manually and compared with the events that were logged in the database. This concerned a validation of three vehicles, all three tracked throughout one day. While it turned out that not all events had been logged, no new deviations were identified.

The deviations observed occurred in all groups (reference and the two APS groups) and are not expected to introduce any bias.

The second validation test [21] validated the processes of data storage and processing. No deviations worthy of mention were revealed.

5. Study of the effect on safety

5.1 Literature study

In order to be able to extrapolate the results of the field operational test to a prediction about the effects on traffic safety in large-scale application, a literature study was first carried out.

In many of the studies found, no verdicts were given about the effects of APS on safety, although mention was made, for example, of a change in headway time and the author intentionally gave no quantitative assessment about the impact of this on safety or the number of accidents. The general quantitative tendency is to suggest that APS should have a positive effect on traffic safety.

A number of studies discussed in this chapter do make a quantitative judgement, though the following remarks need to be made:

- The studies focus generally on cars rather than lorries.
- Often the causality between the measured effect and prediction for safety or traffic flow is poor or not even described.
- If percentages are stated they must be related to the number of accidents to which the respective type of APS relates. These are not percentages that describe an effect on all accidents, so they sometimes appear large while they are not in terms of the total number of accidents.
- The APS settings are usually not supplied.
- In predicting the effects an assumption is made of a penetration level of systems of 100%, so a complete environmental change.

This means that the necessary amount of caution must be taken when using the conclusions of these studies.

Different methods are used in the literature to estimate the effects of APS on safety:

- Comparison of the number of accidents with and without APS.
- By drawing on existing use profiles not involving the use of APS, estimates were made concerning the possible effects of the use of APS.
- By measuring the effects of APS on indirect variables (headway time, variation in speed, braking delay, etc.), a reduction in the number of accidents was estimated.

According to the studies consulted, FCW/HMW systems can have a positive effect on safety. Several studies make no judgements concerning the reduction in the number of accidents but limit themselves, for instance, to a judgement about the reduction in critical situations.

The studies that do estimate direct effects on traffic safety generate very diverse figures ranging from 10% to 21% reduction in the number of accidents, largely attributable to the prevention of critical situations involving short headway times that can be achieved using this system.

It should be noted that the 21% has an uncertainty margin of 24%, which means that the result can also be -3% or 45%.

5. Study of the effect on safety

According to the literature, the use of an LDWA system can also have a positive effect on safety. Specific effects are a decrease in line crossings (intentional and unintentional), an increase in the use of the indicator and elevated alertness. The assumed potential reduction in the number of accidents varies from 5% (on motorways) to 13% (on secondary roads).

As far as the effects of ACC on safety are concerned, the literature paints a positive picture. In general, the use of ACC is responsible for reducing the variation in speeds and longer headway times and headway distances. Estimates indicate that these effects can deliver a reduction in the number of accidents (of 25% on motorways to 49% on secondary roads). However, possible negative (indirect) effects are also reported, in particular an increased risk for traffic travelling behind vehicles with ACC and reduced traffic flow.

Feedback about driving behaviour seems to be capable of having a positive effect on safety, according to the literature. And drivers evidently appreciate feedback. Sometimes the effects appear not to be lasting. If all lorries were equipped with a BBFB system, there would be a significant eduction in the number of accidents involving lorries ranging from 15% to 38%.

No quantitative results for DC were found in the literature. For ESC/ESP (the equivalent of DC for cars) a reduction of between 17% and 27% is expected in the number of accidents. Research studies show that systems that monitor the vehicle's stability and intervene in situations in which there is a chance of the vehicle rolling over or control being lost have a positive effect.

The type of accident on which stability systems can have a positive effect depends, of course, on the particular system's specific function. In addition, the effects appear to be greater on a wet road surface. Incidentally, stability systems can also give rise to an unfavourable behavioural adaptation due to drivers relying too heavily on the system in use.

To summarise, the literature states the following:

- FCW/HMW, LDWA, ACC and BBFB systems can have a positive effect on safety;
- Research shows a positive effect of systems that monitor the vehicle's stability and intervene in situations in which a rollover or loss of control may occur.

However, there is an absence of a generally accepted and usable theoretical framework that attempt more quantitatively to lay a relationship between measured behaviour and the effects on safety. Please refer to the reports [4,5] for the literature consulted and for a more detailed description of the results found.

5. Study of the effect on safety

5.2 SWOV analysis of accidents in the Netherlands

The Dutch national road safety research institute (SWOV) undertook an analysis of the accidents on Dutch motorways for the purpose of this project [26].

The average number of fatalities in Dutch traffic (2004 - 2008) was 810 in 686 registered fatal accidents. The difference can be attributed to the fact that the police do not register everything and that there can be more than one fatality per accident. In around 15% of all fatal accidents a lorry is involved. For hospitalisations this is between 5% and 6%, which - given the fact that lorry accidents are better registered than other accidents - exaggerates the real picture.

Accidents involving lorries are thereby more serious than the average accident, which is unsurprising given their mass and size [28, 29].

In the database of registered accidents in the Netherlands BRON, it is not stated whether the accident occurred on a motorway. It appears to be difficult to ascertain which accidents can be counted as motorway accidents. While the State (Rijkswaterstaat) is responsible for all the motorways, this is not the case for non-motorway roads, as illustrated in Figure 20.

Figure 20: The Dutch principal road network (motorways in dark blue)

By linking the accidents to the ‘current list of roads’ (BRON is coupled to the National Roads database) is it is possible to sect motorway accidents. This reveals, for instance, that each year on State roads 30 fatal accidents occur involving lorries on road sections. For motorways alone the figure is 21 (see Chart 8). Since the incidence of traffic fatalities is the most common traffic safety indicator, one can say that around 3% of the traffic danger relates to accidents involving lorries on motorways, the average total being 810 fatalities per year. On motorway intersections there are few accidents involving lorries, around 1% of the 2,700 or so road section accidents annually. This is because motorway intersections are always on different levels.

The total number of registered accidents involving lorries on motorways, including intersections, was 2,334 in 2008.

Involvement does not mean, of course, that the lorry caused the accident insofar as one party can be held responsible.

5. Study of the effect on safety

Seriousness of accident	2004	2005	2006	2007	2008	Total (2004 - 2008)
Fatal	24	20	22	20	20	106
Hospitalisation	106	111	100	117	93	527
FAO	109	125	106	122	107	569
Light	67	75	44	50	40	276
MDO	2.498	2.499	2.503	2.440	1.965	11.905
Total	**2.804**	**2.830**	**2.775**	**2.749**	**2.225**	**13.383**
MDO (Material Damage Only), FAO = First Aid Only						

Chart 8: Accidents of varying degrees of seriousness on motorway road sections involving lorries

By way of illustration: of the 106 fatal accidents involving lorries on motorways from 2004 to 2008, the lorry was registered as the first collision vehicle ("guilty") in 43 cases, 62 times the second collision vehicle and once neither though involved. The registration of material damage only accidents is probably a little too low given that the police do not give this registration any priority.

In a collision involving a lorry, the driver tends not to be the (most serious) victim; the ratio is around 1 to 12, that is 11 traffic fatalities outside the lorry and one inside. This ratio is different on motorways, around 1 to 5, because there are no cyclists, pedestrians or moped riders on motorways. Each year some 10 lorry occupants die, 4 on motorways.

On 120 km roads there have been 14 lorry driver hospitalisations each year since 2004 (total of 70). A quarter (3 per year on average) comes from abroad.

5.3 Relationship between APS and safety

The effects of APS on safety are influenced by many different factors and importantly include the conduct of the driver. Some of these factors have been explicitly research in the APS field operational test. Some actors have not been studied, for instance because this was difficult to do and they thus fall outside the scope of the project (for example, driver status).

In Figure 18 (Chapter 4.1) the relationship is shown between the APS types and the various indicators that were measured: speed, headway time, etc. These indicators can be considered as elements of the driving behaviour of the driver.

We must take account in the analysis of the fact that these indicators are not influenced solely by APS but also by various other factors (see Figure 21).

Figure 21 reveals that the effects of APS on safety or traffic flow are influenced by a number of factors directly (the third column including 'Driving behaviour of driver') and indirectly since they have an influence on the "direct factors".

The colours show the extent to which the factor is measured in the test as direct or whether the test takes account of the possible influence of this factor. The thick arrows reveal the aspects that were the focus of direct study in this test.

5. Study of the effect on safety

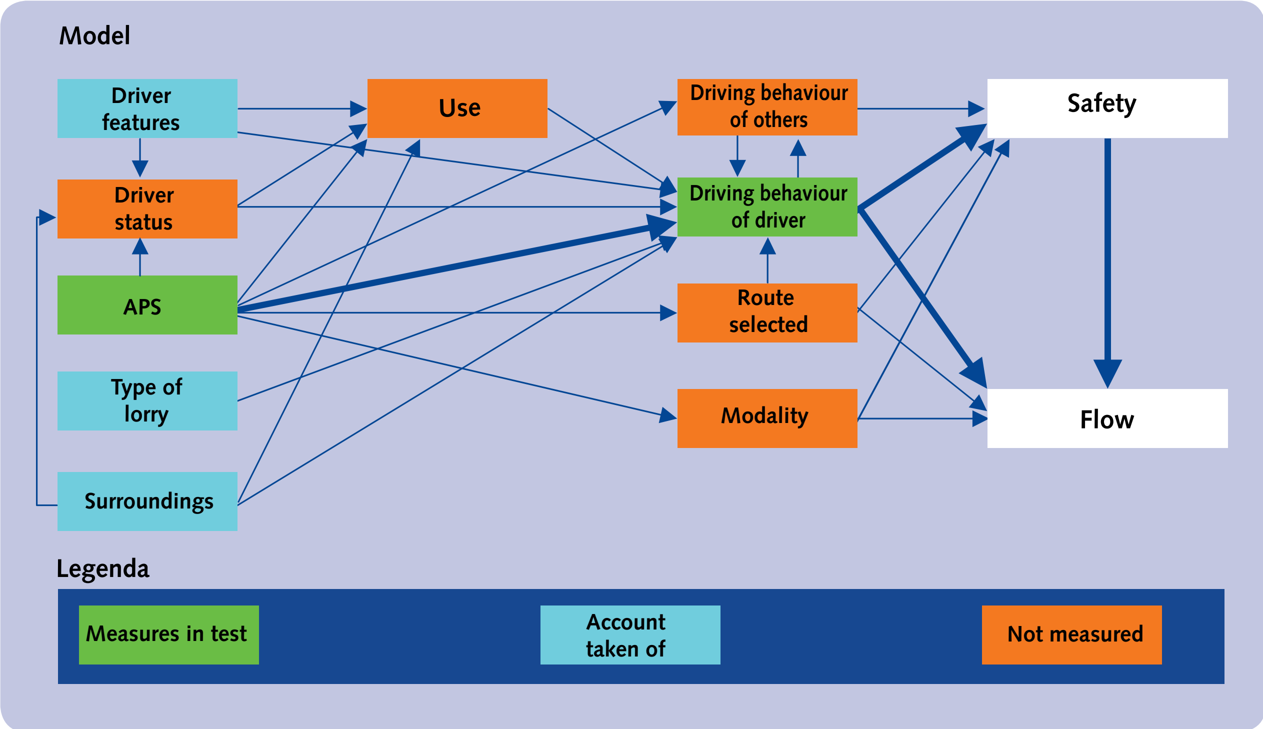

Figure 21: Safety model

Driving behaviour of the driver:

The measurements are a measure of the actual driving behaviour of the driver.

Driver features:

These include the stable properties of the driver, like age and driving style, while beliefs are not directly measured.

Given the scale of the test it can be assumed that any differences will average out.

Type of lorry:

The properties of the lorries are known [27].

Surroundings:

Extreme influence of the surroundings (like weather, road works, traffic picture) are incorporated in the selection of data for analyse.

Driver status:

'Driver status' is a factor not measured in this study.

Use:

In most of the sub-groups the accident prevention system could not be switched off. The ACC can be switched off but this is not logged, just as the Mobileye in SP2. Therefore the test did not log how the driver would use (other APS' or used) ACC any system. System acceptance can be determined through interviews and questionnaires.

5. Study of the effect on safety

Route selected:
It is possible to look retrospectively at the route selected on the basis of GPS data. It cannot be measured whether APS influenced the route selected.

Driving behaviour of others:
The possible effect of APS on other traffic participants and on the selected route are not measured in the test.

Modality:
No effect can be expected by APS on the choice of modality within the context of this test, so it was not measured.

In estimating the safety effects of APS, partial use was made of a methodology used earlier in a project looking at the socio-economic effects of intelligent vehicle safety systems: the eIMPACT project [13].

However, in view of the fact that insufficient clarity still exists about the exact relationships between behaviour variables and the risk of an accident, the conclusions in this report are limited largely to qualitative effects and broad estimates of quantitative effects.

For a detailed description, the reader is referred to the report entitled ‘Conceptual model of safety’ [17].

The eIMPACT study identified nine behaviour mechanisms on which driver assistance systems can have an effect. Each mechanism can result in either positive or negative effects on traffic safety. Within the context of the field operational two mechanisms are important:

- Direct in-car modification of the driving task
    - These are the system’s direct effects, i.e. direct reactions to the system’s output. For example, the system can have an effect on the driver’s mental workload or ensure that the driver brakes. These direct effects can be both intentional (for example: longer headway times) and unintentional (for example: distraction by the system).
- Indirect modification of the user behaviour
    - These are effects caused by the driver’s adaptation to the changing situation, namely driving with the system. In general, these effects are difficult to predict and it takes some time before a driver has developed such behavioural adaptation. Examples of unintentional effects are a decrease in headway time caused by an increased feeling of safety, distraction, etc.

The SWOV database of lorry accidents uses the following accident categories:

- Collision with: pedestrian, parked vehicle, animal, attached object, unattached object;
- Frontal collisions;
- Side collisions;
- Rear-end collisions;
- Single-vehicle accidents.

5. Study of the effect on safety

For the expected effect of APS on traffic safety the lorry must be seen as the 'cause' of the accident so it is important for at least the side and rear-end collisions to recognise the lorry as "first collision vehicle" ('cause').

	Nature of accident	Total 2004-2008	%
Fatal	side	4	4%
	rear-end collision	25	24%
Hospitalisation	side	49	9%
	rear-end collision	105	20%
FAO	side	88	15%
	rear-end collision	154	27%
Light injury	side	49	18%
	rear-end collision	77	28%
MDO	side	2.698	23%
	rear-end collision	2.148	18%

Chart 9: Nature of accidents on motorways involving lorries as first collision vehicle

The percentages in Chart 9 concern all accidents involving lorries on motorways, also where the lorry is not the first collision vehicle. In around half of all serious accidents the lorry is the first collision vehicle and for material damage only accidents this share is higher. The reason is that multiple accidents involving lorries are relatively severe. Single-vehicle accidents tend to involve material damage only or slight injury and the lorry is in such cases, indeed, always the first collision vehicle.

From the above, the accident categories were selected on which the tested systems could have an effect. These are:

- Frontal collisions (FCW/HMW, ACC, DC, LDWA, BBFB);
- Side collisions (LDWA, DC, BBFB);
- Rear-end collisions (FCW/HMW, ACC, BFBB);
- Single-vehicle accidents. (LDWA, DC, BFBB).

Figure 21 shows, among other things, the general relationship between behaviour indicators and safety.

This general relationship is detailed below in terms of which behavioural component relates to which type of accident.

Different APS can have different effects on safety and so on different kinds of accidents. The effects of APS on specific indicators can be categorised into the type of accident.

Chart 10 shows per indicator on what type of accident a change in this variable can have an effect.

Measured variable	Frontal	Side	Rear-end collision	Single vehicle
Headway time			■	
Frequency of short headway times	■	■	■	■
Speed variation	■	■	■	■
Average speed	■	■	■	■
Line-breach frequency		■		■
Large acceleration/deceleration	■	■	■	■
Distance to lane marking		■		■

Chart 10: Summary of accident types whereby measured variable has an effect

5. Study of the effect on safety

Along the horizontal axis the kind of accidents are shown and along the vertical axis the variable. If an area is blue, this means that the variable affects that type of accident. If the area is blank, then no influence is assumed.

Different variable are used to estimate the effects of APS on traffic safety, the main one being speed, speed variation, headway time and frequency of LDWA warnings.

For speed and speed variation formulas are known from literature that can calculate the effect of a change in these variable on the number of accidents or the risk of an accident. For the other variables only critical values are known and not how any change in these critical values influences the risk of an accident.

This means that a quantitative effect per APS can be established purely on the basis of possible changes in speed and speed variation. However, only a qualitative effect can be established on the basis of changes in the other variables.

	DC/ROC	ACC	LDWA	FCW/HMW	BBFB
Average headway time	NSD	6% increase	NSD	NSD	X
Percentage of short headway times (< 1 s)	NSD	3.2% decrease	SP3b: 5.9% increase	NSD	X
Speed variation (standard deviation)	14% decrease	NSD	NSD	NSD	Haulier 1: 24% decrease Haulier 2: 5% increase
Average speed	2% decrease	NSD	NSD	NSD	NSD
LDWA frequency warnings	NSD	35% decrease	SP1: 30% decrease SP3b: 62% decrease	NSD	X
NSD = No Significant Difference, X = No Measurements					

Chart 11: Summary of measured effects of APS on behavioural variables

5.4 Estimating the effect on safety using a model

Based on the conceptual model of safety both the qualitative and quantitative effects of APS on safety were estimated as well as possible. In this chapter an overview of these effects is presented for each system. Where known from eIMPACT [13], the effects of similar systems on safety are reported. Chart 11 shows an overview of the effects of each APS on the measured variables expressed in percentage decrease or increase.

Based on these percentages, the found effects on safety of each system are subsequently described.

DC/ROC

DC/ROC is assumed to have an effect on traffic safety. Based on Nilsson's formula [17], in which the relationship between change in speed and number of accidents is described, it was calculated that a decrease in the average speed of 2% results in a decrease in the number of fatal accidents of 5%. This effect applies to all types of accident.

5. Study of the effect on safety

The decrease in speed variation with the use of DC was too minor to bring about an effect on traffic safety. Moreover, it cannot be attributed to the use of DC, but is more likely to be due to the type of lorry that drives with DC and the driver (tank transport). DC is also typical of a system that intervenes in certain critical situations and thus which often prevents a potential accident. These interventions were not measured in the test.

The eIMPACT study concluded on the basis of earlier studies that ESC (another form of DC/ROC and much used in cars) would deliver in total a reduction of 16.5% in the number of fatal accidents and 6.5% in the number of accidents with casualties (eIMPACT, 2008).

ACC

Looking at the effects of ACC as presented in Chart 11, a minor to reasonable effect of ACC is assumed on traffic safety. A decrease in the percentage of short headway times implies a decrease in the number of rear-end collisions. A decrease in the number of critical headway times can have a favourable effect on all types of accident. A decrease in the number of LDWA warnings with ACC has a favourable effect on the number of flank and one-vehicle accidents.

The eIMPACT study concluded on the basis of earlier studies that ACC would deliver in total a reduction of 1.0% in the number of fatal accidents and 3.5% in the number of accidents with casualties (eIMPACT, 2008).

LDWA

Based on a considerable decrease in the number of LDWA warnings as shown in the table, LDWA is expected to have an effect on traffic safety, i.e. a decrease in the number of flank and one-vehicle accidents.

The eIMPACT study concluded on the basis of earlier studies that LDWA would deliver in total a reduction of 15% in the number of fatal accidents and 11% in the number of accidents with casualties (eIMPACT, 2008 [13]).

FCW/HMW

Based on the data no effect of FCW/HMW on traffic safety is expected. However, in Chapter 4.4 in the analysis of a part of the data, a positive effect is measured at minimum headway time on traffic flow.

BBFB

Despite the fact that with the use of BBFB both a decrease as well as a very minor increase in speed variation was found, it can be concluded based on the formulas of Salusjärvi [16], in which the relationship between change in speed variation and number of accidents is described, that these changes have no effect on traffic safety.

5. Study of the effect on safety

5.5 Number of accidents observed

Only five accidents (with material damage only) were registered or reported during the measuring period and all five were in the reference group whereby the driver is not informed but only data readings are taken. Enquiries among the respective hauliers generated no other figures for the a number of accidents.

The expected number of accidents can be derived in various ways.
Firstly, the population ratios.

- The group of vehicles monitored is around 1% of the total population of lorries on Dutch roads.
- The measuring period is 8 months.
- In 2008 2,334 accidents involving lorries on motorways (see 5.2), including intersections, were registered.
- Based on the population ratio some 16 accidents can be expected.

Secondly, the measured quantity of vehicle kilometres.

- In 2008 2,334 accidents involving lorries on motorways (see 5.2), including intersections, were registered.
- Rijkswaterstaat reports indicate that in 2008 63 billion vehicle kilometres were driven on motorways.
- 15% was driven by lorries: this is around 9.45 billion vehicle kilometres.
- The population monitored drove 77 million kilometres in the Netherlands.
- Based on these ratios some 19 accidents can be expected.

The reference group is some 30% of the total field operational test, so around 6 accidents can be expected in this group. The actual number, 5, deviates very little therefore. The relatively low number of registered accidents is not predicted on the basis of the measurements of the effects of APS in the field operational test. Those effects are really not so large that they could directly explain such a difference.

In theory other explanations are conceivable. For instance, it could be that the drives who knew they were participating in an accident prevention test took this into account in their driving behaviour. On the other hand, all the drivers were aware of their participation, even those in the reference group.

Further research is desirable to investigate the causes, for instance by monitoring the accidents in this group for a longer period of time and analysing the data further.

6. Study of the effect on traffic flow

6.1 Literature study

The accident prevention systems can influence traffic flow in two ways: via an effect on the driver's regular driving behaviour and via an effect on the number of accidents, which in turn can cause traffic jams. These are referred to as direct and indirect effects respectively. In general it is evident from the results of this literature study that each of the systems has a positive effect on traffic flow by causing the number of accidents to decline. The literature is not unequivocal about the extent to which this occurs and the equipment level that is necessary to achieve this effect.

As to the effects on traffic flow achieved through an adaptation of regular driving behaviour, the sources are virtually unanimous with regard to LDWA: the effect on traffic flow that can be expected with this system is none at all or at most a small positive direct effect. For the systems BBFB, DC, FCW/HMW no studies were found that have conducted research into the direct effects on traffic flow. For the most part, a positive effect was found for ACC, under certain conditions for the equipment level and system settings (for headway times in particular). Owing to homogenisation, the lane capacity increases potentially by a couple of per cent, provided the preset headway time is sufficiently low. It may be that a mix of ACC and non-ACC vehicles is required to achieve the maximum effect. In addition, ACC types specially designed for traffic jam driving can limit the time lost in traffic jams by 30% to 60% and raise the outflow from traffic jams by 7%.

To summarise, the following is stated in the literature:

- All five APS have a positive indirect effect on traffic flow since they cause the number of accidents to decline.
- A positive direct effect on traffic flow achieved through the adaptation of driving behaviour is assumed for ACC only, under certain conditions.
- For BBFB, DC and FCW/HMW no results concerning direct traffic flow were found.
- The direct effect of LDWA appears to be neutral, or potentially slightly positive.

6.2 Model

The conceptual model of traffic flow translates the impact of APS on driving behaviour (established on the basis of the actual data) into an effect on lane capacity. In the APS project it was decided to work with a version of the fundamental diagram method. This method was used in two ways: in a hypothetical scenario exclusively with lorries, and in a more realistic scenario involving mixed traffic. Both scenarios are presented in Figure 22. For a larger presentation of the two visuals accompanied by text and explanatory notes, the reader is referred to Appendix 3. The conceptual model is described in more detail in [12].

Data from the APS test are shown in the blue boxes. Data from other sources [Monica data, 13, 14] are shown in yellow boxes.

The two scenarios are represented in the two diagrams.

The two scenarios are represented in the two diagrams. In the left diagram (exclusively lorries) a relationship between the headway time and speed of lorries is sought based on the actual data. From this relationship, the minimum headway time can be derived and then lane capacity estimated for the hypothetical situation of traffic comprising exclusively lorries equipped with APS. To make such an estimate, data for traffic at high intensity, in particular, are necessary.

6. Study of the effect on traffic flow

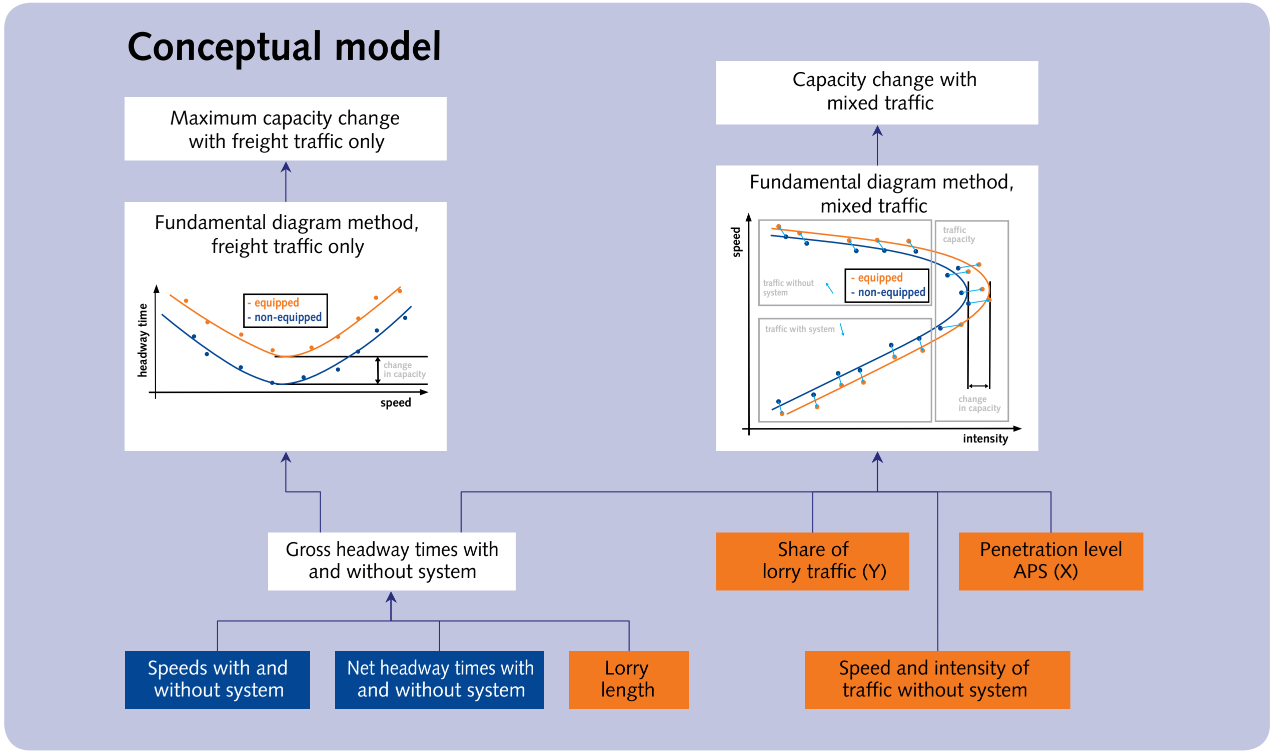

Figure 22: Conceptual model of traffic flow (both diagrams are explained in appendix 3)

Given that lorries drive predominantly at low traffic intensity, with a considerable headway (two seconds or more), a selection was made for the analysis whereby measuring points with short headway times were chosen in order to derive the relationship between headway time and speed. The right-hand diagram (mixed traffic, i.e., equipped and non-equipped lorries and other traffic) presents a fundamental diagram for the reference situation on the basis of data from measuring loops. For the project situation the data points were modified based on the test data. Each data point in the reference situation is thus shifted and a new diagram created. The capacity is the maximum intensity according to this diagram.

6.3 Traffic flow effects as a result of change in driving behaviour

Accident prevention systems may have an influence on the driving behaviour of the driver, who may opt for a different speed or headway distance or a more constant drive. If a large number of vehicles is equipped with APS, these changes can have noticeable consequences for the traffic flow of the total traffic. The number of vehicles participating in the test was far too few compared to the total traffic stream to generate a direct effect on traffic flow; congestion would not be reduced. For this reason, traffic flow effects were not determined directly from the test, but with the aid of a conceptual model (see 3.3.2). This model describes the impact of the system on driving behaviour based on the actual data and translates this into effects on traffic flow. The effect

6. Study of the effect on traffic flow

is expressed in lane capacity, i.e. the maximum number of vehicles that a road section can process in an hour.

This involved making a number of assumptions and choices:

- APS has an effect only on aspects of driving behaviour, such as the choice of speed, lane and headway time. APS has no influence on strategic driving behaviour and transposition choice. The possible effect of APS on the driving behaviour of the other traffic was not included.
- As well as APS, there are many external conditions that can influence driving behaviour or the effectiveness of APS systems such as road type, weather and load. These conditions were taken into account as far as possible in the analysis and set-up of the test, but for practical reasons not all conditions were included in the analysis.
- The effect of APS on lane capacity is proportional to the number of equipped vehicles (or more precisely with the penetration level), i.e. no interaction effects were included [2].
- Effects at network level (network capacity, journey time losses) were not included.
- For ACC only the effect of ownership was determined, not the effect of use.
- Only significant differences evident from the actual data were included in the analysis.

As explained (figure 22, conceptual model of traffic flow) an effect on lane capacity has been derived in two ways: for a hypothetical situation with (equipped) freight traffic only and for the situation with mixed traffic (equipped and non-equipped and other traffic). Since the first method uses a selection of data (namely the data elements with short headway times) and the second method uses all data, the methods may deliver different results. In that case, the second method should be regarded as the most reliable, and the first used only indicatively.

Results of the 'freight traffic only' analysis

- LDWA had a negligible effect on the minimum head way time for non-tank lorries: depending on the lorry type in the SP, the minimum headway time increased or decreased due to LDWA by less than 0.1 second.
- FCW/HMW caused an increase in the minimum head way time for an articulated lorry: in the reference this was 0.062 sec, with FCW/HMW 0.2 sec, an increase of 0.14 sec (228%). The diagram showing this result can be found in Figure 23.
- ACC had a minor effect on non-tank lorries. The minimum headway time fell from 0.44 sec to 0.31 sec, a decrease of 0.13 sec (29%) or around 3 metres' distance at 80 km/h.

In Figure 23 the headway times of vehicles equipped and not equipped (reference) with FCW/HMW are set against the average speed; these are represented by the crosses and circles in the figure. For both equipped and non-equipped vehicles, the fourth-degree polynomial is then shown that provides the best match with the minimum headway times, the blue and pink lines in the figure.

[2] *This is a frequently made assumption in FOTs, stemming from the fact that it is not known what happens to the non-equipped traffic that is confronted with equipped vehicles.*

6. Study of the effect on traffic flow

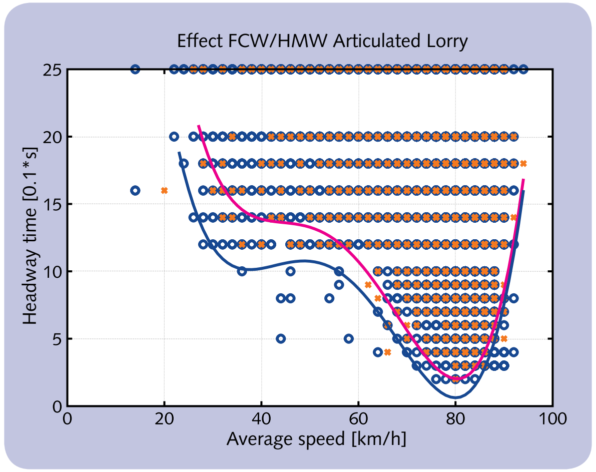

Figure 23: Effect of FCW/HMW on articulated lorry (freight traffic only scenario)

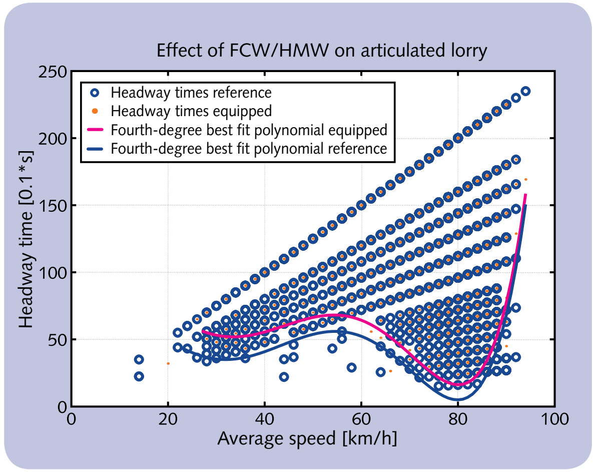

Figure 24: Effect of FCW/HMW on articulated lorry (freight traffic only scenario), with headway times set against average speed

To make Figure 23 clearer the same data are plotted in Figure 24 but with headway distance set against average speed and the headway times converted into headway distances.

What is noticeable is how short the headway distance can be at speeds in the region of 70 to 90 km/h. Secondly, it is clear that FCW/HMW in the average headway time has a tangible positive effect while that was not visible in the percentage of short headway times (< 1 s).

DC is used mostly on container lorries. For DC too few data points were available to make reliable judgements about headway times and, thus, traffic flow.

However, it is expected that drivers of tankers will keep longer headway distances and thus longer headway times due to their safer driving behaviour. This is due to the type of lorry, however, not to DC.

Results of the 'mixed traffic' analysis

For 'mixed traffic' it was necessary to choose the number of equipped lorries since the effect of APS on lane capacity depends on the number of equipped lorries. The APS penetration level is defined as the fraction of the total number of lorry kilometres on Dutch roads travelled by a vehicle equipped with APS.

The penetration level in the test was too low to have any effect on the traffic system. For this reason, the analysis of the traffic flow effects was performed for penetration levels chosen in advance. To determine the effect, the project situation was compared with a reference situation. For the reference situation the APS penetration level was set at 0%, i.e. none of the lorries is equipped with APS. For the project situation two scenarios were investigated: one with 100% penetration, and one with the penetration levels shown in Chart 12.

APS	ACC	LDWA	FCW/HMW	BBFB
Penetration level	25%	50%	50%	25%

Chart 12: Penetration level

6. Study of the effect on traffic flow

Since it is highly likely that effects found for DC would not be attributable to DC but to the type of lorry and the driver, DC was not included in the analysis.

These penetration levels were based as far as possible on a projection taken from eIMPACT [3] [13] of the penetration level of a number of systems similar to APS in the year 2020.

For ACC a significant effect on headway time was found, and for DC a significant effect on speed was found. It is possible, therefore, that these two systems have an effect on lane capacity. For the other systems no significant effect on headway time or speed was observed and thus no significant effect on lane capacity can be expected.

For ACC the effect on lane capacity was determined with the aid of the fundamental diagram.

This assumes a share of freight traffic of 15% [14] (i.e. that 15% of the vehicle kilometres on the Dutch motorways is driven by lorries). The fundamental diagram complete with actual data measured between hectometre poles 40 and 45 on the A2 is shown in Figure 25. The vehicle intensity is shown on the horizontal axis as number of vehicles per hour (Vgt/u), with the average speed of the vehicles on the vertical axis. The blue dots show the actual data from the test; intensity is set against average speed (the fundamental diagram). Two lines have been plotted: the black line for the reference scenario and the green line for the scenario with 100% penetration. The maximum of the curve is the lane capacity.

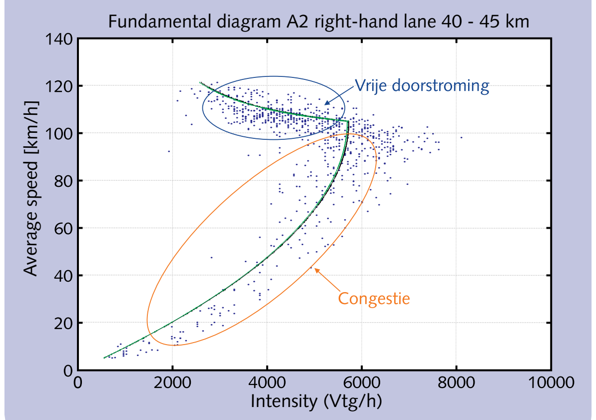

Figure 25: Effect of ACC on lane capacity on a 3-lane motorway (blue dots: actual data; black curve: reference scenario; green curve: scenario with 100% penetration)

The results are summarised in Chart 13. A negative percentage means a decrease in the lane capacity.

APS	Penetration level	Effect on lane capacity as function of penetration level and number of lanes	
		Motorway, 2-lane	Motorway, 3-lane
ACC	25%	-0.14 %	-0.15 %
	100%	-0.56 %	-0.58 %

Chart 13

To give an idea of the percentages: an effect of -0.58% with 100% ACC on a three-lane motorway means a capacity drop of 30 vehicles an hour for a total of 1,700 vehicles per hour per lane.

3 *In the eIMPACT European project (concluded in 2008) an impact assessment was performed for 12 safety systems. Penetration levels for these systems were estimated for the years 2010 and 2020.*

6. Study of the effect on traffic flow

Conclusions:

- It is evident from the 'mixed traffic' analysis that for ACC the effect on lane capacity is very minor and negative, even at 100% penetration.
- From the 'freight traffic only' analysis it follows that LDWA has a negligible effect on lane capacity
- From the 'freight traffic only' analysis it is evident that FCW/HMW causes an increase in the minimum head way time and that ACC is responsible for a decrease in the minimum headway time.

The following comment should be made. With the use of ACC, lane capacity reduces. This appears to contradict the result found earlier that the *minimum* headway time reduces with ACC. However, the *average* headway time rises with ACC, causing the lane capacity to diminish.

In devising the conceptual model, assumptions were made. This means that there is a tolerance with regard to the outcomes. This tolerance is probably greater than the calculated effects. To summarise, it does however remain very plausible that a change in driving behaviour due to the use of APS has no to at most a minor negative direct effect on lane capacity. By means of a reduction in the number of accidents, however, an indirect positive effect can occur. This is discussed in the following chapter.

6.4 Traffic flow effects as a result of accident

Accident prevention systems may reduce the number of vehicle hours lost as a result of traffic jams caused by accidents. This effect is divided into a primary effect (traffic jam upstream in the same lane as where the accident occurred) and secondary effects (knock-on of the jam to other highways and onlooker jams).

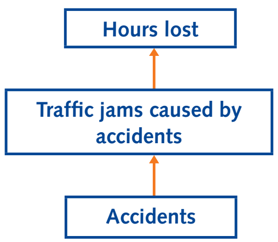

Figure 26: Relation between accidents and hours lost

To establish the traffic flow effects of APS, it is essential to identify the vehicle time lost caused by a lorry accident. To do this information regarding accidents on the motorway in 2007 (registration of incidents from the Monitoring Incident Management programme by DVS) was linked to information regarding traffic flow (Monica data).

The number of hours of vehicle time lost was determined for each accident. Naturally, it is recognised that this vehicle time lost cannot be attributable in all cases to the accident - there are always normal traffic jams to consider. Therefore, the time lost not caused by the accident (the 'reference situation') was subtracted from the total.

Aggregating the effects of the individual accidents results in the total direct effects. These direct effects were scaled up since the available data did not by definition comprise all accidents (these data were sometimes not registered in their entirety and the calculation relied on a representative number of accidents from 2007). A subsequent upscaling took place for the secondary effects referred to above.

The upscaling factors used were determined statistically on the basis of several cases. A detailed description of the method and the results can be found in [15]. Only the motorway was taken into consideration. As a result, the repercussions for the secondary road network were underestimated.

The calculation for 2007 shows that round 1.1 million vehicle hours were lost due to lorry accidents on motorways in the Netherlands, some 1.6% of the total vehicle time lost in that year on these roads. Naturally, there is no possible way all these lorry accidents (and thus these vehicle hours lost) can be prevented by APS.

From section 5.2 no good unequivocal figure follows for the reduction in the number of accidents per year. To be able to estimate the effects, 3 scenarios have been calculated.

To do this, two assumptions were made:

- The accidents that APS can prevent concern all lorry accidents, i.e. all accidents in which lorries are involved. These are both accidents caused by lorries and accidents with another cause.
- The accidents that APS can prevent are evenly distributed; i.e. they cause an 'average' number of vehicle hours lost. A reduction of 1% in the number of lorry accidents in one year causes a reduction of 1% in the vehicle hours lost in that year by lorry accidents.

Reduction in number of accidents (%)	Effect on vehicle hours lost
-5%	-55.000
-10%	-110.000
-15%	-165.000

Chart 14: Saving in terms of vehicle hours lost as a result of fewer accidents

The results for various accident reduction percentages are shown in Chart 14.

7. Study of incentives to use APS

Both drivers and companies were asked about their experiences of using the accident prevention systems and whether they believed the systems had a positive effect on their driving behaviour. Almost 400 questionnaires were completed and 280 interviews held, divided over the various sub-projects.

All participating business owners were asked to submit a company profile so that the results of interviews and online surveys, etc, could be set in the right perspective. 73 business owners (65%) submitted the profiles.

Finally, interviews with the business owners were held in which representatives of most of the participating companies were asked to give their opinions. The business owner sessions drew a total of 30 hauliers and OEMs together to share experiences and opinions. Online surveys [22] and face-to-face interviews [21] enabled the drivers' opinions to be collected while an online company profile form [24] and company sessions [25] generated information about the participating companies and their experiences with APS.

7.1 Results of driver surveys

The feelings of the participating drivers towards the systems tested in the FOT ranged mostly from neutral to positive. Various opinions and experiences of each system were stated, as shown in Figure 27 and Figure 28. In particular, drivers driving with ACC felt positive about the system.

The drivers in the liquid bulk segment were the most positive about the system they drove with. In the test, most drivers in this segment drove with ACC or DC. The driver attitude results can be divided into two categories.

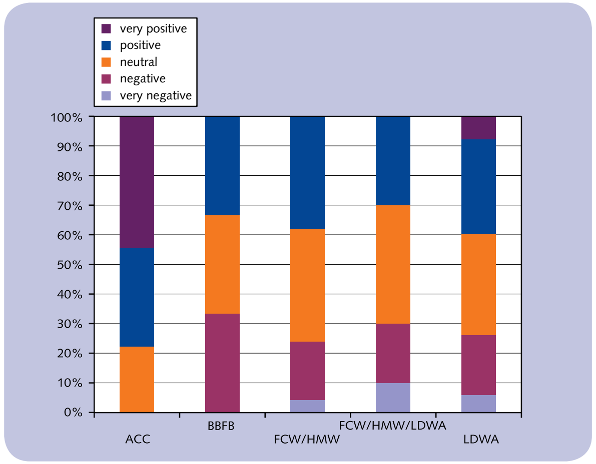

Figure 27: Driver opinion per system

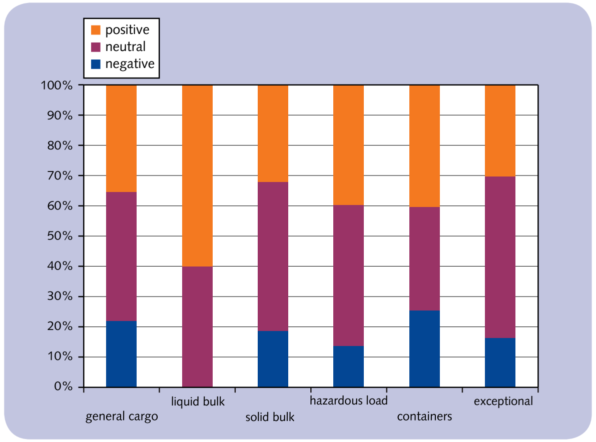

Figure 28: Driver opinion according to type of transport

The first category relates to the presetting of the systems. The second category concerns user experience. Many drivers are irritated by the number of alarms and the type of signal given by various of the APS. In the interviews almost 80% of the drivers mentioned false alarms.

The majority of events regarded as false alarms actually arose from the standard setting chosen for the purposes of the FOT research aims. In practice this setting meant, for example, that LDWA issued an alarm for 'touching the road lines' and FCW/HMW raised the alarm if the lorry

7. Study of incentives to use APS

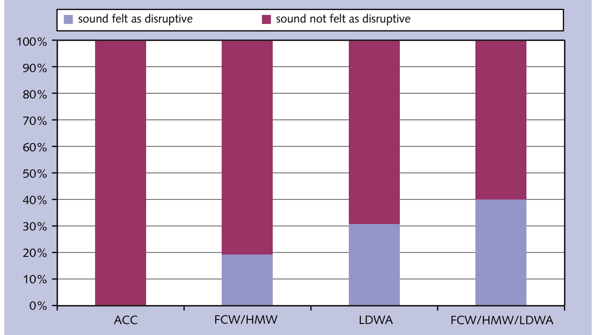

Figure 29: Driver reaction to type of audio signal depending on type of APS

approached the vehicle in front with a headway distance of 2 seconds.

In practice, these settings would evidently be considered very strict. For example, the chance of the LDWA issuing false alarms would be very high on a road with reduced lane width due to road works. This prompted drivers to feel irritated (which was expressed by sabotage efforts, among other things). Drivers driving with ACC experienced no false alarms. How pleasant drivers felt a certain APS to be can be derived from their experience of the system's presetting. On a Van der Laan scale [22] this is set against a system's usefulness.

Figure 30 shows that the drivers did not always find an APS pleasant to use but that all systems were considered useful. A quarter of the drivers thought they would drive more safely.

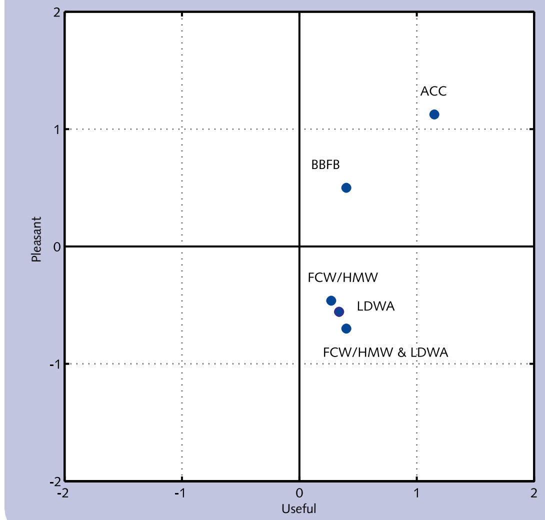

Figure 30: Acceptance: 'pleasant' versus APS 'usefulness'

The sub-group of drivers with ACC is an exception: two-thirds believed that they would drive more safely with ACC. There is no link between the age or experience of the drivers and their opinion.

Figure 31 shows whether drivers wished to continue driving with APS at the end of the study. Of the drivers with ACC, 90% agreed with this statement.

For the other systems, 30% to 70% of the drivers said they wanted to continue driving with APS.

For the BBFB the drivers' responses appeared evenly divided between two extremes: 'agree' to 'strongly agree' and 'strongly disagree'. 34% of the drivers felt that all drivers should be driving with the APS they themselves used. But 24% felt this was not worthwhile. Almost half the drivers were neutral on this point.

7. Study of incentives to use APS

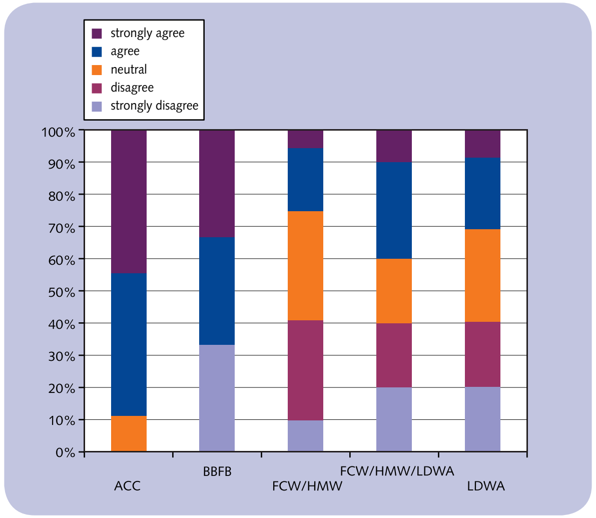

Figure 31: Does the driver wish to continue with APS after the test?

7.2 APS from a business owner perspective

The experiences related to business owners by their drivers match the findings of the questionnaires and interviews.

For the retrofit systems, scope for flexible adjustment was voiced as being very important in view of the range of driving styles, the work carried out by the lorry and the need to prevent false alarms.

For all systems the business owners stated that they are robust enough to operate in the lorries; there is hardly any incidence of system failure.

As far as the operation of systems is concerned, it is noted that the type of signal issued to the driver needs further consideration. A loud audible signal as used during the FOT is irritating. Driver acceptance may well be increased by a different audible signal or some other type of signal (e.g. a light signal). In addition, business owners said that systems have a greater effect at certain times. Drivers seem to feel the system's added value is most evident later in the day and at night or during longer trips. No effects were reported or measured in terms of fuel consumption.

Virtually all the participating companies have indicated a desire to continue using these systems after the end of the test. At least 7 companies have indicated that they will extend use of APS to lorries not currently equipped with the system. The rest still want to have more insight into the costs-benefits analysis of these systems.

From the reactions of the companies it can be expected that based purely on operations the key criteria for the use of APS are:

- Correct operation of the system and flexible setting;
- A proven effect of APS on traffic safety;
- No adverse costs-benefits ratio for APS;
- Clear explanation upon delivery of APS to the driver and company so that they are cognisant of the operation and purpose of the system;
- Acceptance of the systems by the drivers (in part dependent on the explanation of the correct operation of the system).

8. Discussion

Effect on driving behaviour

The field operational test reveals that accident prevention systems have a variety of effects on the driving behaviour of the lorry driver. While these effects may be small, they are statistically significant. This means that the test contains a sufficient quantity of data to be able to reveal such small effects. In other words, if not APS effect could be derived from the data, then the likelihood is that the effect was, despite everything, small to very small.

However, there are disruptive factors. Given that it proved not entirely possible to fully randomly allocate the conditions (APS to lorry/driver/haulier) and to block the settings of the systems, it cannot be excluded that the effects found are the consequence of differences among the various groups. Vice versa, it is possible that the differences among the groups mask effects in the measurements that are actually present. Better insight into these influences can be obtained through further analyses of the data and verification of the hypotheses.

Dutch situation

It is also possible that Dutch motorways differ from those in other countries and that this may be the cause of other effects. There are thus clear indications that in the Netherlands the headway times are relatively short in heavy traffic, shorter than in neighbouring countries. Measurements of average headway times and distances (Figure 24, chapter 6) reveal how very close vehicles drive to each other. At 80 km/h the headway time in many cases is low than 1.5 seconds, and even less than 0.5 seconds. At such headway times the FCW/HMW gives a continuous warning.

These short headway times could have a considerable effect on the driver in the performance of his driving task and the effects of systems on how the driving task is performed. The strongest indication can be found in the ACC results, although it is not known for what period of time the ACC was actually switched on, the behavioural changes found were significant: 6% increase in average headway time and 3.2% reduction in short (<1 s) headway times, both good for safety.

LDWA

A noticeable change in behaviour is that the number of LDWA warnings falls by a good 35% while this is not an intended ACC objective. One theory is that keeping your distance from the vehicle in front (especially if that is a lorry that also hinders the view ahead) in busy traffic is an intensive driver task. ACC takes the strain of that intensive task and thus allows more attention to be paid to another task: keeping on course, resulting in a better performance of the task. The popularity of ACC among the drivers confirms this picture.

For Lane Departure Warning Assist (LDWA) shown contradicting behavioural changes: the large decrease in the number of warnings is coupled with more short headways times, a result that also suggests that the explanation can be found in a driving task model for the driver.

An LDWA system that distracts from the main task of 'queuing' could cause this effect. It is conceivable that a different LDWA setting leads to less or no increase in the driver load whereby a net safety effect is generated. Furthermore, an LDWA could serve as a surrogate 'alertness system' but no research has been done into this.

8. Discussion

Measurements

Assuming that in the Dutch situation, maintaining distance to the preceding vehicle in busy traffic is a key component of the driving task, the measurements support the theory that:

- ACC directly alleviates the main part of the driving task, with indirect support from FCW/HMW;
- DC and ROC actively prevent dangerous limits from being exceeded;
- LDWA is supportive in preventing dangerous deviations provided the set-up is such that the attention of the driver is not distracted from his main task;
- BBFB ensures a more consistent driving behaviour provided the social embedding of the feedback is properly catered for.

A striking result is that just five (with just material damage) registered or reported during the measuring period and all five were in the control group whereby the driver was not informed but that data were measured. For such a sizeable population as in this field operational test (on the basis of kilometres driven and/or number of lorries) an average of 5 - 6 accidents for the reference group and 11 - 13 accidents for the test group were predicted. The reported/registered number of accidents in the reference group with a 'silent' APS was as expected. The absence of registered or reported accidents in the APS test group is a striking deviation. This difference cannot be directly explained from the measured effect of the APS or by differences in the quality of the drivers. Since the reference group was cognisant of the fact they were participating in a test using accident prevention systems, it is unlikely that this knowledge will have made the difference. It is recommended that both the group using APS and the reference group are monitored for a longer period and to continue registering the number of accidents to see whether the number of accidents remains as low as measured for a longer period.

It has been very difficult to lay a direct relationship between the influence of the systems on driving behaviour and the impact of this on traffic safety. This is mainly because the driver is the unknown link between the (informing) systems and driving behaviour in a particular situation. There appears to be little general knowledge about this relationship. Moreover, the detailed and continuous measuring of driving behaviour falls outside the scope of this project. In subsequent research it is recommended to delve deeper into the relationship between engineering systems and behaviour, that is the performance of the driving task by the driver in the context of the surroundings in order to develop better models than are currently available.

The amount of data collected in the FOT is huge and the analysis performed limited given the period of the test. It is recommended to make the dataset available to third parties for further analysis.

Traffic safety

It is recommended to continue providing incentives to use APS, and especially ACC, now that positive experience gained. However, given the adverse economic circumstances in the transport sector, the willingness to invest is currently low.

The total number of lorries involved was around 2,400 from 123 participating companies, which made this a much larger and more extensive field operational test than previous tests of APS equipment. This fact generated both challenges and limitations as well as learning experiences about tackling such large-scale practical trials and data processing. Learning experiences that are quite unique, given the level of (international) interest.

9. Conclusions

Effectiveness of the systems on the test track

The test track experiments and loan test reveal the technical effectiveness of active driver support systems (intervention, information and feedback). They do what they have to do: reliably detect, warn and, where possible, intervene. They appear to be adequately robust and reliable for use in the daily operations of a haulier.

Effectiveness of the systems in practice

The results of the analyses indicate that the systems have an effect on the driving behaviour of the driver.

ACC

While it is not known for what period of time the ACC was actually switched on, the behavioural changes found were significant: 6% increase in average headway time and 3.2% reduction in short (<1 s) headway times, both good for safety.

DC/ROC

The effect of DC and ROC on rollover risk is clearly found in the loan test. Given that these systems intervene autonomously, the certainty that they will have an effect is considerable.

LDWA

The results of the LDWA system reveal a fall of 30% (retrofit) to 60% ('ex-factory') of the number of LD warnings. In both cases the reduction is positive, whereby it is noticeable, to say the least, that for retrofit a lower effect is found than for ACC (35% fewer LD warnings). The differences could be attributable to the research group or the set-up and use of LDWA (the ex-factory systems are, for instance, adjusted by the supplier according to its standard set-up.) The simultaneous increase of 5.9% in short headway times (<1%) found in the group 'ex-factory' (the category where the biggest effect is found on LD warnings -60%) is unfavourable.

FCW/HMW

The variance analysis into the effect of HMW and FCW on the percentage of short headways reveals no significant difference while the analysis of the average traffic flow headway times for a specific group show an increase in the headway times of around 0.14 seconds.

BBFB

One BBFB type was used in the test whereby the behavioural effect varied for different groups, namely a haulier and a group of rented lorries. The first group showed the desired behaviour, 24% less speed variation, while the second group showed slightly undesirable behaviour, 5% more speed variation.

Accidents

There were 5 accidents (with just material damage) registered or reported during the measuring period and all 5 were in the control group whereby the driver was not assisted by an APS. For such a sizeable population as in this field operational test (on the basis of kilometres driven and/or number of lorries) an average of 5 - 6 accidents for the reference group and 11 - 13 accidents for the test group were predicted. The reported/registered number of accidents in the reference group without APS was as expected. The absence of registered or reported accidents in the APS test group is a striking deviation.

9. Conclusions

Effects on traffic safety

A model has been established to enable estimates to be made of active intervening systems and these show that ACC and DC/ROC may be expected to have a larger impact than other systems.

It is clear that DC/ROC has an effect on safety. The effect of SWOV [26] can be calculated as 1 prevented fatality and 5 prevented hospital casualties annually. For all the victims to whom the APS test relates, some 25 fatalities and 135 hospital casualties caused by accidents involving lorries on motorways, this is 4%.

It can be assumed that Adaptive Cruise Control (ACC) will reduce the incidence of victims caused by accidents involving lorries on motorways. Since rear-end collisions (1st colliding vehicle being lorry) and singular accidents make up a substantial proportion of serious accidents, ACC can have a considerable effect.

Although the measurements do not provide an unambiguous picture, it can be assumed that that the application of HMW/FCW will lead to a positive effect on rear-end collisions and singular accidents.

The same applies to BBFB if it is incorporated properly within social behaviour influences.

Effects on traffic flow

The effect of APS on the traffic flow was predicted using a conceptual traffic flow model composed on the basis of literature and expert meetings. The direct effect on traffic flow is minor since hardly any significant deviations of the average speed and headway time could be demonstrated between vehicles containing active APS and the reference group. The indirect effect by avoiding accidents will be present, however, but is difficult to quantify. The magnitude will always be limited given the very modest share (ca. 1.6%) of the lost vehicle hours caused by accidents involving lorries [15].

Stimulating use

Consultation among players in the market and driver questionnaires reveal that these systems are valued by them in practice, provided that they are set up in harmony with practice (prevention of excessive warning). The systems contribute positively to the perception of safe driving and the professionalism of the performance by the driver of his driving task. ACC is particularly experienced as positive and the robustness of all systems considered more than adequate.

Following the practical test the number of APS systems (different from ROC/DC) coming onto the market (ca 1,600) has risen considerably. The systems are not being extended but brought back to their original state and given to the hauliers that collaborated. Virtually all the participating companies have indicated a desire to continue using these systems after the end of the test. At least 7 companies have indicated that they will extend use of APS to lorries not currently equipped with the system.

The rest still want to have more insight into the costs-benefits analysis of these systems.

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Supplementary reports

The reports below form a separate part of this APS report:

[21} APS Project - Data Quality Assessment, Final Report, Ernst & Young, July 2009.

[26] Traffic safety effects of accident prevention systems, Rob Eenink, SWOV, July 2009.

Appendix 1: Explanatory word list

ACC
Adaptive Cruise Control
This system uses sensors to automatically maintain a safe distance to the vehicle in front and to maintain a speed set by the driver. If necessary, it adapts the speed of the vehicle to maintain sufficient headway distance.

Anti-rollover tests
The testing of the effects of the Directional Control and Rollover Control anti-rollover systems during extreme steering movements. This occurred on a test track with the aid of a lorry fitted with side-wheels. Subsequently, measuring data about the rollover risk was collected on the public highways.

APS
Accident prevention systems
Driver assistance system.

APS Detail
During each APS event a fragment van 10 s data is logged in detail. This includes date and time, GPS location (1 Hz), acceleration (in both longitudinal and lateral directions; 10 Hz), signals from the Clifford Electronics/MobilEye (approx. 10 Hz). The maximum limit set on the quantity of this type of data collected per month per lorry was 6 Mb in connection with the GPRS costs.

APS Summary
Detailed information each time that an output signal from an APS changes status, this counts as an event that will be logged. The following are logged: date, time, licence plate number, event type, current speed, GPS location, map matching output. An event is logged only at speeds exceeding 55 km/h and only in the Netherlands.

BBFB
Black Box Feed Back
This registration system measures the driver's behaviour during driving and records, for example, fuel consumption, speed, brake movements and the use of cruise control. The system feeds these data back to the driver.

Bulk
Goods traded based on weight and/or content.

Conceptual model
This model indicates the scope of the research element, the selection of the characteristics (variables), and the relationships between these characteristics. In order to measure the effects on driving behaviour, safety and traffic flow in the test, conceptual models were developed that could translate the outcomes of the analysis into the requested effects.

Crash Detail
Detailed information of each collision; in a fragment of 7 s: date and time, GPS position (1 Hz), acceleration in longitudinal and vertical directions (100 Hz).

Crash Summary
Summary information of each suspected collision; date and time, licence plate number, GPS location, maximum acceleration, collision speed.

DC
Directional Control
A system able to correct over- and under-steering problems. This system controls the brakes when the steering movement deviates too much from the vehicle direction.

Driver group
This subproject looked primarily at driving behaviour. This involved using data from the black box and interviews with

Appendix 1: Explanatory word list

drivers. This subproject was carried out on a large scale among a limited number of companies.

eIMPACT

eIMPACT is a project in the sixth EU framework programme for 'Information Society Technologies and Media'. It analysed the socio-economic consequences of Intelligent Vehicle Safety Systems.

ESC

Electronic Stability Control

ESP

Electronic Stability Program

Built-in active safety element to stabilise the vehicle.

Estimation algorithm

A calculation methodology that calculates an estimate for a certain parameter.

Factory-fit systems

Systems built into new lorries by the manufacturer.

FCW/HMW

Forward Collision Warning/Headway Monitoring and Warning

These systems, which in this study were linked, warn the driver when the lorry approaches another object too closely; the aim is to prevent a collision. At the moment that the vehicle keeps insufficient distance, the system gives an audio and visual signal via a dashboard display.

FESTA

European Commission project in which a method was devised for the performance of large-scale field tests. This project resulted in guidelines for the set-up, performance, and analysis of large-scale field tests. These FESTA guidelines were adhered to in the APS test.

FOT

Field Operational Test or field test

General cargo

All sorts of harmless, conventional goods, such as domestic items, electronics and plastics. Usually packed on pallets or in containers.

GPRS

General Packet Radio Service

Standard for data transmission

GPS

Global Positioning System

Location determination using a satellite system

GSM

Global System for Mobile communication

A designation for a standard for digital mobile telephony.

ITS

Intelligent Transport Systems and Services

LDWA

Lane Departure Warning Assist

This system warns when the vehicle is about to leave the lane. A camera recognises the difference between the road surface and the lines and issues a warning at the moment that the vehicle is about to cross a line; no use of the indicator is involved.

Appendix 1: Explanatory word list

MAUT
LKW-Maut, route-dependent toll for lorries in Germany.

Mobileye
Brand name for the retrofit in-built accident prevention systems.

OEM group
In consultation with various manufacturers, several systems were factory-fitted in lorries and then tracked.

OEMs
Original Equipment Manufacturers
This refers to the manufacturers of cars and lorries.

Operational driving behaviour
This refers to the elementary driving tasks that must be carried out to drive a vehicle, such as operating the pedals, changing gear and steering. Together, these elementary tasks form a manoeuvre.

Predictive algorithm
A calculation methodology that makes a prediction about the value of a certain parameter in the future.

Reference group
A group of vehicles equipped with accident prevention systems that issue no warning but only measure; this was done to enable the measurement of the difference with the systems that issued a warning.

Retrofit group
In this subproject accident prevention systems were built into the lorries and tested over eight or more months.

Retrofit systems
Systems built into lorries some time after they have left the manufacturer.

Request for Quotation
Invitation to suppliers to submit a bid for products or services.

ROC
Roll Over Control
System that counteracts the vehicle's inclination to roll over.

RPAS
Roll over Propensity Assessment System
Sensors and an algorithm coupled to them with which a vehicle's rollover limit is determined.

Silent APS
Accident prevention system that only measures; it issues no warning to the driver.

Strategic driving behaviour
The aims of a trip are determined at the strategic level of driving behaviour, for example, where to, how and how long. Decisions at the strategic level are influenced by costs and risks, as well as by attitudes and the available information.

Tactical driving behaviour
Tactical driving behaviour refers to the manoeuvres performed by drivers, such as overtaking and crossing a junction. During tactical driving behaviour the driver is primarily concerned with the interaction with other traffic and/or with the road. Tactical driving behaviour is determined, on the one hand, by the current situation and, on the other, by the aims set at the strategic driving behaviour level.

Appendix 1: Explanatory word list

TLC

Time to Line Crossing

The time remaining until the vehicle touches the lane markings, provided course and speed remain unchanged.

Trigger level

The level at which a parameter exceeds or falls below a predetermined value.

Trip Detail

More detailed information of each trip; each 2 km, date and time, the GPS position, map matching output (road type, speed limit), average speed over the 2 km covered, current speed, current headway time.

Trip Summary

Summary standard information of each trip; date and time of start and finish of the trip, distance covered, average speed over the entire trip, maximum speed over the entire trip.

TTC

Time To Collision

The time remaining before a collision between two road users, provided course and speed remain unchanged.

Variance analysis

This is a statistical checking procedure used to find out whether the population averages of two or more groups differ significantly from one another.

Appendix 2: List of hypotheses

	DATA SOURCE	Point data	APS Summary	APS Detail	Crash data	BBFB-data	Outcome
0	**General (to test for all APS groups)**						---
0.1a	BBFB has no effect on the average speed					x	VBBFB=85.4km/h VREF=85.8km/h [$p<0.05$]
0.2a	BBFB has no effect on the distribution (s.d.) of the speed					x	STDVBBFB=1.68km/h STDVREF=1.78km/h [$p<0.001$]
0.3a	BBFB has no effect on how often harsh braking occurs					x	Not significant
0.1b	FCW/HMW has no effect on the average speed	x					Not significant
0.2b	FCW/HMW has no effect on the distribution (s.d.) of the speed	x					Not significant
0.3b	FCW/HMW has no effect on how often harsh braking occurs		(x)	(x)			Not testable (NOTE 1)
0.4b	FCW/HMW has no effect on the average headway time	x					Not significant
0.5b	FCW/HMW has no effect on the number of lane changes (per km)			X			Not testable (NOTE 2)
0.1c	LDWA has no effect on the average speed	x					SP1: N.S. SP3a: N.S. SP3b: N.S.
0.2c	LDWA has no effect on the distribution (s.d.) of the speed	x					SP1: N.S. SP3a: N.S. SP3b: N.S.
0.3c	LDWA has no effect on how often harsh braking occurs		(x)	(x)			Not testable (NOTE 1)
0.4c	LDWA has no effect on the average headway time	x					SP1: N.S. SP3a: N.S. SP3b: N.S.
0.5c	LDWA has no effect on the number of lane changes (per km)			X			Not testable (NOTE 2)
0.1d	ACC has no effect on the average speed	x					Not significant
0.2d	ACC has no effect on the distribution (s.d.) of the speed	x					Not significant
0.3d	ACC has no effect on how often harsh braking occurs		(x)	(x)			Not testable (NOTE 1)

Appendix 2: List of hypotheses

	DATA SOURCE	Point data	APS Summary	APS Detail	Crash data	BBFB-data	Outcome
0	**General (to test for all APS groups)**						---
0.4d	ACC has no effect on the average headway time	x					1.68 s ref; 1.77 s ACC [p < 0.05}
0.5d	ACC has no effect on the number of lane changes (per km)			X			Not testable (NOTE 2)
0.1e	ROC has no effect on the average speed	x					81.3 km/h ref; 80.4 km/h ROC [p<0.01]
0.2e	ROC has no effect on the distribution (s.d.) of the speed	x					4.5 km/h ref; 3.9 km/h DC [p < 0.01]
0.3e	ROC has no effect on how often harsh braking occurs		(x)	(x)			Not testable (NOTE 1)
0.4e	ROC has no effect on the average headway time	x					N.S.
0.5e	ROC has no effect on the number of lane changes (per km)			X			Not testable (NOTE 2)
1	**Via BBFB, the use of black box systems will improve better driving behaviour**						---
1.1	With BBFB there are fewer speed variations					x	Not significant
1.2	With BBFB harsh braking occurs less often					x	Not significant
1.3	With BBFB cruise control is used more frequently					x	Not significant
1.4	With BBFB the fuel consumption is lower					x	Not significant
2	**FCW/HMW reduces the number and severity of accidents**						---
2.1	With FCW/HMW the number of accidents (per 1000 km) is lower				x		Not testable (NOTE 3)
2.2	In the event of a collision, the maximum deceleration is lower with FCW/HMW				x		Not testable (NOTE 3)
2.3	In the event of a collision, the collision speed is lower with FCW/HMW				x		Not testable (NOTE 3)
3	**FCW/HMW reduces the number of almost-accidents**						---
3.1	With FCW/HMW less frequent short headway times (< 1 s)	x					N.S.
3.2	With FCW/HMW less frequent low TTCs			(x)			To be completed
3.3	After an FCW/HMW warning: higher minimum headway time			X			Not significant

Appendix 2: List of hypotheses

	DATA SOURCE	Point data	APS Summary	APS Detail	Crash data	BBFB-data	Outcome
3	FCW/HMW reduces the number of almost-accidents						---
3.4	After an FCW/HMW warning: higher minimum TTC			X			To be completed
3.5	With FCW/HMW less frequent short headway distances (Mobileye HMW is red)		x	X			Not significant
4	LDWA reduces the number and severity of the accidents						---
4.1	With LDWA the number of accidents (per 1000 km) is lower				x		Not testable (NOTE 3)
4.2	In the event of a collision, the maximum deceleration is lower with LDWA				x		Not testable (NOTE 3)
4.3	In the event of a collision, the collision speed is lower with LDWA				x		Not testable (NOTE 3)
5	LDWA reduces the number of almost-accidents						---
5.1	With LDWA less frequent unintentional line crossings		x				SP1: 16.3/u ref; 11.1/u LDWA [p<0.001] SP3a: not significant SP3b: 13.0/u ref; 5.0 /u LDWA [p<0.001]
5.2	After a LDWA warning: larger margins re. the road lines (definition of sign: + stays within lines, - is line crossing)			X			SP1: -0.25 m ref; -0.23 m LDWA [p<0.05]; SP3a: not significant SP3b: not significant
5.3	After a LDWA warning: less line crossing			X			Was tested with 5.2
6	ACC reduces the number and severity of the accidents						---
6.1	With ACC the number of accidents (per 1000 km) is lower				x		Not testable (NOTE 3)
6.2	In the event of a collision, the maximum deceleration is lower with ACC				x		Not testable (NOTE 3)
6.3	In the event of a collision, the collision speed is lower with ACC				x		Not testable (NOTE 3)
7	ACC reduces the number of almost-accidents						---
7.1	With ACC less frequent short headway times (< 1 s)	x					12.6% Ref; 9.4% ACC [p<0.01]
7.2	With ACC less frequent low TTCs			(x)			N.S.

Appendix 2: List of hypotheses

	DATA SOURCE	Point data	APS Summary	APS Detail	Crash data	BBFB-data	Outcome
8	**ROC (anti-rollover system) reduces the number and severity of the accidents**						**---**
8.1	With ROC the number of accidents (per 1000 km) is lower				x		Not testable (NOTE 3)
8.2	In the event of a collision, the maximum deceleration is lower with ROC				x		Not testable (NOTE 3)
8.3	In the event of a collision, the collision speed is lower with ROC				x		Not testable (NOTE 3)
9	**DC reduces the number and severity of the accidents**						**---**
9.1	With DC the number of accidents (per 1000 km) is lower				x		Not testable (NOTE 3)
9.2	In the event of a collision, the maximum deceleration is lower with DC				x		Not testable (NOTE 3)
9.3	In the event of a collision, the collision speed is lower with DC				x		Not testable (NOTE 3)

The data source used for the testing of a hypothesis is indicated by an 'x'. '(x)' is used to signify that although data was available with which to test the hypothesis, there was less of it than was desirable.

Where comparisons are made in the hypotheses ('with APS fewer accidents'), this always means 'compared to the situation without APS', in other words compared to the reference group.

In the list of hypotheses no formal null hypothesis and alternative hypothesis are mentioned. Where no clear expectations existed at the start, we express the zero hypothesis ('no effect of APS'). If, however, a clear expectation existed for a specific variable for a specific APS, we mention the alternative hypothesis ('with LDWA fewer unintentional line crossings').

Note 1

It turned out that acceleration had not been saved correctly in the data in SP1 and SP3. As a result, it was not possible to analyse harsh braking.

Note 2

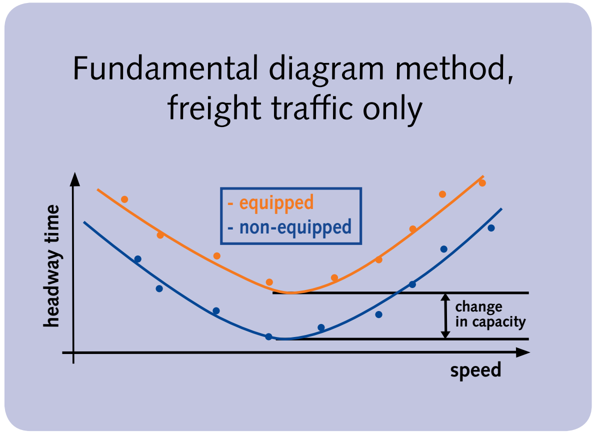
Lane changes such as those established by Clifford Electronics/Mobileye were marked in the Octo Telematics data. However, this applies only to the 10s fragments logged in relation to events. As a result, a general analysis of the lane change behaviour was not possible. As an alternative, the number of lane changes in the events was analysed.

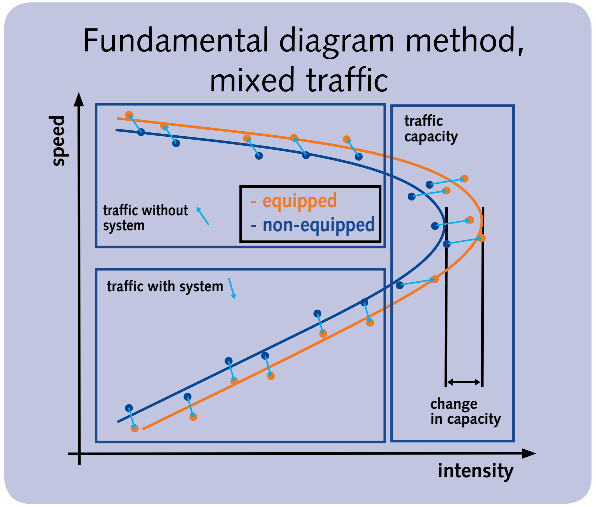
Note 3

This analysis drew on the Crash Summary and Crash Detail files. In total 81,066 possible collisions occurred, all with an acceleration/deceleration of at least 2g. Actual collisions could not be easily selected from this group.

Appendix 3: Figures showing conceptual models of traffic flow

The figures below are enlargements of the diagrams presented in chapter 6.2 (conceptual model of traffic flow).





In the figure above (exclusively lorries) a relationship between the headway time and speed of lorries is sought based on the actual data. From this relationship, the minimum headway time can be derived and then lane capacity estimated for the hypothetical situation of traffic comprising exclusively lorries equipped with APS.

The figure below (mixed traffic, i.e., equipped and non-equipped lorries and other traffic) presents a fundamental diagram for the reference situation on the basis of data from measuring loops. For the project situation the data points were modified based on the test data. Each data point in the reference situation is thus shifted and a new diagram created. The capacity is the maximum intensity according to this diagram.

Appendix 4: Organisation

Programme Consultative Board

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B. van Bree and S. Slütter, Buck Consultants International

Appendix 5: Analysis of measurements taken during field operational test

In the subprojects Retrofit (SP1) and OEM (SP3) data registration took place using registration units produced by Clifford Electronics/Mobileye and Octo Telematics. These units were based on the 'Clear Box' concept developed by Clifford Electronics and Octo Telematics and a Mobileye. With the aid of a GPRS connection, a GPS antenna, an acceleration sensor and a CANbus link with the APS (Mobileye: LDWA, FCW/HMW) three types of data were collected (see [2,3] for detailed specifications).

These data were enhanced by Octo Telematics with GIS data (converted to geo-codes for roads), filtered where necessary, and clustered to form a number of datafiles.

TRIP_SUMMARY, summary standard information of each trip; date and time of start and finish of the trip, distance covered, average speed over the entire trip, maximum speed over the entire trip.

TRIP_DETAIL, detailed information of each trip; each 2 km, date and time, the GPS position, map matching output (road type, speed limit), average speed over the 2 km covered, current speed, and current headway time.

APS_SUMMARY, detailed information during an event; each time that an output signal from an APS changes status, this counts as an event that will be logged. The following are logged: date, time, licence plate number, event type, current speed, GPS location, and map-matching output. An event is logged only at speeds exceeding 55 km/h and only in the Netherlands.

APS_DETAIL, during each APS event a fragment van 10 s data is logged in detail. This includes date and time, GPS location (1 Hz), acceleration (in both longitudinal and lateral directions; 10 Hz), signals from the Clifford Electronics/Mobileye unit (approx. 10 Hz). The maximum limit set on the quantity of this type of data collected per week for each lorry was 1.25 MByte or approx 250 APS Detail measurements. In order to minimise the bias introduced by this limitation, the start moment for the collection of these data per lorry was chosen afresh each week. The concluding moment each week was then determined by the number of events generated by the lorry in question.

CRASH_SUMMARY, summary information of each possible collision is saved (definition: a measured acceleration in longitudinal or lateral direction > 40 m/s2); date and time, licence plate number, GPS location, maximum acceleration, and collision speed.

CRASH_DETAIL, detailed information of each possible collision; in a fragment van 7 s: date and time, GPS position (1 Hz), acceleration in both longitudinal and vertical directions (100 Hz).

Following the first analysis of the outcome of the data registration, various settings and filters were applied to improve the quality of the data and/or to reduce the number of records with useless information:

- Raising the trigger level for accelerations from 2 G to 4 G (20 to 40 m/s2).
  - The shocks to which a lorry chassis is subject are much stronger than those affecting a car. In normal use, the limit of 2 G is very often exceeded as a result of which very many crash detail records without any value are generated.

Appendix 5: Analysis of measurements taken during field operational test

- For the Headway Monitoring and Warning, a 5-second delay was built in concerning the vehicle's resumption of a previous level, i.e. when the distance to the vehicle in front increased and then resumed the warning level. It was evident that without this delay very many records without additional information were generated at the boundary between two levels.
- The blinking light had to cease blinking for at least 2.5 seconds before its use could trigger a new event.

The acquisition system for SP2 differed from all the others because it was generated using the fleet management system produced by CarrierWeb.

The frequency with which the data were saved was once every two minutes. No current values were saved but rather indicators, which were calculated immediately, concerning the elapsed period of 2 minutes, for example the average speed and the maximum acceleration/deceleration. See Table 15 for a list of the saved data.

Variable	Note
CWVehicleID	Licence number
EventTime	Date and time
SpeedMin	
SpeedMax	
SpeedMean	
SpeedStdDev	
AccelerationMin	
AccelerationMax	
AccelerationMean	
AccelerationStdDev	
DecelerationMin	
DecelerationMax	
DecelerationMean	
DecelerationStdDev	
ActualFuel	
TotalKM	
TotalCruiseTime	Time cruise control was on
TotalBrakeApps	Number of brake events
TotalTimeOverspeed	
HarshAccelerations	Number of times rapid acceleration (a > 1.0 m/s^2)
HarshBrakes	Number of times rapid acceleration (a > 1.5 m/s^2)

Chart 15: Data collected in SP2

The raw data from the data registration were quality controlled prior to processing and filtered again, if necessary. During sub-analyses subsets were enhanced with variables of importance to the analysis, such as the files of actual data based on the measured GPS positions, road type, number of lanes, applicable speed limits, etc.

With the conversion and the addition of indexation data, the files that were analysed became larger than the original datafiles.

Table 16 shows the quantity of raw data collected in SP1 and SP3. The total is more than 170 GigaBytes.

Data file	Data Space (Mb)
TRIP_SUMMARY	71
TRIP_DETAIL	49.372
APS_SUMMARY	19.678
APS_DETAIL	103.072
CRASH_SUMMARY	11
CRASH_DETAIL	361
Totaal	**172.860**

Chart 16: Amount of SP1 and SP3 data collected

Appendix 5: Analysis of measurements taken during field operational test

Year	Month	Total km driven	Total journeys	Average kilometres per day	Number of lorries
2008	10	8.145.428	248.417	345	1.043
2008	11	8.173.006	248.136	333	1.223
2008	12	8.818.063	254.757	333	1.304
2009	1	9.259.496	264.454	328	1.350
2009	2	9.203.939	276.281	322	1.469
2009	3	10.800.269	330.630	323	1.493
2009	4	10.218.884	311.555	326	1.498
2009	5	9.033.672	278.108	310	1.547
Total		**73.652.757**	**2.212.338**		

Chart 17: Kilometres driven and measured in SP1 and SP3

Table 17 shows the number of kilometres driven that was logged per month in SP1 and SP3. The number of lorries was determined each month by a range of factors, including the availability of units and the repair and modification of APS and data registration.

Table 18 shows the quantity of raw data collected in SP2. The total is more than 14 GigaBytes.

Table 19 shows the number of kilometres driven and measured in SP2.

The number of lorries was determined each month by a range of factors, including the availability of units delivered factory-fitted and the repair and modification of APS and data registration.

Data file	Data Space (Mb)
Haulier1_data	400
Haulier1_GPSdata	1.200
Haulier2_data	2.400
Haulier2_GPSdata	10.300
Total	**14.300**

Chart 18: Amount of data collected in SP2

Year	Month	Total km driven	Number of lorries
Haulier 1			
	3	101.459	51
	4	227.330	51
	5	253.975	86
Subtotal		**582.764**	
Haulier 2			
2009	2	50.082	71
2009	3	698.452	405
2009	4	800.042	455
2009	5	920.263	453
Subtotal		**2.468.839**	
Total		**3.051.603**	

Chart 19: Kilometres driven and measured in SP2

Appendix 5: Analysis of measurements taken during field operational test

Measurements

Owing to the lengthy measuring period, particularly in SP1 and SP3, all sorts of weather conditions were encountered, from extreme cold in the winter (to -20 °C) to heat in the spring (30 °C), dry weather, wet weather and snow. Data that was influenced by extreme weather, such as the snow in January 2009 that was extreme by Dutch standards, have not been included in the analysis.

The hypotheses presented in Appendix 2 were tested in the data analysis. This involved the use of variance analysis. The analysis was performed on data collected on Dutch motorways. The independent variables were:

- APS (with the conditions LDWA, FCW/HMW and reference serving as examples in SP1).
- The speed limit, with 120, 100 and occasionally 80 km/h as possible values. This variable was correlated with the location where the lorry drove. The limit of 100 km/h is found typically near urban areas and a speed limit of 80 km/h applied at a couple of specific locations.
- Half-day, with day and night as possible values.

This variable includes the effects of both light conditions and weight of traffic.

By way of example, the analysis results for SP1 for average speed are discussed here. Variance analysis revealed the following effects.

- The speed limit has a statistically significant effect [$p < 0.001$]. As Figure 32 shows, the following is true: the higher the speed limit, the higher the average speed.
- The half-day has a significant effect [$p < 0.001$]. Average speed at night is somewhat higher than during the daytime (81.1 and 80.8 km/h respectively: a difference of 0.3 km/h).
- APS has no significant effect [$p = 0.76$]. Thus, the average speed was not influenced by APS.

Visuals such as those shown in Figure 32 show the average values found by means of a small block or a similar symbol. The vertical lines ending in short horizontal lines indicate the reliability interval (95%).

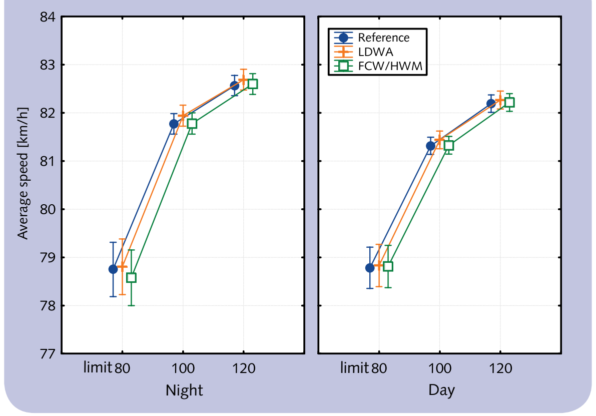


Figure 32: Average speed as a function of APS, speed limit and half-day (average and 95% reliability interval)

These results show that driving with LDWA or FCW/HMW does not result in a higher or lower average speed. At the same time, this variance analysis does show statistically significant effects, even those resulting from small differences in average speed (night versus day: 0.3 km/h).

In the same way, the average speed was analysed for the other groups in SP1 and SP3. The results are summarised in Figure 33.

Appendix 5: Analysis of measurements taken during field operational test

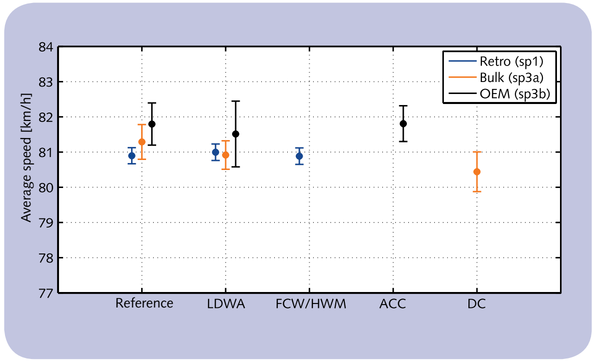


Figure 33: Average speed as a function of APS for all subprojects

The division into groups analysed and associated APS types and vehicle categories is shown in Table 20. SP1 and SP3 are similar in terms of data registration, SP2 differs from them. In order to achieve comparable groups, the analyses in these two groups were performed separately. Two hauliers with different business models cooperated in SP2 (own drivers versus lease of lorries). These are referred to as Haulier 1 (Tr1) and Haulier 2 (Tr2). Since this fact could be influential, it has been included in the analysis.

The number of lorries in Chart 20 is lower than the number of lorries in Figure 19. This is due in part to the removal from the analysis of a number of types of lorry necessitated by there being too few of them to perform a good analysis (for example, some 4-axis lorries). In addition, it was found that some of the lorries had driven almost exclusively outside the Netherlands, as a result of which they provided no data.

The pattern arising from SP1 was confirmed in SP3 (both Bulk and OEM): effects of APS on average speed were not found.

There was one exception to this statement. For the vehicles with DC the average speed was significantly lower [$p < 0.001$] than in the reference group. This concerns an effect of 1.0 km/h.

Data analysis

For an extensive analysis, the reader is referred to [16].

	SP1 Retrofit	SP3 OEM		SP2 Drivers	
		SP3a: Bulk	SP3b: OEM	Tr1	Tr2
APS	LDWA FCW/HMW Reference	DC LDWA (retro) Reference		BBFB Reference	BBFB LDWA + FCW/ HMW Reference
Vehicles	Articulated lorry Motorised vehicle	Articulated container chassis lorry Articulated container lorry	Articulated lorry Articulated container lorry	Articulated lorry (4 x 2 en 6 x 2)	Articulated lorry (4 x 2)
Number	1.230	143	194	78	487
Data	Octo			CarrierWeb	

Chart 20: Classification of APS groups

Appendix 5: Analysis of measurements taken during field operational test

Analysis of data 1 (Octo data registration system)

The subgroups SP1 and SP3 (LDWA, FCW/HMW, DC, ACC, Octo data registration) were analysed together. The results of this can be summarised as follows for each APS:

LDWA

- With the use of LDWA there were fewer lane departure warnings than in the reference group. This applied in both SP1-Retro (11.1 versus 16.0/h) and SP3-OEM (5.0 versus 13.0/h). For SP3a (bulk) the frequency in the reference group was already low and no improvement was achieved with LDWA (see Figure 34).
- In SP3b-OEM a higher percentage of headway times < 1 s was found for LDWA (18.5% LDWA, 12.6% reference).

FCW/HMW

No significant effects were found between the percentage of short headway times (< 1 s). This also applied to the frequency of FCW/HMW warnings (p = 0.64; average of 2.93 warnings per hour in the reference group and 2.89 per hour with FCW/HMW).

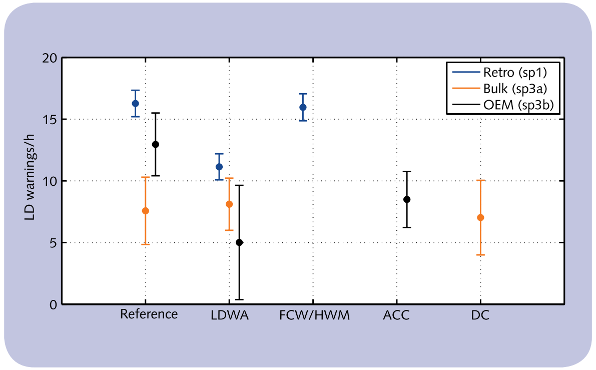


Figure 34: Frequency of LDWA warnings as a function of APS for all SPs (average and 95% reliability interval)

ACC

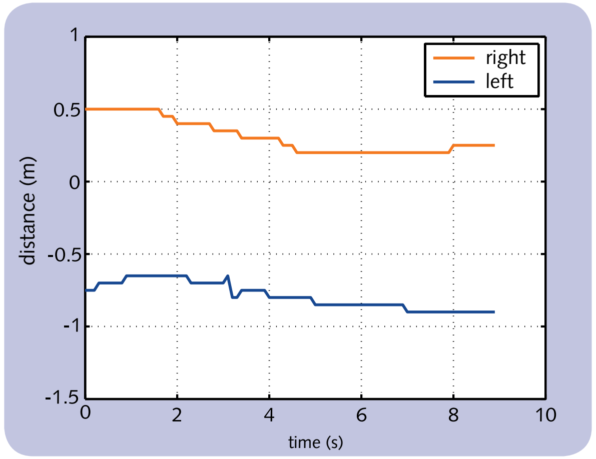
For ACC various significant effects related to headway behaviour were found:

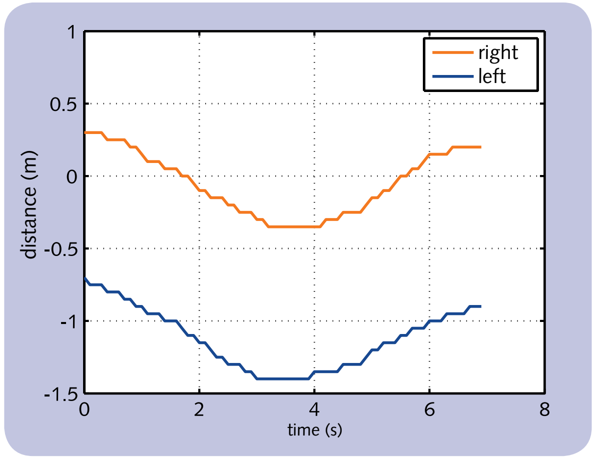
- With ACC the average headway time is longer (1.77 s ACC; 1.68 s reference).
- With ACC the % headway times < 1 s is lower (9.4% ACC; 12.6% reference).
- With ACC there are fewer FCW/HMW warnings (0.9/h ACC; 1.9/h reference)
- With ACC there are fewer LDWA warnings (8.5/h ACC; 13.0/h reference).

DC

As already evident above, a somewhat lower average speed occurred with DC (80.4 km/h DC; 81.3 km/h reference). The same was true of the standard deviation of the speed (3.9 km/h DC; 4.5 km/h reference).

For LDWA, the APS Detail data was examined (the 10 s fragments with detailed data storage) to discover the minimum distance to the line. This is shown in Figure 35.





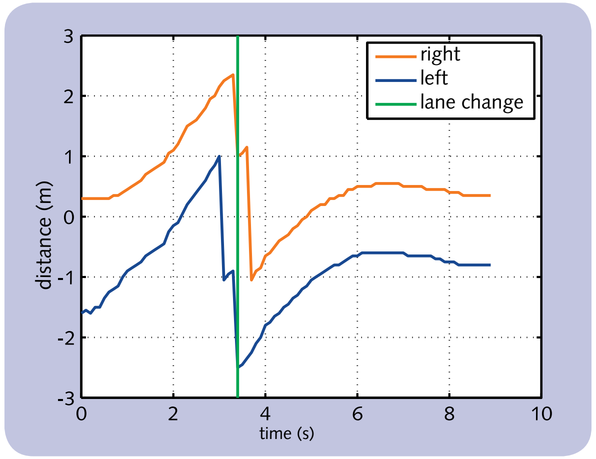


Figure 35: Distance to road lines as a function of time in APS detail fragments, left and right: maintaining a course within the lane (top); maintaining a course with lane crossing (centre); lane change (below)

Figure 35 shows the alerts issued by the Clifford Electronics/Mobileye. The distance right is normally greater than 0; a distance less than 0 means that the vehicle leaves the lane on the right side. For a left-side lane departure the sign is conversely defined: the distance is normally negative; a distance greater than 0 means that the vehicle leaves the lane on the left side.

In the analysis the minimum distance to the line was determined for each available fragment. The sign (both left and right) was chosen such that a minimum distance greater than 0 means that the vehicle stays within the lane. A minimum distance less than 0 indicates that the line was crossed.

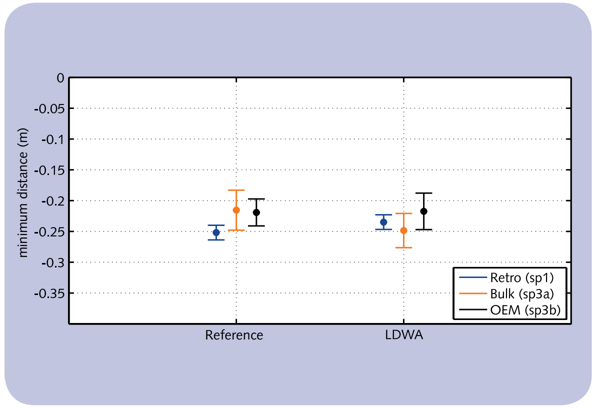


Figure 36: Minimum distance to the line after LDWA warning: average and 95% reliability interval (negative means that the line was crossed)

The results of the analysis are shown in Figure 36. These results show that after both a genuine LD warning and a silent one, a line crossing does on average occur. This crossing is in the order of size of 20 to 25 cm.

Appendix 5: Analysis of measurements taken during field operational test

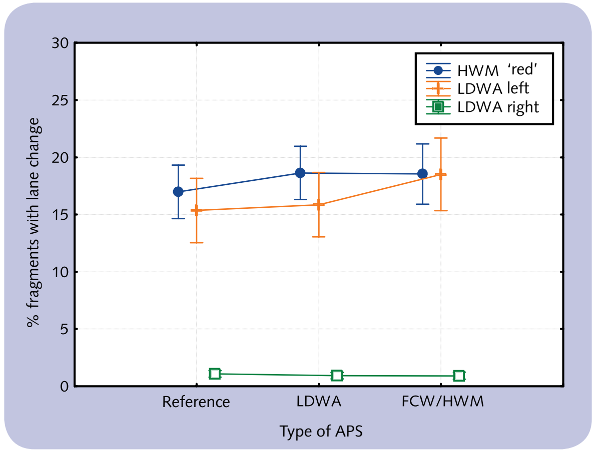


Figure 37: Percentage van 10s fragments in which lane changes occurred as a function of the type of APS system and of the type of event (SP1)

	SP1 Retrofit	SP3 OEM	
		SP3a: Bulk	SP3b: OEM
APS	LDWA FCW/HMW Reference	DC LDWA (retro) Reference	
Vehicles	Articulated lorry Motorised vehicle	Articulated container chassis lorry Articulated container lorry	Articulated lorry Articulated container lorry
Number	1.230	143	194
Data	Octo		

Chart 21

LDWA has a minor effect on the crossing: in only one of the three sub-groups did a significant effect occur (25 cm line crossing without LDWA, 23 cm line crossing with LDWA).

As illustrated in Figure 37 a reading of the detailed data fragments also reveals whether a lane change occurred. Detailed data fragments were registered only if a Mobileye indicated an event; lane changes whereby no LDWA or HMW warning was given are not present in the data. In the analysis it was determined for each vehicle in what percentage of the data fragments a lane change occurred. The average of this percentage was then analysed, broken down into type of APS system and type of event.

For the events 'HMW-red' and 'LDWA left' a lane change occurred on average in 15% to 18% of the cases. This percentage did not differ significantly between lorries with LDWA, FCW/HMW and those in the reference group [$F(2,374) = 1.1$, $p < 0.33$]. In 'LDWA right' events, a lane change occurred on average in just 2% of the cases. Similarly, in SP3a and SP3b APS had no effect on lane changes.

All in all, the data provide no indication that APS influences the percentage of lane changes as registered in the data.

By contrast, the type of event that prompted the storage of the data fragment does influence the percentage of lane changes.

Appendix 5: Analysis of measurements taken during field operational test

The 10 s fragments were also used to determine the minimum headway time that occurred after a 'HMW-red' warning. For both FCW/HMW and ACC, there was no significant difference from the reference group. The average of the headway time minimums was 0.6 s.

To summarise, the clearest effects for the above-mentioned groups are:

- An LDWA reduces the number of warnings per hour. Thus, an LDWA leads to fewer unintentional line crossings or better use of the indicators. In one group it was simultaneously observed that the short headway times increase - a negative effect.
- Various positive effects were found for ACC: higher average headway time higher, % headway times < 1 s lower, fewer FCW/HMW alerts and fewer LDWA alerts.
  However, whether the ACC was switched on or off was not measured in the test. Therefore it cannot be demonstrated whether the effect is due to ACC use or ownership. The driver surveys reveal great satisfac tion with ACC, which could indicate a high level of ACC use.

Analysis of data 2 (CarrierWeb data registration system)

The second analysis was performed on the data for SP2 (BBFB, LDWA + FCW/HMW, CarrierWeb data registration). In SP2 no ACC was used but it was known whether the cruise control was on or off. This fact has been included in the analysis. In addition, in this group LDWA and FCW/HMW were used only in combination with one another.

Haulier 1 employs its own drivers and Haulier 2 leases its lorries.

To begin, the effects on the average speed are discussed.

For Haulier 1, the variance analysis shows the following effects.

- The speed limit has a marginally statistically significant effect [$p < 0.1$]. At a higher speed limit the average speed is higher.
- Half-day has a significant effect [$p < 0.05$]. At night the average speed is a little higher than during the daytime, 84.9 km/h and 84.2 km/h respectively.

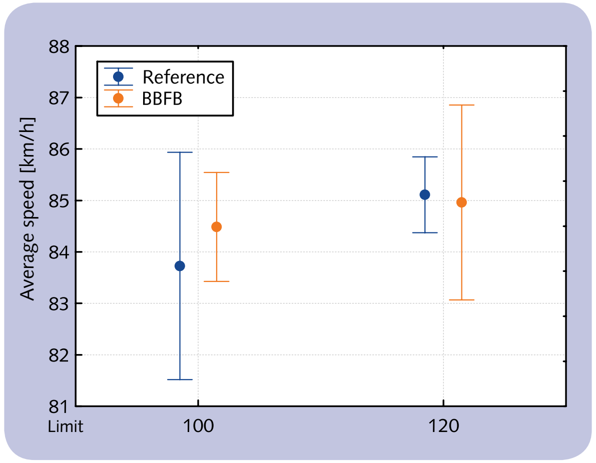


Figure 38: Effect of the speed limit on the average speed (average and 95% reliability interval)

- Cruise control has a significant effect [$p < 0.05$]. With cruise control on, the average speed is higher than with cruise control off, 85.7 km/h and 83.5 km/h respectively.
- APS has no effect [$p = 0.3$].

Appendix 5: Analysis of measurements taken during field operational test

For Haulier 2, the variance analysis shows the following effects.

- The speed limit has a statistically significant effect [$p < 0.001$]. At a higher speed limit the average speed is higher, 86.3 km/h and 85.0 km/h respectively.
- Half-day has a significant effect [$p < 0.001$]. At night the average speed is higher than in the daytime, 86.0 km/h and 85.1 km/h respectively.
- Cruise control has a significant effect [$p < 0.001$]. With cruise control on, the average speed is higher than with cruise control off, 86.8 km/h and 84.5 km/h respectively.
- APS has an effect [$p < 0.05$]. For the group using LDWA and HMW/FCW, the average speed is a little lower than that of the reference group, 84.4 km/h and 85.8 km/h respectively. No effect of BBFB on average speed was found.

Thus, for both hauliers the results show no effect of BBFB on average speed. LDWA and HMW/FCW appear to have a (small) effect on average speed. Average speed was 0.4 km/h lower compared to the reference group.

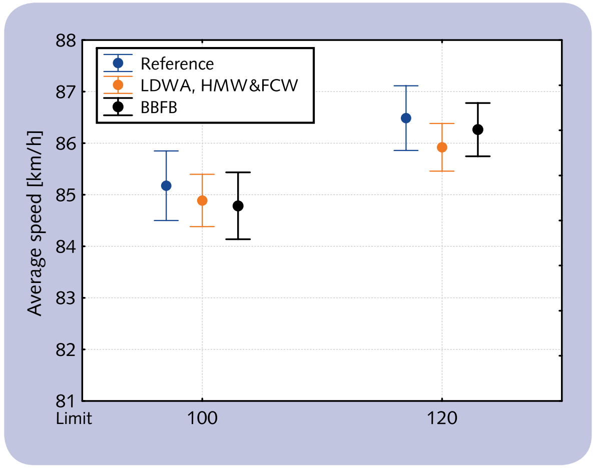


Figure 39: Effect of speed limit

	SP2 Haulier	
	Tr1	Tr2
APS	BBFB Reference	BBFB LDWA + FCW/ HMW Reference
Vehicles	Articulated lorry (4 x 2 en 6 x 2)	Articulated lorry (4 x 2)
Number	78	487

Chart 22

Appendix 5: Analysis of measurements taken during field operational test

The results are summarised as follows for the above-mentioned group:

LDWA + FCW/HMW

These are the results for Haulier 2 since Haulier 1 had no LDWA + FCW/HMW in its lorries.

- With LDWA + FCW/HMW the average speed was significantly lower (0.4 km/h) than in the reference group, 85.4 km/h as opposed to 85.8 km/h.
- With LDWA + FCW/HMW the standard deviation of the speed was significantly lower (0.1 km/h) than in the reference group, 1.68 km/h as opposed to 1.78 km/h.

BBFB

- For both hauliers, the use of BBFB was found to have no effect on average speed.
- For both hauliers, the BBFB had an effect on the standard deviation of the speed. For Haulier 2 this effect was marginal ($p = 0.09$). For Haulier 1, the BBFB was responsible for a reduced standard deviation of the speed compared to the reference group (1.38 km/h as opposed to 1.81 km/h). For Haulier 2 the standard deviation of the speed was higher than for the reference group, albeit marginally, 1.87 km/h as opposed to 1.78 km/h.
- The BBFB was not seen to have any effect on the use of cruise control. An analysis of the whole dataset, i.e. both hauliers together, was performed for the number of times harsh acceleration occurred (> 1.5 m/s2) and the number of times harsh deceleration occurred (< -0.8 m/s2). The BBFB group braked harshly marginally less often [$p < 0.1$] than the reference group and less often [$p < 0.01$] than the group with the Clifford Electronics/Mobileye system (FCW/HMW and LDWA); [0.011/1000 km] as opposed to [0.018/1000 km] and [0.021/1000 km] respectively.

Cruise control

- With the cruise control an effect on the average speed was found for both Haulier 1 and Haulier 2. The average speed was significantly higher [$p < 0.001$] for the situation with cruise control on as opposed to the situation with cruise control off, 85.4 km/h as opposed to 83.2 km/h and 86.7 km/h as opposed to 84.0 km/h, respectively.

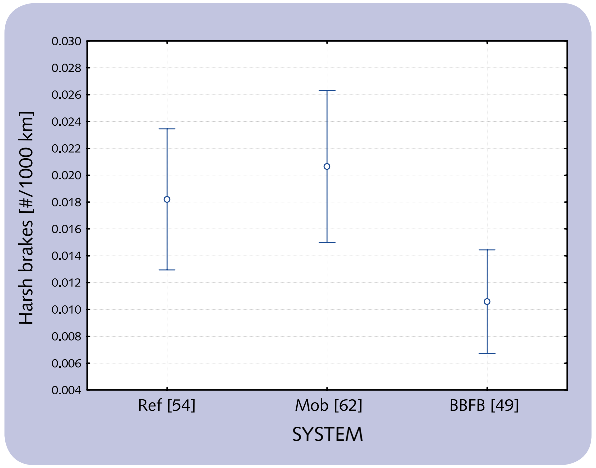


Figure 40: Number of 'harsh brakes' as a function of the system used

- An effect of cruise control was also found on the standard deviation of the speed for both Haulier 1 and Haulier 2. The standard deviation of the speed was significantly [$p < 0.001$] lower for the situation with the cruise control on than with the cruise control off, 1.0 km/h as opposed to 2.3 km/h and 1.0 km/h as opposed to 2.5 km/h respectively.

For a detailed analysis, the reader is referred to [19].

Appendix 6: Summary of SWOV report

The SWOV has estimated for Connekt the effects of accident protection systems (APS) on traffic safety for lorries on Dutch motorways as tested in a large-scale Field Operational Test (FOT) in the context of the FileProof programme of the Ministry of Transport.

The purpose of this test was to determine the contribution that accident prevention systems make to preventing accidents or (serious) injuries and thereby reduce the incidence of traffic jams and lost vehicle hours.

This report focuses solely on the prevention of accidents and relates to the following systems:

Headway Monitoring and Warning/Forward Collision Warning (HMW/FCW)

- whereby a signal is given if a preceding vehicle is too close or is approached too fast. This system aims to prevent rear-end collisions.

Adaptive Cruise Control (ACC)

- whereby a preset speed is maintained and is automatically lowered if the headway time to the preceding vehicle dips below the set value. This system aims to boost drive comfort although it can also be assumed to help prevent rear-end collisions.

Lane Departure Warning Assist (LDWA)

- whereby a signal is given if a preset distance to the lane marking is breached or too quickly approached. This system aims to prevent single-vehicle accidents whereby a vehicle deviates from the road.

Directional Control (DC)

- a system that continuously compares the steering angle with wheel (revolution) speed and brakes per wheel if these deviate from the norm. This system prevents a vehicle from skidding or limits the consequences of skidding.

Black Box Feed Back (BBFB)

- the driver is informed about his driving behaviour with the aim of improving this behaviour. If successful, this will have an effect on all types of accident, in principle.

This SWOV study is based on the results of literature research, interviews, questionnaires and (behavioural) measurements as collected by the project organisation (Connekt/ITS Netherlands, TNO and Buck Consultants International), though limitations do apply to a few cases. The SWOV undertook an independent accident analysis based on the data it had available.

By linking literature knowledge, behavioural measurements and accidents, a qualitative and, where possible, quantitative estimate was provided of the effect on victims. The field operational test limited itself to Dutch motorways; reason for the SWOV to also keep within this limit.

For Directional Control it is estimated that this system on Dutch motorways can prevent 1 death and 5 - 8 hospitalisations each year if present in all lorries.

For Adaptive Cruise Control, this can be assumed to have a positive effect on safety, though this cannot be quantified on the basis of the information currently available.

Appendix 6: Summary of SWOV report

Literature suggests that a positive behavioural effect could be expected for the other systems (HMW/FCW, LDWA and BBFB) but this was not confirmed by the measurements. The measurements, literature and discussions prompted hypotheses that could be verified in a follow-up study and this may well lead to modifications of the accident protection systems where a (measurable) safety effect can be achieved.

To be able to ascertain whether the recommendation should promote or compel the use of accident prevention systems in lorries from a traffic safety perspective, further research is desirable. This may in the first instance target a more penetrative analysis of the data currently available. It is also necessary to include other types of road than motorways in this study since safety could also be enhanced on such roads.

Colophon

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