CHALMERS
UNIVERSITY OF TECHNOLOGY

Evaluation of AEBS Real Life Performance

A Method for Using Limited Log Data Applied on Volvo Trucks

Master's Thesis in Automotive Engineering

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Department of Applied Mechanics
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

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Abstract

Rear end crashes where a Heavy Goods Vehicle (HGV) drives into another vehicle from the rear can lead to severe or fatal injuries to the occupants in the hit vehicle and often gives long term consequences. Advanced Emergency Braking System (AEBS) is an active safety system for HGVs which is designed to avoid and/or mitigate these kind of crashes and since the 1st of November 2015 it is mandatory for all new HGVs in Europe to be equipped with AEBS. To evaluate the real life performance of AEBS, this project has developed a method which uses a limited set of parameters considered to be logged in all HGVs during normal driving. The method has been tried out on a small dataset of 261 Volvo HGVs with a high number of AEBS brake interventions. The parameters considered for AEBS have been *Current date and time*, *Current odometer value*, *GPS positions* and *Duration of intervention* and these have also been combined with data considered logged for other safety systems as Forward Collision Warning (FCW), Brake Assist and Driver Alert Support (DAS). Further have information for activation and deactivation of AEBS been considered to find out the level of use of the system. When investigating AEBS activation and deactivation events only, the analysis possible to perform have been very limited but in combination with FCW activation and deactivation information, it have been possible to make estimations of the reasons for deactivation events. The coordinates of the interventions were analysed manually and showed on potential for finding interesting spots but the process needs to be automated and preferably combined with a road database to increase the use. Further have few combined interventions between AEBS and other safety systems been found due to a small dataset and possibly overwritten intervention logs. Recommended further work is to use the method for a large dataset and automate the process of plotting coordinates as well as increasing the number of parameters considered for storing of AEBS interventions.

Keywords: *Active Safety, AEBS, HGV Safety, Logged Data, Method Development*

Preface

The series of events which led me to this master thesis started almost exactly two years ago when I was attending the International Technical Conference on the Enhanced Safety of Vehicles (ESV) as a volunteer. The last day I decided to go talk to Volvo Trucks to ask them how they work with safety and got to talk to my current manager, Erik. Just before leaving, and after some hesitation, he gave me his visit card and I kept in touch and got a summer job the year after. I enjoyed working in the group and when it was time for me to write my master thesis and they came up with a suggestion tailor made for me, where I could take advantage from my previous knowledge and combine it with active safety, the choice was easy.

There are a lot of persons that I would like to thank and which have helped me in different ways during these months. To my supervisor Peter Wells; thanks for making it fun being here and sharing your knowledge. To my manager Erik Sandahl; thanks for the great efforts you have made to help me reach out to the right people and try to speed up the process of data extraction. Thanks also to Andreas Ekfjorden for good input, being a fun-to-talk-to desktop neighbour and help with treating the data. Thanks also to Laurent Decoster for helping me out when needed despite a lot of other things to do.

There are several more persons that I would like to thank at Volvo but I'll do it in groups. Thanks to the people on "the other side" for input and help regarding the AEBS and Matlab. Thanks to the rest of my work group for fun runs on Thursdays and thanks also to the trainees (Tekniksprångare) sitting next to me for giving me company in an otherwise sometimes quite empty office.

Last but not least, thanks to all my friends and family for being patient and put up with me constantly being busy the last months.

Ronja Örtlund, Gothenburg, June 2017

Abbreviations

ABS	Anti-lock Braking System
AEB	Autonomous Emergency Braking (passenger cars)
AEBS	Advanced Emergency Braking System (HGVs)
AIS	Abbreviated Injury Scale
CW-EB	Collision Warning with Emergency Brake (AEBS in Volvo HGVs)
DAS	Driver Assistance System
DVR	German Road Safety Council
ECU	Electronic Control Unit
FCW	Forward Collision Warning (system)
HGV	Heavy Goods Vehicle
HMI	Human Machine Interface
HUD	Head Up Display
NVDB	National Road Database in Sweden (nationell vägdatabas)
OBD	On-board diagnostics (connection)
VIN	Vehicle Identification Number
VRU	Vulnerable Road User (e.g. pedestrians and bicyclists)
PTW	Powered Two Wheelers (moped and motorcycles)

Explanations

Activation	The enabling of a system
AEBS intervention	Prebrake or fullbrake intervention
Deactivation	Disabling of a system
Ego Vehicle	The vehicle equipped with the system
Event	A combination of interventions within a specified time frame or activation or deactivation of a system
Intervention	When an enabled system perform an action, for AEBS an intervention is either prebrake or fullbrake, for DAS and FCW a warning is considered and for Brake Assist an intervention is when the system increases the brake pressure
False Negative	No intervention was made but should have been
False Positive	An intervention was made but should not have been
Heavy Goods Vehicle	In this report considered to be a goods vehicle (truck) with a gross weigth above 8 tonnes
Subject Vehicle	See Ego Vehicle
Time Headway	Distance to vehicle in front divided by ego velocity
Target Vehicle	Vehicle detected by the sensors of ego vehicle
True Negative	No intervention was made and should not have been
True Positive	An intervention was made and should have been
Odometer	A device measuring the distance travelled by a vehicle

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1 Introduction

Every year, 1.25 million people are killed in traffic crashes around the world [1] and in Europe alone (EU28) over 26 000 people lost their lives in traffic related crashes in 2015 [2]. Heavy Goods Vehicles (HGVs) were involved in about 15% of these cases which gives an approximate number of 2900 people killed in crashes involving HGVs [3].

The Volvo Trucks Safety Report 2017 [4] estimate that in 10% of all crashes between a HGV and a passenger car, which leads to fatal or severe injuries among the car occupants, are the result of the passenger car getting hit from the rear by the HGV (rear end crash). For crashes with fatal or severe injuries to the HGV occupants, rear end crashes between two HGVs are responsible for 15-20% of the crashes [4].

Studies performed by Kullgren et al. 2002 [5], Krafft 1998 [6] and Nygren 1984 [7] have shown that a majority of long term injuries with disabling consequences are due to rear end crashes and the symptoms are often caused by soft tissue neck injuries. Stigson, Gustafsson, Sunnevång et. al. 2015 [8] says that 50% of the injuries leading to long-term consequences are cervical spine injuries with AIS 1 and according to Kullgren et. al. 2013 [9] are 43% of these injuries due to rear end crashes. Another study by Kullgren 2008 [5] investigated the relation between impact speed in rear end collisions and the resulting injury risk and found that the number of injured persons is lowered with a decrease in impact speed. A common cause for rear end crashes are distracted drivers [10].

Fortunately, there are means to decrease the number and severity of these crashes. According to Kullgren there are three main ways to attack the problem with traffic crashes; reducing the severity of impacts, the number of crashes or the injury risk at a given impact [5]. Active safety systems which can avoid or mitigate crashes are thus useful in the two first cases.

An active safety system for HGVs specifically developed for the situations addressing rear end crashes is Advanced Emergency Braking System (AEBS). If the equipped vehicle (in this case a HGV) is closing up to a vehicle which is slower moving or even standing still and the system judges the situation to be dangerous, it provides a warning to get the driver's attention. In case he or she does not start braking or if the action taken is not enough, the system brakes the vehicle autonomously in order to avoid or at least mitigate the crash. Since the 1st of November 2015 it is also mandatory for all new HGVs in Europe (with some exceptions) to be equipped with AEBS [12].

Similar systems have been used on passenger vehicles for several years [11] and are then called Autonomous Emergency Braking (AEB), not to be confused with AEBS. For Volvo Trucks, the first introduction of AEBS was made on the FH truck which was launched in 2013.

Previous studies by e.g. Bao et. al. 2012 [13] , Woodrooffe et. al. 2013 [14] and Strandroth et. al. 2015 [15] have shown a predicted benefit from the system on reduced number of injuries. The better the system is, the higher the benefit from it can be. For example is it important that the warnings provided are correct to avoid annoying the drivers so that they turn off the system or causes a cry-wolf effect where the drivers stop trusting the warning due to too many false warnings. In order to find out and improve AEBS, knowledge about the real life performance is necessary.

1.1 Problem Description

For passenger vehicles, the AEB system is evaluated in the Euro NCAP performance tests [11] but there is no equivalent for HGVs except from the legal requirement (described further in section 2.3) which includes two test scenarios. These two test scenarios make sure the AEBS fulfils the legal requirements but are not able to represent all real life situations that might occur. For example are both scenarios taking place at straight road sections without any other objects in the nearby while the real life driving contains curves, hills, bridges, rail guards, traffic signs etc.

How well the AEBS manage to handle different situations in normal driving have not yet been evaluated but could give valuable knowledge about the system. Some of this knowledge is intuitively gained by the engineers but an evaluation based on data available is needed to be able to perform the work in a scientific way. The first step of this process is to investigate which data that is available and how it can be used.

It can also be concluded that if being able to draw useful conclusions of the data already logged in the HGVs, it would be a much cheaper way to evaluate the system than to perform e.g. naturalistic driving studies even if the later would provide more information. An evaluation based on data which is continuously logged could also be performed as a long term follow up.

1.2 Aim

The aim of the project is to investigate how logged data from trucks can be used to evaluate the performance of an AEBS function.

1.3 Limitations

The thesis is carried out in collaboration with Volvo Trucks and the parameters, tools and data discussed in this report are not the exact ones used by Volvo Trucks. Instead these should be seen as representative for any HGV manufacturer. In the cases where Volvo confidential data have been treated and results have been found, these are presented in an internal report at Volvo and no further comment is left for what is excluded.

The AEBS in total consists of both warning and braking interventions but for this project the interest has been in the later. An AEBS intervention is therefore defined as either a prebrake or fullbrake intervention while the warnings have been considered to belong to the FCW system.

The project's main area of focus is Europe and other countries/continents are only briefly addressed in some situations. The reason for this is a combination of the data set mainly containing European HGVs together with the legal requirement only being mandatory for vehicle type approval in Europe. Other contributing factors are the differences in HGV style and differences among the continents regarding traffic regulations.

The Human Machine Interface (HMI) is not evaluated in this project due to the complexity and the need of other kinds of data such as naturalistic driving data, simulator studies or driver interviews which are not available for this study.

Volvo has several different models of HGVs in the medium and heavy duty segment, however in this project only the models FM and FH are considered due to the large volumes of these models.

The data used will be subject to a quality check but except from identifying the limitations, no deeper study of the way Volvo stores the data will be made. The project will assume that the data to large extent is correct.

1.4 Objectives

Objectives of the project are to identify possibilities and limitations with the data available and situations where the system has, or has not, worked as intended. Based on this will updates to the requirements for data collection be given. From the project, also conclusions and recommendations for further studies will be given.

2

Background Information

2.1 Volvo FM/FH Models

The Volvo HGV models FM and FH (front medium and front high) are both made for distribution and the main difference is the height of the entry. The medium high entry of the FM makes it more used inside cities while the FH with its high entry is more often seen as a long haul HGV [16].

Both vehicles have a wide range of variants of engines, axle configurations etc. to choose between and are sold as either a tractor unit or what is called a rigid HGV. To carry load with a tractor unit, a semitrailer needs to be connected. The rigid HGV has room for load inside the HGV but additional trailers can be attached. Examples of FM and FH and the difference between tractor unit and rigid HGV can be seen in Figure 2.1 [16].

Figure 2.1: To the left, a Volvo FM as rigid HGV and to the right a Volvo FH as tractor unit [18, 19].

2.2 The AEBS in Volvo HGVs

AEBS is an active safety system designed to reduce the severity of, and in best cases, avoid rear end collisions. The system is automatically enabled at start and is active in speeds above 15km/h [16]. Volvo uses the following words to describe the system:

'The purpose of this function is to avoid collisions or reduce the severity of the impact forces with forward targets in its path and same direction as the ego vehicle (rear end collision).' - Internal report at Volvo

Different brands have their own systems and to provide a reference, the Volvo system, called Collision Warning with Emergency Brake (CW-EB) is explained [4]. The CW-EB system uses two sensors, a radar placed in the grill and a camera which is positioned behind the windshield to detect and classify objects, Figure 2.2. The radar determines the distance and speed of the vehicle in front while the camera is used to classify it as e.g. a passenger car, bus or HGV [20].

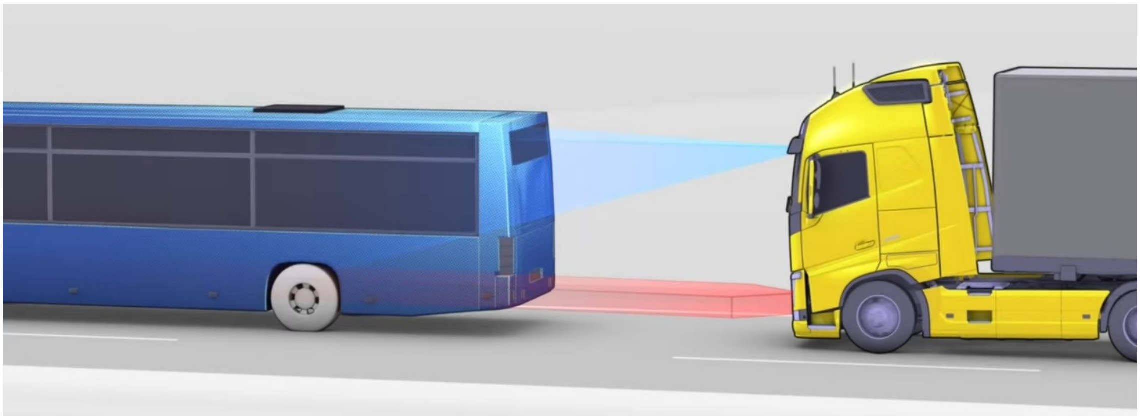

Figure 2.2: Illustration of the CW-EB system by Volvo, the red light illustrates the radar and the blue light the camera [21].

The warnings and brake interventions are divided into four steps distributed over three phases, illustrated in Figure 2.3. The first phase is the prewarning and here is only a visual warning provided to the driver by having a steady red light projected onto the windscreen by a head up display (HUD). This early warning is possible to turn off and is otherwise enabled with the system activation at speeds above 15km/h. The second phase is the warning phase and is divided into two steps, where the first thing is that the projected light starts to flash at the same time as an acoustic signal is provided. If the driver still does not react, the second part is the system slightly applying the brakes, called prebraking. In the final phase the emergency brake kicks in and brakes the vehicle autonomous until the vehicle stands still or the threat is avoided. The last intervention is called fullbrake [22].

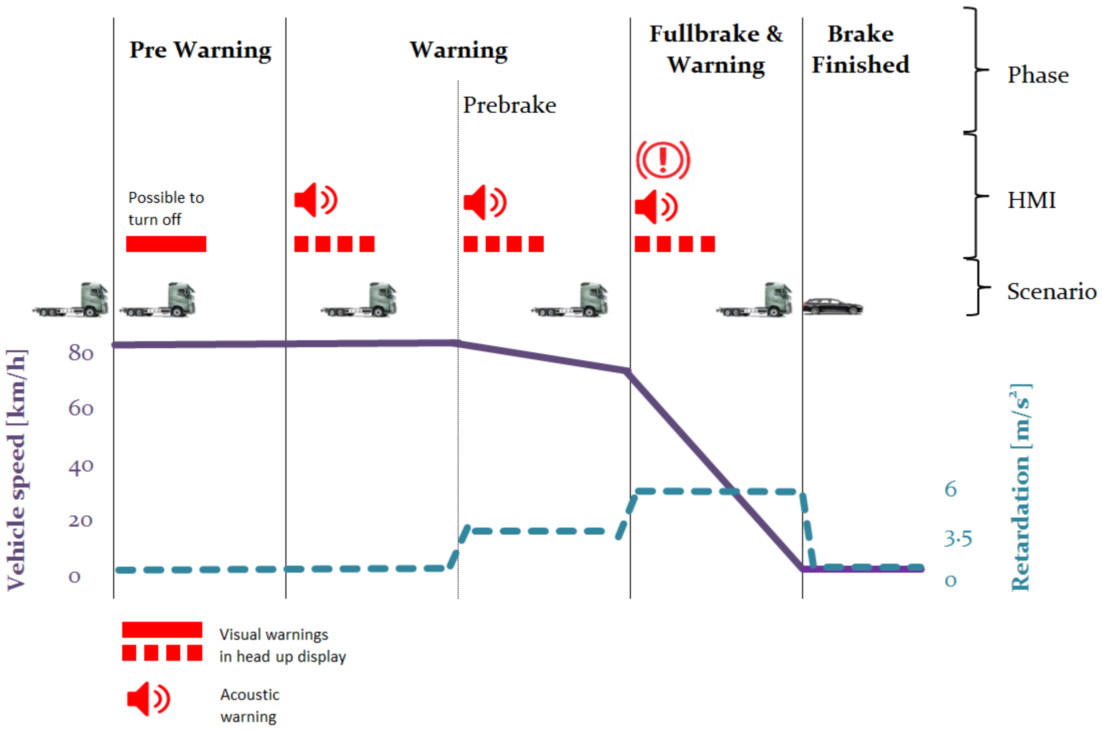

Figure 2.3: The phases of the CW-EB system.

It is important to keep in mind that the CW-EB system currently is designed for rear end collisions and not for crossing accidents or head on threats. The sensors are capable of detecting cars, HGVs, busses etc specified in ISO 3833 Road Vehicles [16] but are not guaranteed to detect Vulnerable Road Users (VRUs) as Powered Two Wheelers (PTWs), bicyclists or pedestrians [4]. VRUs can still be detected by the sensors in some cases but since the classification might contain uncertainties, no interventions is made by the system to avoid false braking interventions [17].

2.3 Commission Regulation 347/2012

For all new HGVs (with some exceptions) which are applying for a type approval in any of the member states of the European Union, it is from November 1st 2015 mandatory to be fitted with AEBS. The requirements are stated in the Commission Regulation (EU) 347/2012 issued by the European Commission and a brief summary is provided in the following section [12].

The regulation is divided into two approval levels which are introduced in steps. Approval level 1 entered into force for all new HGVs with a maximum weight above 8 tonnes on the 1st of November 2015 and is thus the one valid now. Approval level 2 is to be entered into force for all new HGVs in 2018. The regulation is also addressing coaches and some city busses [12].

The two approval levels are based on the same test scenarios but with different values for passing the tests. The requirements are addressing two scenarios, both taking place on straight road. The first one is the HGV approaching a stationary target (soft target of passenger car) and where the HGV speed should be reduced with a certain value. The second scenario is the HGV approaching a moving target (going ahead in the same lane) and the requirement is that a collision should be avoided. The differentiation between the approval level for this scenario is the speed of the moving target. The speed for the HGV is 80km/h for both scenarios and the numbers for the approval levels can be seen in Table 2.1 [12].

Table 2.1: Overview of approval level differences [12].

		Stationary Target	**Moving Target**
	Year of introduction	Speed reduction of ego vehicle at crash	Speed for target vehicle. Crash should be avoided
Approval level 1	2015	10km/h	32 ± 2km/h
Approval level 2	2018	20km/h	12 ± 2km/h

In addition to the speed reduction, the legal requirement also includes directives about the warnings given before the emergency braking starts. These are the same for both approval levels and states that a haptic or acoustic warning should be provided not later that 1.4s before the start of the emergency braking phase. Not later than 0.8s before the same, a warning from at least two warning modes (optical, haptic, acoustic) should have been provided to the driver, Figure 2.4. It is allowed to have a prebraking during the warning phase but "Any speed reduction during the warning phase shall not exceed either 15km/h or 30% of the total subject vehicle speed reduction, whichever is higher." [12]

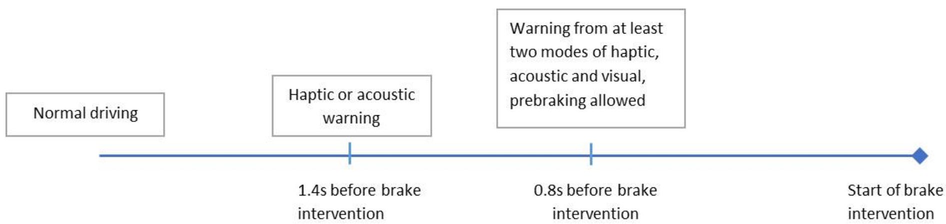

Figure 2.4: Illustration of warning modes and times required [12].

Besides the regulation stating when the system should be active, there is also a demand of the system being automatically deactivated if a trailer without fully operational Anti-lock Braking System (ABS) is connected. The regulation also states that the driver must be informed when the AEBS is not fully operational but parts of the system not concerned can still be enabled. For example is it allowed to provide warnings despite the braking functionality being disabled.

2.4 Safety Systems Used in Analysis

To get more information about the performance of the AEBS than the AEBS interventions, it is necessary to combine it with the information provided from several driver assist and safety systems. Once again, the systems by Volvo are presented as a reference but other HGV manufacturers have their own similar systems.

2.4.1 Driver Alert Support

The Driver Alert Support (DAS) system is monitoring the driving in order to find signs of the driver being tired or distracted. If such behaviour is detected, an acoustic warning and a message advising the driver to take a brake is provided in the display [22]. The warning provided is here referred to as DAS warning.

2.4.2 Forward Collision Warning

The Forward Collision Warning (FCW) system is made to alert the driver when there is a risk for a collision with the vehicle in front. The visual warning for the FH and FM model of Volvo trucks, is made by a HUD. FCW is part of the AEBS [17].

2.4.3 Brake Assist

When the system assesses that the driver is making an emergency braking (presses the brake pedal very fast), the system helps by increasing the brake performance. The level of brake assist is dependent on the actions of the driver [17].

2.5 Logging and Extraction of Data

The increased use of integrated computers, so called Electronic Control Units (ECUs), in HGVs has enabled increased possibilities to log and store data from different systems while driving. This data can then be used by the manufacturers to e.g. monitor the use and functioning of safety systems, follow up fuel consumption or provide the location of the HGV by a fleet management system, e.g. the Dynafleet system by Volvo Trucks [25]. Depending on the system used for storage of the data, the information might be lost if HGV is not turned off properly or if the hardware for any reason needs to be exchanged.

Accessing logged data can be made in different ways where one often used is to extract the data while the HGV is at service. The extraction of data is then made by a diagnostic tool connected to the HGVs On-board Diagnostics (OBD) connection in the same way as e.g. fault codes are retrieved from the HGV. To be able to store the data and access it from the office, some kind of storage place (database) also needs to be set up.

Since the connection of the diagnostic tool is only sustained as long as the HGV remains connected to the diagnostic tool at the service spot, the data needs to be prioritised to retrieve the most important data first. Since the length of the service stop can vary from very short to long, the data retrieved for each session will contain different amounts of parameters. It can also be that the diagnostic tool is connected several times during the same service stop if the truck for example is tested on the road in between two readings or the tool is connected and disconnected for another reason.

Data retrieved with a diagnostic tool method can therefore contain multiples and readouts which do not have all the wanted parameters. To get the most useful information out of the data, the query for data request needs to be adapted to the specific purpose regarding e.g. time interval and the dataset needs to be sorted in order to remove multiples and non complete readings.

For some situations, there can be a need to access data for one or more HGVs without requiring them to visit a service centre. To solve this HGV manufactures can take advantage of the mobile network over which data can be sent and retrieved.

Sending data over the mobile network is often connected with an additional cost and is therefore often used only when needed. The systems for doing this are different among the manufacturers but will need to contain a specific reference for the requested HGVs, for example the Vehicle Identification Number (VIN) and a specification of the parameters requested. It is also neccessary for the HGV to be turned on to be able to send the requested information and often is there a timeout of the demand if no data have been sent within a certain time. Requesting the data by the mobile network decreases the need for sorting but the query still needs to be designed and a quality check to be performed.

Regardless of the method used, it is important to follow the laws regarding data collection and storing of personal information. In Sweden this is regulated by "Personuppgiftslagen, PuL" [26] and on European Union level, there are also regulations and directives that must be followed [27].

An illustration of these different ways to read data is presented in Figure 2.5.

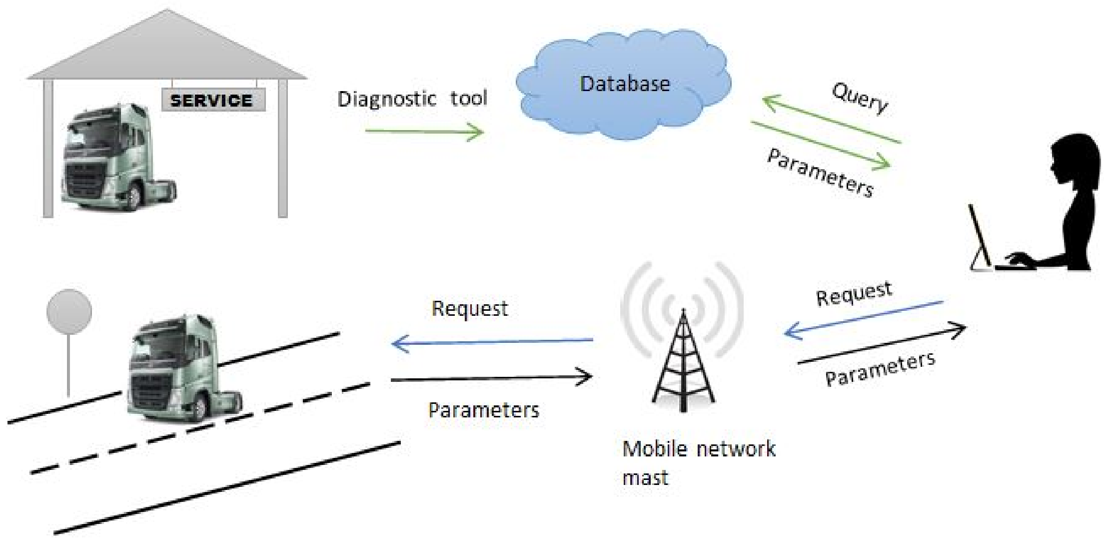

Figure 2.5: Example of methods for extracting data from a HGV. On the top by using a diagnostic tool when the HGV is at service and below by requesting parameters over the mobile network.

3

Literature

The aim of the following section is to provide an overview of the state-of-art work which have been published regarding AEBS on HGVs. Most studies have been performed with the aim to evaluate the improvement in reducing injuries and fatalities but no study investigating where the largest room for improvement of the system has been found. However, the German Road Safety Council have published a list with comments and possible improvements to the commission regulation 147/2012 [12].

There are sometimes large differences in vehicle and accident types and traffic situations between different regions such as between Europe, USA and Australia. The differences are for example the length of the cabin and which regulations that applies to maximum load. Despite the differences between the continents, the found studies have all shown a positive effect on the traffic safety when equipping HGVs with AEBS.

Bao, LeBlanc, Sayer, Flannagan (USA 2012)
Heavy-Truck Drivers' Following Behavior With Intervention of an Integrated, In-Vehicle Crash Warning System: A Field Evaluation [13]
The study investigated the change in time headway held by professional HGV drivers with and without a crash warning system (FCW system) based on naturalistic driving data. When the drivers received warnings the time headway increased with 11% (0.28s) when the traffic was dense (compared to a baseline period). For driving in adverse weather, the corresponding increase in time headway was found to be 7% (0.2s). It was also found that the driver response time to forward conflicts were shortened with 0.26s when driving with the safety system activated compared to the baseline. The study did not include any emergency braking but only the warning.

Woodrooffe et. al. (USA 2012)
Effectiveness of a Current Commercial Vehicle Forward Collision Avoidance and Mitigation Systems [14]
The project investigated the estimated benefit from a AEBS system with FCW in the United States. The group started with a system which was already on the market and to find out the algorithm behind it, reverse engineering and testing on a test track was used. When having found out e.g. times for warnings and interventions, the algorithm was further applied to a virtual database of crashes. The database

was built up from crashes and near crashes identified from naturalistic driving data with applied variations in order to increase the number of cases.

The project concluded that the annual reduction in fatalities could be estimated to 24% and 25% for injuries if the system would be fitted on all semitrailers. For rigid trucks, the corresponding reductions were found to be 22% for fatalities and 21% for injuries (numbers relative to base population).

German Road Safety Council (2015)
Advanced Emergency Braking System for Commercial Vehicles - Resolution taken on 9 September 2016 based on recommendations of the DVR Executive Committee on Vehicle Technology [23]
In a recommendation for updates to the EU regulation 147/2012, the German Road Safety Council (DVR, Deutscher Verkehrssicherheitsrat) refer to an in depth study of accidents on German highways resulting in fatalities or seriously injured persons and which involved at least one goods vehicle. The investigation listed the accidents in which AEBS would have been relevant and in how many of these that the system would have been able to prevent for two different performance levels of AEBS, Figure 3.1. Current "optimal" AEBS refers to the insight that the best performing AEBS systems for HGVs on the market far exceeds the approval level 2 limits.

It is important to note that the numbers are for accidents on the highway which are considered to have larger benefit from the system.

			DVR estimate of the potential for accident prevention by current AEBS for goods vehicles >7.5 t versus real accident occurrence in 2015	
	All accidents on German motorways in 2015 which result in fatalities/seriously injured persons and involve at least one goods vehicle [6]	whereof AEBS-relevant [1]	Current AEBS in compliance with approval level 2	Current "optimal" AEBS
Accidents	1,707	566	-137	-488
Fatalities	232	104	-37	-98
Seriously injured persons	2,053	701	-559	-671
Slightly injured persons	1,048	527	-178	-473

Figure 3.1: Result from the in depth study on accidents on German highways [23].

L. Budd and S. Newstead (Austalia 2014)
Potential safety benefits of emerging crash avoidance technologies in Australasian heavy vehicles [24]
Researchers in Australia investigated the benefit from different active safety systems on heavy vehicles in terms of savings ranging from fatalities to property damage only crashes. AEBS were one of the system investigated by the use of police reported data from the last three years. The findings were converted to annual crash reductions if all heavy vehicles would have been equipped with the system. Heavy vehicle in this study is defined as a rigid truck above 4.5 tonnes, a tractor with or without trailer or a bus with a seating capacity of at least 10 persons. The result of the study based on the police reported data is presented in Table 3.1.

Table 3.1: Expected reduction in crashes of different severities with mandatory fitment of AEBS on all heavy vehicles in Australia and New Zealand [24].

	Fatalities	Serious injuries	Mild injuries	Prop. dam. only
Australia	8-25%	5-17%	-5 to -3%	0-2%
New Zealand	8-24%	4-14%	-2 to -1%	No information

Strandroth et. al. (Sweden 2012)
Head-on collisions between passenger cars and heavy goods vehicles: Injury risk functions and benefits of Autonomous Emergency Braking [15]
Study which investigated frontal accidents between cars and HGVs in Sweden and the potential benefit of AEBS in these. The study was performed with data from crash pulse recorders and Abbreviated Injury Scale (AIS) coded injuries from traffic accidents together with 70 in-depth cases. If both the car and the HGV would have been equipped with AEBS for oncoming situations, a 30% reduction in impact speed was found, leading to an injury reduction of injuries from AIS2 and higher with 73%. The corresponding impact speed reduction if only the HGVs should be equipped with AEBS for head on collisions is 18km/h.

Despite head on collisions not being handled by the AEBS today, the study by Strandroth et. al. has been included in the literature study presentation to show on the potential of the system.

4
Method

The development of the method itself has been an important part of the project and both methods of retrieving data in Section 2.5, have been considered. The method has also been tried out on a limited dataset but from which no conclusions regarding the whole HGV fleet by Volvo can be drawn.

The project has been divided into two phases where the first one is the preparation of data and the second one is the results, Figure 4.1. The data preparation contains parts as choice of parameters to request and the sorting of it. For the results, the work has been split up into three different areas, overview, uptime of system and combination of interventions. The overview aims at providing a better understanding of the data provided, uptime of system contains e.g. reasons for deactivations of AEBS. The section combinations of interventions focuses on how data from different systems can be used to better estimate whether an intervention is due to a true or false positive.

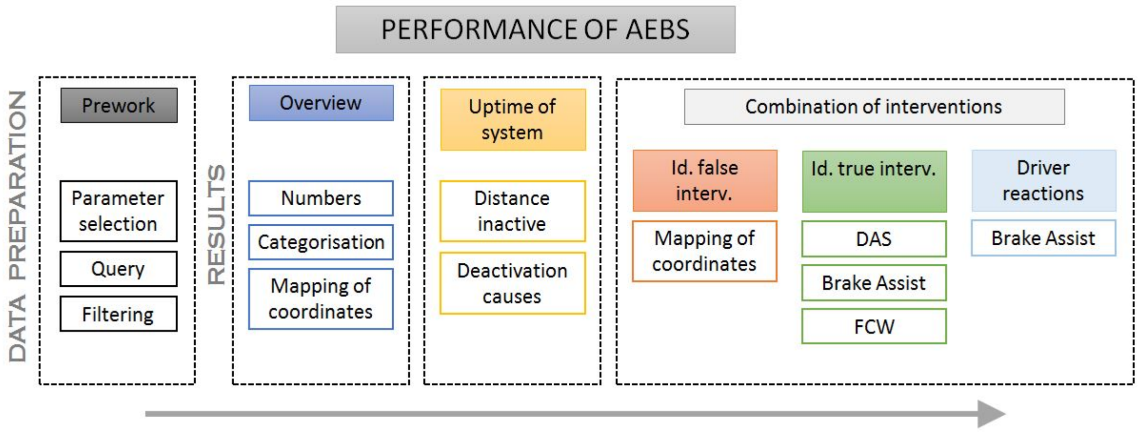

Figure 4.1: Presentation of the systems and methods used for different parts of the project.

4.1 Data Used

As described earlier, both methods of retrieving data require queries to be designed and postprocessing to be performed in order to get data of high quality. How this has been done is described in this section.

4.1.1 Parameters Used

The selection of parameters to discuss has been made with respect to make the most out of the least data and instead combine information from different systems to retrieve more information. The assumption made is that for each of the safety systems, there is data saved about the latest interventions by the system and counters of the total number of interventions. Saving all interventions would require a large storing space which increase the cost. In this project, data from the last ten interventions for each of the addressed system have been considered.

Despite only saving a limited number of interventions, a continuous process of extracting the data would make it possible to retrieve and store all interventions. However, the access to previous saved data is not considered in this project.

For the interventions, there are some data which are of interest for all safety systems, these are presented below:

- Time and date
- Current odometer value
- GPS longitude
- GPS latitude
- GPS direction
- Duration of intervention

To be able to make an estimation of the benefit from a system, it is also important to know the uptime of the system and reasons for deactivations. Two ways to keep track of the uptime are to log the last activations and deactivations of the system and the accumulated distance which the system has been inactive.

For the AEBS there is two different types of interventions of interest, prebrakes and fullbrakes. Since these can take place either isolated (only prebrake or only fullbrake) or together and both types are important, these are considered to be stored separately.

4.1.2 Query and Data Filtering for Diagnostic Tool Data

Two readouts from the diagnostic tool data have been performed in order to find out which HGVs that are suitable for the method evaluation. Since only HGVs equipped with the AEBS version designed to fulfil the legal requirement and of model FH/FM have been of interest, the first limitation made to the queries used have been to exclude all other HGVs. The parameters of interest have been:

- Number of prebrake interventions
- Number of fullbrake interventions
- Odometer status
- Information about vehicle model

The odometer have been used to calculate number of AEBS interventions per distance and to be able to assess which readouts to use.

The first query constructed was based on the latest readout from all HGVs but did not provide sufficient with data whereof the query was adjusted and another try made. The second query allowed for all readouts made the last six months but had no demand for all HGVs to be present. An interval of six months were chosen since it allows most of the HGVs in use to have been in for service but still give an amount of data which is able to handle.

The data was sorted in a way which only allowed for the latest readout containing all wanted information to be kept. In case that the readout would be a duplicate, it was made sure that only one readout remained. Further, the HGVs used as test vehicles by Volvo were removed since these could provide results which is not from ordinary driving. Also other HGVs which have been identified as test or demo vehicles, see section 4.1.3, have been removed.

In cases where a value ha been obviously wrong (physically impossible), those readouts have also been removed. This has been done after the initial sorting and has not been replaced with another readout from the same HGV.

The dataset after sorting contains approximately 50 000 unique vehicle ID's.

4.1.3 Query and Data Filtering for Mobile Network Data

The query for requesting data over the mobile network was based on the diagnostic tool readout performed. The 300 HGVs with the highest number of fullbrake engagements were selected to get the most interventions to analyse.

The data request were made at two occasions where the second one only contained the HGVs which had not provided any data at the first try (e.g. due to time out). The HGVs which had not provided any data after the two occasions were then rejected. Out of the requested 300 vehicle IDs were data received for 268 and another 7 were removed later after being identified as test or demo vehicles, see Section 4.4.1, or were operating outside Europe. The remaining dataset thus consists of 261 HGVs of FM and FH model, operating in Europe. The ten vehicles with the highest number of fullbrake interventions have also been checked manually by plotting the coordinates to check that the interventions have taken place on public roads. The HGVs removed for the mobile network dataset were also removed for the diagnostic tool data.

Further have all interventions which do not have time and date been considered empty and removed since a large part of the analysis requires the time for the intervention to be correct. In cases where an intervention has been logged but the GPS position has not been available, these have been kept since the GPS positions is not subject to any statistical analysis. The odometer values have been checked as well and are all considered to be within a reasonable span.

4.2 Providing an Overview of the Dataset

The data analysis was started with providing an overview of the dataset in terms of e.g. registration country and number of AEBS interventions. In combination with this was also the AEBS interventions divided into three categories depending on how they take place in relation to each other. This since the interventions are not always taking place as a prebrake followed by a fullbrake but can also occur as a single intervention of either prebrake or fullbrake. The interventions were categorised as single prebrake, single fullbrake or as a combined interventions when there was at least one prebrake and one fullbrake intervention within a specified time frame.

The time frame used was 10 seconds which is long enough to cover the duration of most interventions but still short enough that it can be assumed that the interventions belong to the same event. When decreasing the time frame to two seconds, slightly fewer combinations were found and between 10 and 20 seconds time frame, the numbers are stable.

4.3 Determining Uptime of System

The legal requirement [12] in its current version allows for the system to be disabled by the driver but must automatically be activated at ignition turn on. AEBS will only be useful when the system is activated and determining if and possibly why the system have been disabled is therefore important for several reasons. Not least to be able to put in relations to the findings but also since different reasons for deactivation requires varying actions.

If the system often is shut down due to the sensors being covered with e.g. snow, heavy rain or due to other errors [17], then the problem is connected to the development of e.g. the sensors or positioning of these. If the AEBS is automatically disabled by the system, the problem might instead be associated to the ABS system of a trailer or the connection between the trailer and the HGV. A broken electrical connector can for example cause the AEBS to be shut down since the system can not detect whether the trailer has a functioning ABS. To solve problems of this kind, it can for example be necessary to sharpen the regulations for HGVs and trailers. In cases where there is a possibility for the driver to shut down the system, a high frequency of deactivations by the driver might indicate a bad system design and/or HMI, irritating the driver. But it can also be due to other reasons such as the driver not being able to use the system due to e.g. an attached snowplough which covers the sensors and then totally different actions are needed to increase the use.

Several ways of determining the uptime of the system can be used, for this project two different means have been considered; analysing the cumulative distance of AEBS inactive and analysing stored events of activation and deactivation of AEBS. For the latter, four different events have been considered together with information about date and time and odometer to be able to separate the events. The parameters considered have been:

- **Deactivation by system**
  AEBS has been automatically disabled due to e.g. blockage of sensors, connected trailer without ABS or error on other sensors of importance for AEBS.
- **Deactivation by switch**
  AEBS has been manually deactivated by the driver.
- **Activated by system**
  AEBS has been automatically activated, e.g. while turning on the ignition, disconnecting a trailer without ABS or due to sensor error removal.
- **Activated by switch**
  AEBS has been manually activated by the driver.
- **Current date and time**
- **Current odometer value**

For coming sections, "deactivation" will refer to "deactivation by system" and in the cases where deactivation by switch is addressed, this is clarified. Considered for accumulated distance of AEBS deactivated have been a simple counter of odometer type and the percentage of total distance driven have been calculated in the post processing.

The legal requirements states that the driver must be informed when the AEBS system is not fully functional [12] but does not require the entire system to be shut down regardless of which part that is not functioning. Due to this it is for example allowed to provide collision warnings even if the prebrake and fullbrake interventions are disabled. However will the possibility to do so depend on the system design and differ between manufacturers. For this project, a system design where FCW and AEBS interventions are separated but use the same sensors is considered to open up for the possibility to combine activation and deactivation events to get a better understanding of the causes. For example the FCW, which only provides warnings, will not be affected by an error on the brake system but if for example the radar is blocked, both FCW and AEBS will need to be disabled. With both systems considered to be automatically activated at ignition turn on and the same parameters stored for FCW activation and deactivation events as for AEBS, it is possible to combine the data to get more information.

The combinations which have been considered when comparing activation and deactivation events of AEBS and FCW is presented below. Note that AEBS activated and FCW deactivated is not included due to its illogical combination and conflict with the legal requirement which requires warnings to precede an AEBS intervention.

- Both systems activated
- Both systems deactivated
- Both systems deactivated by switch
- AEBS deactivated and FCW activated

To compare activation and deactivation events as well as combination of data between systems, the method described later in section 4.5 have been used. The time frame have been chosen to ± 1s since it allows for some delay for sending the signals but will likely not capture an eventual restart of the HGV. Further have also the type of activation and deactivation events for AEBS which was isolated from FCW events been investigated. The time frame used here was also ± 1s.

4.4 Mapping of GPS Coordinates for Interventions

The infrastructure at the place for AEBS interventions can be useful for evaluating the real life performance of the AEBS since it makes it possible to gain more knowledge about how the system is working. It can for example be about finding hotspots of interventions to be able to investigate whether they are due to the infrastructure and traffic situations or due to the system. The ultimate aim of AEBS is to avoid rear end crashes and in some cases, the aim can also be fulfilled by making changes in the infrastructure and then the logged interventions can be used to identify such spots. Analysing the hotspots can also gain information about in which situations the system is most needed and be used to further improve the performance.

Another part of mapping the coordinates is to find suspected false positive interventions which even if being few, is important to find. For this project, no individual classification of each intervention or statistical analysis have been made. Instead the focus have been on laying the foundation for an automated process by investigating what situations that can be identified. Another purpose with plotting the coordinates have been to visualise and provide an overview of the dataset.

For this project the online service “my maps” by Google [29] has been used but any similar tool or program would be as useful. Since the service used is an online service, all information uploaded have been unidentified so that no information will make it possible track the positions to neither Volvo nor the AEBS. The vehicle IDs have been replaced with a fictive serial number, starting on 1 and counting up. The time and date information is completely removed and the only clue to what type of intervention that has taken place is a "P" for prebrake interventions and a "F" for fullbrake interventions. The information was made anonymous in Matlab while preparing the data list to upload, and to keep track of the information was a translation table created at the same time.

4.4.1 Finding Test and Demo Vehicles

The test vehicles owned by Volvo were removed in the initial sorting of the data but it is possible that other manufacturers have used Volvo HGVs to find out more about the AEBS. Identification of test vehicles have primarily been to be able to sort out the interventions caused, to avoid bias of the data.

The criteria for considering a HGV being a test vehicle has been at least five AEBS interventions in an area which is not considered to be part of the public road network. Examples of such places are for example military airports and race tracks and these have been identified manually from the map.

4.4.2 Finding Suspected False Positive Interventions

It is known that infrastructure objects like tunnels and bridges in some cases can cause a false positive activation of the AEBS. The reason for this is sometimes unknown but it is important to find these spots to be able to prevent them (e.g. by software updates).

Signs used to identify suspected false targets have been a collection of AEBS intervention within a limited area and an infrastructure object such as a bridge or a tunnel close to the interventions.

4.4.3 Finding Other Road Sections of Interest

Identifying road sections with many AEBS interventions might not help the development of the AEBS but can be of interest and importance from an infrastructural and traffic safety point of view.

4.4.4 Identifying Plausible True Positive Interventions

In dense traffic, queues are often build up in connection to road elements such a crossroad with traffic lights, roundabouts or motorway entries. Vehicles which are standing still in a queue or slow moving traffic might not be observed by a distracted driver and thus induce an intervention by the AEBS. An intervention in such environment therefore increases the likeliness of the event being a true positive.

True positive interventions can also be assumed when an intervention has taken place on a straight road without any infrastructure elements thought to provide false positive interventions.

4.5 Finding Combined Interventions

The data which have been considered in this project is limited and to develop a method which extract as much information possible from it, combinations with other systems as Brake Assist or FCW have been made. The knowledge gained from each combination is depending on which data that have been used and fulfils different purposes but the process has been the same.

For each of the combinations of interventions, a time frame has been defined to state within which time interval two interventions should take place to be considered a combined intervention. The suitable time frame differs between the combinations and is motivated later in this section. For all system combinations, a control has also been made of how the number of found events differ with varying time frames.

To find the combined interventions, the starting point has been the data from the main system for the analysis, most often the AEBS. For the main system and the type of intervention which has been of interest, the HGVs have been looped through one by one. All interventions belonging to the specific HGV have then been extracted from both systems and compared with each other by going through the main system interventions one at the time and compare with the second system interventions. In this way, every intervention by the main system has been either coupled to one or more interventions by the second system or considered to be isolated.

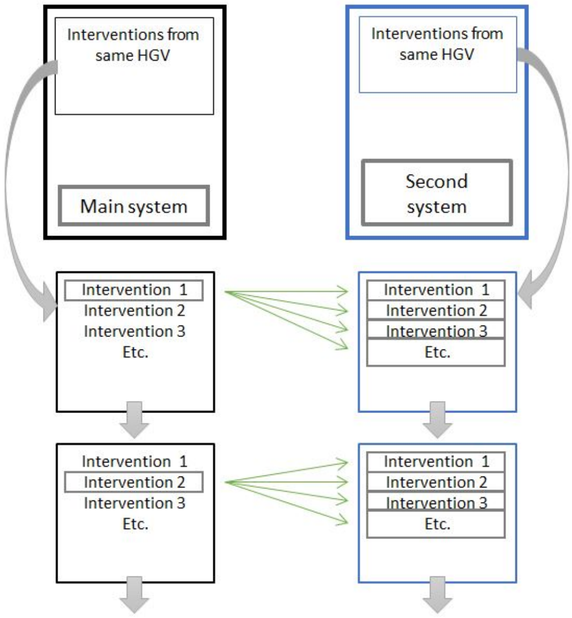

Figure 4.2: The interventions by the main system are gone through and compared one by one to the interventions by the secondary system to see if they fall within the specified time frame and to be considered combined.

If the data storage is limited to a certain number of interventions, it needs to be taken into account that interventions might have been overwritten at the time for data extraction. This can make an intervention appear isolated despite that it was combined with another intervention, Figure 4.3. For this project, the storing spots are considered to be limited to ten. Data which have been overwritten will not be able to recreate (if not having it saved from previous readouts) and therefore induces an uncertainty.

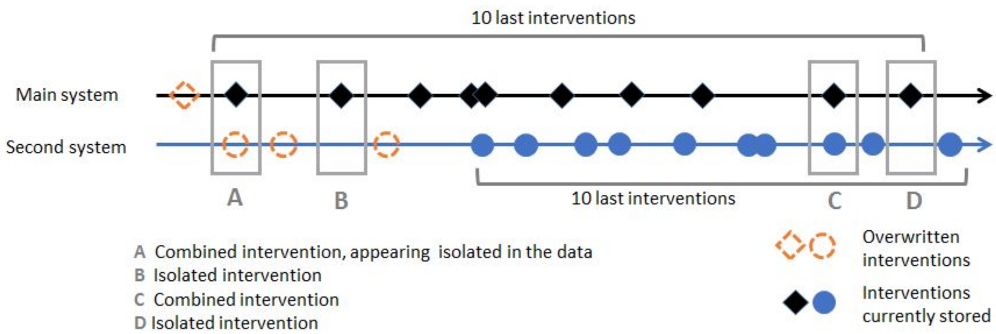

Figure 4.3: Illustration of the problem with interventions being possibly overwritten.

To get an estimation of the level of possibly overwritten interventions, a comparison between the times for the main system's newest interventions and the second system's oldest intervention have been made. The time interval which contain interventions from both systems have been called "overlap" and is illustrated in figure 4.4. By also investigating the number of storing spots filled for the secondary system after the time for the latest intervention by the main system, it is possible to estimate whether a small number of combined interventions are due to new intervention logs being saved afterwards or if there have been no interventions.

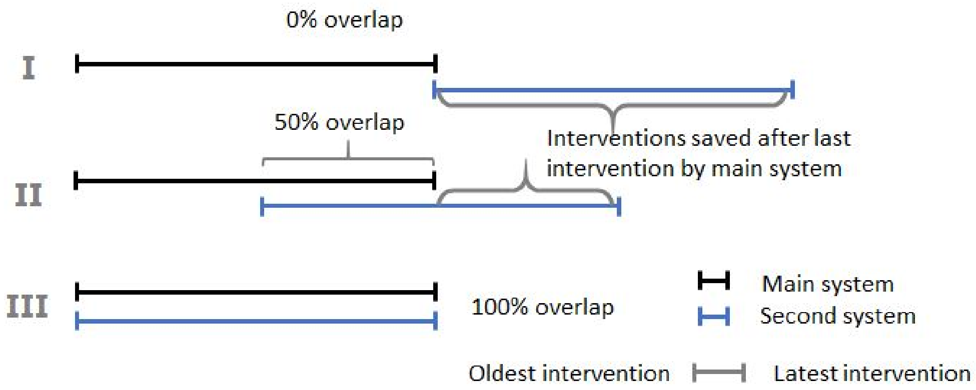

Figure 4.4: Illustration of what is meant with overlap, no overlap (I) means that no combined interventions will be able to find and full (II) means that if there are combined interventions, they can be found.

4.5.1 AEBS and FCW Interventions

Having a warning preceding the prebrake or fullbrake interventions increases likeliness that the intervention is a true positive since false positive interventions often are very short. A FCW intervention with only a prebrake following (and no fullbrake), could also indicate that the FCW warning alerted the driver and that he/she took action. To better judge whether the driver took action or not, the FCW interventions can be combined with the Brake Assist system which is discussed later.

Since the FCW intervention takes place immediately before a possible AEBS intervention, the time frame is chosen to be relatively short and set to 5 seconds.

4.5.2 AEBS and DAS Interventions

DAS warnings provided to the driver before a prebrake or fullbrake activation could indicate a tired or distracted driver. Knowing that the driver was distracted is no proof of a following AEBS intervention being a true positive but without other signs as e.g. objects suspected to be able to provide false positives, the likelihood increases.

The signs of a tired or distracted driver does not necessarily take place in the immediate proximity to the AEBS intervention and therefore allows for a longer time frame. A longer time frame will however increase the uncertainties. There might for example have been a change of driver, or the driver has taken a brake and is no longer as tired or distracted when starting driving again. The used time frame have been between 1 and 3 hours.

4.5.3 AEBS and Brake Assist Interventions

Since the Brake Assist system is only activated when the driver is initiating the braking, it can be used to see whether the driver reacted to the situation. Even if there is a risk that the driver would brake also due to a false warning, it is more likely that the driver only brakes when he or she has discovered the threat himself, which would indicate a true positive intervention. In the longer term Brake Assist interventions could also be used when trying to identify false negatives. However situations where the driver have needed to perform a hard braking can also be due to events which only involves the ego HGV and for which the AEBS therefore not is designed to intervene for, e.g. an unexpected braking due to a missed exit or a traffic light turning to red. To possibly identify false positive interventions with Brake Assist interventions, additional information would therefore be needed.

The time frame for this analysis have been set to 20 seconds.

5 Results

The results obtained from the method evaluation are not representative for the HGV fleet by Volvo in total since they are based on a dataset of 261 out of the 300 HGVs with the highest number of fullbrake interventions. The results can therefore not be used to draw conclusions for the performance of the system. However will the results still be valuable for understanding the method and interpreting the results and are therefore presented. The results are split into two sections where the first one is presenting findings from the diagnostic tool method data and the second one findings from the dataset with the highest number of fullbrake interventions, described in section 4.1.3.

5.1 Diagnostic Tool Data

From the dataset containing diagnostic tool data which was used to find the HGVs with the highest number of fullbrake interventions, it was also possible to get the distribution of AEBS interventions for the approximate 50 000 HGVs. The distribution is presented in Table 5.1.

The by far largest part of the HGVs have no AEBS intervention stored and for the rest, it is more common to have had a prebrake intervention than a fullbrake intervention. From the results it have also been found that 85% of the HGVs have had neither a prebrake or a fullbrake intervention and 95% have not had a fullbrake intervention.

Table 5.1: Percentage distribution of prebrake and fullbrake distribution for diagnostic tool data.

	Interventions			
	0	1-3	4-6	More
Prebrake	85%	10%	3%	2%
Fullbrake	95%	5%	<0.1%	<0.1%

5.2 Mobile Network Data

For the analysis of the mobile network data, several different methods and systems have been used and combined. The work follows the structure presented in Figure 4.1 from Chapter 4 and is presented in coming section. The exact percentages are not provided for the figures due to confidential reasons. Due to the small dataset and the selection criteria of highest number of fullbrake interventions, they would neither be representative for the system in total.

5.2.1 Overview

The overview section is provided to give a better understanding of the dataset as well as making important analysis of the categorisation of interventions.

5.2.1.1 The Mobile Network Dataset in Numbers

The 261 HGVs present in the dataset with the highest number of fullbrake interventions are registered in 24 different countries around Europe, Figure 5.1. The HGVs can (and are) still driven in other countries but gives an indication of the spread of the data. Germany and Britain are found to have the highest shares of HGVs in this dataset and this is also reflected later when plotting intervention coordinates on a map. No comparison with the distribution of sold HGVs has been made.

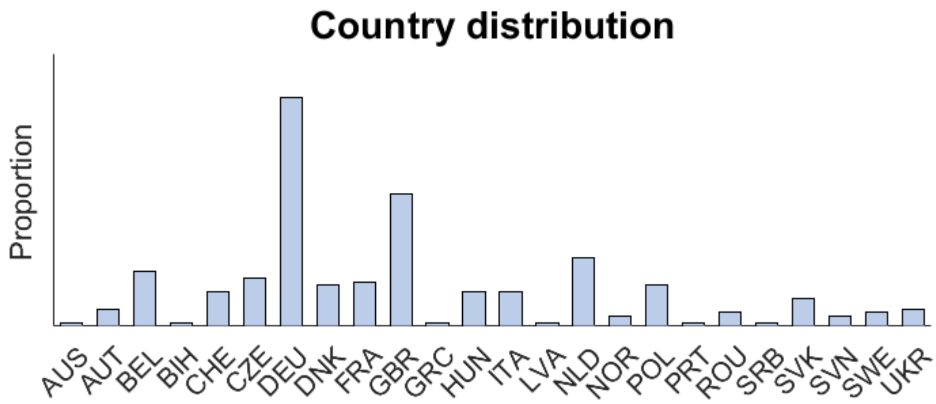

Figure 5.1: Overview of registration country for trucks in mobile network dataset. Germany and Great Britain have the largest shares but 24 different countries are represented.

AEBS Interventions
The distribution of AEBS interventions was used for the understanding of the dataset and also to compare with the diagnostic tool data to highlight the difference between them. Table 5.2 shows the percentage of HGVs with the specified

number of AEBS interventions. If comparing with figure 5.1 it can clearly be seen that this data have much higher shares of HGVs with several AEBS interventions (as intended when selecting data).

Table 5.2: Percentage distribution of prebrake and fullbrake interventions for mobile network data.

	Interventions			
	0	1-3	4-6	More
Prebrake	1%	9%	15%	75%
Fullbrake	0%	64%	30%	7%

The duration of the interventions is interesting since it provides information about the characteristics of the interventions. The distribution has also been used to determine suitable time frames for different combinations of interventions. The durations are however dependent on the situation and circumstances such as road friction or driver reactions and therefore only give a rough indication.

From the findings, it have been seen that the prebrake interventions generally are shorter than the fullbrake interventions. For 93% of the HGVs, the prebrake interventions lasted for less than 3 seconds compared to the fullbrake interventions where the corresponding share is 84%. A few interventions were found with a duration longer than ten seconds and can be e.g. due to low friction and longer stopping distance.

5.2.1.2 Categorisation of Interventions

The categorisation of interventions complements previous section in providing an overview of the characteristics for the logged interventions. It is also of interest to see the frequency of different combinations.

It have been found that the vast majority of interventions are isolated prebrake interventions followed by isolated fullbrake interventions. The least share is the interventions where there is at least one prebrake intervention followed by a fullbrake intervention within a time frame of ten seconds.

The results are presented in Figure 5.2, for the combined interventions, the prebrake and fullbrake interventions are counted as one together.

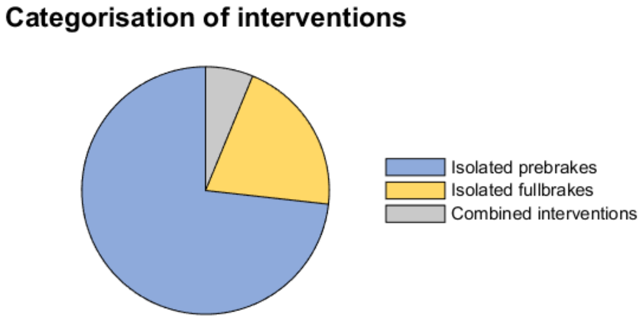

Figure 5.2: Distribution of intervention categories. The combined interventions are at least one prebrake and one fullbrake intervention within ten seconds.

The share of isolated prebrake interventions includes e.g. situations where either the driver has reacted to the system and taken action, the HGV has been able to avoid the situation only by prebrake or the threat has disappeared. False positive interventions might also be included in this group, but without combinations with other systems, it is not possible to say how many. This is however discussed later in the report.

The situations where there is only a fullbrake intervention are often connected to situations where there is no time for a prebrake. This is for example when the time headway is too short. If the target vehicle then brakes hard, the AEBS is forced to demand a fullbrake intervention directly to handle the situation. Another possible scenario is when a vehicle changes lane and cuts in just in front of the HGV and brakes.

Combined interventions are for example a result of situations where the HGV approaches a vehicle which is standing still or slower moving but there are no other objects which obscures the view. Note that this is the scenarios which are tested in the legal requirement.

5.2.2 Uptime of the AEBS

The uptime which AEBS have been activated is important since the performance of the system is directly affected, if AEBS is deactivated, no crashes can be avoided. To evaluate the uptime, both the distance of AEBS inactive and the reasons for the deactivations have been investigated.

5.2.2.1 Distance of AEBS Inactive

The cumulative distribution for which AEBS has been deactivated for the HGVs is presented in Figure 5.3. For over 50% of the HGVs, the distance which AEBS have been disabled is less than 5% of the total driven distance for each HGV. The plot includes all types of deactivations considered in the next section. It should be remembered that this is the values for the HGVs with the highest number of fullbrake interventions.

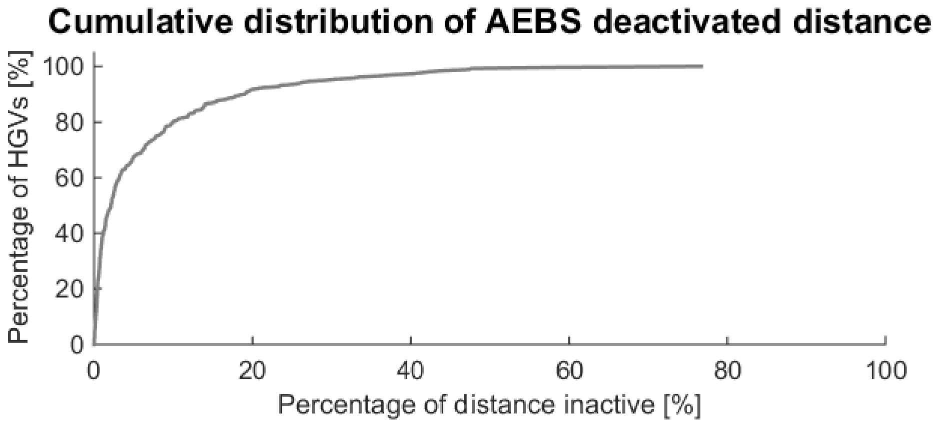

Figure 5.3: The cumulative distribution shows that above 50% of the trucks in the dataset had a distance of AEBS inactivated less than 5% of the total distance driven.

5.2.2.2 Different Types of Deactivations

The reasons for AEBS to be deactivated can be several, from blocked sensors and connected trailers without ABS to the system being deactivated by the driver. Regardless is it important to find out the reasons for deactivation so the right means of actions can be taken to increase the time possible for the system to be active.

When considering the ten last stored activation and deactivation events in combination with the requirement of AEBS being automatically activated at ignition turn on, several of the logged events will be activations, which is also visible in Figure 5.4 where the share of activations by system is high. Automatic activation of AEBS can also be due to e.g. a trailer with erroneous ABS being disconnected and the system can also be manually connected by the switch. Despite the many activation events logged, only a few percentages of the vehicles have had only activation events stored. The cases where AEBS have been disabled by the switch is very few.

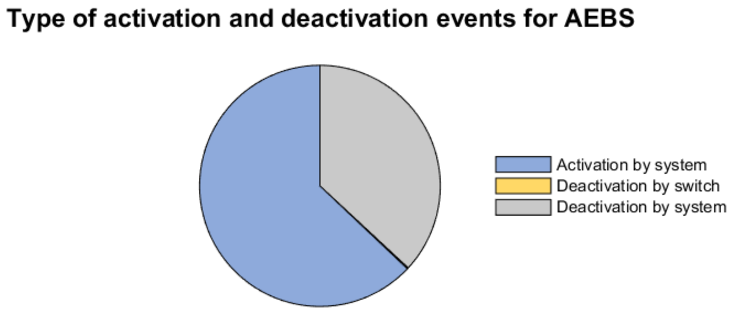

Figure 5.4: Different types of activation and deactivations for AEBS.

It is not possible to, with high certainty, tell from the ten last events if this pattern is valid for all the driven distance. Also if the HGV is started and restarted with a trailer with malfunctioning ABS connected, four of the ten storing spots will be occupied with data from only "one event", giving a higher bias.

5.2.2.3 Combinations of AEBS and FCW Activation and Deactivation Events

To see if it is possible to extract more information about the type of deactivation and activations of AEBS, the AEBS data was combined with the corresponding data for FCW.

When combining the activation and deactivation events for AEBS and FCW which takes place within a time frame of 1s it was found that approximately 30% of the AEBS events could be matched with a simultaneous event by FCW. From these, the largest part is found to be simultaneous activation of both systems, Figure 5.5, which is likely to be when the truck is started and both systems are working as they should. The second largest part is the combination of both AEBS and FCW being disabled at the same time. From this data alone is it not possible to determine if this is happening when turning on the ignition or during driving but it is possible to say that these deactivations are not due to non compatible trailers (brake system related errors) only.

The part of the combinations which could indicate a brake system related error as e.g. a trailer without ABS (AEBS deactivated and FCW activated) is small, but it is important to keep in mind that the dataset is small and these are only events taking place within a very small time frame. If a trailer is connected after starting the HGV, the activation of FCW and deactivation of AEBS will not take place simultaneously. This since the FCW will be activated at ignition turn on and the AEBS deactivated when the trailer is connected.

The category of other cases includes a few cases where there for unknown reason have been logged more than one FCW and one AEBS activation or deactivation within the specified time frame. Additionally have a few cases of both systems being deactivated by switch been found.

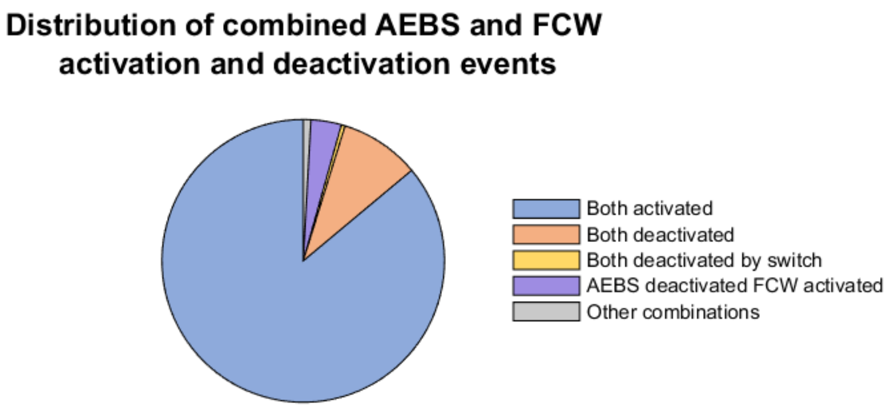

Figure 5.5: AEBS activation and deactivation events in relation to FCW activation and deactivation events. The largest share is when both systems are activated at the same time but variations are found as well. The time frame has been +-1s.

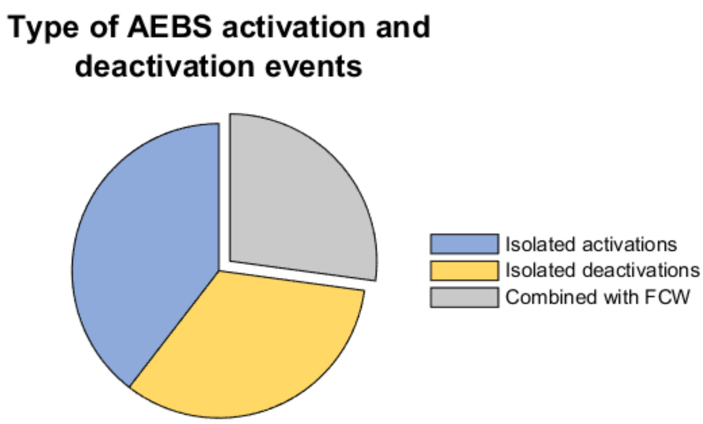

Figure 5.6: Distribution of isolated AEBS activation deactivation events in relation to the share which have been able to combine with FCW system activation and deactivations. Isolated deactivations includes deactivations by both system and switch.

To get more information about the activation and deactivation events which were not concurrent with each other, the AEBS events were also split into groups of isolated deactivations and activations. These are events taking place when no FCW activation or deactivation event takes place within the same time frame ($\pm$1s). Figure 5.6 shows the result.

The shares of isolated activations and isolated deactivations is something which could indicate connected and disconnected trailers, if so, probably in the beginning and the end of a drive. Regardless does these large groups of activation and deactivation events show that something is happening which needs further investigation. The next step in the process could e.g. be to start looking at fault codes.

5.2.3 Mapping of Coordinates

The mapping of coordinates was done to see the potential for estimating whether an intervention have been due to a true or false target and to provide an overview. When analysing all interventions at the same time, there are a lot of data points to keep track of, Figure 5.7 shows a map over Europe and locations for prebrake and fullbrake interventions. It is important to remember that no information is provided about the routes of the HGVs, and it is therefore not possible to draw any conclusions from road sections without AEBS interventions.

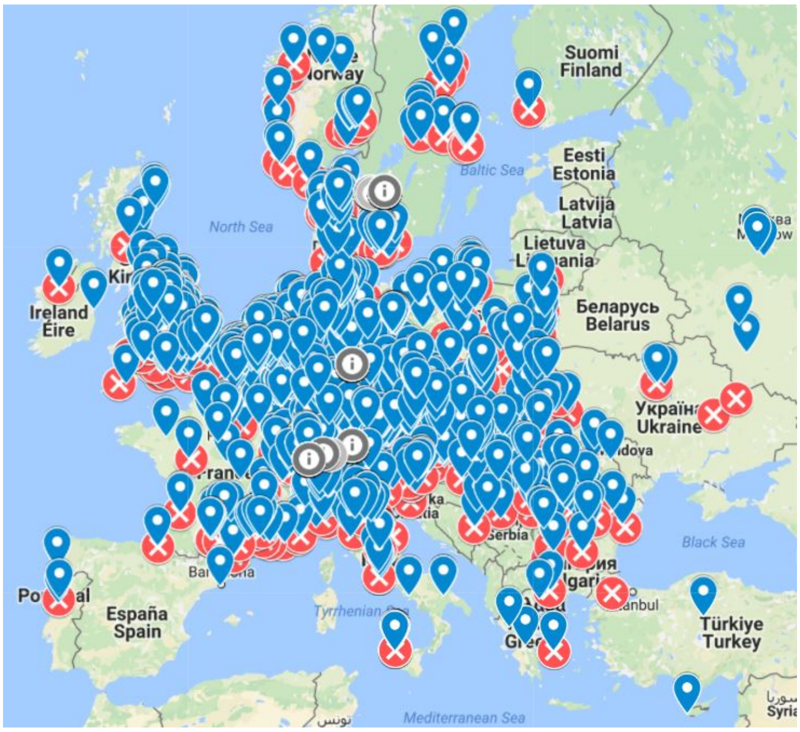

Figure 5.7: Overview of the coordinates for prebrake and fullbrake interventions. Blue markers indicates a prebrake intervention and red markers are for fullbrake interventions. The grey markers are identified test or demo HGVs.

5.2.3.1 Finding Test and Demo Vehicles

The main reason for finding test and demo HGVs is to avoid bias of the data since the interventions logged by these HGVs are not part of normal driving on public roads. Identifying suspected test vehicles have been found easy when the zoom is high and the markers are able to differentiate from each other. When the zoom level is low, the detection is obstructed since the markers are close enough to each other to be mistaken for one AEBS intervention. With the manual process of finding test sites and vehicles, it is hard to know if all these spots have been found and some level of automation would be needed. Figure 5.8 illustrates the difference in appearance for two zoom levels. For a few cases HGVs identified as test vehicles have also had logged interventions outside the test sites. No further action have been taken except removing the HGV from the dataset.

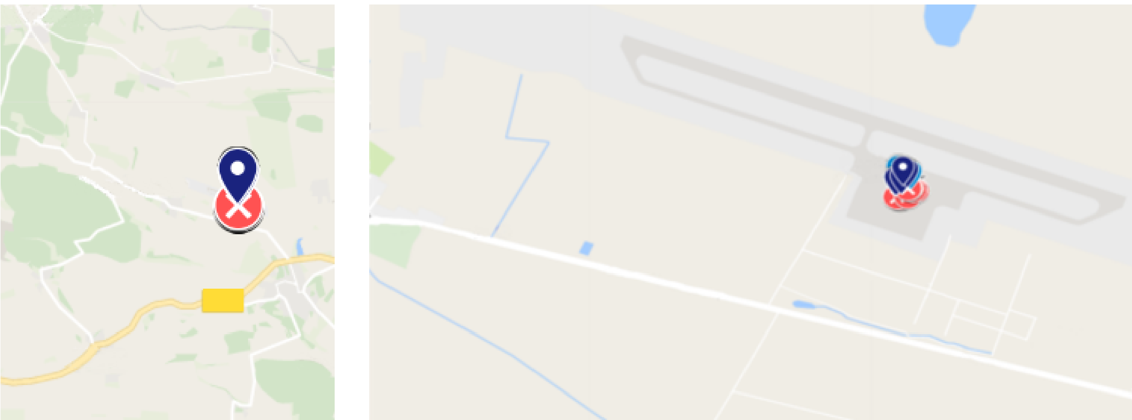

Figure 5.8: Vehicle on test site, to the left with a lower level of zoom and to the right with higher zoom.

5.2.3.2 Finding Suspected False Positives

False positive interventions are uncommon but still important to find since they could cause dangerous situations and decrease the driver's trust to the system. Figure 5.9 shows an example of how it can look like when having a suspected false positive, however it can not be determined only from map data whether this interventions are due to true or false positives. In this case the suspicions are raised since there are several AEBS interventions within a tunnel with no interventions logged in the nearby outside, something which otherwise could indicate that it is the traffic situation which causes the interventions.

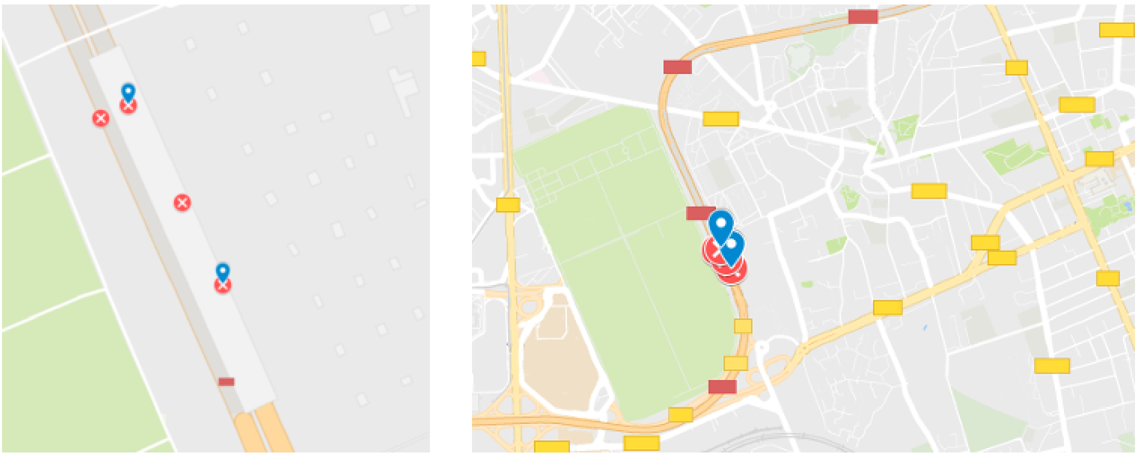

Figure 5.9: Several AEBS interventions by two different HGVs in a tunnel without interventions outside, a hotspot which needs further investigation.

In this first example, one can quite easy spot the tunnel even from the plain map, for some other cases the view from the plain map does not give as much information. On the leftmost picture in Figure 5.10 is it hard to see that the road actually goes underneath the railroad and that the infrastructure is as complex as shown in the middle and rightmost figure. The infrastructure is of the kind which could cause a false positive intervention but it is also likely that the interventions are true positives due to high traffic density or piled up traffic. As in previous example, the place can be interesting to investigate further in order to find out the reason but no conclusions can be drawn.

Figure 5.10: Roadsection with multiple interventions of AEBS and an infrastructure which is not easily revealed at first sight. Red arrow indicates north.

5.2.3.3 Finding Plausible True Positives

Finding and confirming interventions which have been true positive interventions is useful to limit the uncertainties and make it easier to analyse and draw conclusions from the data.

Situations where true positive interventions are likely are for example in the nearby of a crossroad where traffic can be assumed to be piled up, Figure 5.11. Another example of a situation which is likely to be a true positive is when there is an intervention taking place on a straight road without anything which could possibly cause a false positive intervention, Figure 5.12.

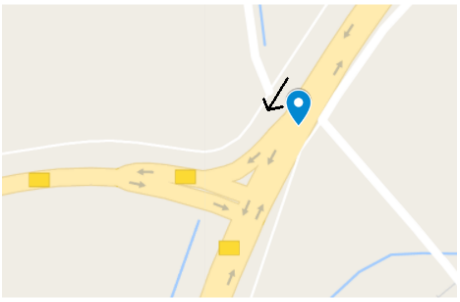

Figure 5.11: Interventions in the nearby of places where traffic can be assumed to be piled up, as crossroads, are likely true positive interventions. The arrow indicates direction of travel for the HGV.

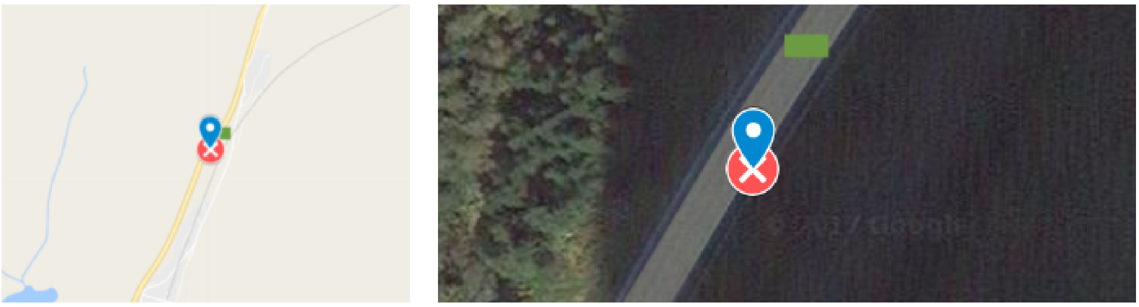

Figure 5.12: An intervention on a straight road without any obstacles is likely to be a true positive intervention.

5.2.3.4 Road Section with Several Interventions

Road sections where there are many interventions might be due to heavy traffic and queuing, but can also be a result of e.g. a complex infrastructure. Finding these road sections and investigating the circumstances for the interventions closer can help improve the understanding for and development of AEBS. An example of a road section found which has interventions from several different HGVs is shown in Figure 5.13.

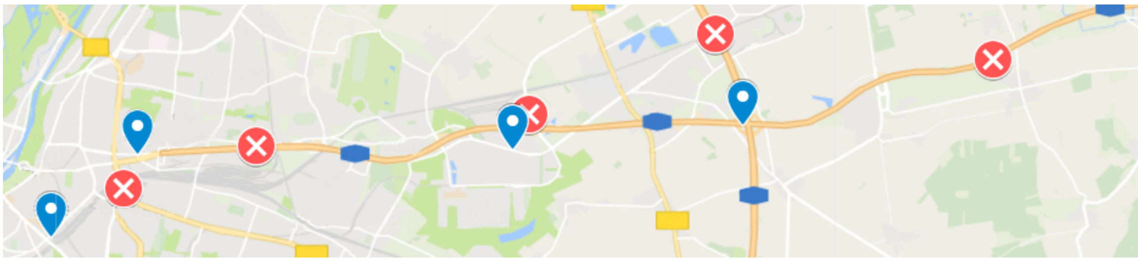

Figure 5.13: A road section which has both prebrake and fullbrake interventions from different HGVs.

5.2.4 Combination of AEBS and Other Systems

While investigating whether it is possible to combine AEBS interventions with interventions from other systems (FCW, DAS, Brake Assist), the number of found combinations have been small. Reasons to the small number of interventions found are likely the dataset of only 261 HGVs, differences in system designs and possibly overwritten intervention logs. An example of a system design difference which might limit the number of combined interventions found between AEBS and DAS is that the latter is only activated at speeds above 65km/h while AEBS is active above 15km/h. If a driver for example has been driving at a road in 50km/h, no DAS warning would therefore have been provided, regardless of how many signs of distraction the driver has shown. The findings are treated as confidential and will not be provided in detail, however, a general overview is presented.

The AEBS and FCW systems were compared based on the hypothesis that an intervention of both systems within the specified time frame strengthens the assumptions for an intervention being a true positive. For the few interventions where a FCW has been provided in combination with an AEBS intervention, the vast majority has been a FCW followed by a prebrake intervention only.

For the combination of AEBS and DAS, the intention was to see whether it is possible to determine if the driver had been distracted in close relation to the AEBS intervention. A few combinations have been found, but in combination with the time between the interventions being long, no conclusions can be drawn.

Interventions from the Brake Assist system were of interest since the system only intervenes when the driver himself takes action. If there is a Brake Assist intervention at the time for the AEBS intervention, it would be possible to tell that the driver had reacted to the situation. The combined interventions found were however to few to draw any conclusions.

6
Discussion

In the project, a method was developed for evaluating the real life performance of AEBS. The method was tried out on a limited dataset with 261 of the 300 HGVs with the highest number of fullbrake interventions and some result were presented. Even if no conclusions regarding the HGV fleet in total can be drawn, the findings still have provided valuable information about the method and the system.

By testing the method on the limited dataset, it has been possible to see the potential of the method but ideally it should also be applied on and evaluated for a large dataset. The parts about for example AEBS activation and deactivation events and categorisation of AEBS interventions were performed in Matlab and it should not be any difference for making this for a large set of data. However, the part where coordinates were plotted on a map and then manually analysed, will not be suitable for a large dataset and shall just be seen as part of the preparation work. To use that part of the method, more work needs to be performed in order to categorise the interventions based on e.g. location and surrounding infrastructure. It will also be needed to design a program which can automate the process and at least highlight sections or locations which should be subject to further analyses.

A basic limitation for the method developed have been the absence of a "known answer". If it would be possible to know what really happened at the time for the interventions, the assumptions which the method provides could be confirmed or rejected. If possible (due to time and money) it would therefore be desired to perform a naturalistic driving study where the considered data still would be logged but with complementary information in shape of e.g. video recordings.

The method developed has also been used to identify limitations and possibilities with the considered data and found examples of both. When considering the data used for the AEBS alone, the information available does not provide the level of details wanted for all situations. For example can the activation and deactivation events be seen but since no further information have been considered, it has not been possible to separate between e.g. the system being disabled by sensor related items or due to no information about (or absence of working) ABS on a connected trailer. However, this limitation could to some extent be overcome by considering the same information stored by the FCW system where different combinations could provide hints about the reasons. The assumptions have not been able to confirm with the data considered but shows on a need for further investigation in combination with e.g. fault codes. By performing a study which uses fault codes to describe the deactivation cause, and compare it to the data provided by the method, it could be found whether the data used today is enough to describe the events.

Another limitation with the data used for activation and deactivation events has been that no GPS information has been considered for this. Using the GPS position for the activation and deactivation events could provide valuable information about where and for what reason the system has been deactivated. Combination of GPS position together with time and date for the event could for example be used to see whether there are more deactivations by system in conditions where snow (or other weather conditions thought to affect the sensors) is expected to be present, something which could indicate deactivation due to sensor coverage. By also including information from a weather database for the time and place for an event, the certainty of these assumptions could be higher. GPS positions could also be used to easier see if a deactivation by system is assumed to be due to a trailer connection if the deactivation for example take place off the road. An even simpler way to retrieve the information about the reasons for activation and deactivation of the system would be to store a comment about this together with the event log. The comment could for example be "deactivated due to no ABS signal" or "deactivated due to blocked radar".

From the data available from the AEBS only, it have also been possible to see whether the interventions have taken place as isolated prebrake or fullbrake interventions or combined with at least one prebrake with a following fullbrake intervention. This information have been found important since it gives an indication that a considerable share of the interventions take place as isolated fullbrake interventions. These interventions which are thought to be due to e.g. cut in scenarios are not included in the legal requirement today.

It is recommended to further examine what causes interventions of this kind and update the test scenarios used for the legal requirement in order to further improve the performance and use of AEBS. It is worth noting that the share of interventions where there is a combined intervention with both prebrake and fullbrake and for which the scenarios from the legal requirement can be assumed is small. It can however not be known from this information if the share of isolated prebrake interventions contains such scenarios as well. Ideally AEBS should alert the driver to self take action and then the isolated prebrake interventions could indicate a good performance of AEBS.

Considering the plotting of coordinates for the intervention, the full potential of the data can be reached first when the process can be automated and combined with e.g. road databases. From a road database as for example the national road database in Sweden (NVDB) [30] additional information about e.g. allowed speed, road type and traffic density can be retrieved. The gained information can then be used to further investigate in which situations AEBS interventions have taken place. By cooperation with e.g. authorities responsible for roads and infrastructure, studies can also be performed to improve the infrastructure and surroundings where needed to possibly decrease the need for AEBS and improve traffic safety. Similar work can today be performed based on crash statistics but being able to identify places which have a high share of interventions opens up for the possibility to take action before having crashes.

Considering the attempt to combine AEBS with other safety systems used in HGVs, a large limitation have been the low number of combined interventions found. The reason for this have not been found as one single factor and is likely to be a combination of factors. To start with was the dataset limited to only 261 HGVs and further are differences in the systems thought to be contributing factors. The systems are for example designed for different situations where some are more frequently intervening than others. When considering a limited number of interventions, this induces the problems with possibly overwritten intervention logs and thereby problems with identifying combined interventions. To some extent this problem could be overcome with readouts with shorter intervals and storing of the data. It can neither be assumed that closer intervals of extracting data with a diagnostic tool method would provide all the data logged since the aim is to minimise the time a HGV spend at service.

Another way of making sure that no data is lost would be to have the HGV autonomous upload data to a database when the memory is full to then be able to clear the memory. The uploading could for example be made with some kind of reversed mobile network method (the data is send without a request). If this is not already done, it would likely require changes to be made to the IT-infrastructure.

The information which the additional systems were aimed at finding, such as for example if the driver has reacted to the situation would have been valuable. However, this project only investigated whether this information have been possible to retrieve from interventions by other systems. There is a possibility to find other means to decide whether a driver for example have been distracted, as for example with the steering wheel input.

The HGVs in the mobile network dataset were chosen due to their high number of fullbrake interventions and therefore have several interventions logged, Table 5.2. When comparing with the number of prebrake and fullbrake interventions for the diagnostic tool dataset, it is however clear that the vast majority of the HGV have less interventions saved, Table 5.1. For the diagnostic tool dataset, nearly all HGVs have had 3 or less fullbrake interventions, and 85% 3 or less prebrake interventions, which indicate that there might be a better use for storing spot 4-10.

By limiting the number of stored AEBS interventions to 3 for each type (prebrake and fullbrake), it could be possible to store more details for these few interventions without the need to make changes of the hardware. The details added could preferably be of the kind which was tried to extract from the combination with the other systems. If there for example was a Brake Assist intervention at the time for the AEBS intervention, this could be included in the data stored for the AEBS intervention. The same principle is also applicable for the other systems as DAS and FCW. In this way would there no longer be a problem with a possible overwriting of wanted information.

The choice of using the HGVs with the highest number of fullbrake interventions has most likely caused a bias to the results. The level of bias is not known but the personal reflections of the author is that it could be easier to find combined interventions for the safety systems for a randomised dataset. This since the many fullbrake interventions in the used dataset might indicate that the drivers have been distracted or stressed, something which could also influence the number of interventions made by other safety systems. Many interventions by the other safety systems increases the number of possibly overwritten combinations. A HGV with less stored interventions by both AEBS and the other system therefore increases the likeliness to find combined interventions, *if* they have taken place.

Another personal reflection from the author is that the share of cases where AEBS have been disabled by switch would be higher due to the drivers being annoyed by the system after the many interventions. However, it can also be the other way around, that due to the many AEBS interventions, the drivers have recognised the use for AEBS and keep it on. It is also not known whether there are HGVs in the diagnostic tool dataset which has a large share of AEBS deactivation by switch but which otherwise would have had several interventions logged. This since no data is considered to be logged for a deactivated system.

7

Conclusions and Further Work

The method used in combination with the considered data has not been enough to with certainty identify situations where the system has been working as intended or not. The method has however been able to show on what needs to be done in order to get this information. Both possibilities and limitations have been found, where the first one for example is the combination of AEBS and FCW activation and deactivation events to get more information. Limitations have primarily been found when combining the AEBS interventions with interventions for other systems were few combinations were able to be found.

To increase the information provided by logged data, suggestions to the set of parameters considered are to add a comment about the reasons for deactivation of AEBS, and decreasing the number of AEBS intervention logged to instead store information indicating e.g. if the driver took action.

With the method used, several interesting areas for further work have been investigated and are presented below:

- Apply the method on a large set of data.
- Perform a study with naturalistic driving data to confirm or reject assumptions made in the method.
- Develop a tool to combine the intervention positions with data from e.g. road databases.
- Investigate which other parameters that could be suitable for finding out driver status and reactions at the time for an AEBS intervention.
- Investigate closer which scenarios that are included in the different categories and suggest updates to test scenarios for the legal requirement. This would be especially interesting for the share of isolated fullbrake interventions.

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