Evaluation of Rear-End Collision Avoidance Technologies based on Real World Crash Data

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Abstract: Over the last decade, collision avoidance technologies targeting rear-end collisions have been introduced by many vehicle manufacturers. However, evaluation of the real world performance of these systems are rare. The objective of this study was to evaluate the real world effectiveness of systems called Forward Collision Warning and Brake support combined with Adaptive Cruise Control (CWB+ACC). These systems were introduced as optional equipment in Volvo car models in 2006. The data analyzed comes from a detailed, representative dataset based on insurance claims. The rate of rear-end frontal collisions was compared for cars with and without CWB+ACC, controlling for different generations of CWB+ACC as well as presence of Low-speed Emergency Braking functionality. For cars with CWB+ACC, rear-end crashes with frontal impacts were reduced with 38%. Also, the data showed a clear progress in crash avoidance efficiency as a function of CWB+ACC development. For the third generation of CWB+ACC, the estimated collision avoidance effect was 45%. In future studies, the additional safety performance that collision avoidance technologies bring in the form of crash mitigation needs to be investigated.

Keywords*:* Insurance claims data, Safety efficiency analysis, Forward Collision Warning and Auto Brake

1. INTRODUCTION

Collision avoidance systems help drivers to avoid or mitigate crashes using warnings and/or interventions, based on information about the traffic situation. Two major groups of systems addressing crashes with vehicles in front of the car that are positioned in, or traveling along the same path as the vehicle equipped with the functionality (i.e. rear-end frontal collisions) have been introduced **to** the market:

1. Collision Warning and Brake support combined with Adaptive Cruise Control (CWB+ACC)

2. Low-speed Emergency Braking (Low-speed_AEB)

Volvo Cars released a first version of CWB+ACC in 2006 (Coelingh et al., 2006), where the driver was assisted by a warning and brake support (pre-charge and increased sensitivity for the Emergency Brake Assist system). The functionality was restricted to objects moving in the same direction as the host vehicle. In the next generation of the system, introduced in 2007, standing still vehicles were distinguished, thus allowing for system activation for stationary vehicles as well (Coelingh et al., 2007). Also, auto brake up to 5m/s² was provided. In 2010, the third generation delivered full automatic emergency braking up to 10 m/s² and expanded to detect other conflict situations than rear-end scenarios (Lindman et al, 2010). All these systems were available as optional equipment in the car models presented in Fig1.

In addition to these functionalities, Low-speed_AEB operating at speeds up to 30 km/h was introduced as a standard mounted system in Volvo car models from 2008 and onwards, see Fig 1. In its second generation, Low-speed_AEB works at speeds up to 50 km/h. For cars equipped with both CWB+ACC and Low-speed_AEB, there is an overlap between the functionalities, Fig 1. Depending on various traffic situation parameters, e.g. travelling speed and speed reduction needed to avoid the crash, either one of the functionalities will intervene.

Numerous prospective studies have been performed, where the effectiveness of CWB+ACC was predicted, but research in the area of real world follow-up, i.e. summative evaluations of CWB+ACC studies are limited. One reason for this is that CWB+ACC often is offered as optional equipment and car individuals with the system need to be identified. Also take rates for these optional systems have been low, hence, the evaluation of the CWB+ACC system is hard to perform due to low numbers of equipped cars. Data from insurance claims is one good source of information for solving this issue. HLDI reported in 2012 a reduction in insurance claims for cars of different makes equipped with CWB+ACC systems (HLDI, 2012). Also, the real world effectiveness of the standard mounted Low-speed_AEB system was first evaluated in HLDI (2011, 2013) and in Isaksson-Hellman and Lindman (2012). Later, Low-speed_AEB was also evaluated in police reported data (Rizzi et al., 2014; Fildes et al., 2015).

The aim of this study was to investigate the crash reducing effect in real-world traffic of CWB+ACC systems, controlling for the crash conflict situation, car model and presence of Low-speed_AEB. The different generations of the CWB+ACC functionality were also evaluated.

2. METHOD

In this study, CWB+ACC were evaluated by using insurance claims from crashes in Sweden. The rate of rear-end frontal collisions per 1000 vehicle years was compared for vehicles with and without the technology. First, an overall evaluation of the CWB+ACC system was performed, by comparing car individuals with and without the optional system. All cars included in this evaluation were also equipped with the standard Low-speed_AEB system. Next, the development of CWB+ACC was evaluated by comparing different generations of the technology. Finally, for the most recent generation of CWB+ACC an analysis was performed within sedan-, station wagon- and cross country models separately.

2.1 Data

Insurance data was found to be valuable in safety performance evaluations based on real world crashes for collision avoidance technologies (HLDI, 2011-2013; Isaksson-Hellman and Lindman, 2012, 2015).

A comprehensive motor insurance for cars covers both injuries to people involved in a crash as well as damage to vehicles and property. The Collision Damage insurance pays for vehicle damage to the policy holder's own car, while the Third Party Liability insurance covers personal injuries and damage to other vehicles and property. In addition, Volvia/If Insurance handles a unique warranty, Car Damage Warranty, which provides an excellent opportunity to study the number of collisions for all new Volvo cars in traffic. This Car Damage Warranty is a unique Swedish concept, valid the first three years and covers damage to the policy holder's own car. The warranty is a Swedish standard and is funded by each car manufacturer.

The insurance claims data used for this study included information on crash type from two-vehicle collisions, car model, model year, date when the insurance started and ended, damaged parts, ownership, and estimated mileage per year. It was also possible to identify the car individuals equipped with the optional functionality CWB+ACC.

The introduction and occurrence of the different generations of CWB+ACC technologies for different car models and car model years is shown in Fig. 1. In parallel, the Low-speed_AEB functionality was successively introduced as standard equipment in Volvo models.

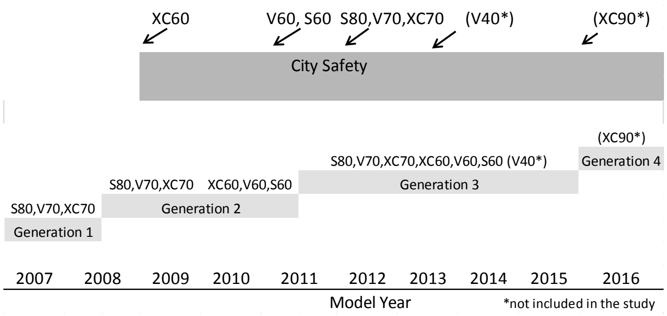

Fig. 1. Overview of the occurrence of the different generations of CWB+ACC and Low-speed_AEB for different Volvo car models and model years.

For the optional system CWB+ACC, the take rate, i.e. the share of cars equipped with the systems, has grown from 2% when it was introduced in 2006, up to approximately 15% in 2014, Fig. 2.

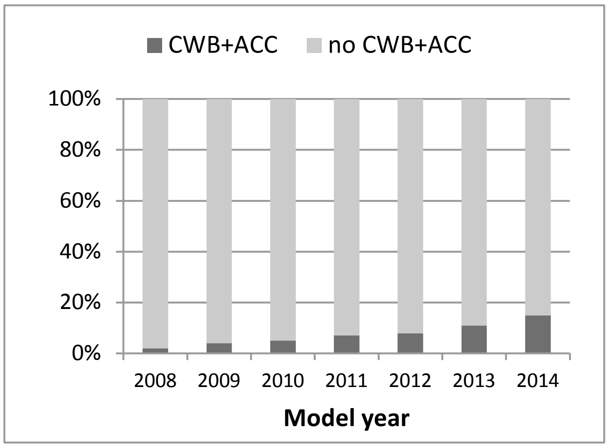

Fig. 2. Take rate for CWB+ACC systems by model year.

2.2 Data selection

Volvo car models selected for the study were new models launched before 2013, including car model years 2007-2014 where the CWB+ACC and/or Low-speed_AEB were provided. Data from crashes between 1 January, 2012 and 31 December, 2014, was used in this study. Rear-end frontal collisions were selected from two vehicle collisions in the database and the exposure was calculated by summing up the total number of insured vehicle years between 1 January, 2012 and 31 December, 2014.

An overall evaluation of the CWB+ACC system was performed by comparing car individuals with and without the optional system. All cars included in this evaluation were models also equipped with the standard Low-speed_AEB system. The exposure (number of insured vehicle years) for vehicle models and model years in the subset is presented in Table 1.

Table 1. Number of insured vehicle years (exposure) and model years for car models with and without CWB+ACC included in the overall evaluation of the CWB+ACC functionality

Exposure (Number of insured vehicle years) 1 Jan2012-31 Dec 2014			
Model	**MY**	**With CWB+ACC** incl. Low-speed_AEB	**Without CWB+ACC** incl. Low-speed_AEB
S80	2012-2014	650	1 748
S60	2011-2014	2 008	13 127
V70	2012-2014	2 821	41 773
V60	2011-2014	5 893	46 894
XC70	2012-2014	3 155	15 921
XC60	2010-2014	9 663	31 958
Total		24 190	151 421

The development of CWB+ACC was evaluated by comparing different generations of the technology. By using information on car individuals and start of production, subsets were generated for generation 1, 2 and 3 of CWB+ACC. Subsets were also created for cars without the system produced during corresponding time periods.

For the models equipped with generation 1 (S80, V70 and XC70, MY 2007-2008), the driver was assisted by a warning and brake support in situations where the object was moving in the same direction as the host vehicle. Also targeting rear-end frontal situations, the ACC functionality was a part of the optional equipment package while Low-speed_AEB was not available.

In CWB+ACC generation 2 (MY 2008-2011), rear-end situations with both stationary and moving vehicles were targeted. Also, auto brake up to 5m/s² was provided. Generation 2 was present in car models with Low-speed_AEB (S60, V60 and XC60) and in car models without Low-speed_AEB (S80, V70 and XC70).

The third generation of CWB+ACC that was introduced in MY 2011 delivers full automatic emergency braking up to 10 m/s². MY 2012-2014 was selected for the analysis in order to only include models with Low-speed_AEB, see Table 2.

Table 2. Number of insured vehicle years (exposure) and model years for car models with and without CWB+ACC generation 1-3, included in the dataset used for comparing different generations of CWB+ACC

Exposure (Number of insured vehicle years) 1 Jan2012-31 Dec 2014			
AEB generation/Model	**MY**	**With CWB+ACC**	**Without CWB+ACC**
Generation 1 CWB+ACC S80,V70,XC70 No Low-speed_AEB	2007-2008	1 475	33 628
Generation 2 CWB+ACC S60, V60, XC60 incl. Low-speed_AEB	2008-2011	6 153	31 404
Generation 2 CWB+ACC S60, V60, XC60 No Low-speed_AEB	2008-2011	4 609	116 231
Generation 3 CWB+ACC S80, V/XC 70, S/V/XC 60 incl. Low-speed_AEB	2012-2014	18 204	123 350

For the most recent generation of CWB+ACC, an analysis was performed for different types of car models, i.e. Sedan cars (S80, S60), Station wagon cars (V70, V60) and Cross country car models (XC70, XC60) separately.

Table 3. Number of insured vehicle years (exposure) and model years for *type* of car model with and without CWB+ACC, generation 3, included in the analysis of different types of car models

Exposure (Number of insured vehicle years) 1 Jan2012-31 Dec 2014				
Model	**Type**	**MY**	**With CWB+ACC** incl. Low-speed_AEB	**Without CWB+ACC** incl. Low-speed_AEB
S80/S60	**Sedan**	2012-2014	1 597	8 432
V70/V60	**Station wagon**	2012-2014	7 139	79 388
XC70/XC60	**Cross country**	2012-2014	9 468	35 530

2.3 Statistical methods

The evaluations were conducted by comparing rate of rear-end frontal collisions per 1,000 insured vehicle years for different groups of car models with and without the technologies under study. The rate of rear-end frontal collisions for CWB+ACC was defined as:

$$\text{Rate}_{\text{w CWB+ACC}} = (n_{\text{w CWB+ACC}} / VY_{\text{w CWB+ACC}}) \quad (1)$$

where

$n_{\text{w CWB+ACC}}$ = Number of rear-end frontal collisions for cars with CWB+ACC

$VY_{\text{w CWB+ACC}}$ = Number of insured vehicle years for cars with CWB+ACC

The rate of rear-end frontals for cars without CWB+ACC was defined in the same way. The number of claims occurring can be considered using a Poisson distribution, and the 95% confidence interval for the rate was calculated by using a normal approximation to this distribution.

$$\text{Rate}_{\text{w CWB+ACC}} \pm 1.96 * \sqrt{\text{Rate}_{\text{w CWB+ACC}}/VY_{\text{w CWB+ACC}}} \quad (2)$$

To evaluate if CWB+ACC equipped vehicles have a different rate of rear-end frontal collisions, the difference between the rates for vehicles with and without the system was calculated together with a 95% confidence interval.

$$RD = \text{Rate}_{\text{wo CWB+ACC}} - \text{Rate}_{\text{w CWB+ACC}} \quad (3)$$

Poisson distribution and test-based methods were used to construct the confidence interval. (Sahai and Kurshid, 1995).

$$\chi^2 = \left(n_{\text{w CWB+ACC}} - \frac{m * VY_{\text{w CWB+ACC}}}{VY}\right)^2 / \left(\frac{m * VY_{\text{w CWB+ACC}} * VY_{\text{wo CWB+ACC}}}{VY^2}\right)$$

Where

m= the total number of events observed

VY= the total number of insured vehicle years

The confidence limits were then calculated by

$$RD_L = RD \pm 1.96 * \sqrt{RD^2/\chi^2} \quad (4)$$

The effectiveness of CWB+ACC is calculated as a difference between rates for models without and with CWB+ACC divided by the rate for models without CWB+ACC:

$$e = \frac{Rate_{wo\ CWB+ACC} - Rate_{w\ CWB+ACC}}{Rate_{wo\ CWB+ACC}} \quad (5)$$

The rates of rear-end frontal collisions were calculated during the same time period for the different groups with or without the system, from 1 January, 2012 to 31 December, 2014, in order to control for environmental conditions and other factors that could influence claim rates. The study also aimed at comparing vehicles age-wise as equal as possible

3. RESULTS

3.1 Overall evaluation of CWB+ACC, including Low-speed_AEB

A comparison of cars with and without the CWB+ACC technology, all with Low-speed_AEB as standard as listed in Table 1 was performed. The rate of rear-end frontal collisions estimated by insurance claims per 1,000 insured vehicle years, was 2.5, 95% CI [1.8, 3.1] for car models with CWB+ACC and Low-speed_AEB, as compared to 4.0, 95% CI [3.7, 4.3] for vehicle models without CWB+ACC and Low-speed_AEB only. A significant difference was estimated between the rates of rear-end frontal collisions in models with and without CWB+ACC on the 95% significance level;

RD = 4.0 – 2.5 = 1.5, 95% CI [0.7, 2.4]

The efficiency was 38%, calculated by using (5).

3.2 Evaluation of the development of CWB+ACC technology for the different generations 1 to 3.

Table 4. Rate differences (RD) and estimated effect (e) for car models with and without CWB+ACC for the three generations of CWB+ACC

Results / generation of CWB+ACC			
AEB generation/Model	MY	RD, CI	e
Generation 1 CWB+ACC S80, V70, XC70 no Low-speed_AEB	2007-2008	0.4, 95% CI [-2.8,3.7]	
Generation 2 CWB+ACC S60, V60, XC60 incl. Low-speed_AEB	2008-2011	0.0, 95% CI [-1.6, 1.6]	
Generation 2 CWB+ACC S80, V70, XC70 no Low-speed_AEB	2008-2011	**1.8, 90% CI [0.1, 3.6]**	**38%**
Generation 3 CWB+ACC S80, V70, XC70, S60, V60, XC60 incl. Low-speed_AEB	2012-2014	**1.9, 95% CI [0.9,2.8]**	**45%**

No significant effect was found for the first generation CWB+ACC technology, but there was an indication of a decrease in rate of rear-end frontal impacts of approximately 10%.

A reduction of 38%, significant on the 90% confidence level, was found for cars with the CWB+ACC system compared with cars without the system when *no* additional Low-speed_AEB was present. The rate difference was:

RD = 4.9 – 3.0 = 1.9, 90% CI [0.1, 3.6]

With Low-speed_AEB, no additional effect was found for the CWB+ACC generation 2 functionality, see Table 4.

For the third generation of CWB+ACC a significant reduction of 45% was found on a 95% level, see Table 4. The rate difference was:

RD = 4.1 – 2.3 = 1.8, 95% CI [0.9, 2.8]

3.3 Evaluation of the development of CWB+ACC technology for different types of car models.

Comparing types of car models, there was significant reduction of 43% on a 95% significance level for the station wagon models as well as a significant reduction of 45% for the cross country models, Table 5. Rate differences were:

RD (Station wagon) = 4.2 – 2.4 = 1.8, 95% CI [0.3, 3.3]

RD (Cross country) = 4.2 – 2.3 = 1.9, 95% CI [0.5, 3.3]

Due to low exposure (Table 3), no significant conclusion about the sedan models could be drawn, although a reduction of the rates at the same magnitude as for the other type of models was indicated.

Table 5. Rate differences (RD) and estimated effect (e) for different types of car models with and without CWB+ACC generation 3 (with Low-speed_AEB)

Results / Type of car generation 3 of CWB+ACC			
AEB generation 3 Type	MY	RD, 95% CI	e
Sedan S80, S60	2012-2014	1.7, 95% CI [-1.1, 4.5]	
Station wagon V70, V60	2012-2014	**1.8, 95% CI [0.3, 3.3]**	**43%**
Cross country XC70, XC60	2012-2014	**1.9, 95% CI [0.5, 3.3]**	**45%**

4. DISCUSSION

From the results presented in this report, it can be concluded that collision avoidance technologies targeting rear-end frontal collisions were effective in reducing the number of crashes. On average, a reduction of 38% rear-end frontal crashes was estimated for cars with both CWB+ACC and Low-speed_AEB technology. In a subset of cross country car models with the third generation of the system, an even higher crash reducing performance of 45% less rear-end frontal crashes was found. The progress in crash avoidance efficiency resulting from the evolution of the CWB-functionality was evident in the analysis of rear-end collision rates of different CWB+ACC generations. As anticipated, there were more crashes avoided with the third system generation that provides full automatic emergency braking and identifies the opponent vehicle in moving as well as standing still scenarios compared to the first generation that only includes driver warning and brake support in situations where the opponent vehicle is moving.

The number of cars in the subsets representing cars equipped with different generations of CWB+ACC varied considerably, see Table 2. The estimated crash reduction for cars equipped with the first generation of CWB+ACC indicated a low effect of real world crash avoidance, although not significant. One reason for this is the small amount of cars equipped with FCW without Autobrake, see Table 2. Considering the uniqueness of the analysis on a real world crash data sample with cars equipped with Collision Warning and ACC without autonomous braking in rear-end frontal crashes, this was still a very interesting finding. A straight comparison of the crash avoidance effect of the first and the most recent CWB+ACC versions was not possible to perform, since the presence of Low-speed_AEB varied in cars of these two groups of the CWB+ACC generations. The crash avoidance effect of Low-speed_AEB was estimated to 28% less rear-end frontal crashes for cars with CWB+ACC and 25% for cars without CWB+ACC in a recent study (Isaksson-Hellman and Lindman, 2015), thus indicating the importance of controlling for the presence of Low-speed_AEB when evaluating CWB+ACC functionalities. Additionally, in the present study no significant effect of the CWB+ACC system was found when investigating the second generation of CWB+ACC, providing auto brake up to $5 m/s^2$, in a sample of cars equipped with Low-speed_AEB. In cars without Low-speed_AEB, a significant crash reducing effect on the 90% confidence level, of 38% was found. When comparing the second and third generation of CWB+ACC providing auto brake up to $5 m/s^2$ and $10 m/s^2$ respectively, a significant larger effect was found in the latter, demonstrating the need for intervention performance in speeds beyond the range considered by Low-speed_AEB. As expected, the results showed that the CWB+ACC and Low-speed_AEB functionalities are working in combination and produce a total effect that not can be considered as additive.

In addition to the systems evaluated in this report, the car models with the second and third generation of CWB+ACC systems were also equipped with the active safety systems Lane Departure Warning and Driver Alert. Some of the car individuals studied were also equipped with Blind Spot Warning. However, these systems are not expected to influence the outcome of the CWB+ACC systems evaluation, since they target other crash conflict situations than rear-end frontal crashes.

Some limitations of the study were apparent. While the insurance data used for the present analysis were detailed enough for classifying the collision type of interest, rear-end frontal collisions, there was some information needed to perform further evaluations, e.g. to control for driving speed and ACC use. Also, it was not known whether the driver had turned off the systems prior to the crash. Yet, turning off the functionality is not expected to be a frequent behaviour. In a qualitative study on HMI concepts for Active Safety systems (Lövsund and Wiberg, 2007), 15 out of 20 participants stated that they do not make any personal adjustments of the systems. So, theoretically there is a possibility that FCW and ACC settings varies for the cars in the datasets analysed and that this influence the results. Further, it can be assumed that the CWB+ACC systems that were optional features to a higher degree were chosen by persons driving their cars in a non-representative way. For example, it can be discussed whether or not these drivers were more aware of traffic safety, or if the drivers rely on the systems in a way that made them change their driving behaviour. These are all questions that are not possible to answer by using crash databases that are currently available.

In the present study, crashes not avoided but where collision avoidance technologies contributed to crash mitigation was not included in the scope of the analysis. A significant reduction of soft tissue neck injuries in rear-end impacts is expected since these are frequent in occupants of both the impacting and the impacted car, (Avery and Weekes, 2008; Jakobsson, 2004; Jakobsson et al., 2004; Kullgren et al., 2000). The total safety effect from CWB+ACC and Low-speed_AEB functionalities is therefore an important area for future studies. Also, other conflict situations than rear-end scenarios were not studied. Recent collision avoidance systems, such as the most recent generation of CWB+ACC, available as standard mounted equipment in the Volvo model XC90 MY2016, targets car to pedestrian-, car to cyclist crashes as well as crashes in intersections.

The unique study presented in this report met the challenges in real world safety performance follow-up methodology by using a representative dataset that included relevant details such as crash configuration, car equipment information and real exposure statistics. These are features of crash databases not found in other datasets available. The dataset used provided the possibility to compare cars with and without CWB+ACC in an efficient and unambiguous analysis.

6. CONCLUSIONS

This study is the first of its kind presenting real world traffic effects of non-standard mounted rear-end collision avoidance technologies in the relevant traffic conflict situation (rear-end frontal collisions). For vehicles with CWB+ACC, rear-end frontal collisions were reduced with 38%. For the third generation of CWB+ACC, the estimated collision avoidance effect was estimated to 45%. By providing relevant details in a representative dataset including real exposure statistics, insurance data proved to be an effective source of information when it comes to evaluating the effectiveness of collision avoidance technologies in real world traffic.

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