REAL-WORLD PERFORMANCE OF CITY SAFETY BASED ON SWEDISH INSURANCE DATA

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Paper Number 15-0121

ABSTRACT

The number of passenger cars equipped with Auto Brake functionalities in traffic is increasing rapidly. Following this, the opportunity to study real world performance of these systems is growing. The low-speed Auto Brake system City Safety, launched in 2008 and a standard feature on all recent Volvo Cars' models, is a technology designed to help the driver mitigate and in certain situations avoid rear-end collisions at low speed by automatically braking the vehicle. Previous analysis of the City Safety technology showed promising results in terms of reducing real world crashes.

In this study, further evaluation of City Safety was performed based on insurance claims data. Using a unique dataset containing all new Volvo cars in traffic in Sweden from 2010 to 2014, including the possibility to control for other advanced driver assistance systems such as ACC, FCW and Auto Brake functionalities, the rate of rear-end frontal collisions per insured vehicle years was studied. First, car models with and without City Safety were compared. Second, the same car model with and without City Safety was compared, thereby controlling for specific characteristics in different models. Finally, the second generation of City Safety, that operates at speeds up to 50 km/h, was compared to the first generation (<30 km/h). Results showed that the overall claim frequency of rear-end frontal collisions was 28% lower for City Safety equipped models than for other Volvo models without the system. The result of the comparison between the same models was similar while no significant collision avoidance effect of the upgraded system to speeds up to 50 km/h was found. The expected crash mitigating effect of City Safety can be added to these results, providing a further potential to be explored in future real world follow-up studies.

This study confirms previous encouraging results of the crash reducing effect of the City Safety functionality. The findings of Auto Brake safety performance in real world traffic, shows the relevance of this type of vehicle systems for increased traffic safety and emphasizes the importance of the introduction of such systems on the market.

INTRODUCTION

In 2008, the world first standard mounted passenger car collision avoidance system was introduced in Volvo cars, targeting low-speed rear-end frontal collision situations. City Safety uses a lidar sensor monitoring the area in front of the vehicle and initiate braking if a crash is imminent (Distner et al., 2009). A limited number of real world follow-up studies are available. HLDI (2011, 2013) presented the first indications of the real-world effect of City Safety, as insurance claims data for cars with and without City Safety were compared. Claim frequency rates for the XC60, equipped with City Safety, were lower than for all other midsize luxury SUVs combined. A similar effect was found for other Volvo cars. When studying Swedish insurance claims, it was found that the rate of rear-end frontal collisions was significantly reduced by 23% in the Volvo XC60 equipped with City Safety compared to other Volvo car models without City Safety registered during the same period of time (Isaksson-Hellman and Lindman, 2012). In Swedish police-reported injury crashes 2010-2014, a reduction of striking rear-end crashes was found that ranged between 35% and 41% for cars with City Safety (Rizzi et al., 2014). The limited number of real world follow-up studies on collision avoidance systems indicates that finding datasets of appropriate content is challenging. Fields et al. (2013) suggest improving the follow-up study process by combining data from several databases using meta-analyses and thus obtain results more quickly, but so far, research into this approach has been limited.

The aim of this study was to calculate the effect of City Safety by comparing cars with and without the standard mounted low speed Auto Brake system. The overall effectiveness was studied as well as the specific performance of selected car models. Also, the first and second generations of the system were compared. A dataset comprising all new Volvo cars in crashes in Sweden noted in insurance claims was analyzed to evaluate the real world performance of City Safety. The influence of non-standard mounted advanced driver assistance systems (ADAS) was considered in the effect estimations.

METHODS

Crashes in Sweden form the basis for this evaluation of City Safety. By using data from claims at the insurance company Volvia/If, rear-end frontal collisions were identified and the rate per insured vehicle years was calculated. Three different analyses were performed. First, an aggregated group of Volvo models with City Safety was compared with a group of models without the system. Then, the effectiveness of City Safety was evaluated for two selected Volvo car models, V70 and XC70. Finally, the updated version of City Safety launched in MY 2013, which operates at speeds up to 50 km/h, was compared with the first generation of the City Safety, with functionality at speeds up to 30 km/h. Separate analyses were performed in order to control for the effect of other (non-standard mounted) ADAS, e.g. Adaptive Cruise Control (ACC), Forward Collision Warning (FCW) and Auto Brake functionalities, that partly address the same crash situations.

Data

Insurance data is an important source of information regarding real world crashes. 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. CDW (Car Damage Warranty) is a unique Swedish concept, valid the first three years and covers damage to the policy holder's own car. This warranty has been a Swedish competitive standard a long time and is funded by each car manufacturer. On behalf of Volvo Cars, Volvia Insurance handles this unique warranty which provides an excellent opportunity to study the number of collisions for all new Volvo cars in traffic.

Crashes reported to the insurance company cover all levels of crash severity, from slight crashes with only minor damages to the car to severe crashes with fatal injuries and heavily damaged cars. These data are advantageous compared to other crash databases where the quantity and the representativeness of data often is a problem in car safety evaluations. For example, considering low speed collision avoidance system effectiveness evaluations, the collection criteria in crash databases often exclude low-severity crashes. The insurance claim data include information on crash type, damaged parts, car model, ownership, insured vehicle years, and estimated mileage per year. The variable crash type makes it possible to identify rear-end frontal collisions, giving the opportunity to evaluate the conflict situation for which City Safety was designed.

Data from SMHI, (Swedish Meteorological and Hydrological Institute) was used to evaluate temperature variations for the winter season.

Data Selection

The data selected for this study cover insurance claims from 1 July, 2012, to 30 June, 2014. The number of rear-end frontal collisions, see Figure 1, were counted for each model, and the exposure was calculated by summing up the number of insured vehicles from vehicle years starting on July 1, 2012 and ended on June 30, 2014. Only cars with model year 2010 and later were included. Situations taken into account were collisions with vehicles in traffic, collisions with parked vehicles were excluded.

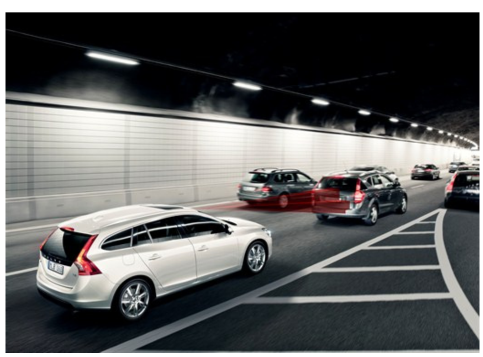

Figure1. Illustration of a rear-end frontal collision situation (white car).

Three subsets were selected for the different analyses. First, for an overall estimation of the effectiveness, a group of Volvo vehicle models with City Safety was selected to be compared with a group of vehicle models without the system, Table 1. Next, the rate of rear-end collisions and the effectiveness of City Safety was evaluated for the same Volvo car models: V70 and XC70 in order to control for possible unique characteristics in different car models. The Volvo car models XC60, V60, and S60, were introduced with City Safety as standard mounted equipment, while the Volvo car models S80, V70 and XC70 were first introduced without the system, see Table 1. From MY 2012 and onwards, the City Safety functionality was available also in these models.

Table1.
Exposure (number of insured vehicle years) and model years for car models with and without City Safety included in the study.

	With City Safety		Without City Safety	
	All		All	
	MY	Insured vehicle years	MY	Insured vehicle years
S80	2012-2014	1632	2010-2011	2902
V70	2012-2014	30724	2010-2011	36271
XC70	2012-2014	12549	2010-2011	6275
S60	2011-2014	10172		
V60	2011-2014	35912		
XC60	2010-2014	27733		
Total		**118722**		**45448**

Finally, the second generation of City Safety, operating at speeds up to 50 km/h, was compared with the first generation with functionality at speeds up to 30 km/h. In Table 2, the vehicle models, model years included and exposure are presented. Cars of MY 2012 were compared with cars of MY 2013-2014 during a one year period, between 1 July, 2013 and 30 June, 2014.

Table2.
Vehicle models, model years and exposure for the first and second generation of City Safety.

Models: S80, V70,XC70 S60 V60,XC60	City Safety 30km/h		City Safety 50km/h	
	MY	Insured vehicle years	MY	Insured vehicle years
	2012	22163	2013-2014	37642

Along with City Safety, other ADAS addressing the same crash situations were introduced as optional features in the same car models. The number of cars with these optional systems is increasing as shown in Figure 2. Samples with car individuals not equipped with optional ADAS were identified, to control for the effect in rear-end frontal collisions not related to City Safety, see Table 3.

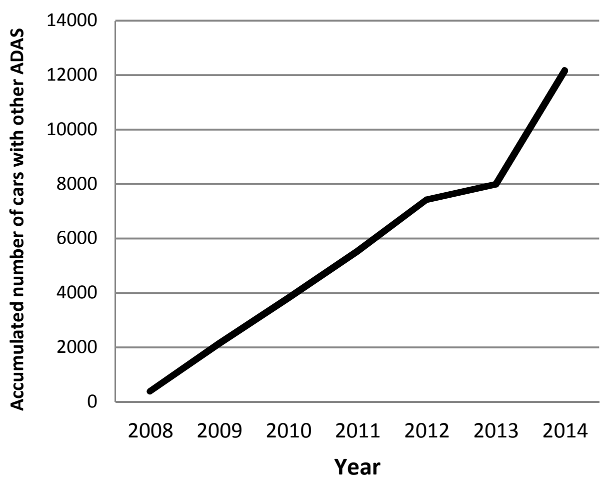

Figure2. Accumulated number of cars equipped with optional advanced driver assistance systems (ADAS), 2008-2014.

Table3.
Exposure and model years for models with and without City Safety and optional ADAS functionalities.

		With City Safety				Without City Safety	
	MY	With ADAS	Without ADAS		MY	With ADAS	Without ADAS
		Insured vehicle years	Insured vehicle years			Insured vehicle years	Insured vehicle years
S80, V70, XC70	2012-2014	**15848**	**102874**	**S80, V70, XC70**	2010-2011	**2681**	**42767**
S60, V60	2011-2014						
XC60	2010-2014						

Additionally, the rate of rear-end frontal collisions per insured vehicle years for the Volvo XC60 was studied by stratifying for seasonal effects. Road conditions, an important factor influencing the rate of rear-end collisions, varies a lot in Sweden due to variations in climate between summer and winter, (Isaksson-Hellman et al., 2012). Road conditions during the winter also vary a lot between years, and between different geographical locations in Sweden. The rate of rear-end frontal collisions for the winters in the study presented in Isaksson-Hellman et al., (2012), December 2009-February 2010 and December 2010-February 2011 and for the winters in the present study, December 2012-February 2013 and December 2013-February 2014 was compared together with the average temperature (°C) retrieved from SMHI, at three different locations in Sweden.

Statistical methods
To evaluate the effect of City Safety, the rates of rear-end frontal collisions per insured vehicle years were calculated and vehicle models with and without the system were compared.

The rate of rear-end frontal collisions was estimated by the number of claim frequency per insured vehicle years

$$Rate_{w\,CS} = (n_{w\,CS} / VY_{w\,CS})$$

Where

$n_{w\,CS}$ = Number of rear-end frontal collisions for cars with City Safety

$VY_{w\,CS}$ = Number of insured vehicle years for cars with City Safety

The rate of rear-end frontals for cars without City Safety was defined in the same way. The number of claims occurring over insured vehicle years 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.

$$\text{Rate}_{\text{w CS}} \pm 1.96 * \sqrt{\text{Rate}_{\text{w CS}}/\text{VY}_{\text{w CS}}}$$

To evaluate if City Safety 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.

$$\text{RD} = \text{Rate}_{\text{wo CS}} - \text{Rate}_{\text{w CS}}$$

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

$$\chi^2 = \left(n_{\text{w CS}} - \frac{m * \text{VY}_{\text{w CS}}}{\text{VY}}\right)^2 / \left(\frac{m * \text{VY}_{\text{w CS}} * \text{VY}_{\text{wo CS}}}{\text{VY}^2}\right)$$

Where

m= the total number of events observed

VY= the total number of insured vehicle years

The confidence limits were then calculated by

$$\text{RD}_L = \text{RD} \pm 1.96 * \sqrt{\text{RD}^2/\chi^2}$$

The effectiveness of City Safety can also be presented as a difference between rates for models without and with City Safety divided by the rate for models without City Safety:

$$e = \frac{\text{Rate}_{\text{wo CS}} - \text{Rate}_{\text{w CS}}}{\text{Rate}_{\text{wo CS}}}$$

RESULTS

First, Volvo car models equipped with City Safety, and Volvo car models without City Safety were compared to estimate the overall effect of the system. The rate of rear-end frontal collisions estimated by insurance claims per 1,000 insured vehicle years, was 4.0, 95% CI [3.6, 4.3] for vehicle models with City Safety and, 5.5, 95% CI [4.9, 6.2] for vehicle models without the system. The results showed a significant difference between the rates of rear-end frontal collisions in models with and without City Safety on the 95% significance level;

5.5 – 4.0 = 1.5, 95% CI [0.8, 2.3]

The effectiveness was estimated to

$$e = \frac{5.5 - 4.0}{5.5} = 28.3\ \%.$$

The result was estimated for vehicle models where an optional ADAS were available. Considering City Safety only, the rate of rear-end frontal collisions estimated by insurance claims per 1,000 insured vehicle years was 4.2, 95% CI [3.8, 4.6] for the cars with City Safety and without ADAS, and 5.6, 95% CI [4.9, 6.3] for cars without City Safety and without ADAS. The results showed a significant difference between the rates of rear-end frontal collisions, comparing groups of Volvo models with and without City Safety with any optional ADAS;

5.6 – 4.2 = 1.4, 95% CI [0.6, 2.2]

The effectiveness for City Safety when controlling for non-standard ADAS was estimated to

$$e = \frac{5.6 - 4.2}{5.6} = 25\ \%.$$

Specifically, the effectiveness of City Safety was evaluated for the same Volvo car models: V70 and XC70. These models were first introduced without the system but from a certain MY, the City Safety

functionality was available also in these models. In the comparison of the same Volvo car models with and without City Safety, the rate of rear-end frontal collisions was 4.1, 95% CI [3.5, 4.7] for the car models with City Safety, while the rate for the same models without City Safety was 5.8, 95% CI [5.1, 6.5]. Considering the comparison for the same models without ADAS the rate per 1000 insured vehicle years was
4.3, 95% CI [3.6, 4.9] and 5.8, 95% CI [5.1, 6.6] respectively for cars with and without City Safety. Both results showed a significant difference between the rates of rear-end frontal collisions on a 95% level;

With non-standard ADAS 5.8 - 4.1 = 1.7, 95% CI [0.7, 2.6]

Without non-standard ADAS 5.8 - 4.3 = 1.5, 95% CI [0.5, 2.5]

The effectiveness was estimated to; 29% and 26% respectively.

Finally, the evaluation of the City Safety systems' update to its second generation showed that for cars with the City Safety version operating at speeds up to 30 km/h, the rate of rear-end frontal collisions was 3.7, 95% CI [2.9, 4.5], while for the system operating at speeds up to 50 km/h, it was 3.6, 95% CI [3.0, 4.2]. The rate of rear-end frontal collisions was lower, but no significant difference was found:

3.7 – 3.6 = 0.1, 95% CI [-0.9, 1.1]

The effectiveness was estimated to 3% for the second generation of City Safety compared to the first generation of the system.

In Figure 3a, average temperatures (°C) for winter seasons in Isaksson-Hellman et al. (2012), (December 2009-February 2010 and December 2010-February 2011) and winter seasons included in the present study (December 2012-February 2013 and December 2013-February 2014) were compared for three different locations in Sweden. The average temperature during the previous winter seasons was lower than in the present study. The rate of rear-end frontal collisions was shown to be larger during the previous winters than during the winters in the present study.

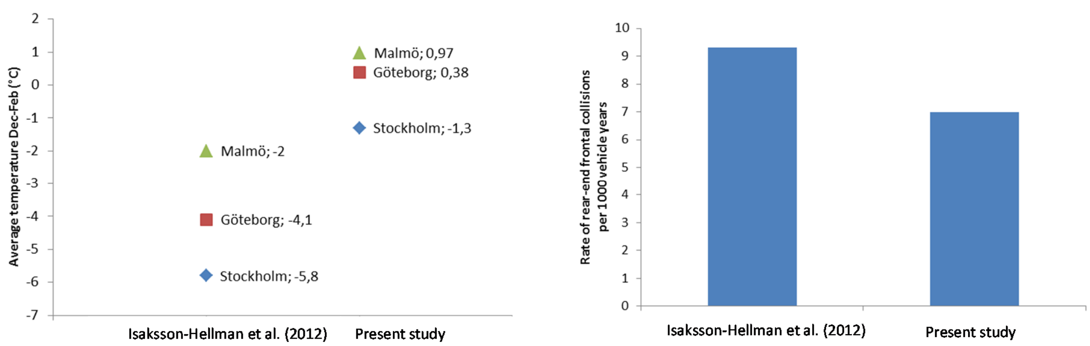

Figure3a. Average temperature (°C) during the winters for three geographical locations in Sweden.
Figure3b. Rate of rear-end frontal collisions in corresponding time periods.

DISCUSSION

This evaluation of the City Safety performance, based on insurance claims from real world traffic crashes in Sweden, strengthen the previously presented findings that City Safety is effectively preventing rear-end frontal collisions. The benefit of City Safety is reflected in lower rates of crashes per insured vehicle years. This study shows that cars with City Safety were exposed to 28% less rear-end frontal collisions than cars without the system.
The overall crash reduction effect was slightly larger than the one reported in Isaksson-Hellman et al. (2012). In the present study, additional car models with the City Safety functionality were available and a different period of time was studied. Also, two influencing factors were further explored, providing insight into the performance of City Safety. First, and most significant, the importance of considering non-standard mounted ADAS in a City Safety evaluation was confirmed in this study. This has been presented as one of the main limitations in previous real world follow up studies presented (HLDI, 2011, 2013; Isaksson-Hellman et al., 2012; Rizzi et al., 2014). A notable increase of ADAS take-rate over the last years was found in the Volvo car population, Figure

2. When controlling for optional ADAS, the benefit of City Safety was estimated to 25%. The other aspect considers the refined City Safety technology. In MY 2013 the second generation of City Safety was launched, which operates at speeds up to 50 km/h in comparison to 30 km/h in the first generation. A non-significant effect of 3% less rear-end frontal collisions from the increase in operating speed was noted. In a prospective study (Lindman et al., 2012) no additional crashes avoided were predicted for the 50 km/h City Safety compared to the 30 km/h version based on a sample of crashes with at least one injured occupant. Considering that the data in the present study also comprised crashes of lower severity as it was collected from a larger sampling frame, the result was sound in relation to the prediction study. Adding up to the collision avoidance effect there is a crash mitigating effect expected that was not estimated in this study. Since the relative risk for injuries in frontal impacts increases with impact speed up to high crash severity levels (Kullgren et al., 2000), decreasing the impact severity by means of autonomous braking will contribute to occupant injury reduction.

When comparing the same vehicle model with and without City Safety, the bias resulting from different car model characteristics was decreased. For example, it is possible that drivers that chose to purchase car models with City Safety differ in ways that could affect crash likelihood. The effectiveness of City Safety for the V70 and XC70 models was estimated to 29% for all cars and 26% when controlling for other ADAS. This is only slightly different from the overall effectiveness, indicating robust overall results.

There is also a possibility that traffic environmental aspects influence the results. Road conditions due to seasonal changes was shown to influence the rate of rear-end collisions (Isaksson-Hellman et al., 2012). In the present study, it was shown that in the cold winters included in the 2012 analysis, a higher rate of rear-end frontal collisions was found compared to in the relatively mild winters in the present study. Reports from SMHI (Swedish Meteorological and Hydrological Institute) confirmed presence of more snow and ice resulting in more adverse road conditions all over Sweden during the period studied in Isaksson-Hellman et al., (2012). Despite the differences in rear-end frontal collision rates, the effect presented in 2012 and in this study were similar suggesting that the findings on the City Safety performance were robust.

A challenge when evaluating the safety performance in real world traffic is to secure the amount and quality of data needed to be able to perform reliable analyses. Data from insurance claims is one excellent source of information for that purpose. This was demonstrated as the three first real world data analyses of City Safety were performed by using insurance data (HLDI, 2011, 2013; Isaksson-Hellman et al., 2012). Still, some limitations are obvious. 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 still fine points missing in the information needed to isolate the exact operating situations of City Safety. It was not possible to control for driving speed in order to evaluate the driving situation for which City Safety was designed.

Additionally, it was not known whether the driver had turned off the system prior to the crash. However, since turning off the functionality requires substantial navigation in the car settings menu and since the system always is default on at every start, it is not likely that many trips were driven with the system disabled.

In future research, the additional effect of crashes mitigated due to City Safety lowering the speed in the crash should be studied. Concerning occupant injuries, 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). In this study, only reductions of host vehicle rear-end frontal collisions were evaluated. Occupant injury reduction in the host and lead vehicle is yet to be quantified in future studies.

CONCLUSIONS

The overall benefit of City Safety is estimated to 28% fewer rear-end frontal impacts for cars with the system than for cars without it. When controlling for non-standard mounted collision avoidance systems such as ACC, FCW and Auto Brake functionalities, the effect was 25%. The pronounced collision avoidance performance was confirmed in a comparison of the same car models with and without the system. When evaluating the second generation of City Safety that operates in higher speeds than the first generation, a non-significant collision avoidance effect of 3% was found. Adding up to the collision avoidance effect, there is a crash mitigating effect expected that was not estimated in this study. The possibility to control for the presence of ADAS represents a significant improvement of the Auto Brake safety evaluation method.

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