ADVANCED SEAT BELT REMINDER SYSTEM FOR REAR SEAT PASSENGERS

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ABSTRACT

Advanced seat belt reminder systems with audiovisual warnings have proven to be highly effective in increasing the belt wearing rates of a vehicle's front seat occupants. While the availability of such advanced SBR systems for the front seats is almost common in some markets and fast-growing in others, also thanks to NCAP incentives, the systems available on the rear seats have so far only offered a basic functionality. In 2014, an upgraded SBR function entered the mass market, and the world's first car with an advanced rear seat SBR system including occupant detection was launched on the Japanese market. This vehicle, the Subaru LEVORG, offers an advanced audiovisual SBR warning for the rear outboard seating positions. This advanced function is enabled by occupant detection sensors designed to detect human rear seat occupants, while being robust against the detection of child restraint systems (CRS) or other objects frequently transported on a vehicle's rear seats. The robustness of the occupant detection and the object non-detection has been tested extensively. Occupants shifted their position forward and laterally away from the nominal seating position. A multitude of CRSs and objects were tested to ensure that they do not trigger unnecessary warnings. Advanced rear seat SBR systems have the potential to significantly increase the belt wearing rates, especially as those tend to be much lower on the rear than on the front seats in almost all countries. As belt load limiters and belt tensioners are more and more available for the rear seats, the advanced SBR systems ensure that more rear seat occupants will benefit from the restraint system enhancements.

INTRODUCTION

Seat belts have proven to be highly effective in reducing the likelihood of severe or fatal occupant injuries in vehicle collisions. Additional technologies like seat belt tensioners and load limiters have helped to improve the seat belt effectiveness and to reduce belt induced injuries to the chest area. Many people, however, do not buckle up, for various reasons, often simply forgetting about it. Seat belt reminder (SBR) systems with audiovisual warnings have proven to be highly effective in increasing the seat belt use. The number of unbelted drivers is reduced by 80% in vehicles with advanced SBR systems meeting the Euro NCAP requirements [1]. For the front seat passengers the reminder effectiveness is comparable [2]. As seat belt reminders have such a significant impact on the belt wearing rates, the large majority of NCAP programs have decided to introduce incentives for front seat SBR systems into their rating. These incentives were very successful in motivating the vehicle manufacturers worldwide to fit SBRs in an increasing number of vehicle models [3]. In addition to the front seat SBR systems with audiovisual warnings, more simple systems had been developed for the rear seats, providing the driver with visual information on the buckle status on the rear seats. However, the effectiveness of those simple systems is limited as they are highly dependent on the driver response to the information. In 2014, a first car with an advanced seat belt reminder system also providing an audiovisual warning to the rear seat occupants entered the Japanese market. This paper describes the motivation behind this development, as well as the challenges that had to be solved with regards to occupant detection on the rear seats.

MOTIVATION FOR ADVANCED REAR SEAT SBR

Subaru's roots go back to an aircraft manufacturer, so safety is one of the company's core values. In the domain of active safety, Subaru has proven this philosophy with its award-winning EyeSight technology, which was the first system ever to use only stereo camera technology to support functionalities like Adaptive Cruise Control, Lane Departure Warning and Autonomous Emergency Braking.
But also in the area of passive safety, Subaru identified additional road safety potential, aiming to reduce the number of vehicle occupant fatalities, namely by increasing the seat belt wearing rates on the rear seats. Although belt usage on rear seats has been mandatory since 2008, the rear belt wearing rates tend to be low in Japan, resulting in easily preventable occupant injuries and fatalities. Advanced seat belt reminder systems have

proven to be effective in raising the belt wearing rates on the front seats, but no such system had ever been implemented on a vehicle's rear seats. One key component for such a system, a rear seat occupant detection sensor simply did not yet exist.
In a joint development effort, Subaru and sensing system specialist IEE created the world's first advanced rear seat SBR system for a production vehicle, the Subaru LEVORG, launched in 2014. The expectation is that the system will increase the belt wearing rates, thus reducing the number of injuries or fatalities in Subaru vehicles.

Rear Seat Belt Wearing Rates

Seat belt wearing rates on the rear seats are lower than those for the front seats in all countries for which data is available. The reasons for this difference in belt usage behaviour are manifold, possible contributing factors are:

- rear seat occupants feel safer because of the backrest in front of them
- belt usage on the rear seats was mandated much later than for the front seats, so fewer people have acquired the habit to use the seat belt on the rear bench
- a lower enforcement level by police, also because belt usage is more difficult to verify
- unavailable or less effective seat belt reminders

Seat belt wearing data from Japan for front and rear seat vehicle occupants is shown in Figure 1 for the time frame 2005 to 2014. It shows the data for public highways (cities and rural roads). Additional data had been collected for express highways [4]. The belt wearing rates are highest for the driver (driver SBR fitment has been mandatory in Japan since 2005), closely followed by the front passenger. Belt wearing rates for the rear seat occupants are much lower, only about 1/3 (35.1 %) of the rear passengers buckle up on public highways. On express highways the belt usage increases to 70.3%, but is still far below the front seat usage rates. Seat belt usage on the rear seats was made mandatory in 2008, which explains the significant increase in the belt wearing rate for that year.

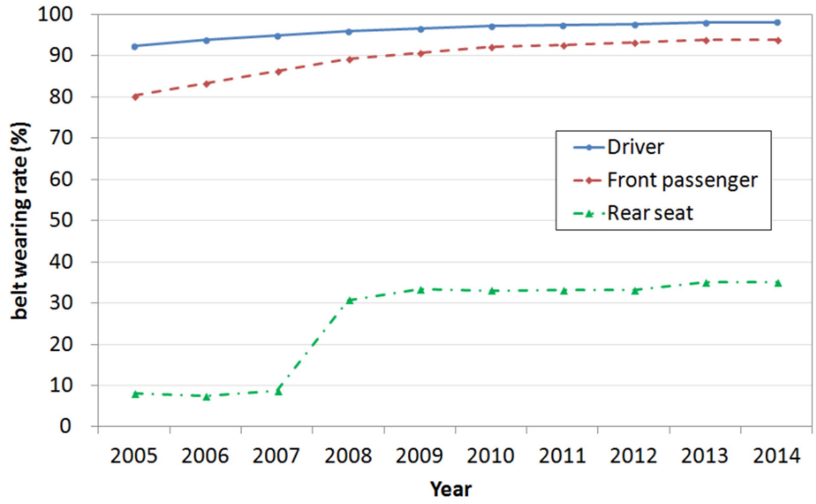

Figure 1. Seat belt wearing rates in Japan on public highways.

Rear seat belt usage in the US [5] is also lower than for the front seats, as shown in Figure 2. However, the difference is less important than in Japan. At 75%, the rear seat belt wearing rate in the US is only about 10% lower than the one for the front seats, while in Japan the rear seat usage rate is about 60% lower compared to the front seats. However, it should be noted that front seat belt usage in Japan (driver 98%, front passenger 94%) is about 10% higher than in the US (86%).
The US data also allows the analysis of rear seat belt usage by age group. The lowest belt wearing rate can be found for the age group teenagers and young adults (age 16 – 24), where only 67% buckle up, compared to the overall average of 75% belt users. The highest belt use can be found for children aged 8 to 15 (83%) and occupants aged 70 and higher (80%).

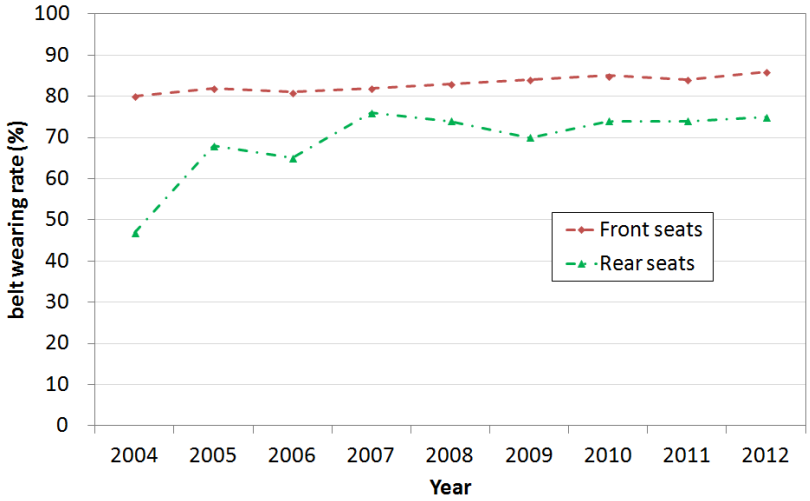

Figure 2. US seat belt wearing rates for front and rear seat occupants.

In Europe, large differences in rear seat belt usage can be found when comparing the different countries [6]. While the belt wearing rates of the rear seat passengers tend to be high with more than 80% for the Western and Northern European countries, much lower belt use is observed in most Eastern and Southern European countries.

Table 1. Front and rear seat belt use rates for a selection of European countries.

Country	Belt use - front seat	Belt use - rear seat
Austria	89%	75%
Belgium	86%	80%
Czech Republic	97%	66%
France	98%	84%
Germany	98%	98%
Greece	71%	21%
Italy	60%	50%
Poland	80%	43%
Spain	91%	81%
UK	95%	89%

In Korea, belt usage on the rear seats is significantly lower than on the front seats [7]. Only 19% of the rear seat occupants are belted, versus 84% of the front seat occupants.

Rear Seat SBR Effectiveness

The simple monitoring of the rear seat belt buckle status only allows for visual information to the driver and optionally the rear seat passengers at vehicle start. A brief audible warning can only be triggered if there is a "change of status", i.e. if a belted rear seat occupant unbuckles during the trip. The lack of a continuous audible alert limits the effectiveness of those simple systems.

Very little data is available on the effectiveness of such SBR systems. In a comment to NHTSA in 2010 [8], Volvo stated: *"…Volvo surveyed Volvo owners in Sweden and Italy in 2005. The survey clearly demonstrated that the belt usage rate in the rear seat, with the monitoring system as compared to without belt reminders, had increased from around 60% to around 82%"*. This would correspond to a reminder effectiveness of approximately 50%.

A laboratory study was conducted in Japan in 2012 [9], comparing the effect of various optical and audible SBR warnings on the belt use of rear seat passengers. Table 2 summarises the most important study results. The initial belt wearing rate without SBR warning was 38%. When an optical warning was only presented to the driver, who then reminded the rear seat passengers, the belt use increased to 56%. When both, driver and rear seat passengers were presented with an optical warning, the usage rose to 72%. And when an audiovisual

warning was used, 97% of the rear seat passengers buckled-up. So audiovisual SBR warnings motivated up to 95% of the initially non-belted rear seat occupants to buckle up. For visual-only warnings the effectiveness was limited to 50% (in line with the Volvo data above).

Table 2. Belt wearing rates for various SBR warning systems.

		Rear seat passenger information		
		No SBR information	Ceiling icon, blinking with frequency change, no audible signal	Ceiling icon, blinking with frequency change, audible signal with frequency change
Driver information	No SBR information	38 %	-	-
	Meter cluster icon, blinking with frequency change, no audible signal	56 %	72 %	-
	Meter cluster icon, blinking with frequency change, audible signal with frequency change	-	-	97 %

As the first vehicle with an advanced rear seat SBR system only entered the market in Japan in June 2014, no field-data is available with regards to its effectiveness in increasing the belt wearing rates. But the laboratory study indicates a clear trend with regards to the effectiveness of various warning strategies.

OCCUPANT DETECTION SENSOR DEVELOPMENT

Occupant detection on the rear seat can be achieved in principle in a similar way as on the front seat, a foil-based pressure sensitive sensor, integrated between seat foam and trim, is activated by the occupant's weight. However, some rear seat peculiarities have to be taken into consideration. The rear bench is often used to transport various objects, child restraint systems (CRS) are predominantly installed there, and the backrest can be folded down. For those scenarios sensor activation has to be prevented. In addition, the occupant himself often has a higher freedom of movement on the rear seat compared with the front seat, due to missing or less distinct side bolsters. Therefore sensor design and size have to be adapted to the specific rear bench needs.

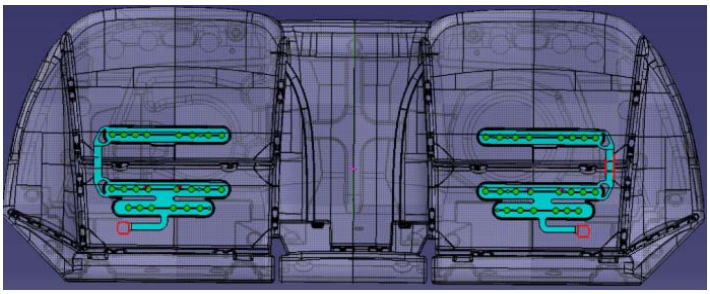

Figure 3. Top view onto rear bench with occupant detection sensors on outboard positions.

A dedicated test matrix has been developed to ensure robust sensor performance for occupant detection and object non-detection. Typically occupant detection has to be guaranteed for a 5% female, but also smaller occupants like young teenagers can be taken into consideration. Occupancy detection tests are performed with occupants of the specified size and weight. In addition to the nominal seating position, testing includes some forward and lateral position shifts. Non-detection is among others tested with beverage packs, rice and potato bags and a multitude of child restraint systems. In particular ISOFIX CRS with an integrated harness should not actuate the sensor, as those don't require the 3-point seat belt of the car to fix the CRS or to secure the child. Another non-detection test puts some weight onto the folded backrest to simulate a heavy trunk load.

A rear seat specific sensor layout and an IEE patented interconnection of the sensor's pressure sensitive cells allows the differentiation of the pressure profiles typically generated by humans from those generated by CRS or other test matrix objects. Figure 4 shows pressure profiles of a 5% female and various CRS, recorded with a high resolution pressure sensitive mat on a front passenger seat. The pressure distribution looks similar on the outboard rear seats. Although CRS or other objects can also exercise some load on the area usually covered by a human buttock, a smart senor design can almost entirely exclude unnecessary SBR warnings. For objects that are heavy enough to nevertheless activate the sensor, it is recommended to secure them with the belt or to load them into the trunk, as otherwise they are a potential danger for vehicle occupants if there is a crash.

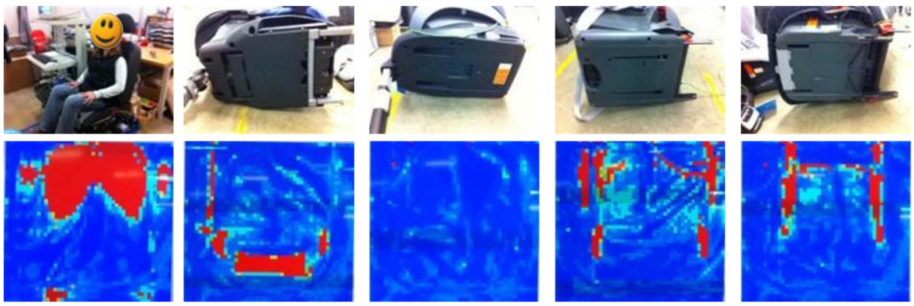

Figure 4. High resolution pressure profiles of human and CRS on a vehicle seat.

The system integrated into the Subaru model "LEVORG" has occupant detection only on the outboard seating positions. A system covering three positions on the rear bench is under development in order to cover all seating positions with an advanced seat belt reminder function.
The current system has the sensors and buckles connected to the car's wire harness via cables and connectors. For vehicles with highly flexible seat configurations or removable seats, a wired system layout could be considered a limiting factor. Therefore a wireless prototype concept has been developed by IEE to address those concerns. It is based on the same communication technology as currently used by tire pressure monitoring or keyless-go systems. A serial feasibility evaluation for the wireless system, as well as other occupant detection technologies that could be used for rear seat passenger detection, is currently under investigation.

EXISTING AND FUTURE NCAP INCENTIVES

NCAP star ratings for a vehicle only have real-life relevance if occupants are belted during a collision. A five star car can only provide a "five star protection" if the occupants are buckled-up. That was the motivation for many NCAP programs to promote effective seat belt reminder systems, with a focus for the front seats. Several NCAP programs have now started to perform crash tests with adult dummies on the rear seats. One aim is to motivate the vehicle manufacturers to make restraint system technology that's widely available for the front seats, like belt tensioners and load limiters, also available on the rear seats in a larger number of vehicle models. However, as for the front seats, the rear seat occupants can only benefit from those improved belt systems if they are buckled up. Hence the NCAP programs have an increasing interest to promote more efficient SBR systems for the rear seat, especially taking into consideration the generally lower belt wearing rates on the rear compared to the front seats.

Japan NCAP

When Japan NCAP introduced an overall rating scheme in 2011, SBR points became part of the evaluation. Since then, the overall rating score has been based on the sum of three elements: occupant protection (up to 100 points), pedestrian protection (up to 100 points) and seat belt reminder (up to four points for the front passenger seat and up to four points for the rear seats) [10].
J-NCAP was the first NCAP program to create an incentive for advanced seat belt reminders on the rear seats. Simple buckle monitoring only systems limited to telltale/display-type information are awarded with a maximum of two points, with the score depending on display location and its visibility to the occupants. Two additional points can be scored if the rear SBR alert includes an audible warning of at least 30 seconds. Such a warning, however, can only be triggered if passenger presence information is available.
The Subaru LEVORG is the first car where such an advanced SBR functionality will be assessed for the rear outboard seating positions, and it is expected to score between 3.0 and 3.33 points for the rear SBR system (official results not yet published at paper deadline).

Euro NCAP
Euro NCAP was the first NCAP to introduce SBR bonus points in 2002. Their SBR protocols evolved over time, and currently two combined points are available for advanced SBR systems covering both front seats, and one point for the buckle monitoring variant on the rear seats. The Euro NCAP protocol recommends occupant detection on the rear seats, but does so far not require it.
In its "2020 Roadmap" [11] Euro NCAP announced to introduce incentives for advanced rear seat SBR systems in 2018. Out of 2 points available for rear seat SBR, 1.5 points will be available for the buckle monitoring function (all rear seats), and 0.5 point will be allocated to additional occupant detection covering the 2nd row outboard seating positions, enabling an advanced reminder function.

Australasia NCAP
Australasia NCAP has announced it will fully harmonise with the Euro NCAP rating from 2018 on, so advanced rear seat SBR systems will become rating relevant in Australasia NCAP too.

Other NCAPs
Some NCAPs are now about to introduce incentives for the simple rear SBR systems into their rating (Korea NCAP in 2015, ASEAN NCAP in 2017, Latin NCAP – year to be confirmed). It can be assumed that incentives for more advanced systems will follow a couple of years later.

CONCLUSIONS AND RECOMMENDATIONS

The relatively simple rear seat SBR systems so far used in cars, warning only via telltale or text message, have a limited effectiveness on increasing the belt wearing rate. Now the time has come to extend the concept of advanced SBRs to the rear seats and to address the issue of occupant detection in an environment with a higher variability than on the front seats.

Driven by Subaru's safety strategy and Japan NCAP incentives, a first vehicle model with an advanced rear seat SBR system has entered the Japanese market. Occupant detection sensors, dealing with the specific needs of the rear seat environment have been developed by IEE.

Although field data on the effectiveness of an advanced rear seat SBR system is not yet available, a laboratory study on various rear seat SBR variants and the proven effectiveness for front seat occupants raise the expectation that rear seat belt wearing rates, typically much lower than those for the front seats, can be increased significantly.

And with NCAPs worldwide increasingly addressing the safety of rear seat occupants, it makes sense that they also create incentives for systems that ensure high belt wearing rates for those occupants. Euro NCAP and Australia NCAP will follow Japan NCAP, and start rewarding advanced rear seat SBR systems from 2018 on. By achieving higher belt wearing rates in combination with improved rear seat restraint systems one can expect to achieve additional road safety benefits in the future.

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