VALIDATING VEHICLE SAFETY USING META-ANALYSIS: A NEW APPROACH TO EVALUATING NEW VEHICLE SAFETY TECHNOLOGIES

Michiel van Ratingen
Euro NCAP
Belgium

Brian Fildes
Monash University Accident Research Centre,
Australia

Anders Lie
Swedish Transport Administration (Trafikverket) and
Chalmers Technical University, Sweden

Michael Keall
Monash University Accident Research Centre,
Australia

Claes Tingvall,
Swedish Transport Administration (Trafikverket) and
Chalmers Technical University, Sweden

Paper Number 15-0267

ABSTRACT

In a world of rapid developments in the field of vehicle safety, robust and reliable methods are essential to evaluate the safety effects in real traffic. Only with significant evidence-based findings can OEMs, governments and consumers act to encourage the most important systems. The Euro NCAP Validating Vehicle Safety using Meta-Analysis (VVSMA) consortium was assembled, comprising a collaboration of government, industry consumer organisations and researchers, using pooled data from a number of countries and the established MUNDS method. Technologies of immediate interest included low speed autonomous emergency braking (low speed AEB or AEB City), and Lane Departure Warning (LDW) technologies in current model passenger vehicles. Real-world crash data were assembled by 6 countries for the analyses and induced exposure methods were adopted to control for any extraneous effects. To date, the findings for AEB City technology found that while individual countries analyses failed to show significant reductions in crashes, robust statistically significant reductions were found overall from the meta-analysis due to the increase in the amount of data. The analysis for Lane Departure Warning technology is currently in process. Greater difficulty is experienced with evaluating this technology due to it only being available as optional equipment. The findings show how safety benefit analyses can be performed in a timely manner, using data from many countries in a meta-analysis procedure.

INTRODUCTION

The safety of modern passenger cars has improved substantially in recent years. The reasons for this improvement include international vehicle regulations that specify minimum levels of occupant protection, and consumer tests that rate vehicle safety (Stucki, *et al*, 1996; Broughton *et al*, 2000; Ward, 2012; Newstead *et al*, 2013). Improvements have come from greatly improved vehicle structures and materials, as well as new safety technology to better restrain the occupant in a crash and to mitigate against serious injuries. This passive safety approach has focused on preventing injuries, rather than stopping the collision or mitigating injuries. More recently, industry and government initiatives have shifted their focus to improving active safety in vehicles (Giebel *et al*, 2008). In-vehicle safety technologies aimed at preventing the crash are developing fast across the world, driven by the market place, rather than in response to new regulations. However, there is only a limited understanding of the possible (and actual) benefits for most of these systems. An outline on how these technologies are expected to work is shown in Figure 1.

The Crash Sequence (matching human error and crash protection)

Human error

What we might hit:

Normal driving	Deviation from normal driving	Emergency situation	Critical situation	Crash unavoidable	Pedestrians, Cyclists, Powered Two Wheelers, Cars, Trucks, Road furniture, Poles, Other rigid objects, etc.
• Education • Motivation • Cognition, etc. • Enforcement • Economic incentives	• Unawareness • Inattention • Violation	• Too close • Drifting • Sudden event	• Skidding • Loss of control		
• Access to road transport system	• Comfort • Economy • Social conformity	• Warning system • Supporting system	• Intervention in driving	• Immediate correction	• Preparation for crash	• Crash protection

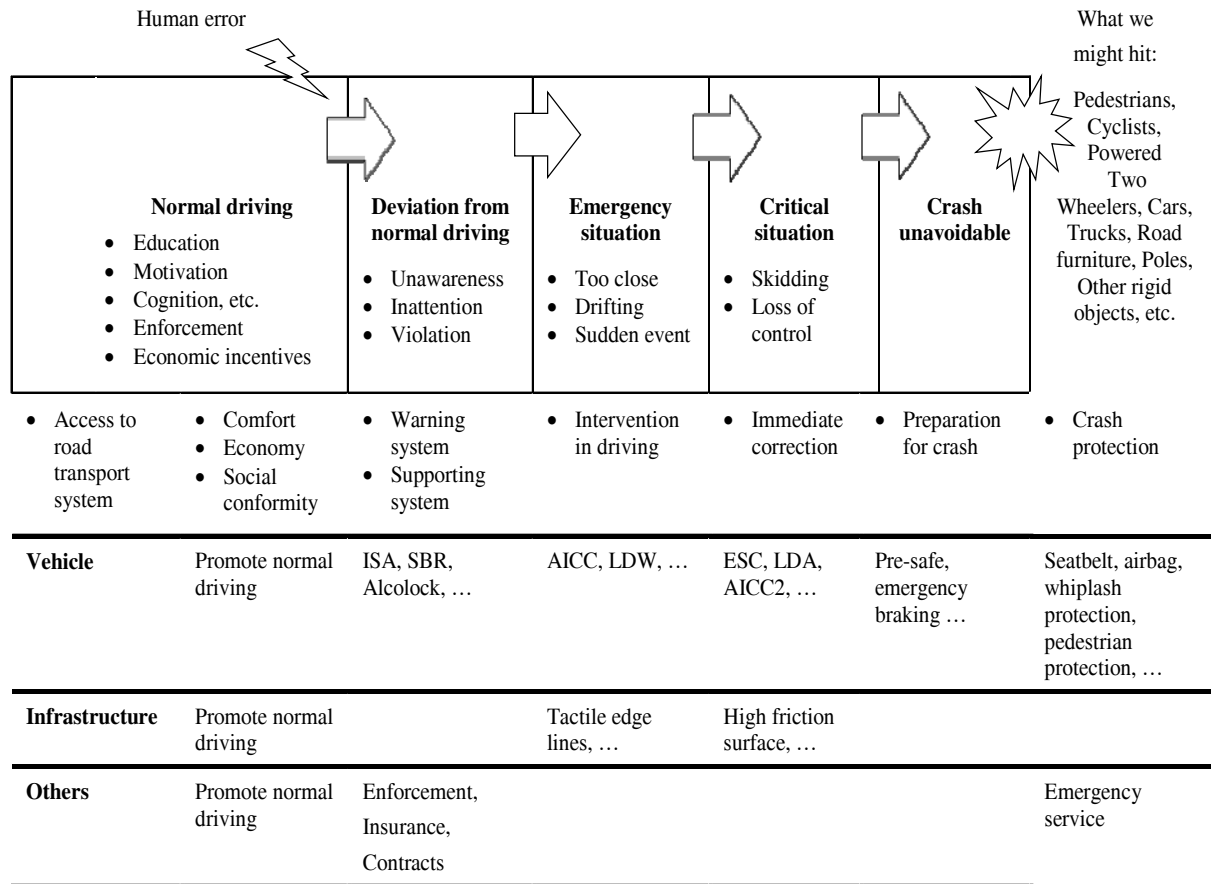|	Normal driving	Deviation	Emergency	Critical	Crash unavoidable	What we might hit
Vehicle	Promote normal driving	ISA, SBR, Alcolock, …	AICC, LDW, …	ESC, LDA, AICC2, …	Pre-safe, emergency braking …	Seatbelt, airbag, whiplash protection, pedestrian protection, …
Infrastructure	Promote normal driving		Tactile edge lines, …	High friction surface, …		
Others	Promote normal driving	Enforcement, Insurance, Contracts				Emergency service

Figure 1. The integrated safety chain

For new systems there are often benefit analyses done based on target population estimates and laboratory verifications of these systems. However, in the hands of everyday drivers the systems may have a different performance. Real world benefits of active safety technologies, are often hampered by the lack of sufficient real-world crash and non-crash data to obtain early and reliable effects of new innovative safety systems in cars. There are simply not enough systems available in each market individually to conduct these analyses. One way of potentially speeding up this process would be to investigate the possibility of collecting and analysing crash data on a broader basis than one country can conduct from their limited crash numbers.

To address this problem, a new approach was developed using a meta-analysis approach, the so-called "MUNDS" method (Fildes *et al*, 2013) where those with suitable data from various countries, conduct their own analysis using a common strategy, and these are then pooled together to form a better estimate of effects of car technologies. The benefits with this approach are several. First, by pooling, a larger amount of data becomes available, allowing for early analysis of a new system performance, and much sooner than any one country can provide. Second, results can be generalized across countries, still allowing national variation and comparison. Moreover, no raw data needs to be given away from the national statistics of each country.

To help guide manufacturer, government, and consumer group judgments about which technologies ought to be encouraged, it is critical to establish their potential savings in crashes and injury mitigation. It is expected this will help encourage their introduction and ensure market penetration is optimized.

THE VVSMA CONSORTIUM

To address this need, the Validating Vehicle Safety using Meta-Analysis (VVSMA) consortium was formed under the auspices of Euro NCAP to conduct analyses of the safety benefits of two emerging technologies, namely AEB City, and Lane Departure Warning (LDW) or Lane Keeping Assist (LKA) using the MUNDS approach. The VVSMA consortium involved a number of government, industry, consumer groups and research organisations from Sweden, France, Germany, UK, Italy, Netherlands, and Australia (Table 1) and commenced their activities in 2012. The European Automobile Manufacturer's Association ACEA maintained a watching brief on the consortium's deliberations.

Police data from six countries with a common analysis format were used in these analyses. Induced exposure was employed to control for extraneous factors across these databases. A major challenge with the approach was identifying crashed vehicles with and without the technology in each database and having the necessary analytic variables. Identifying the crashes that are potentially influenced by the safety system was also important. For reasons of maintaining confidentiality, it was agreed that the individual results for each country would not be identified in any subsequent analysis.

Table 1: Members of the VVSMA Consortium

Member	Organisation
Claes Tingvall - Founding Chair	Trafikverket, Sweden
Anders Lie - Chairman	Trafikverket, Sweden
Michiel Van Ratingen - Host	Euro NCAP, Belgium
Brian Fildes - Secretariat	ANCAP, Australia
Nils Bos	SWOV, Netherlands
David Brookes	Thatcham, UK
Sebastian Döering	VW, Germany (ACEA)
Michiel Keall	MUARC, Australia
Anders Kullgren	Folksam, Sweden
Olaf Jung	BMW, Germany (ACEA)
Yves Page	Renault (ACEA), France
Lucia Pennisi	ACI, Italy
Claus Pastor	BASt, Germany
Matteo Rizzi	Folksam, Sweden
Simon Sternlund	Trafikverket, Sweden
Johan Standroff	Trafikverket, Sweden
Pete Thomas	Loughborough, UK (DfT)

METHODOLOGY

There were a number of steps involved in the MUNDS analysis process.

1. First, was the need to identify which vehicles in each country's database had the relevant technology on-board. Where the technology was offered as a standard feature on particular makes and models, it was possible to simply identify these vehicles by make and model year in the crash data which were then nominated as "case" vehicles. Where the technology was only fitted as optional, a different process was needed to identify the case vehicle. This is explained in more detail below.

2. For comparison, it was necessary to identify similar vehicles that did not contain the technology, and these were labelled as "control" vehicles. For an analysis involving a standard technology, controls consisted of a number of vehicles that embraced the range of case vehicle types (body designs, masses, similar market categories, and so on). For a technology only offered as "optional", the controls were then the same makes and model vehicles but those without the technology onboard.

3. As these technologies are designed to work on specific crash types, it was important to restrict the analyses to those "sensitive" crash types only. This was judged from the experience of the members of the consortium and other available sources. The induced exposure measure was determined from the control exposure that matched that of the case crashes. The appropriate formula for making the AEB City assessment in both sensitive and non-sensitive crash situations was:

$$E = 1 - (A/B) / (C/D)$$

where:

    A= AEB fitted vehicles as **striking** vehicle

    B= AEB fitted vehicles as **struck** vehicle

    C= Non-AEB vehicles as **striking** vehicle

    D= Non-AEB vehicles as **struck** vehicle

4. Once the parameters of the analysis were defined, the various data providers then conducted their own analyses and provided these for inclusion in the meta-analysis. Other factors that might have a bearing on the analysis such as the speed of the crash were also identified and adjusted for in the analysis procedure. Further factors such as driver age and sex can also be controlled for, as in an analysis of ESC effectiveness (Fildes et al., 2013).

Meta-analysis is a standard statistical procedure involving logistic regression and data merging techniques that estimate the relative rate of sensitive crashes for the case vehicles compared to that of the equivalent control vehicles. The meta-analysis was weighted by the inverse of the variance of the effectiveness measure for each jurisdiction (as is standard in meta-analysis) and tested for the homogeneity of the effect size. Where possible, separate analyses can be conducted for road type and speed zone if needed to further explain the range of effectiveness of the technology.

RESULTS SO FAR

The work of the consortium comenced late in 2012 and many of the early months involved identifying suitable data, defining the process, and understanding the method. As most of the members of the consortium were new to the approach, it required time for them to appreciate it and the techniques involved.

Of the two technologies nominated for the effectiveness analysis, (AEB City and Lane Departure Warning systems LDW and LKA), the analysis of AEB City has now been completed and LDW/LKA is currently under investigation. The analysis of AEB City was relatively simple to analyse, given that is was fitted to a number of production models dating back to 2008 as standard equipment and possible to identify case vehicles from each of the databases.

Lane Departure Warning systems on the other hand tends to be fitted by most OEMs as optional equipment which places a greater requirement on identifying crashed vehicles in each database that have the technology onboard. The consortium is currently working through processes to identify case vehicles for this analysis and expects to have the meta-analysis completed later in 2015.

Low Speed AEB Effectiveness (AEB City)

CarAdvice (2014) noted that Low Speed AEB or City Safe technologies are marketed under a variety of names, including City Brake Control (Fiat), Active City Stop (Ford), City Emergency Brake (Volkswagen) and City Safety (Volvo). As their names suggest, this type of AEB technology is geared towards low speed situations, generally under 30km/h. These systems rely on radar sensors detecting an emergency situation and apply the brakes as needed. They tend to work most effectively over short distances, usually 12m or less (CarAdvice, 2014).

A paper is currently in press on the full details of this analysis and should be available later this year (Fildes *et al*, 2015). Briefly, the findings show a strong and significant reduction in rear-end crashes for vehicles fitted with the technology over those that don't. While the benefits are mainly in low speed urban areas, there seemed to be a small, non-significant, benefit in rural areas too, although this needs further research, given there were very few cases and the likelihood that rural rear-end crashes are relatively rare.

Of importance, however, while the meta-analysis was highly significant, most of the individual countries analyses failed to reach significance in their own right. This further confirmed the need for, and advantage of, the meta-analysis approach used here. While the meta-analysis was able to show the effectiveness of the technology in a relatively short period of time, it would take considerably more years for any one country to report on the benefits of

the technology based on real-world crash data. In short, it confirms the need and advantage of the approach in conducting real-world evaluations of the benefits of emerging active safety technologies.

Land Departure Warning Effectiveness (LDW/LKA)

Lane Departure Warning and Lane Keeping Assistance system are designed to warn a driver when the vehicle begins to move out of its lane (unless a turn signal is on in that direction) on freeways and arterial roads or apply positive feedback to correct these encroachments. These systems are designed to minimize accidents by addressing the main causes of collisions: driver error, distractions and drowsiness. As noted earlier, it is difficult to identify vehicle makes and models that have the technology onboard due to optional fitment. In Europe this means, that there are very few cars where LDW/LKA is standard in Europe. There are other issues as well, e.g. unlike low speed AEB or ESC, the systems are often default off and cannot automatically assumed to be active when they should. The expected overall effectiveness is therefore lower and generally difficult to identify in these data.

As far as the fitment issue is concerned, this generally requires access to the Vehicle Identification Number (VIN) of the crashed vehicles that are known to offer the technology and then to match the particular VIN number with the presence or absence of the technology. This involves gaining access to VIN details of the individual make and models of each potential case vehicle to identify cases (fitted) as well as the controls (not fitted).

VIN is not freely available in most databases. As the VIN is uniquely linked to a car and its owner, there are privacy implications in use and hence, both industry and governments are sensitive to its use. This makes the analysis process difficult, but not impossible – some countries do list VIN and there are some data sources that can help identify the fitment of optional safety equipment from the VIN number. The VVSMA consortium is currently working towards overcoming these challenges and ensuring that the real-world effectiveness of LDW/LKA can be established using the meta-analysis approach.

DISCUSSION

There are various methods adopted to estimate the likely effectiveness of new safety technologies. The auto industry for instance invests considerable resources in developing forecasting (prospective) systems based on simulations of real accidents, using traffic, vehicle and driver models (Page *et al*, 2015). This pre-production "Prospective Effectiveness Assessment for Road Safety (PEARS)" approach relies on virtual analyses by means of simulation, assuming various driver behavioral characteristics. Alternative approaches, such as the MUNDS method used by the VVSMA consortium, analyses real-world crash data to assess the post-production safety benefits of these technologies. This is not to say that one method is superior to another as both methods are really complementary. It depends what purpose you have in mind whether one is more useful than the other.

Meta-analysis is a procedure that is frequently used by medical researchers in establishing the extent of medical conditions and successful treatments, using published randomised controlled trials and clinical controlled studies. The most well-known application of meta-analysis publications in the medical field is the Cochrane Reviews that through meta-analysis, provides evidence-based health care findings based on best available research evidence (Cochrane Collaboration (2014).

The medical approach, however, relies on published studies that fit their criteria, and hence is subject to long delays in evaluation time. The MUNDS approach adopted by the VVSMA consortium speeds up these evaluations by assembling multiple independent aggregate analyses from several countries using a common study design. This brings together a much larger pool of data than any one country has available and speeds-up the process of evaluating safety technologies.

The evaluation of Low Speed Autonomous Emergency Braking (AEB City) in rear-end collisions was a successful first attempt by the VVSMA Consortium using the meta-analysis approach. As noted earlier, the analysis revealed a significant reduction in rear-end crashes for vehicles fitted with the technology. It was facilitated by the relatively easy identification of target vehicles in these databases, given that the technology was standard equipment. The second analysis of Lane Departure Warning technology currently underway has additional challenges in that this

technology is only fitted to some vehicles as optional equipment. This was discussed in some detail in an earlier section.

The need for early evaluation of these technologies was noted. They promise substantial benefits in reduced crashes and mitigating injuries yet very few can support these claims using real-world crash data. In an earlier report by Fildes *et al* (2013), they noted that the evaluation period can be reduced by half, using the MUNDS approach which means that these evaluations can play an important role in demonstrating real reductions in road trauma and motivation for their widespread fitment to the whole vehicle fleet. Moreover, early findings may also highlight the need for modifications and/or fine tuning to improve their effectiveness. It is critical to establish their likely crash benefits to help guide manufacturer, government and community judgments about which technologies should be pursued to encourage their widespread introduction and ensure maximum market penetration.

Finally, the collaborative approach adopted in this work through Euro NCAP proved to be both positive and productive in achieving its aims. Bringing governments, OEMs, NCAP groups and researchers together to address a common objective led to a creative and innovative evaluation that otherwise would not have been possible.

Limitations

There are limitations with this meta-analysis approach that need to be noted. First, the databases used in this study inevitably differ in terms of the way and accuracy of data collection across each of the regions. Some data contain a higher proportion of minor collisions to others and the police attendance strategies at these crashes is likely to vary. Furthermore, the composition of the vehicle fleet and the crash patterns may differ from country to country. Indeed, in the Low Speed AEB analysis, there were observed differences in the ratio of striking and struck impacts. While this was unlikely to have affected the results, it does reveal national data differences across countries. To the extent that the focus crashes are subject to the same sorts of reporting errors as the control crashes, the effectiveness formula can be expected to adjust for any such biases at a country level.

As each database is inevitably structured around local definitions and variables, it can be difficult to undertake a range of additional analyses beyond the core analysis. Again in the low speed AEB analysis, the use of side impacts as an additional induced exposure approach was not possible as these crash types could not be identified in all databases.

As the vehicle fleets differed across countries, these findings may not be representative of the effectiveness in any one country. This is not necessarily a major problem for the analysis though as the findings probably have more relevance overall than a series of single studies from individual countries. This adds to decisions about the need for widespread international fitment of these technologies even stronger.

Finally, in conducting these meta-analyses, it is assumed that the benefits calculated in these univariate analyses are for the technology under examination. Yet, as vehicle safety technologies increase and become integrated with others, there is the potential for the benefits to be confounded. While the VVSMA approach is aware of this possibility and has taken this into account to some degree in the selection of sensitive crash types for the AEB City and LDW/LKA effectiveness studies, nevertheless, this will present an additional challenge as the extent of these integrated systems expands. The means of addressing these potential confounding effects in meta-analysis is beyond the scope of the work conducted to date and warrants further research.

CONCLUSIONS & RECOMMENDATIONS

In conclusion, the use of the meta-analysis approach by the VVSMA consortium is seen as a valuable and important technique for evaluating new active safety technologies. The results showed that while individual country analyses were unable to show significant reductions in crashes for the AEB City technology, statistically significant reductions were obtained from the meta-analysis due to the increase in the amount of data. The approach to pool individual analyzes to achieve a common result worked well without the need to share data records. In addition, the collaborative approach between governments, industry, consumer groups, and researchers was successful with high levels of cooperation. The main challenge when evaluating new safety systems is to get an early and robust

indication of the real world performance in traffic. Often, the virtual predicted benefits of new technology can be influenced by human intervention. With a substantial increase in available data, statistically significant real-world findings can be obtained within much shorter timeframes using the meta-analysis approach. A major challenge is to identify vehicles with a specific safety feature when it is only offered as optional equipment. This paper has presented a bold new approach to evaluating the real-world crash benefits of safety technologies and recommends the approach for others to follow.

ACKNOWLEDGEMENTS

REFERENCES

Broughton J, Markey K A and Rowe Supt D (1998). A new system for recording contributory factors in road accidents. TRL Report 323. TRL Limited, Crowthorne.

CarAdvice (2014). Autonomous emergency braking explained, (downloaded December 2014)
http://www.caradvice.com.au/293366/autonomous-emergency-braking-explained/

Cochrane Collaboration (2014). Cochrane Reviews, Evidence –based health care.
http://community.cochrane.org/cochrane-reviews

Fildes B, Keall MD, Thomas P, Parkkari K, Pennisi L, Tingvall C (2013) Evaluation of the Benefits of Vehicle Safety Technology: The MUNDS Study, *Accident Analysis & Prevention* 55:pp. 274-281

Fildes B., Keall M., Bos N., Lie A., Page Y., Pastor C., Pennisi L. , Rizzi M., Thomas P., Tingvall C. (2015). Effectiveness of low speed Autonomous Emergency Braking in rear-end crashes. *Accident Analysis & Prevention*, (in Press).

Giebel T., Meinecke MM., Gonter M. & Widmann U. Current trends in vehicle active safety and driver assistance development, ATZAUTOTECHNOLOGY e-Magazine, 2008-09.
 http://www.atzonline.com

Newstead, S.V., Watson, L.M and Cameron, M.H. (2013). Vehicle Safety Ratings Estimated From Police Reported Crash Data: 2013 Update - Australian and New Zealand Crashes during 1987-2011, Report No. 318, Monash University Accident Research Centre, Clayton, Australia.

Page Y., Fahrenkrog, F., Fiorentino, A., Gwehenberger, J., Helmer, T., Lindman M., Op den Camp, O., van Rooij, L., Puch, S., Fränzle, M., Sander, U., Wimmer, P., (2015) A comprehensive and harmonized method for assessing the effectiveness of advanced driver assistance systems by virtual simulation: the PEARS Initiative, Paper Number 15-0370, 24th International Technical Conference on the Enhanced Safety of Vehicles (ESV) Gothenburg, Sweden, June 8-11, 2015.

Stucki SL, and Biss DJ (2000). A study of the NASS/CDS system for injury/fatality rates of occupants in various restraints and a discussion of alternative presentation methods, Presented at the 44th Annual Proceedings of the Association for the Advancement of Automotive Medicine (AAAM), Chicago, October 2-4, 2000.

Ward D. (2012). From Research to Global Policy and Action, 2012 Bertil Aldman Award Lecture, IRCOBI Conference, Dublin, Ireland.

.