MUNDS: A NEW APPROACH TO EVALUATING SAFETY TECHNOLOGIES

Brian Fildes,
Monash University Accident Research Centre, Melbourne, Australia

Michael Keall
Otago University, New Zealand

Pete Thomas,
Loughborough University, UK

Kalle Parkkari,
Finnish Motor Insurers' Centre, VALT, Finland

Lucia Pennisi,
Automobile Club of Italy

Claes Tingvall,
Swedish Transport Administration, Sweden

Paper No. 13-0073

ABSTRACT
Real-world evaluations of the safety benefits of new integrated safety technologies are hampered by the lack of sufficient data to assess early reliable benefits. To address this, a new approach was developed using a case-control, meta-analysis of coordinated national police data from Australia, Finland, Italy, New Zealand, Sweden and the UK, in assessing the benefits of Electronic Stability Control (ESC). The results showed that single-vehicle injury crash reductions varied between 21% and 54%, dependent on the speed zone of the crash and the road condition (significantly more effective in wet/icy road conditions than dry roads). For injury crashes involving more than one vehicle, ESC was twice as effective preventing crashes in high speed than lower speed zones. The findings using this new approach were consistent with those published by various equivalent individual studies, bearing in mind their wider international scope in terms of driving conditions and vehicle fleets studied. It was concluded that this new approach using a "prospective" meta-analysis method has the potential to expedite the process of evaluating emerging vehicle safety technologies that would otherwise be subject to much greater delays before sufficient evidence could be collected.

INTRODUCTION

The evaluation of the safety benefits of new integrated safety technologies using real-world crash data takes considerable time for sufficient crash data to become available, given the slow take-up rates of new vehicles in the vehicle fleet, and improved crashworthiness and roadworthiness (Sabow, 1994). Estimates from evaluation studies carried out across individual countries suggest that it can take at least 5-years for sufficient data to accumulate to permit a robust statistical analysis of the safety effects, and even longer for technology with a relatively narrow application to particular crash types. Given the pressing need for governments, manufacturers, and community groups to know how effective integrated safety technologies are in terms of preventing crashes and serious injuries, a new approach was desperately needed to provide early reliable evidence of the real-world effectiveness of these technologies.

Meta-Analysis

Meta-analysis has been defined as a "systematic method of evaluating statistical data based on the results of a number of independent studies of the same problem" (Medical Dictionary, 2013). They note that Meta-analysis has the advantage that it can produce a stronger conclusion than that of any individual study (ibid). In classic use, meta-analysis combines the findings of various existing published studies on a common theme. While the approach has been used in the medical arena for many years (eg, Cochran Collaboration, 2013) the approach has also recently been used in evaluating ESC in vehicles by Erke (2008) and Høye (2011). While meta-analyses is useful in assessing clinical and vehicle safety improvements, the approach relies on assembling already published in the scientific literature ***retrospectively***, and thus is subject to long delays due to the publishing process.

An alternative meta-analyses approach would be to initiate a collaborative study involving the assembly of a number of independent aggregate analyses from several countries ***prospectively***, 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. Furthermore, it would provide a more internationally relevant and detailed assessment of the safety benefits than any one single country can provide. These were the motivations for setting up the MUNDS (**MU**ltiple **N**ational **D**atabase **S**tudy) programme.

The MUNDS Approach

Researchers, government officials and auto manufacturers came together to develop a new prospective meta-analysis method for assessing the safety benefits of vehicle technologies. It was apparent that the only way in which these analyses could be undertaken more quickly using national crash data was to expand the availability of these data.

The MUNDS objectives were two-fold. First, to see if such an approach was feasible and valid, and second, to demonstrate the benefits in terms of time saved and additional insights from the approach.

METHOD

National data from Australia, Finland, Italy, New Zealand, Sweden and the UK were available, involving crashes of light passenger vehicles manufactured between 2000 and 2010. While the fitment of ESC is not routinely coded in national crash data, supplementary records were used by each country to identify those fitted with ESC in their databases. Only records where ESC was or was not definitely confirmed were included in the analysis.

Given that those who own or manage crash databases could not provide individual case records, the MUNDS team structured a series of blank summary tables containing the relevant data for the multivariate analysis which were sent to each data provider for them to complete and return. These tables and associated details were forwarded to the MUNDS statistician who then combined them as input for a series of overall analyses.

Different severity thresholds for recording crashes were identified and the highest common threshold was chosen to overcome potential difficulties with the analysis. Independent variables included vehicle size and type (small, large or SUV), year of manufacture, driver age, driver injury, crash type (frontal, side or rear-end), single or multiple vehicle collision, speed zone (above or below 75km/h), road condition (dry, wet or snow) and whether ESC was fitted or not.

Modelling Procedure: These compatible data were then pooled to enable statistical models to be developed, using logistic regression. Estimates were adjusted for the independent variables that could confound estimates of ESC effectiveness such as vehicle ages, types and sizes; road conditions, and driver age.

Quasi-induced exposure methods (Keall and Newstead, 2009) were used where counts of rear-end crashes represented a measure of exposure to risk of an injury crash. Logistic models were fitted to an outcome variable where Y=1 were crashes that excluded rear-ends, and Y=0 involved a rear-end crash. The odds of a non-rear-end crash using this data set are equivalent to the *risk* of non-rear-end crash involvement. These risk estimates could then be derived directly from the estimated coefficients generated by fitting the logistic models.

Explanatory variables included whether ESC was fitted or not, country; year of manufacture, vehicle type; driver age, speed zone, road condition, and any significant interactions between these factors. The interaction terms and other covariates served to control for potentially confounding effects that could otherwise bias the estimates of ESC effectiveness. The "forwards-selection" approach was used where one variable was added at a time to the model until a point was reached where no remaining variable made a significant partial contribution to predicting the odds of a non-rear-end crash.

The final models all fitted well, with no problems indicated by Hosmer-Lemeshow (2000) goodness-of-fit statistics. There was some modest over-dispersion, symptomatic of some degree of clustering of the observations or heterogeneity within classes. This was allowed for by estimating an over-dispersion factor by using quasi-likelihood estimation in the model fitting.

RESULTS

The results section is structured into two distinct sections. The first shows the results for the various country databases together with the time benefits of the approach, while the second outlines the findings for ESC and the validation of the approach.

Efficacy of the MUNDS Approach

The individual country findings obtained from the various countries is shown in Table 1 below.

Table 1: ESC numbers and benefits for all injury crashes (excluding rear-ends)

Country	Total Cases	ESC Fitted	ESC Benefit*	95% CI
Australia	25,571	1,247	-4%	(-21%, 10%)
Finland	3,989	343	1%	-43%, 32%)
Italy	**19,648**	**14,614**	**19%**	**(11% ,26%)**
NZ	3,022	194	-3%	(-55%, 32%)
Sweden	**17,739**	**4,880**	**29%**	**(22%, 35%)**
UK	31,114	7,172	3%	(-4%, 10%)
Overall	**101,083**	**28,450**	**13%**	**(9%, 17%)**

**A negative value indicates an increase in the crash rate*

While there were differences in the number of cases and their data periods, most showed positive benefits in ESC fitment (Australia and NZ were exceptions). The overall effect was a 13% significant reduction in injurious crashes with narrower confidence intervals.

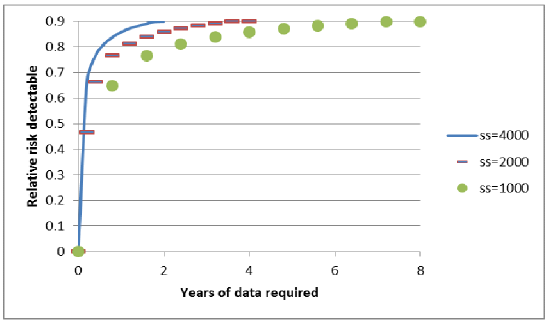

Figure 1: Time savings using the MUNDS approach

These findings show that while the estimated individual country benefits were not all statistically significant, the overall results were. This is essentially a consequence of smaller sample sizes for some countries individually, compared with the larger numbers overall obtained from using the prospective meta-analysis approach.

Figure 1 shows the number of years (and data) needed for a study to detect a 10% improvement in risk (a relative risk of 0.9) for three different sample sizes, which could feasibly be from three different sized countries with the specified numbers of crashed vehicles fitted with the technology. The country with the smallest prevalence of these crashes of interest (sample size=1,000) would take eight years to detect a safety benefit, compared to only two years for the study involving 4,000 crashed vehicles of interest. This latter larger study could be considered to be a MUNDS-type analysis in which the data from several countries are pooled.

Both these sets of results confirm the efficacy of adopting a prospective meta-analysis. The next set of analyses show the benefits of ESC for the independent variables under examination in the MUNDS analysis.

ESC Benefits (Single Vehicle Crashes)

As noted earlier, adopting a prospective meta-analysis procedure was expected to enable a more comprehensive set of results, given the additional power associated with the combined database. These estimates are presented by vehicle size, road conditions and speed limit (crash severity).

Table 2: Crash reductions in single-vehicle crashes where driver was injured

Crash Factor	Crash risk ESC Vehicle	Crash risk for non-ESC vehicle	Estimated crash (risk) Reduction	95% confidence limits
Dry roads	0.157	0.225	30%	(23%, 37%)
Wet/snow/ice	0.274	0.489	44%	(36%, 51%)
Speed Limit <75km/h	0.182	0.241	25%	(16%, 32%)
Speed Limit ≥75km/h	0.286	0.547	48%	(41%, 54%)
Small cars	0.168	0.241	30%	(23%, 37%)
Large cars	0.242	0.405	40%	(31%, 48%)
SUVs	0.222	0.462	52%	(30%, 67%)

The risks shown in Table 1 are estimated by the relative rates of the given type of single vehicle crash compared to the rates of rear-end crashes for the same vehicle/weather/speed limit conditions. So a lower rate for small cars, for example, indicates they have higher rates of the comparison crash type. This can arise when the vehicle is used more in congested traffic, where rear-end collisions are more common. It is therefore important that the relative risks are used (comparing column 3with column 2 of the table) to control for these different patterns of vehicle usage.

ESC Benefits for the factors of interest

Table 2 shows the findings for the ESC benefits for the three factors road condition, speed limit and vehicle size, included in the modelling. These benefits relate to single vehicle injury crashes only.

Road condition: While there were significant reductions in injury crashes for ESC fitted vehicles for all road conditions, those on wet, icy and snowy roads) were significantly greater as shown in Table 2. This result is consistent with previous studies by Lie et al (2004, 2006) and Thomas (2006).

Speed limit: This factor was included as a proxy for crash severity (higher speed limited areas are more likely to experience higher severity crashes). The findings here confirm that reductions in single-vehicle injury crashes were almost twice those in lower speed limited areas. While Sferco et al (2001), Aga and Okada (2003), and Dang (2004) speculated that the effects of ESC are likely to be greater at higher speeds where vehicle dynamic performance plays a greater part in the crash, this finding has not been previously quantified.

Vehicle size and type: The reduction in injury crashes was significant for both passenger cars and SUV models, but greater as vehicle size increased and for SUVs. Similar findings for vehicle size and type have been previously reported by Dang (2004), Green and Woodroffe (2006), Farmer (2006), Thomas (2006) and Scully and Newstead (2007), consistent with those found in Table 2.

Individual and overall benefits across countries

Table 3: By country: single vehicle benefits by road condition and speed limits

Country	Wet <75km/h	Wet ≥75km/h	Dry <75km/h	Dry ≥75km/h
Australia	12% (-24%,37%)	**43% (20%,60%)**	-8% (-48%, 21%)	**31% (3%, 51%)**
Finland	2% (-49%, 36%)	**38% (5%, 59%)**	-19% (-80%, 21%)	24% (-15%, 49%)
Italy	**38% (25%, 49%)**	**61% (51%, 68%)**	**25% (13%, 35%)**	**52% (42%, 60%)**
NZ	22% (-61%, 63%)	50% (-3%, 76%)	5% (-96%, 54%)	39% (-26%, 71%)
Sweden	**49% (38%, 58%)**	**67% (60%, 73%)**	**37% (26%, 48%)**	**60% (51%, 67%)**
UK	7% (-14%, 24%)	**40% (28%, 50%)**	-14% (-38%, 6%)	**27% (13%, 39%)**
Overall	**34% (23%, 43%)**	**54% (46%, 60%)**	**21% (11%, 29%)**	**44% (36%, 51%)**

Wet includes snow and ice. Figures in BOLD were statistically significant

The results in Table 3 again show that the estimated reductions in single-vehicle injury crashes from ESC fitment differed considerably across countries and speed zones. This is not surprising as quite different road conditions exist for say Australia compared to Sweden, and as ESC has been shown to be more effective in road conditions that provide less traction for tyres, such as wet/snowy/icy roads, which are more common in Sweden.

ESC and vehicle size and type

Table 4: Combined countries: single vehicle benefits by vehicle size, speed zone, and road condition

Vehicle Size	Speed Zone	Road Condition	Reduction
Small Car	<75km/h	Wet/Snow/Ice	31% (18%-41%)
Small Car	<75km/h	Dry	17% (8%-27%)
Small Car	≥75km/h+	Wet/Snow/Ice	51% (41%-59%)
Small Car	≥75km/h+	Dry	41% (31%-49%)
Large car	<75km/h	Wet/Snow/Ice	37% (24%-48%)
Large car	<75km/h	Dry	25% (11%-36%)
Large car	≥75km/h+	Wet/Snow/Ice	55% (46%-63%)
Large car	≥75km/h+	Dry	46% (36%-55%)
SUV	<75km/h	Wet/Snow/Ice	52% (28%-67%)
SUV	<75km/h	Dry	42% (16%-60%)
SUV	≥75km/h+	Wet/Snow/Ice	66% (49%-77%)
SUV	≥75km/h+	Dry	59% (40%-72%)

The results in Table 4 show that the reduction in single-vehicle injury crashes from ESC fitment was greater on wet, snow and icy road conditions and in higher speed zones. For some of the individual country comparisons (especially Sweden and Italy) there were consistent statistically significant benefits estimated, albeit with wide confident limits. Such a fine disaggregation by vehicle type and road conditions has not been previously reported, and only achievable here from the amount of data included using the prospective meta-analysis approach.

ESC Benefits (Multi-Vehicle Crashes)

Unlike other earlier individual studies, the MUNDS analysis was able to show some marginal benefits also for ESC in multiple vehicle crashes, due to the additional data available, as shown in Table 5.

Table 5: Multi-vehicle crashes benefits speed zone overall and by individual country

Country	<75km/h	≥75km/h
Australia	-7% (-24%, 9%)	6% (-12%, 21%)
Finland	-14% (-72%, 25%)	0% (-53%, 35%)
Italy	9% (-1%, 18%)	**20% (9%, 30%)**
NZ	-11% (-70%, 28%)	3% (-50%, 37%)
Sweden	**20% (12%, 27%)**	**29% (19%, 38%)**
UK	-3% (-13%, 5%)	**9% (0%, 17%)**
Overall	**7% (1%, 12%)**	**14% (6%, 21%)**

Figures in BOLD were statistically significant

There were significant reductions in injury risk from ESC in multi-vehicle crashes by country and speed limit zone. This result, too, has not been previously reported.

MUNDS VALIDATION

The final analysis undertaken here was to compare the results obtained from the MUNDS analysis with similar results previously published.

Crash Type	MUNDS	Farmer (2006)	Lie et al (2006)	Scully & Newstead (2007)	Høye (2011)
All single vehicle crashes	22-26%	33%	17%	27%	32%
All multi-vehicle crashes	7-14%	25%	unk	unk	6%
Crashes in Wet	44%	unk	49-56%	unk	unk
SUV - Single	71%	49%	unk	68%	50%

It is acknowledged that this is not so much a test of validity but more an indication of the worth of the prospective meta-analysis approach. It should also be noted that there were differences in the approaches adopted to control for differences in exposure in different studies. Most studies used an induced exposure method, although others used licensed vehicles or no measures at all. This needs to be taken into account when comparing across studies as it can influence the result obtained.

Of interest, though, these results do show a degree of consistency between the MUNDS findings reported above and those from other published studies. Of particular interest was the finding from Høye (2011) which used a retrospective meta-analysis involving a number of relevant international publications.

The MUNDS findings are generally within the broad range of earlier reported results, for all single vehicle crashes, multi-vehicle crashes and SUVs, albeit towards the top end of magnitude of effects found. The divergences in these findings should not be too surprising. Apart from differences in methods and exposure measures, there are quite different road, speed, and weather conditions across these individual countries as well as differences in the rates of ESC fitment, and motoring cultures more generally. The degree of consistency achieved supports the prospective meta-analysis approach as a useful additional tool for evaluating vehicle safety technologies.

GENERAL DISCUSSION

This study set out to test the value of the prospective meta-analysis approach and to demonstrate the benefits in terms of time saved and additional insights from the approach. The ESC safety technology was chosen for comparison, given the range of previous studies already reported on the benefit of this technology. The results outlined above directly impact on these objectives.

The effectiveness of ESC in reducing injury-related crashes, using the prospective meta-analysis approach involving national police data from 6 countries in Europe and Australasia, was confirmed. While one or two of the individual country analyses were statistically significant, the overall meta-analysis of all databases proved to be both more robust and with less variance. This translates to an ability to produce results in a much shorter timeframe than any one country could achieve by itself, using this approach.

We attempted to clarify the importance of the approach to aggregate data across countries. The main benefit consists of a narrowing of the confidence intervals, which is mainly a function of increased sample size. It is therefore an expected result that some of the MUNDS confidence intervals exclude estimates generated by smaller studies. But it is worth noting that apart from one early result (Becker et al, 2004), the MUNDS estimates and CIs essentially overlap with other reported figures, given the crash type variations.

Furthermore, the prospective approach of combining common aggregate analyses reduces the need for combining individual records in a common database, thereby eliminating difficulties in sharing confidential and private records, but still achieving more timely results of technology effectiveness.

A larger database obtained here not only achieved the benefits in improved timing to report important findings for governments, industry and the community generally, but did reveal some additional insights from the prospective meta-analytic approach.

There are always issues of representation when conducting effectiveness evaluations. Individual countries have their own characteristics which always beg the issue of how general the finding might be internationally. Thus, combining data from several different countries can at least partially if not fully overcome this weakness. Thus, new findings become available that previously known.

The results of this study confirmed many of the benefits of ESC previously reported, albeit of different intensity in many cases. For instance, the effect of vehicle size and type by the road condition at the time across countries with differing weather patterns was better controlled for here. The effects of ESC on single-vehicle crashes were replicated again in this study but so too, were benefits of the technology in multi-vehicle injury crashes which has not always been found presumably because the benefits are smaller, and thus not detectable by smaller sample sizes. The approach enabled multiple comparisons of synergistic effects between the three key independent variables to be modelled and reported. New findings for the effects of crash severity (expressed in terms of different speed zone crashes) were reported here which to the authors' knowledge is a novel finding, not previously quantified.

Validation of the technique

A major objective in this study was to validate the prospective meta-analysis application and ensure that the technique did not provide spurious results. Of course, this could not be done in a precise manner here, given the variations across studies in terms of road design and driving conditions, annual mileage, vehicle fleet mix and driving culture, to mention a few. Nevertheless, it was possible to control for some of the differences between countries by the use of regression modelling to overcome the obvious sources of biases such as driver and vehicle age.

The findings for all single vehicle crashes reported here of between 22 and 26 percent was within the spread of earlier finding by Farmer (2004, 2006), Lie et al (2006) and Scully and Newstead (2007) for similar-aged vehicles and crash periods. The findings for wet roads of 44% was not that different to Lie et al (2006) figure of 49 to 56 percent, especially when considering that Lie's findings were based on Swedish roads where inclement weather is severe. The advantage of ESC in single-vehicle crashes involving Sport Utility Vehicles (SUVs) was much higher than for passenger cars, consistent with those reported by Farmer (2006), and Scully and Newstead (2007). Importantly, there was good consistently with the retrospective met-analysis of ESC by Høye (2011) involving prior reports from similar regions.

It is acknowledged however that the validation process conducted here was hardly a rigorous test of the method's validity. Nevertheless, there were some interesting comparisons found that go some way to sanctioning the approach.

Exposure to risk

One of the important methodological issues in conducting the validation exercise was the choice of an appropriate measure of exposure to control for varying traffic volumes and crash types. As noted in the text, rear-end crashes were used as a measure of overall exposure to risk across all countries in the model and thus the effects of ESC could then be estimated by a reduction in prevalence of other crash types (those presumably affected by ESC) in relation to the prevalence of rear-end crashes (those not affected by ESC).

The induced exposure method has been used in many similar evaluations and the particular procedure used here has been adopted from previous peer-reviewed findings (Tingvall et al, 2003: Page and Cluny, 2006; Lie et al, 2004, 2006; Scully and Newstead, 2007; and Keall and Newstead, 2009). Farmer (2004, 2006) used number of registered vehicles as a measure of exposure, but these figures were not always readily available in the MUNDS countries. Nevertheless, it is argued that induced exposure has many benefits for its use in studies such as this one and that it provides a more rigorous and viable measure of exposure for applications such as this one.

Study limitations

It is acknowledge that the MUNDS study analysis, like all technology evaluations, was not without its limitations. First, there were likely inconsistencies between the databases used in this study. While each contributor used national data, differences in the way and accuracy of data collection across the regions is common. In particular, the way each study reported injuries and their severity likely differed across databases. The Finnish database, for example, only included crashes that resulted in injuries to the driver, which is a source of some heterogeneity. This of course is also a problem for "retrospective" analyses from different studies that also use different databases.

Differences in vehicle fleets and annual mileage were likely across countries, meaning that the findings here might not be representative of any particular country. While this was an important for international representativeness, the results are probably more representative of Europe as a whole than other regions. In addition, the use of speed zone as a proxy for crash severity is not without some criticism. It implicitly assumes that higher speed zones are associated with higher speed crashes, and lower speed zones with lower speed crashes. Newstead *et al* (2010) have used this technique in assessing real-world vehicle crashworthiness with some success. Although such assumptions may not affect analyses of large datasets as were available here, it would be useful if this assumption was able to be tested in future research.

The set of comparison crashes used to provide a measure of exposure to risk has been identified by previous research as one of the better induced exposure measures, although driver age and vehicle type are two factors across which the rear-end crashes provide biased measures of exposure (Keall and Newstead, 2009). However, by including these factors as covariates in our models, we have accounted for at least these sources of bias in forming our estimates.

CONCLUSIONS

This study set out to test the value of the prospective meta-analysis approach and to demonstrate the benefits in terms of time saved and additional insights from the approach. Its hypothesis was that the results of the MUNDS effectiveness analysis (for Electronic Stability Control – ESC) would be consistent with those published earlier. We contend that the results reported here support the validity of the MUNDS approach to estimating technology effectiveness.

Several new findings are reported in the interaction between the independent variables of road condition, speed zone and vehicle size and type in single-vehicle crashes. Given the larger and common database assembled, multi-vehicle crashes also benefited from ESC, albeit of less impact. In addition, the percentage reductions reported for the independent variables of road condition and vehicle size and type were shown to be consistent with previous published findings.

The new methodology developed here using a prospective meta-analysis approach has the advantage of expediting the process of evaluating new vehicle safety technologies. In reality, it is the only feasible approach to study real-world safety benefits when one data source is not sufficient. Drawing from a larger pool of crash data enhances the likelihood of demonstrating statistical significance with tighter confidence bounds. The MUNDS approach will be of potential benefit to vehicle manufacturers and suppliers, governments and consumer groups and advocates in prioritising future road safety improvements in active safety. While a number of limitations were identified with the findings that should be addressed in future research, nevertheless, the MUNDS approach needs to be adopted widely for the benefit of all road users.

Acknowledgements

The authors would like to thank the project sponsors, the Swedish Transport Administration in Sweden and The Australian Government Department of Infrastructure and Transport in Australia for their support for this project and the support of the MUNDS Committee including Manuel Aviles, Spanish Ministry of Transport; Joerg Bakker, Daimler AG; Ola Bostrom, Autoliv Incorporated; Samantha Cockfield, TAC Victoria; Robert Hogan, Australia Dept. Infrastructure and Transport; Anja Kohsiek, Volkswagen; Anders Kullgren, Folksam Insurance; Nils Lubbe, Toyota Motor Corp.; Stuart Newstead, MUARC; Claus Pastor, BASt; Michiel van Ratingen, Euro NCAP; Jean-Louis Martin, IFSTTAR

REFERENCES

Aga, M, Okada, A, (2003). *Analysis of Vehicle Stability Control (VSC)'s Effectiveness from Accident Data,* Enhanced Safety of Vehicles Conference, Paper #541, Nagoya, Japan.

Becker, H., Busch, S., Zobel, R., (2004). Methods for the evaluation of primary safety measures by means of accident research. In: 30th FISITA World Automotive Congress, Barcelona.

Cochran Collaboration (2013). The Cochrane Collaboration: Working together to provide the best evidence for health care, 1993 to 2013. http://www.cochrane.org (downloaded 31/1/13 @ 15:00)

Cochran WG. (1954). The combination of estimates from different experiments. Biometrics, 10: 101–129

Dang, J.N. (2004). *Preliminary Results Analyzing the Effectiveness of Electronic Stability Control (ESC) Systems* NHTSA Evaluation Note, DOT HS 809-790; September 2004.

Erke, A. (2008). A. Effects of electronic stability control (ESC) on accidents: A review of empirical evidence, *Accident Analysis and Prevention 40* pp167–173

Farmer, C.M. (2004). *Effect of electronic stability control on automobile crash risk, Traffic Injury Prevention, 5*: pp317–325.

Farmer, C.M. (2006). Effects of electronic stability control: an update. *Traffic Injury Prevention 7*, pp319–324.

Green, P.E., Woodrooffe, J. (2006). The effectiveness of electronic stability control on motor vehicle crash prevention. University of Michigan Transport Research Institute, special report 12.

Hosmer, D.W. [Jr], Lemeshow, S. (2000). *Applied Logistic Regression*, Second Edition, New York: John Wiley & Sons

Høye, A. (2011). The effects of Electronic Stability Control (ESC) on crashes—an update, *Accident Analysis and Prevention 43* pp1148–1159.

Keall M.D, Newstead S. (2009). Selection of Comparison Crash Types for Quasi-Induced Exposure Risk Estimation. *Traffic Injury Prevention*. 10 (1): pp23-29.

Lie, A., Tingvall, C., Krafft,M., Kullgren, A.(2004). The effectiveness of Electronic Stability Program in reducing real life accidents. *Traffic Injury Prevention 5*, pp37–41.

Lie, A., Tingvall, C., Krafft, M., Kullgren, A.(2006). The effectiveness of electronic stability control (ESC) in reducing real life crashes and injuries. *Traffic Injury Prevention 7,* pp38–43.

Medical Dictionary (2013). Meta-analysis: definition of meta-analysis in the medical dictionary. http://medical-dictionary.thefreedictionary.com/meta-analysis *(downloaded 31/1/13)*

Newstead, SV, Watson, L. Cameron, MH. (2010). Vehicle safety ratings estimated from police reported crash data: 2010 update. Australian and New Zealand crashes during 1987-2008, Monash University Accident Research Centre, Report No. 297

Page Y., Cuny S. (2006). Is electronic stability program effective on French roads? Accident *Analysis and Prevention 38* pp357–364

Sabow G (1994) "The influence of technical defects on accidents" , *Proceedings of 6th World Congress of the International Road Safety Organisation*, Cape Town, Oct 1994.

Scully J., Newstead S. (2007). Preliminary evaluation of Electronic Stability Control effectiveness in Australasia, Report 271, Monash University Accident Research Centre, Melbourne, Australia.

Scully J., Newstead S. (2008). Evaluation of electronic stability control effectiveness in Australasia, *Accident Analysis and Prevention 40* pp2050–2057

Sferco, R, Page, Y, LeCoz, J, Fay, P. (2001). *Potential Effectiveness of Electronic Stability Programs (ESP) – What European Field Studies Tell Us,* ESV, Paper, 2001-S2-O-327, Netherlands.

Thomas, P. (2006). Crash involvement risks of cars with electronic stability control systems in Great Britain, *Int. J. Vehicle Safety*, Vol. 1, No. 4, pp267–281.

Tingvall C, Krafft M, Kullgren A, Lie A. (2003). The Effectiveness of ESP (Electronic Stability Programme) in Reducing Real Life Accidents*,* Enhanced Safety of Vehicles Conference, Paper #261, Nagoya, Japan.