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Feasibility of using various data sources to carry out accident studies into primary safety of cars – phase 2

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Transport Research Laboratory

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Feasibility of using various data sources to carry out accident studies into primary safety of cars - phase 2

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Executive summary

The development of sophisticated electronic control systems has led to new vehicles being equipped with an increasing range of new primary safety functions designed to avoid accidents. However, assessing the actual effectiveness of such primary safety (accident avoidance) features in reducing the number of casualties in road accidents can be very difficult. Probably the main reason for this difficulty is that if a primary safety feature is fully effective then there would be no accidents of the relevant type and, therefore, no data for comparison.

This project has drawn together two related innovative ideas that had been submitted to the TRL Academy with the aim of making progress in this area. Recent research that had been part-funded by the TRL Academy (Knight and Broughton, 2006[1]) had recommended that predictive and retrospective analyses of the current range of primary safety systems should be carried out, using current data and the best analytical technique available. Access to the TRL version of the STATS19 database needed to be updated in order to maximise its use and to allow the application of more sophisticated analytical approaches.

The project was carried out in two phases, phase 1 in 2008 and phase 2 in 2009. This is the main report of phase 2, which has had three objectives:

i. to develop a user-friendly software interface for the TRL copy of the STATS19 accident database. An unpublished TRL report documents the developments that were made and provides user guidance for the new software. The ultimate aim is that this improved access will support the development of more sophisticated analytical techniques such as those applied in this research to assess the effectiveness of Electronic Stability Control (ESC),

ii. to obtain details of which car models had been fitted with ESC from the UK Motor Insurance Repair Research Centre (widely referred to as Thatcham, after the Centre's location),

iii. to make a practical assessment of the effectiveness of ESC based on analyses of STATS19 accident data. Knight and Broughton (2006) identified alternative analytical approaches that had previously been applied to assess the effectiveness of primary safety systems such as ESC. All involved implicit or explicit assumptions which potentially could affect the outcome. This project tested an approach that is relatively uncommon in the primary safety literature, although widely used in other contexts.

The basic approach used to assess the effectiveness of ESC under (iii) has been to compare the accident-involvement rates of cars with and without ESC, identifying which cars had ESC from the 'Thatcham data' (ii). Analyses were completed for eight of the most popular car models, both individually and collectively. ESC was found to reduce the overall accident-involvement rate by about one fifth, although the effect was less for serious accidents and not significant for fatal accidents. The effects varied widely among car models, and analyses failed to yield satisfactory results for several models because of the low number of cars of these models that had ESC fitted as standard.

Previous studies of the effectiveness of ESC have generally used the 'odds ratio' approach. This approach is compared with the new approach based on accident-involvement rates. While there are strong similarities, there is a key difference. The 'odds ratio' approach requires an assumption about which manoeuvres made by accident-involved vehicles may be susceptible to ESC, and this assumption is shown to be questionable. The new approach avoids the need for this assumption, so its results should be more reliable.

[1] Knight I and Broughton J (2006). *Techniques for assessing the effectiveness of vehicle primary safety features using accident data.* TRL Published Project Report 201.

It is found, however, that a basic assumption of many studies of ESC effectiveness may be violated, in which case their results would not be valid. These studies implicitly assume that cars with and without ESC are driven in similar circumstances, for similar mileages and with similar drivers, so that any differences in their accident-involvements can be interpreted as the effects of ESC. Analyses of STATS19 accident data demonstrate, however, that the driver profiles of the two groups of car may well differ in terms of age and sex.

The report shows how the basic approach of comparing accident-involvement rates may be developed to compensate for the bias introduced by such differences. The suitability of this development has been demonstrated, but there has not been sufficient time during this project to complete the development and examine whether other potential confounding factors may need to be treated in a similar way.

Abstract

The development of sophisticated electronic control systems has led in recent years to many new vehicles entering production that are equipped with various new primary safety features designed to avoid accidents. The assessment of the casualty reduction effectiveness of such features can, however, be very difficult. One reason for this is that when a primary safety feature is fully effective, there is no accident and no data for comparison. This project has attempted to assess the effectiveness of Electronic Stability Control (ESC).

The project was carried out in two phases, phase 1 in 2008 and phase 2 in 2009. This is the report of phase 2 which has had three objectives: to develop a user-friendly software interface for the TRL copy of the STATS19 accident database; to obtain details of which car models had been fitted with ESC from the UK Motor Insurance Repair Research Centre; to make a practical assessment of the effectiveness of ESC based on analysis of STATS19 accident data.

Each objective has been achieved. The effectiveness of ESC was analysed for the eight of the most numerous current car models, both individually and as a group.

1 Introduction

In recent years, the development of sophisticated electronic control systems has led to new vehicles being equipped with an increasing range of new primary safety functions designed to avoid accidents. However, assessing the casualty reduction effectiveness of such primary safety (accident avoidance) features can be very difficult. One of the underlying reasons for this is that when a primary safety feature is fully effective, there is no accident and, therefore, no data for comparison.

Knight and Broughton (2006) undertook a research project to investigate techniques to improve the ability of researchers to estimate the benefit of primary and active safety systems on vehicles. The rationale behind the research was that Governments require evidence of the cost-effectiveness of solutions before they can make policy decisions about those systems. The lack of rigorous estimates of the effectiveness of primary and active safety systems was considered to risk preventing or delaying such policy decisions. In turn, this was considered likely to mean that the implementation of advanced safety features would be slowed or poorly targeted.

The research made a wide range of recommendations, including:

1. Undertake effectiveness analyses of current systems using a variety of techniques with the twin aims of providing the best currently available estimates of effectiveness and identifying the best techniques for assessment and where they required improvement.
2. Investigate the use of Electronic Data Recorders in the UK to provide better accident and exposure data.
3. Develop improved vehicle performance, specification and exposure data.
4. Carry out naturalistic driving studies or field operational trials.
5. Develop improved research tools.

The TRL Academy therefore commissioned TRL to undertake further research in this important area. The research was intended to contribute to points one, three and five in the list above. The main objectives were to:

1. Improve access to the STATS19 database as a tool for researchers (STATS19 is the national system used by British police forces to record details of road accidents that lead to personal injury)
2. Collect vehicle specification data to identify vehicles that are fitted with Electronic Stability Control (ESC; a system that detects loss of control and autonomously applies braking at individual wheels to correct the instability)
3. Explore the potential for linking the above two data sources to allow statistical analysis of the effectiveness of ESC

The research has been carried out in two phases. Phase 1 was carried out in 2008 and tested the feasibility of the approach; Keigan et al (2009) presents full details. Phase 2 has been carried out in 2009, and has completed the work begun in Phase 1. This report presents full details of Phase 2, and includes details of Phase 1 as necessary to provide a complete account.

TRL is unique in receiving a copy of the full STATS19 data files from the UK Department for Transport (DfT), including confidential fields such as the breath test field and vehicle data that has been enhanced using the vehicle registration mark to access DVLA records. However, the data is held centrally in a format that cannot be easily accessed by the majority of researchers. One part of the work has involved developing a user-friendly software interface for the STATS19 database at TRL which will allow researchers with no special knowledge of the database to access the data directly. Vadgama and Keigan (Unpublished TRL Report, 2010) documents the developments made during Phase 2 and provides user guidance for the software. The ultimate aim is that this improved access will support the development of more sophisticated analytical techniques such as those recommended by Knight and Broughton (2006).

To achieve the second of this year's objectives, details of the car models currently available with ESC work have been obtained and combined with data obtained previously. These details were supplied by the UK Motor Insurance Repair Research Centre (widely referred to as Thatcham, after the Centre's location).

To achieve the third objective, a practical assessment of the effectiveness of ESC has been carried out. Phase 1 of this project had selected an appropriate analytical approach and applied it to the case of the Ford Mondeo. Knight and Broughton (2006) identified alternative analytical approaches that had been applied to assess the effectiveness of primary safety systems such as ESC, all of which involve implicit or explicit assumptions which could potentially affect the outcome. This project has applied an approach that is widely used in other contexts, although relatively uncommon in the primary safety literature. The primary safety literature tends to focus on the "odds ratio"; section 3 shows that the "new" approach is very similar but avoids an assumption which will be demonstrated to be questionable.

Previous studies have generally grouped together car models as a preliminary to comparing the rates of cars with and without ESC. This might bias the comparisons if accident rates varied among models, so it is better in principal to analyse individual car models to check results from grouped analyses. Section 3 presents results for individual models as well as the grouped models.

This is the final report from this project and describes the methods and results in full. Section 2 introduces the data sources. Section 3 describes the statistical methodology, analyses the data and presents results about the effectiveness of ESC. Section 4 discusses the results, and Section 5 presents the principal conclusions.

1.1 Exposure measures

Suppose that the STATS19 data showed that 10 times as many cars not fitted with ESC were involved in accidents as were fitted with ESC. A measure of "exposure to risk" is required to interpret this finding. ESC would be shown to reduce accident risk if the exposure to risk of cars with ESC was less than 10 times the exposure of cars without ESC. In other words, we need to compare the accident-involvement rate (the number of cars involved in accidents per unit of exposure) of cars with and without ESC. If the accident rate of cars with ESC is less than the rate of cars without ESC then it would appear that fitting a car with ESC reduced accident risk.

Much has been written about how to measure "exposure to risk", the strengths and weaknesses of the various alternatives. In order to be useful, however, it is clear that the selected measure must be available at the same level of detail as the accident data being analysed. In the present context, the measure needs to be available for models of car with and without ESC, i.e. at a fine level of detail. The most suitable measure that is available at this level is the number of registered cars. This is available from the Driver and Vehicle Licensing Agency (DVLA), using the same system for coding make and model of car as the STATS19 data. Thus, the accident rate to be analysed in this project is the number of cars involved in accidents per thousand registered cars per year.

Knight and Broughton (2006) discussed the features that exposure data used in primary safety analyses would ideally possess. They found that all available candidates fell short of the ideal, but that the DVLA registration data came nearest. Section 3.5 shows that the limitations of this source can bias the analytical results, and section 3.6 illustrates a potential solution based on the concept of "induced exposure".

1.2 Background STATS19 data

ESC is intended to detect loss of control and apply braking at individual wheels to correct the instability. The proportion of cars in Great Britain that are equipped with ESC has risen in recent years (as illustrated in section 3.3) so it would have been expected that the incidence of loss of control in car accidents would have tended to decline. Instead, a series of TRL reports has tracked the increase over at least a decade of the proportion of cars that lost control when involved in accidents. This has been measured by several indices:

- the proportion of casualties that occurred in single vehicle accidents,
- the proportion of casualties in cars that hit objects off the carriageway,
- the proportion of casualties in cars that overturned.

The validity of this approach has been demonstrated by analyses of the contributory factors that had been reported using the TRL system between 1999 and 2004. Broughton and Buckle (2007) presented contributory factor analyses that helped to understand the reasons for cars overturning. For five-sixths of casualties in overturned cars, the driver had lost control of the car, compared with less than half in cars that did not overturn. Unpublished analyses for the other two accident types produced similar results.

Broughton and Knowles (2009) present the latest data, which are summarised in Figure 1.1 (KSI=Killed or Seriously Injured). The number of car occupants killed or seriously injured has tended to fall over this period, but within these declining totals the proportion of casualties who were injured in 'loss of control' accidents has risen. The fact that this proportion has increased over a period when the proportion of cars equipped with ESC has also increased raises important questions about the actual effectiveness of ESC in preventing accidents.

The fact that the casualty proportions in these figures are higher for Killed than for KSI suggests that 'loss of control' accidents tend to be relatively severe, and this is confirmed by current STATS19 data. Consider those accidents that occurred between 2006 and 2008 in which car occupants were injured. When drivers lost control (i.e. 'Loss of Control' was among the contributory factors recorded), 3.4% of accidents were fatal and 16.4% were serious. Only 0.7% of the remaining car accidents (i.e. 'Loss of Control' was not recorded) were fatal and 7.4% were serious. Since ESC is designed to help drivers to retain control, ESC seems likely to be particularly effective in avoiding fatal accidents.

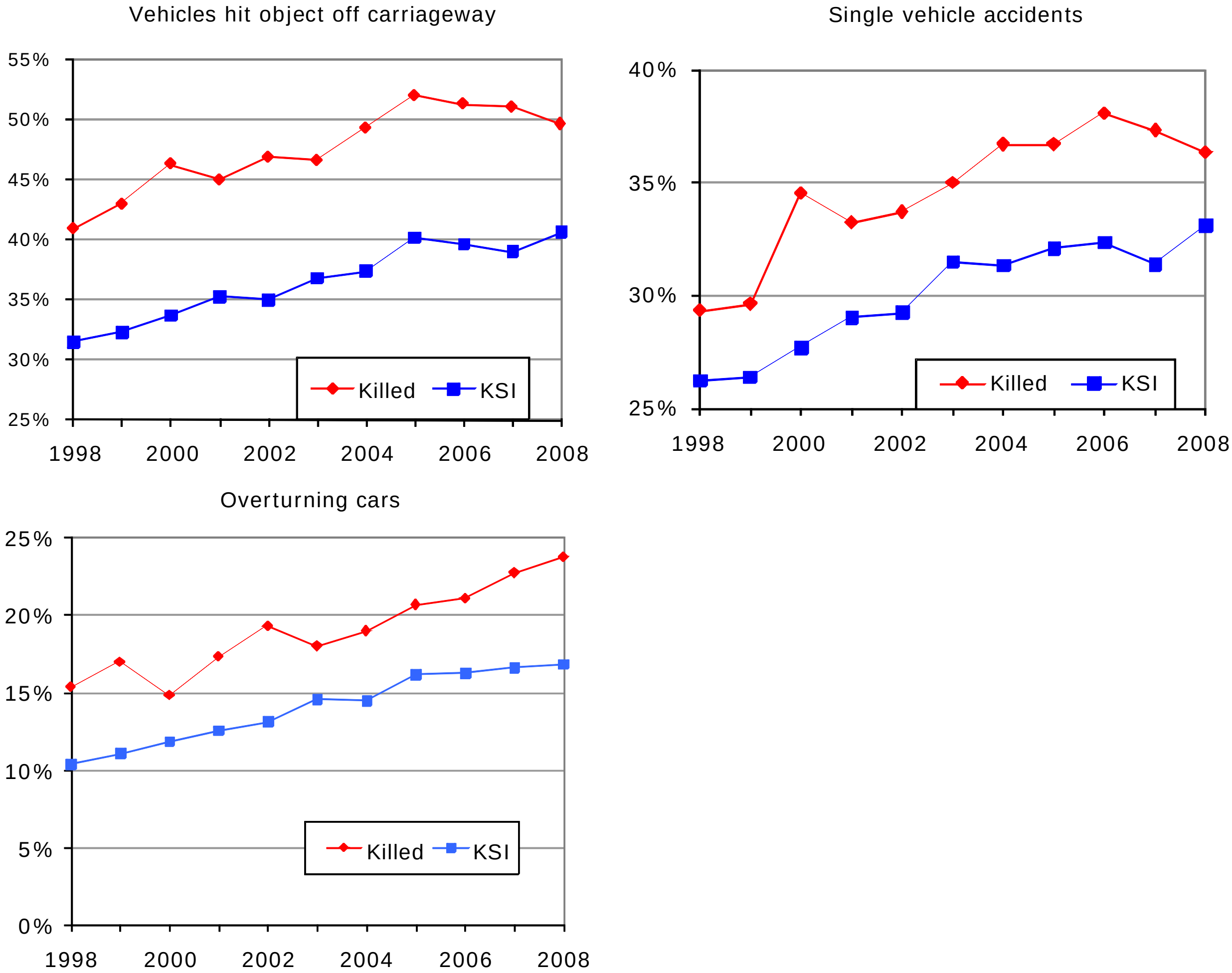

Figure 1.1 Proportion of occupant casualties in cars that are likely to have loss of control

2 Data sources

The analyses of the effectiveness of ESC require data from three sources.

- Section 2.1 introduces STATS19, the national database of statistical information about road accidents that result in personal injury.
- Section 2.2 describes how details of the number of registered cars have been obtained from the Vehicle File maintained by the Driver and Vehicle Licensing Agency (DVLA).
- Section 2.3 introduces the information about which car models are equipped with ESC that has been collected by the Motor Insurance Repair Research Centre at Thatcham.

2.1 The STATS19 database

STATS19 is the national database that is compiled from police reports of road accidents that result in injury. TRL currently holds over 25 years of data, for the period from 1979 to 2008. The database holds accident, vehicle and casualty data for all road accidents involving human death or personal injury occurring on the Highway ('road' in Scotland) and notified to the police within 30 days of occurrence, and in which one or more vehicles are involved.

The Vehicle Registration Mark (VRM) is among the details held on the STATS19 vehicle record. This allows the Department for Transport to enhance the STATS19 vehicle details with information derived from the DVLA files, such as make, model and year of first registration. These details are available for about 70% of cars recorded in STATS19. The DVLA list of vehicle makes and models contained 45,930 records in mid-2009, and is added to continuously as manufacturers introduce new models or variants. It was decided to focus this research on the top ten best selling cars available in Great Britain in 2008. Two examples of each of these makes and models are reproduced in Table 2.1.

Table 2.1: A sample of DVLA make/model codes

Make	Model	Make code	Model code	Model detail
Ford	Fiesta	F0	549	FIESTA LX
Ford	Fiesta	MA	239	FIESTA TDCI
Ford	Focus	M1	900	FOCUS ZETEC AUTO
Ford	Focus	MB	77	FOCUS ST500
Ford	Mondeo	MA	1	MONDEO ZETEC
Ford	Mondeo	MB	65	MONDEO TITANIUM X A
Peugeot	207	LP	173	207 S
Peugeot	207	LP	175	207 SPORT 87
Renault	Clio	LE	89	CLIO EXPRESSION 16V
Renault	Clio	LR	370	CLIO CAMPUS I-M 65 DCI
Vauxhall	Astra	DC	60	ASTRA 16V COMFORT DUALFUE
Vauxhall	Astra	DD	201	ASTRA TWIN TOP SPORT
Vauxhall	Corsa	DC	387	CORSA DESIGN TWINPORT
Vauxhall	Corsa	DD	48	CORSA SXI
Vauxhall	Vectra	DD	149	VECTRA EXCLUSIV
Vauxhall	Vectra	DD	697	VECTRA SRI NAV XPII VVT
Vauxhall	Zafira	DB	653	ZAFIRA COMFORT 16V
Vauxhall	Zafira	DD	731	ZAFIRA BREEZE PLUS
Volkswagen	Golf	MC	28	GOLF SPORT TDI
Volkswagen	Golf	MC	483	GOLF GTI EDITION30 230 SA

2.2 The vehicle registration data

As discussed in section 1.1, the analytical approach of this project requires a measure of the exposure to risk of cars with and without ESC that can be compared with the measures of accident-involvement of cars with and without ESC. Knight and Broughton (2006) reported that the most appropriate exposure measure currently available is the number of registered cars. Although vehicle mileage is in principal a superior measure, in practice it is not available in this country at the necessary level of detail.

The vehicle registration data come from the same DVLA file as the STATS19 enhanced vehicle details (section 2.1). The fact that the same codes for vehicle make/model are used with the STATS19 and the registration data is an important strength of the approach being followed: it ensures consistency between the two datasets that are being linked. A copy of the full file is provided by DVLA to DfT statisticians at the end of each calendar year, and they process this to prepare a statistical summary of the national vehicle fleet. One output from this process is a detailed Excel spreadsheet that was supplied to TRL. This provides the number of vehicles registered at the end of a particular year, by make/model code (as in Table 2.1) and year of first registration.

A sample of Ford Mondeos extracted from this spreadsheet is shown in Table 2.2. This shows for example that at the end of 2008, 2067 Ford Mondeo ST TDCIs in the DVLA file were first registered in 2007, 3475 in 2006 and 894 in 2005. Other models entered the market more recently; for example, all Mondeo TITANIUM X TDCI125 models were first registered in 2007 or 2008.

Table 2.2: A sample of the vehicle registration data

		Number of vehicles on the road			
Code	**Description**	**2005**	**2006**	**2007**	**2008**
MA564	MONDEO GHIA X TDCI	154	783	139	0
MA565	MONDEO TITANIUM TDCI 155	45	295	122	0
MA566	MONDEO TITANIUMX TDCI 155	273	983	333	0
MA567	MONDEO ST TDCI	894	3475	2067	0
MA568	MONDEO TITANIUM TDCI S-A	21	1	0	0
MA569	MONDEO TITANIUM X TDCI SA	14	0	0	0
MA575	MONDEO EDGE 125	0	685	1946	0
MA576	MONDEO EDGE 115 TDCI	0	628	624	1
MA577	MONDEO EDGE 130 TDCI	0	731	1512	1
MA578	MONDEO EDGE 145	0	331	307	0
MA579	MONDEO EDGE 155	0	248	314	2
MB001	MONDEO EDGE	0	0	799	1352
MB002	MONDEO ZETEC	0	0	1022	1970
MB003	MONDEO TITANIUM	0	0	78	470
MB004	MONDEO TITANIUM X	0	0	365	449
MB005	MONDEO GHIA	0	0	413	355
MB007	MONDEO TITANIUM TURBO	0	0	15	52
MB008	MONDEO TITANIUM X TURBO	0	0	669	442
MB009	MONDEO GHIA TURBO	0	0	44	48
MB011	MONDEO EDGE TDCI 100	0	0	297	801
MB012	MONDEO EDGE TDCI 125 5G	0	0	738	1488
MB013	MONDEO EDGE TDCI 125 6G	0	0	1275	1647
MB014	MONDEO ZETEC TDCI 125	0	0	3201	3341
MB015	MONDEO TITANIUM TDCI 125	0	0	180	1211
MB016	MONDEO TITANIUM X TDCI125	0	0	816	812
MB017	MONDEO GHIA TDCI 125	0	0	429	768

2.3 The ESC data

The Motor Insurance Repair Research Centre (Thatcham) has supplied TRL with information on ESC fitment to cars. They compile this information from manufacturers' brochures, so the sources are all publically available. An alternative source of information on the fitment of ESC to cars was identified in the course of this project. Glass's Auto Index (2009) describes the optional and standard equipment that is available for the various makes and models of cars (sample checks identified some differences between the details of ESC fitment). The Thatcham source was used to provide the ESC details for this research, but future projects might find Glass's Index to be more useful.

The Thatcham data are categorised by make and model and do not include the DVLA codes used in the enhanced STATS19 data and the vehicle registration data. The ESC fitment is defined as standard, optional or not available by make and model. As an example, the Thatcham data for Ford Mondeos registered in or before 2006 is shown in Table 2.3. The Thatcham file refers to 'model variants', and the number of these matches the number of DVLA codes (as shown in Table 2.2) closely but not exactly. Almost one quarter of variants were definitely fitted with ESC (it was standard), almost one tenth were definitely not fitted with ESC (it was not available), and there is doubt about the remaining two-thirds (ESC was optional). All Ford Mondeos manufactured in 2007 or 2008 had ESC fitted as standard.

Table 2.3: Thatcham ESC data for Ford Mondeos registered in or before 2006

Ford Mondeo	LX	Edge	Zetec	Zetec Nav	Ghia	Ghia X	Ghia X (V6)	Titanium	Titanium X	ST TDCi	ST220
ESC fitted	o		o	o	o	o	s	o	s	s	s
Number of model variants	18	12	18	10	18	15	6	14	18	3	3
		derivatives	135	100%							
		standard	30	22.2%							
		optional	93	68.9%							
		not available	12	8.9%							

Note: ESC fitment o=optional, s=standard.

While the Thatcham data show whether or not models are equipped with ESC, they do not show what other primary safety features might also be fitted. In particular, vehicles equipped with ESC will almost always be equipped with the most sophisticated form of Brake Assist system (BAS); vehicles that are not equipped with ESC may or may not have BAS but if they are then it will certainly be with a less sophisticated system.

Hence, any benefit that is identified in section 3 for ESC would consist in part of a benefit that should actually be attributed to BAS. Without hard evidence about the fitment of BAS, it is not possible to estimate this potential effect.

2.4 The linked dataset

The difference between the way in which make and model are categorised in the STATS19 enhanced data and the Thatcham data meant that it was not possible to match the two datasets automatically. One way forward was to limit the number of car models that would be compared by focussing on the most common models, to achieve the greatest return (in terms of statistical power) from the effort involved in coding the data. The fitment data vary by year of registration, so it was important for the marker to vary by year of registration. The convention used was:

1 = ESC not available
2 = ESC optional
3 = ESC standard

The approach adopted to assess the effectiveness of ESC relies on comparing cars with ESC (code 3) and without ESC (code 1). It will be seen in section 3.3 that the majority of cars are of variants with optional ESC (code 2). This presents a real statistical problem: the confidence intervals from comparing two relatively small sets of data will be relatively wide.

Information from manufacturers suggests that car buyers seldom choose to pay for ESC when it is available as an optional item, so it would be plausible to assume that no cars from the variants listed by Thatcham as having optional ESC were fitted with ESC, i.e. to combine codes 1 and 2. Nevertheless, it is likely that a few of these cars models were actually fitted with ESC, so it would be desirable to avoid the assumption if possible.

It is important to recognise that the exposure and accident-involvement data for a particular model in the linked dataset both make use of the same ESC codes. Hence, if there are errors in these codes then the consequences for the accident-involvement rate (as defined in the Introduction) should be minor as the errors would affect both numerator and denominator in the rate calculation.

3 Statistical Analysis

3.1 Alternative methods of analysis

The Introduction introduced the accident-involvement rate, and explained that data availability means that the rate that will be analysed in this study is

$$\text{Accident-involvement rate} = \frac{\text{Number of cars involved in accidents}}{\text{Number of registered cars}}$$

If R_0 is the rate for a model without ESC and R_1 is the rate for a model with ESC then the effectiveness of ESC in reducing the rate can be written:

$$E = 1 - R_1/R_0$$

If ESC reduces the accident-involvement rate then $R_1<R_0$ and E would be positive. If, on the other, ESC were counterproductive then $R_1>R_0$ and E would be negative.

The classical statistical approach of hypothesis testing can also be adopted, comparing the proportion of cars involved in accidents that have ESC with the proportion of registered cars that have ESC. If ESC is effective in reducing the number of accidents then the proportion of accident-involved cars with ESC should be less than the proportion of registered cars with ESC.

It can be demonstrated mathematically that these approaches are equivalent. For a particular model, let the number of registered cars with ESC and the number involved in accidents be C_1 and A_1, with the corresponding numbers of cars without ESC being C_0 and A_0. The proportion of registered cars with ESC is $P_C = C_1/(C_1 + C_0)$, so $C_1/C_0 = P_C/(1 - P_C)$. Similarly, if the proportion of accident-involved cars with ESC is P_A then $A_1/A_0 = P_A/(1 - P_A)$. Consequently,

$$E = 1 - R_1/R_0 = 1 - [A_1/C_1] / [A_0/C_0] = 1 - [P_A.(1 - P_C)] / [P_C.(1 - P_A)]$$

$$= [P_C - P_A] / [P_C.(1 - P_A)] = [1 - P_A/P_C] / [1 - P_A]$$

As a check, if ESC is effective then P_A would be less than P_C and E would be positive.

The Introduction also mentioned a third approach. The primary safety literature has tended to use the "odds ratio" to investigate the effectiveness of equipment such as ESC, although Aga and Okada (2003) did study the "accident rate" which corresponds to the definition adopted above. This will now be described, then compared with the first two approaches.

Frampton and Thomas (2007) provide a typical example of the use of the 'odds ratio'. Their method "also requires vehicle manoeuvres[2] to be separated into those where ESC may have an effect and those where no ESC effect is assumed". They assessed the effects of ESC by identifying:

a) Case vehicles (equipped with ESC) and Control vehicles (not equipped with ESC)

b) Control manoeuvres (no ESC effect assumed) and Other manoeuvres (ESC effect possible)

The total of accident-involved cars is distributed as follows:

	Control manoeuvre (no ESC effect assumed)	**Other manoeuvre (ESC effect possible)**
Case vehicle (with ESC)	N_{00}	N_{01}
Control vehicle (no ESC)	N_{10}	N_{11}

[2] i.e. the manoeuvre recorded in the accident report for the vehicle at the time of the accident

then, they calculate

$$Odds_{ESC} = N_{00} / N_{01} \text{ and } Odds_{No\ ESC} = N_{10} / N_{11}$$

If ESC had no effect then one would expect that $N_{00} / N_{01} = N_{10} / N_{11}$, since the ratio of control to other manoeuvres would be unaffected by the presence of ESC. On the other hand, if ESC was effective then proportionately fewer equipped vehicles would have been involved in accidents while making other manoeuvres. N_{01} would be reduced so $N_{00} / N_{01} > N_{10} / N_{11}$: the greater the difference, the more effective the equipment. The effectiveness of ESC is estimated by:

$$E = 1 - (N_{11} N_{00}) / (N_{10} N_{01})$$

3.2 Comparison of the three methods

It has been seen that the first two methods (comparing accident-involvement rates and comparing proportions of accident-involvements and of registration numbers for equipped and non-equipped cars) are equivalent. They will now be compared with the odds ratio method. The following notation is used, based on the Frampton and Thomas paper:

	Accident-involved vehicles	Registered vehicles
Case vehicle (with ESC)	N_0	C_0
Control vehicle (no ESC)	N_1	C_1

then

$$Rate_{ESC} = N_0 / C_0 \text{ and } Rate_{No\ ESC} = N_1 / C_1$$

If ESC had no effect then one would expect the two rates to be equal, i.e. $N_0/C_0 = N_1/C_1$. On the other hand, if ESC was effective then $Rate_{ESC}$ would be less than $Rate_{No\ ESC}$ and the effectiveness of ESC is estimated by:

$$E = 1 - Rate_{ESC} / Rate_{No\ ESC} = 1 - (C_1 N_0) / (C_0 N_1)$$

This shows that the two approaches are closely linked, but that there is a crucial difference. For the odds ratio approach, the control used to estimate ESC effectiveness is provided by accident-involved cars making 'control' manoeuvres, i.e. manoeuvres where no ESC effect is assumed. For the accident-involvement rate approach, the exposure (registration) data provide the control.

The classification of manoeuvres used by Frampton and Thomas for the odds ratio approach is shown in Table 3.1. Other researchers have used a slightly different approach, for example Lie et al (2006) use rear end collisions on a dry road surface as the control.

Table 3.1: Case and Control Manoeuvres (from Frampton and Thomas, 2007)

Control Manoeuvre (no ESC effect assumed)	Other Manoeuvre (ESC effect possible)
Reversing Parked Waiting to go ahead but held up Stopping Starting Waiting to turn left Waiting to turn right	U turn Turning left Turning Right Changing lane to left Changing lane to right Overtaking moving vehicle on its offside Overtaking stationary vehicle on its offside Overtaking on nearside Going ahead left hand bend Going ahead right hand bend Going ahead other

Although this classification of the STATS19 manoeuvres may appear uncontroversial, it actually requires a major assumption. It assumes that the ratio of control to other manoeuvres for accident-involved cars with ESC would, in the absence of ESC, have been identical to the ratio for cars without ESC. While this may be superficially plausible, there are reasons for concern. For example, several of the other manoeuvres may involve braking, and section 2.3 noted the tendency for ESC-equipped cars to have the superior version of Brake Assist. Hence, part of the apparent benefit of ESC could be the result of the better braking achieved by BAS (the same is also true of the alternative methods).

It is simple to construct artificial examples where the assumption is false which do not involve speculation about drivers' reactions to ESC. Suppose that all cars except sports cars were equipped with ESC. Several years ago, before ESC was available, it would have been seen that the proportion of overtaking manoeuvres was higher for sports cars than for other cars. The list of other manoeuvres includes three types of overtaking manoeuvre, so $N_{00}/N_{01} < N_{10}/N_{11}$ and E>0. Thus, the results of the odds ratio calculation would have suggested that ESC was effective – even at a time when ESC was not available.

A more plausible example can be prepared. Cars with ESC tend to be better equipped and hence more expensive than those without, so they tend to be bought and driven by older (more affluent) drivers. These drivers are less likely to be involved in 'loss of control' and overtaking accidents than younger, less affluent, drivers. In the period before ESC became available, comparison of the accident data for the two groups of driver would again have suggested that ESC was effective.

These hypothetical examples show that the results of the odds ratio calculation are unreliable if the accident distributions of case and control vehicles are not well matched. Observe that it is impossible to test whether the distributions are well matched once ESC is widely available since any difference would be interpreted as an effect of ESC.

An actual example from the data to be studied in section 3.4 confirms the point. It will be seen (Figure 3.2) that no Ford Fiestas and only 0.5% of Vauxhall Corsas were fitted with ESC as standard in 2005-08, also that relatively few had optional ESC, so ESC is very unlikely to have affected the accident distribution of either model in this period. The odds ratio calculation thus requires the two models to have the same accident distributions, for any difference would be interpreted as evidence of an effect of ESC – yet we know that ESC can have had no appreciable effect for either model.

Table 3.2 shows that the proportion of cars making control manoeuvres (manoeuvres where it is claimed that no ESC effect is possible) is lower for Fiestas than for Corsas. Thus, a simple analysis of STATS19 data shows that what might have been dismissed as merely a theoretical concern about the assumption underlying the odds ratio approach is real.

Table 3.2 Proportion of accident-involvements with 'control' manoeuvres, by accident severity, 2005-08

Model	Manoeuvre	Fatal	Serious	Slight	All
Fiesta	Control (non-ESC)	5	81	1347	1433
	Other (ESC)	65	477	3227	3769
		7.1%	14.5%	29.4%	27.5%
Corsa	Control (non-ESC)	6	87	1517	1610
	Other (ESC)	48	462	3370	3880
		11.1%	15.8%	31.0%	29.3%
t		-0.75	-0.62	-1.69	-2.04

The t-value refers to the difference between the Fiesta proportion and the Corsa proportion
The cars were first registered between 2005 and 2008

Results for the Vauxhall Vectra are also interesting, although they have not been included in the table because the proportion with optional ESC was much higher (89%

for the Vectra compared with 26% for the Corsa, and only 0.5% of either model was fitted with ESC as standard). Each of the non-fatal percentages was higher for the Vectra than for the Corsa (the fatal percentage was marginally lower, 10.6%). The t-values for the non-fatal differences between the Fiesta and the Vectra proportions were higher than those shown in the table: -0.80, -2.66 and -2.70.

The issue of models with optional ESC that was raised in section 2.4 clearly affects both approaches. The statistical implications are greater for the odds ratio, however, since the number of accident-involvements has to be split between control and other manoeuvres. The statistical problems are compounded by the fact that other manoeuvres greatly outnumber control manoeuvres, as illustrated by Table 3.2.

Section 2.3 shows that the coding of ESC is not as straightforward as it might seem. Any miscoding would affect the numerator and denominator of the accident-involvement rate in similar ways, so the rate should be relatively insensitive to miscoding. The effect on the odds ratio is more complex, so this is likely to be more sensitive to miscoding.

There is an implicit assumption underlying all three approaches: that ESC-equipped vehicles would have the same rate of accident-involvement as unequipped vehicles if their ESC systems were switched off. This implies that vehicles with ESC are driven in similar circumstances as those without, for similar mileages and with similar drivers. The assumption is arguably more realistic in the case of accident-involvement rates for single car models, since the fleet of vehicles being studied is relatively homogenous, but section 3.5 will examine whether driver characteristics may vary even for a single model. On the other hand, studies such as that reported by Frampton and Thomas typically compare heterogeneous fleets of vehicles, based on the availability of data about ESC fitment and the desire to boost statistical power by including as many models as possible.

3.3 Registration and ESC data

This study has focused on the ten most numerous models of cars, based on new car sales in 2008. The approach could be applied equally well with less common models, but the chances of achieving statistically robust results would be less. The STATS19 and registration data come from the four years 2005 - 2008. Table 3.3 lists the models and summarises the number of cars first registered over this period. The registration data used in the study are highly detailed, with one row for each DVLA make/model code in each of the four years as illustrated by Table 2.2.

Table 3.3: Summary of registration data, 2005-2008

Model	New registrations	Proportion
Ford Focus	389,189	16%
Vauxhall Astra	374,357	15%
Ford Fiesta	342,429	14%
Vauxhall Corsa	323,560	13%
VW Golf	228,360	9%
Renault Clio	182,891	7%
Ford Mondeo	169,609	7%
Vauxhall Vectra	160,686	7%
Vauxhall Zafira	158,230	6%
Peugeot 207	124,056	5%
Total	2,453,367	100%

Figure 3.1 shows the increasing availability of ESC between 2005 and 2008 among these ten models. Even by 2008, however, only one quarter of these cars had ESC fitted as standard, and it was an optional feature for more than one half.

Figure 3.1 Availability of ESC within the selected 10 models

Figure 3.2 shows the availability of ESC by model, summed over the period from 2005 to 2008. At one extreme, ESC was available as an optional feature on a small minority of Fiestas, and not available as standard on any Fiesta variant. At the other extreme, ESC was fitted as standard on all VW Golfs.

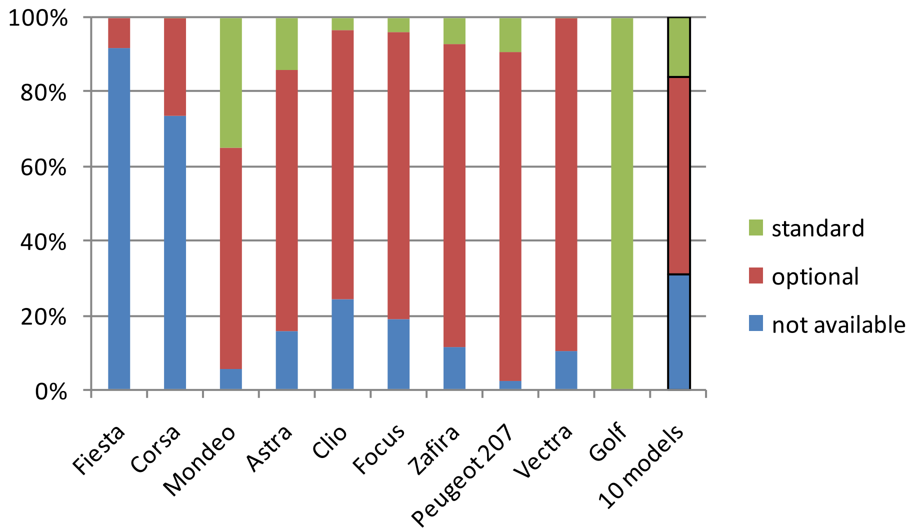

Figure 3.2: Availability of ESC by model, 2005-08

While it is possible to analyse the data for these 10 models *en masse* to establish the effectiveness of ESC in avoiding accidents, it would be preferable to analyse data for individual models. This allows for the possibility that effectiveness may vary from model to model, also that model-related differences in accident patterns might obscure the effects.

The ideal conditions for analysing the effectiveness of ESC in avoiding accidents would be to have one or more models with substantial numbers 'on the road' in the 'ESC standard' and 'ESC not available' categories. While the '10 models' column in Figure 3.2 seems to offer a reasonable split between the two categories, only the Astra and the Mondeo (to a lesser extent) offer a similar split. As ESC is standard on all Golf variants, there are no unequipped Golfs with which to compare the equipped Golfs. Conversely, ESC is not standard on any Fiesta variant, so there are no equipped Fiestas with which to compare the unequipped Fiestas. Hence, it will not be possible to examine the effectiveness of ESC as fitted to Golfs or Fiestas.

The accident-involvement data from the spreadsheet are summarised in Table 3.4. The first part of the table illustrates the relatively sparsity of the data for fatal accidents by individual model. The second part covers the involvement of all 10 models in accidents of each severity for the four years. Note that the vehicle make and model are only recorded in STATS19 when the Vehicle Registration Mark has been reported by the police, so the actual numbers are greater than these reported numbers. There is no evidence, however, that this under-reporting may be selective, so the comparisons presented below should not be biased on this account.

Table 3.4 Number of accident-involved cars, 2005-08

Model	Accident severity	ESC is: not available	optional	standard	any
Ford Focus	fatal	6	61	3	70
Vauxhall Astra	fatal	25	44	15	84
Ford Fiesta	fatal	61	9	0	70
Vauxhall Corsa	fatal	44	9	1	54
VW Golf	fatal	0	0	43	43
Renault Clio	fatal	9	25	0	34
Ford Mondeo	fatal	1	20	17	38
Vauxhall Vectra	fatal	12	34	1	47
Vauxhall Zafira	fatal	0	11	1	12
Peugeot 207	fatal	1	9	1	11
All 10 models	fatal	159	222	82	463
	serious	1,291	2,198	574	4,063
	slight	11,435	18,610	4,727	34,772
	all	12,885	21,030	5,383	39,298

3.4 Results

The initial results will come from analyses of the grouped models, followed by results for the individual models. The initial results (section 3.4.1) will be presented in greater detail to illustrate the steps involved. The VW Golf and Ford Fiesta will be omitted in both cases as all Golfs registered in 2005-08 were fitted with ESC and no Fiesta variant was fitted with ESC as standard. This omission will enhance the comparability of the groups of cars to be analysed.

3.4.1 Group of 8 models

The initial analysis will be of the grouped data, comparing the proportion of cars involved in accidents that have ESC with the proportion of registered cars that have ESC, and their accident-involvement rates. The preferred comparison will exclude the 'ESC optional' variants, so compare 'ESC unavailable' and 'ESC standard' cars. A secondary comparison will include 'ESC optional' cars, so the comparison will be between 'ESC unavailable or optional' and 'ESC standard' cars.

The former comparison is preferable because of uncertainty over the number of 'ESC optional' cars that are actually fitted with ESC. The results of a secondary comparison would only be of interest if certain of the numbers involved in the preferred comparison were too small to provide statistically robust results. In this case, the effectiveness estimate relies on the assumption that none of the 'ESC optional' cars are actually fitted ESC. It can be proved that, in the absence of confounding factors and random effects, the results of a secondary comparison would underestimate the effectiveness of ESC to an extent that is proportional to the (unknown) level of ESC fitment in the 'ESC optional' cars.

Only cars first registered since 1 January 2005 are included in the analyses since the earliest Thatcham ESC data are for 2005. The basic count of accident-involved cars recorded in the STATS19 data from 2005-08 is as follows:

Table 3.5: Number of cars in STATS19 vehicle records, 2005-08

	Accident year	Year of first registration 2005	2006	2007	2008	Grand Total
ESC not available	2005	856				856
	2006	1,257	614			1,871
	2007	1,216	1,084	220		2,520
	2008	1,154	1,007	457	303	2,921
Total		4,483	2,705	677	303	8,168
ESC optional	2005	1,693				1,693
	2006	2,442	1,567			4,009
	2007	2,134	2,345	1,869		6,348
	2008	2,150	2,281	3,017	1,047	8,495
Total		8,419	6,193	4,886	1,047	20,545
ESC standard	2005	75				75
	2006	142	150			292
	2007	141	232	256		629
	2008	148	254	501	398	1,301
Total		506	636	757	398	2,297
Grand Total		13,408	9,534	6,320	1,748	31,010

Table includes cars of the models listed in Table 3.3 except the VW Golf and the Ford Fiesta

By themselves, the STATS19 data of Table 3.5 show nothing about the effectiveness of ESC. Section 1.1 has shown that a measure of 'exposure to risk' is required, and that the DVLA registration data provides the most detailed exposure measure; this is especially useful since the same coding system is used with the STATS19 data. Table 3.6 shows the registration data corresponding to the STATS19 data in Table 3.5. It is obtained by summing over the individual variants recorded in the DVLA file.

Table 3.6: Number of newly registered cars, 2005-08

	Year of first registration 2005	2006	2007	2008	Grand Total
ESC not available	161,812	121,376	37,970	51,260	372,418
ESC optional	304,743	326,698	420,312	231,832	1,283,585
ESC standard	21,642	35,653	81,304	87,976	226,575
Grand Total	488,197	483,727	539,586	371,068	1,882,578

Table includes cars of the models listed in Table 3.3 except the VW Golf and the Ford Fiesta

The DVLA registration data come from a census of the DVLA vehicle file that is conducted at the end of each calendar year. Some older cars will be omitted from the census because they were scrapped during the year, but that should not apply with these relatively new vehicles. On the other hand, cars that were newly registered during a year will have been 'on the road' for an average of 0.5 years by the end of December, and the exposure measure calculated below is adjusted accordingly.

Despite selecting the best-selling modern cars, Table 3.7 shows that this subset of cars represents only about 3% of cars involved in STATS19 accidents between 2005 and 2008, although the proportion has risen steadily as additional cars have been registered. The relatively low proportion is partly caused by the exclusion of pre-2005 cars and the fact that the VRM is missing from some STATS19 vehicle records.

Table 3.7: Percentage of accident-involved cars in the subset being studied

Accident year	2005	2006	2007	2008	All
Cars registered in or after 2005	2,624	6,172	9,497	12,717	31,010
All accident-involved cars	281,810	267,991	255,891	236,923	1,042,615
% represented by these models	0.9%	2.3%	3.7%	5.4%	3.0%

Table includes cars of the models listed in Table 3.3 except the VW Golf and the Ford Fiesta

Table 3.8 brings together the accident-involvement and exposure data for the eight models. For example, of the cars involved in fatal accidents between 2005 and 2008:

i. 98 were of variants which did not have ESC,

ii. 213 were of variants with optional ESC, and

iii. 39 were of variants with standard ESC.

The preferred comparison involves (i) and (iii), so N=98+39=137 and p=39/137=0.285. The secondary comparison assumes that none of group (ii) had ESC, so (i) and (ii) are in effect merged: N=98+213+39=350 and p=39/350=0.111. In this example, the standard errors for the preferred comparison are acceptably small, so the results from the secondary comparison are not needed. Note that the incomplete recording of VRM in STATS19 means that the numbers of accident-involvements should actually be about 40% higher, but the proportions should be reliable (i.e. unbiased).

Table 3.8: Proportion of cars known to be equipped with ESC, 2005-08

Accident severity	Preferred comparison N	proportion	s.e.	t	Secondary comparison N	proportion	s.e.	t
Fatal	137	0.285	0.039	0.70	350	0.111	0.017	1.60
Serious	1,050	0.237	0.013	-1.57	3,180	0.078	0.005	-1.31
Slight	9,278	0.217	0.004	-9.61	27,480	0.073	0.002	-7.26
All	10,465	0.219	0.004	-9.43	31,010	0.074	0.001	-7.01
Exposure (car-years)	1,283,191	0.258	0.000		3,912,920	0.085	0.000	

Table includes cars of the models listed in Table 3.3 except the VW Golf and the Ford Fiesta

In statistical terms, the null hypothesis to be tested is that ESC has no effect, in which case the proportions of accident-involvements should be equal to the proportion of exposure. The t-statistics test this. Conventionally, a t-value in the range ±1.96 means that the difference would be described as not significant. If ESC were to be effective, however, the accident-involvement proportions would be significantly less than the proportion of exposure.

The table shows that the proportion of cars involved in slight accidents is significantly below the proportion of exposure, while the proportion approaches significance for serious accidents. On the other hand, while it is not possible to reject the null hypothesis that ESC has a beneficial effect in fatal accidents, there are weak indications that it may have an adverse effect. The results for the preferred and secondary comparisons follow the same pattern in this case.

Table 3.9 shows the accident-involvement rates corresponding to the proportions of Table 3.8. The effectiveness is estimated by comparing the rates for ESC not available (a) and standard (c), so corresponds to the 'preferred comparison'. If the ESC data had meant that it was necessary to rely on the 'secondary comparison' then the rate for ESC not available/optional (d) would have been used in place of the rate for ESC not available.

Table 3.9: Accident-involvement rates and effectiveness estimates

Accident severity	Variants with ESC: not available (a)	optional (b)	standard (c)	n.a./optional (d)	Effectiveness
Fatal	103	81	118	87	-0.15
Serious	841	810	753	818	0.11
Slight	7,633	6,922	6,073	7,111	0.20
All	8,577	7,813	6,943	8,016	0.19

Rates are number of accident-involvements per million registered cars
Table includes cars of the models listed in Table 3.3 except the VW Golf and the Ford Fiesta
Effectiveness is estimated by comparing (a) and (c)

The accident-involvements of cars with and without ESC can be compared by any field from the STATS19 vehicle record. Two examples are presented, by first point of impact and by vehicle manoeuvre. The same approach is adopted in each case:

- actual data show the STATS19 numbers for cars with ESC as standard,
- expected data show the numbers expected for cars with ESC as standard under the null hypothesis that the distribution for these cars matches the distribution for cars with ESC not available.

Table 3.10 compares the actual and expected data by first point of impact, separately for fatal&serious and for slight accidents. The reason for the separation is that the distributions differ significantly (chi-sq test) for slight accidents but not for fatal&serious accidents. For example, 97 cars with ESC as standard were involved in slight accidents but 'Did not impact', whereas if the first point of impact had been distributed as for cars with ESC not available then the number would have been only 133.2. The same pattern is found in fatal&serious accidents, which suggests that ESC allows equipped cars to avoid an impact when involved in accidents.

Table 3.10: Number of accident-involved cars with ESC as standard, by first point of impact, 2005-08

	Fatal&Serious accidents		Slight accidents	
	actual	expected	actual	expected
Did not impact	21	32.7	97	133.2
Front	156	143.8	839	881.5
Back	34	32.0	593	489.3
Offside	39	37.2	266	275.3
Near side	38	42.3	214	229.7
Total	288	288.0	2009	2009.0

Table includes cars of the models listed in Table 3.3 except the VW Golf and the Ford Fiesta
expected data are calculated under the assumption that the distribution for cars with ESC as standard matches the distribution for cars with ESC not available

Table 3.11 compares the actual and expected data by vehicle manoeuvre, using the 18 categories provided in STATS19. The distributions differ significantly for both accident severities (chi-sq test). The differences do not have a clear pattern, but the cars with ESC had fewer accidents at bends than would be expected from the experience of cars without.

Table 3.12 groups together the manoeuvres into control and other manoeuvres, as defined in Table 3.1 and used with the odds ratio approach. For all three accident severities, the cars with ESC made few other manoeuvres relative to the cars without, which is consistent with the proposed effect of ESC. The slight accident distributions differ significantly, but the fatal and serious distributions do not (chi-sq test).

Table 3.11: Number of accident-involved cars with ESC as standard, by vehicle manoeuvre, all accidents, 2005-08

	Fatal&Serious accidents		Slight accidents	
	actual	**expected**	**actual**	**expected**
Reversing	2	4.2	37	22.4
Parked	13	10.6	80	78.5
Waiting to go ahead but held up	19	10.3	248	217.0
Slowing or stopping	12	9.6	199	176.6
Moving off	5	4.8	69	66.9
U turn	8	3.2	14	17.7
Turning left	9	7.4	68	73.3
Waiting to turn left		0.0	13	20.2
Turning right	29	26.3	191	193.5
Waiting to turn right	1	3.2	63	43.1
Changing lane to left		2.2	27	13.8
Changing lane to right	4	1.9	7	15.2
Overtaking moving vehicle on its offside	5	8.3	33	28.7
Overtaking stationary vehicle on its offside	3	4.2	20	19.3
Overtaking on nearside	1	2.2	6	6.1
Going ahead left hand bend	14	19.2	63	66.6
Going ahead right hand bend	14	22.1	82	93.2
Going ahead other	149	148.3	789	856.9
Total	288	288.0	2009	2009.0

Table includes cars of the models listed in Table 3.3 except the VW Golf and the Ford Fiesta
expected data are calculated under the assumption that the distribution for cars with ESC as standard matches the distribution for cars with ESC not available

Table 3.12: Number of accident-involved cars with ESC as standard, by grouped vehicle manoeuvre, all accidents, 2005-08

	Fatal accidents		Serious accidents		Slight accidents	
	actual	**expected**	**actual**	**expected**	**actual**	**expected**
Control Manoeuvre	2	2.4	50	39.5	709	624.7
Other Manoeuvre	37	36.6	199	209.5	1300	1384.3
Total	39	39.0	249	249.0	2009	2009.0

Table includes cars of the models listed in Table 3.3 except the VW Golf and the Ford Fiesta
expected data are calculated under the assumption that the distribution for cars with ESC as standard matches the distribution for cars with ESC not available

3.4.2 Ford Focus

Table 3.13 presents the ESC effectiveness estimates for the Ford Focus, combining the main elements of Table 3.8 and Table 3.9. It could be confusing to present results from the preferred and secondary comparisons, so only results from the preferred comparison are presented (i.e. data for variants with optional ESC do not contribute to the table).

The proportion of cars with ESC involved in accidents at each level of severity exceeds the exposure proportion, and the differences are significant for non-fatal accidents. Consequently, each accident rate for cars with ESC exceeds the rate for cars without, and the effectiveness estimates are all negative. This is clear evidence that Ford Focuses with ESC are <u>more</u> likely to be involved in accidents than Focuses without. (The results of the secondary comparison have the same pattern, but none of the differences are significant).

Table 3.13: Accident-involvement rates and effectiveness estimates, Ford Focus

Accident severity	N	Proportion	s.e.	t	Rate for cars with ESC	Rate for cars without ESC	Effectiveness
Fatal	9	0.333	0.157	1.00	79	34	-1.34
Serious	139	0.259	0.037	2.24	945	577	-0.64
Slight	1,140	0.234	0.013	4.64	7,009	4,892	-0.43
All	1,288	0.238	0.012	5.19	8,032	5,503	-0.46
Exposure (car-years)	216,556	0.176	0.001				

Results come from the preferred comparison

3.4.3 Vauxhall Astra

Table 3.14 presents the ESC effectiveness estimates for the Vauxhall Astra, using the format of Table 3.13. Again, only results from the preferred comparison are presented. The proportion of cars with ESC involved in accidents at each level of severity is less than the exposure proportion, and the differences are significant for non-fatal accidents. Consequently, the effectiveness estimates are all positive, and in fact there is little variation by severity. This is clear evidence that Vauxhall Astras with ESC are less likely to be involved in accidents than Astras without. (The results of the secondary comparison have the same pattern, but the difference for serious accidents is not significant and the effectiveness estimates are around 0.16).

Table 3.14: Accident-involvement rates and effectiveness estimates, Vauxhall Astra

Accident severity	N	Proportion	s.e.	t	Rate for cars with ESC	Rate for cars without ESC	Effectiveness
Fatal	40	0.375	0.077	-1.22	138	203	0.32
Serious	228	0.377	0.032	-2.84	792	1,152	0.31
Slight	1,953	0.367	0.011	-9.29	6,591	10,034	0.34
All	2,221	0.368	0.010	-9.78	7,521	11,388	0.34
Exposure (car-years)	231,913	0.468	0.001				

Results come from the preferred comparison

3.4.4 Vauxhall Corsa

Table 3.15 presents the ESC effectiveness estimates for the Vauxhall Corsa, using the same format. Cars with ESC as standard account for only 0.5% of exposure of this model, so the likelihood of finding significant evidence the effects of ESC is low. Moreover, cars with optional ESC account for only 26% of exposure, so results from the secondary comparison have little interest. The proportion of cars with ESC involved in accidents at each level of severity does not differ significantly from the exposure proportion. Consequently, there is little sign that ESC as fitted to Corsas is effective.

Table 3.15: Accident-involvement rates and effectiveness estimates, Vauxhall Corsa

Accident severity	N	Proportion	s.e.	t	Rate for cars with ESC	Rate for cars without ESC	Effectiveness
Fatal	45	0.022	0.022	0.71	330	96	-2.44
Serious	394	0.005	0.004	-0.42	660	855	0.23
Slight	3,755	0.007	0.001	0.27	8,582	8,133	-0.06
All	4,194	0.007	0.001	0.27	9,573	9,084	-0.05
Exposure (car-years)	461,525	0.007	0.000				

Results come from the preferred comparison

3.4.5 Renault Clio

Table 3.16 presents the ESC effectiveness estimates for the Renault Clio. Of the 9 Clios involved in fatal accidents, none had ESC fitted as standard, which implies a high level of effectiveness; however, the significance of the difference of the proportions is exaggerated as the t-test may well give misleading results with these small numbers. Overall, the evidence that ESC may be effective in Renault Clios is weak.

Table 3.16: Accident-involvement rates and effectiveness estimates, Renault Clio

Accident severity	N	Proportion	s.e.	t	Rate for cars with ESC	Rate for cars without ESC	Effectiveness
Fatal	9	0.000	0.000	-131	0	92	1.00
Serious	85	0.165	0.040	0.80	940	728	-0.29
Slight	817	0.119	0.011	-1.22	6,511	7,385	0.12
All	911	0.122	0.011	-0.98	7,451	8,205	0.09
Exposure (car-years)	112,395	0.133	0.001				

Results come from the preferred comparison

3.4.6 Ford Mondeo

Table 3.17 presents the ESC effectiveness estimates for the Ford Mondeo. Cars with ESC 'not available' account for only 6% of exposure for this model, so the preferred comparison provides weak results and the secondary comparison is used, i.e. the effectiveness estimates in Table 3.17 assume that no Mondeos of variants with optional ESC were actually fitted with ESC. The proportion of cars with ESC involved in non-fatal accidents is less than the exposure proportion, and the differences are significant for slight and all accidents. Consequently, the effectiveness estimates for non-fatal accidents are positive. This is clear evidence that Ford Mondeos with ESC are less likely to be involved in accidents than Mondeos without. In view of the possibility that a few Mondeos with optional ESC actually were fitted with ESC, the effectiveness of ESC in the Mondeo may well be slightly greater than shown by the results of the secondary comparison presented in the table. (The results of the preferred comparison have a different pattern, and all effectiveness estimates are negative.)

Table 3.17: Accident-involvement rates and effectiveness estimates, Ford Mondeo

Accident severity	N	Proportion	s.e.	t	Rate for cars with ESC	Rate for cars without ESC	Effectiveness
Fatal	38	0.447	0.081	1.22	136	90	-0.51
Serious	279	0.305	0.028	-1.62	679	831	0.18
Slight	2,104	0.329	0.010	-1.97	5,526	6,050	0.09
All	2,421	0.328	0.010	-2.22	6,341	6,971	0.09
Exposure (car-years)	358,602	0.349	0.001				

Results come from the secondary comparison

3.4.7 Vauxhall Vectra

Table 3.18 presents the ESC effectiveness estimates for the Vauxhall Vectra. As with the Vauxhall Corsa, cars with ESC fitted as standard account for only 0.5% of exposure of this model, so the likelihood of finding significant evidence of the effectiveness of ESC is low. There are weak indications that ESC may be effective in non-fatal accidents. Only 12 Vectras with standard ESC were involved in slight accidents, so not surprising that none were involved in serious accidents. (The results of the secondary comparison show effectiveness in slight and all accidents as virtually zero.)

Table 3.18: Accident-involvement rates and effectiveness estimates, Vauxhall Vectra

Accident severity	N	Proportion	s.e.	t	Rate for cars with ESC	Rate for cars without ESC	Effectiveness
Fatal	13	0.077	0.074	0.45	646	355	-0.82
Serious	59	0.000	0.000	-40.24	-	1,748	1.00
Slight	357	0.034	0.010	-1.07	7,749	10,219	0.24
All	429	0.030	0.008	-1.62	8,395	12,322	0.32
Exposure (car-years)	35,309	0.044	0.001				

Results come from the preferred comparison

3.4.8 Vauxhall Zafira

Table 3.19 presents the ESC effectiveness estimates for the Vauxhall Zafira from the secondary comparison. There are weak indications that ESC may be effective in slight and all accidents. (The effectiveness estimates of the preferred comparison are all negative.)

Table 3.19: Accident-involvement rates and effectiveness estimates, Vauxhall Zafira

Accident severity	N	Proportion	s.e.	t	Rate for cars with ESC	Rate for cars without ESC	Effectiveness
Fatal	12	0.083	0.080	0.14	43	37	-0.16
Serious	248	0.077	0.017	0.24	820	773	-0.06
Slight	2,129	0.064	0.005	-1.53	5,912	6,720	0.12
All	2,389	0.066	0.005	-1.33	6,775	7,530	0.10
Exposure (car-years)	319,604	0.073	0.000				

Results come from the secondary comparison

3.4.9 Peugeot 207

Table 3.20 presents the ESC effectiveness estimates for the Peugeot 207 from the preferred comparison. There are significant differences for non-fatal accident-involvements that suggest that ESC in this model is highly effective in non-fatal accidents. The effectiveness estimates vary little by accident severity. This is clear evidence that Peugeot 207s with ESC are <u>less</u> likely to be involved in accidents than 207s without. (The effectiveness estimates of the secondary comparison are about half of these values.)

Table 3.20: Accident-involvement rates and effectiveness estimates, Peugeot 207

Accident severity	N	Proportion	s.e.	t	Rate for cars with ESC	Rate for cars without ESC	Effectiveness
Fatal	2	0.500	0.354	-0.90	62	275	0.78
Serious	15	0.467	0.129	-2.72	431	2,202	0.80
Slight	137	0.453	0.043	-8.56	3,819	20,647	0.82
All	154	0.455	0.040	-9.02	4,312	23,125	0.81
Exposure (car-years)	19,866	0.817	0.003				

Results come from the preferred comparison

3.5 Age and sex of driver

Section 3.2 mentioned the implicit assumption underlying all three approaches, that ESC-equipped cars would have the same rate of accident-involvement as unequipped vehicles if their ESC systems were switched off. This implies that cars with and without ESC are driven in similar circumstances and with similar drivers. It appears possible, for example, that cars with ESC will tend to be better equipped and hence more expensive than those without, so they would tend to be bought and driven by older (more affluent) drivers who tend to have fewer accidents. There is also anecdotal evidence that ESC is more likely to be fitted to sportier models of car.

The Introduction demonstrated the need for the exposure measure to be able to differentiate between cars with and without ESC, which led to the use of DVLA registration data. In order to investigate whether drivers of cars with and without ESC are similar, the exposure data would also need to be differentiated by driver details – at least by age and sex. Unfortunately, this cannot be done because the original DVLA records do not include even the age and sex of the registered keeper. The STATS19 data can be used as a proxy exposure measure, however, as the STATS19 vehicle record includes driver age and sex (but no other driver details).

The approach follows that adopted in section 3.4.1. The age and sex of drivers of cars from the group of 8 models have been analysed, and the distribution of drivers of cars with ESC as standard is compared with the distribution of drivers of cars with ESC not available. The results are shown in Figure 3.3, and it is clear that the distributions differ significantly. It is most unlikely that these differences are caused by differential effects of ESC. The likely explanation is that relatively few females and 0-20 year old males drive cars with standard ESC, compared with drivers of cars with ESC not available.

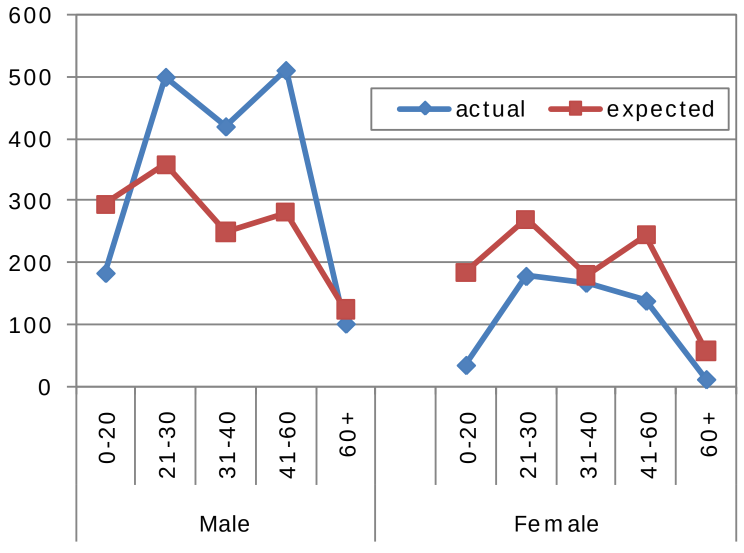

Figure 3.3: Number of accident-involved cars with ESC as standard, by age and sex of driver, group of 8 models, 2005-08

Figure 3.4 shows the corresponding distributions for the 8 individual models. Although all pairs of distributions differ significantly according to the chi-sq test, the pairs of distributions for the Astra and the Mondeo are reasonably well matched.

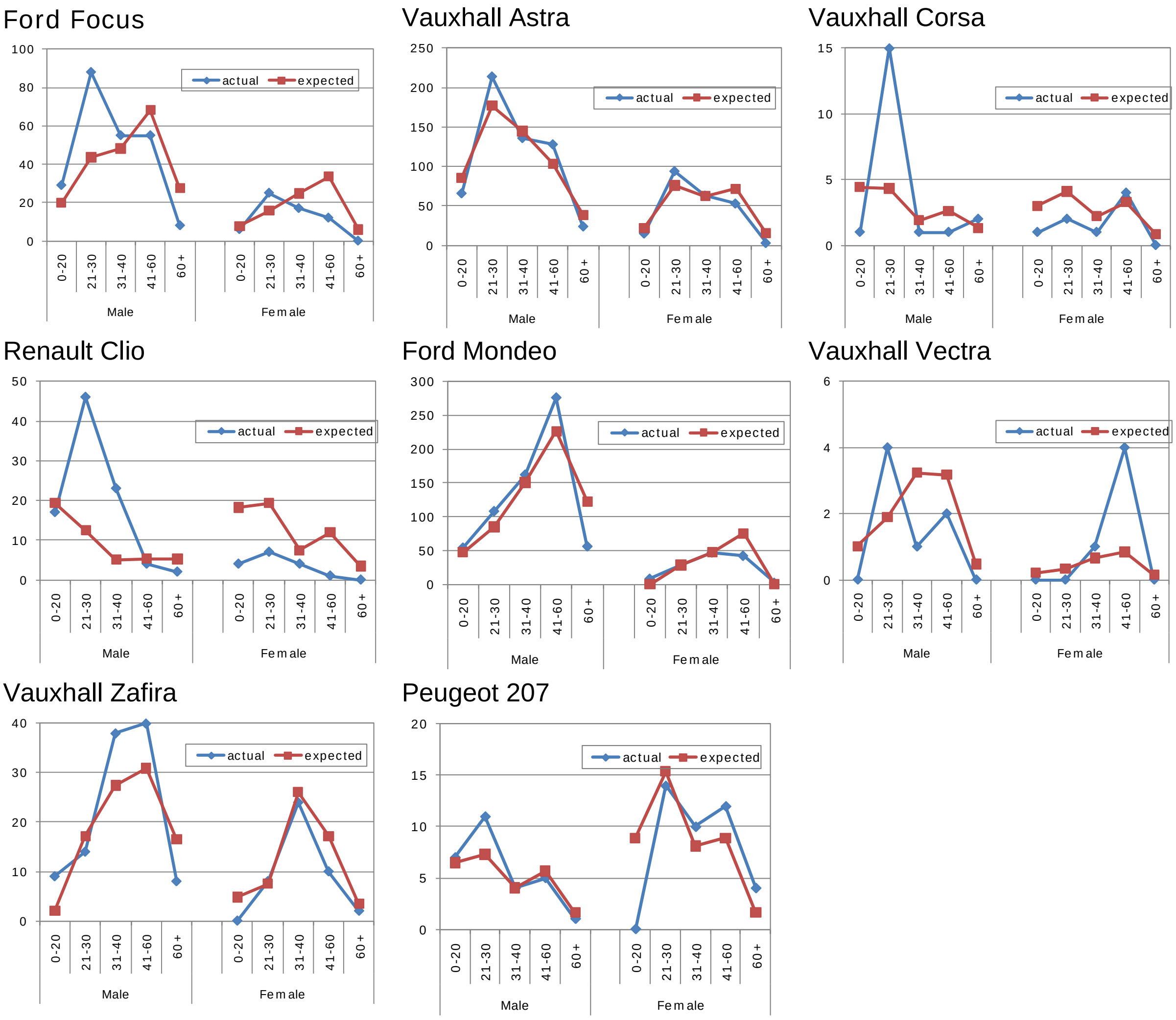

Figure 3.4: Number of accident-involved cars with ESC as standard, by age and sex of driver and model of car, 2005-08

3.6 A disaggregate modelling approach

The previous section has shown that the assumption that the exposure of ESC-equipped cars matches the exposure of unequipped vehicles can be false. The question of how to extend the analysis to allow for differences is complex. It should be recognised that they may extend beyond driver age and sex to, for example, the types of road upon which the different groups of vehicles are driven. A possible way forward is sketched out below; the analysis will demonstrate that differences between the distributions in Figure 3.3 above can affect the effectiveness estimate.

The issue has been addressed by at least one previous study of the effectiveness of ESC. Dang (2007) fitted a logistic regression model to the accident and registration data, with explanatory variables for driver age (16-24, >24) and sex, whether the accident occurred at day or night, on a rural roadway, or on a freeway. The paper, however, focuses on results relating to ESC and presents few details of the modelling. In principal, however, the model should compensate for any bias caused by differences in exposure, although results in the previous section suggest that it would have been useful to include more age groups.

The problem of allowing for differences in exposure is illustrated by the following table which uses data for the group of 8 models; it illustrates the data that are available and the data {e(0,1)…e(1,10)} which are required to calculate accident rates and then effectiveness. These data are not available, so they must be estimated.

		Male					Female					Total
	ESC	0-20	21-30	31-40	41-60	60-99	0-20	21-30	31-40	41-60	60-99	
Exposure	n.a.	e(0,1)	e(0,2)	e(0,3)	e(0,4)	e(0,5)	e(0,6)	e(0,7)	e(0,8)	e(0,9)	e(0,10)	952.4
(car yearsx10³)	standard	e(1,1)	e(1,2)	e(1,3)	e(1,4)	e(1,5)	e(1,6)	e(1,7)	e(1,8)	e(1,9)	e(1,10)	330.8
Drivers	n.a.	1,044	1,272	888	1,000	442	655	960	637	868	202	7,968
in accidents	standard	183	500	420	511	101	34	178	167	138	11	2,243

'Induced exposure' is the name of the general class of techniques that make use of plausible assumptions to estimate detailed exposure data from available (generally accident) data. In the present case, it is known that the drivers' accident-involvement rate varies with age and sex of driver. If the exact relationship were known then the driver numbers shown in the table could be used to estimate {e}.

Figure 3.5 has been prepared by dividing the number of accident-involved car drivers recorded in the STATS19 data over four years by the estimated number of drivers with full licences (the number of licence holders is estimated using data from the National Travel Survey). These are relative rates that compare the involvement rate for each group of drivers with the rate for 41-60 year old males, so the rate shown for 41-60 year old males is 1.0 by definition.

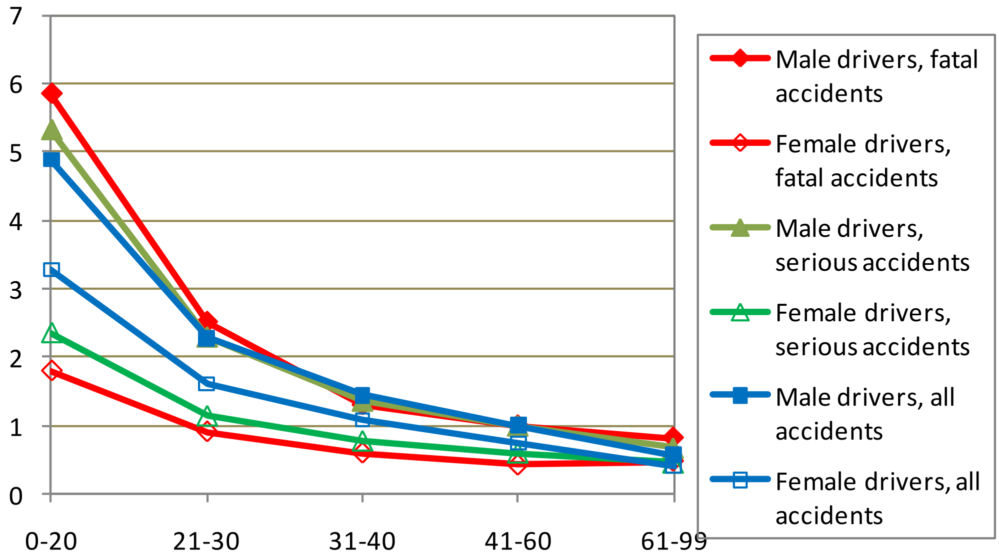

Figure 3.5 Estimated driver relative accident-involvement rate, 2005-2008

The 'all accidents' rates will be used for the calculation, but it should be recognised that various limitations apply to these rates and that the results based on them should be regarded as preliminary. The most important limitations are:

- Many car drivers involved in accidents are either unlicensed or have provisional licences, so the denominator of the rate calculation is underestimated and the rate is overestimated,
- The underestimation probably varies with age and sex, and the riskiest drivers (young males) are probably most affected,
- The data used are for all cars, so the relationship may be different for cars of this age or these types – but the exposure data for this subset of cars do not exist.

Table 3.21 shows the exposure data that are obtained using the 'all accidents' rates from Figure 3.5. It also includes the accident-involvement rates calculated with the induced exposure data.

Table 3.21 Estimates of disaggregate exposure data

		Male					Female					Total
	ESC	**0-20**	**21-30**	**31-40**	**41-60**	**60-99**	**0-20**	**21-30**	**31-40**	**41-60**	**60-99**	
Exposure	n.a.	32.7	85.6	94.0	153.3	118.0	30.6	91.3	90.2	179.7	77.0	952.4
(car yearsx10^3)	standard	7.2	42.2	55.7	98.2	33.8	2.0	21.2	29.6	35.8	5.3	330.8
Accident rate	n.a.	31.9	14.9	9.4	6.5	3.7	21.4	10.5	7.1	4.8	2.6	
(all severities)	standard	25.5	11.9	7.5	5.2	3.0	17.1	8.4	5.6	3.9	2.1	

Each accident rate for cars with standard ESC is 20% less than the rate for cars with ESC not available, implying that ESC has an effectiveness of 0.20. This lack of variation is a consequence of the fact that the same relative rates were used for the two groups of cars, so this approach is not capable of examining the possibility that effectiveness might vary by age and sex of driver.

The effectiveness estimate of 0.20 from this more detailed calculation is close to the earlier value of 0.19 in Table 3.9, so it appears in this case that differences between the age/sex distributions in Figure 3.3 have introduced little bias. The case of cars with optional ESC shows, however, that the differences can lead to appreciable bias. The effectiveness estimate for this group (not shown in Table 3.9) should be very low since it is likely that few of these cars are equipped with ESC. The value calculated by comparing the *basic* rates of cars with ESC optional and ESC not available is, however, 0.09; this is implausible since the result implies that almost one half of cars with ESC optional are equipped with ESC. The value calculated by comparing the *disaggregate* rates, however, is -0.01, i.e. effectively zero. This demonstrates that the disaggregate approach can provide improved results, even in this initial form.

To summarise, analytical techniques exist that can compensate for the differences in the exposure patterns of cars with and without ESC. The failure of most previous studies to take account of these differences could well account for the high levels of ESC effectiveness that have been reported. While this section has demonstrated one suitable approach, more work will be required to develop it fully, in particular:

- to improve the estimation of the relative rates,
- to consider whether other confounding factors such as road type need to be taken into account, and
- to examine the three levels of accident severity separately.

4 Discussion

The work carried out in the course of this project has achieved in large measure the objectives set out in the Introduction. The effectiveness of ESC in reducing the involvement in accidents of many of the most popular car models has been quantified using a statistical approach that differs from the approach that has generally been used for this type of investigation. A clearer view of the limitations of this previous approach has emerged from analyses of actual accident data. Nevertheless, the complexity of the analysis required to fully quantify effectiveness has been demonstrated, and ideally the disaggregate approach developed in section 3.6 would be developed further.

The main statistical result is that ESC reduces the number of cars that are involved in accidents by about one fifth, based on analyses of the group of 8 models. This result is driven by the measured effectiveness in slight accidents, however; the effectiveness measured in serious accidents is less, and it appears that ESC might actually lead to more fatal accidents. This is the reverse of the effect that might have been expected from accident statistics, that ESC would be particularly effective in avoiding fatal accidents (see section 1.2).

When the eight models were analysed individually, the study was hampered by the availability of "sufficient" cars in both the 'ESC not available' and the 'ESC standard' groups. Nevertheless, ESC was found to be effective in the Vauxhall Astra (about one third fewer accidents at each level of severity), the Ford Mondeo and the Peugeot 207. In the latter case, however, the effectiveness appears to be so great as to call the reliability of the ESC fitment data for this model into question. On the other hand, it appears that ESC is counterproductive in the Ford Focus (about one half more accidents). The results for the other four models were not statistically significant.

In physical terms, in order to avoid an accident, a car should be both responsive (i.e. responds quickly and accurately to sudden swerves to avoid obstacles) and stable (sudden inputs of any kind not liable to cause the vehicle to spin). In traditional chassis design, this was a compromise; vehicles that were more responsive tended to be less stable and vice versa. The development of ESC has helped to mitigate this compromise by using braking at individual wheels to either compensate for unresponsive chassis or to stabilise responsive ones. This means that in physical terms on a test track there is a strong interaction between the fundamental handling performance of the vehicle and the behaviour of ESC. Research in the USA, based on subjective rating of handling performance in terms of responsiveness and stability, highlights the differences that can occur between different vehicles with and without ESC.

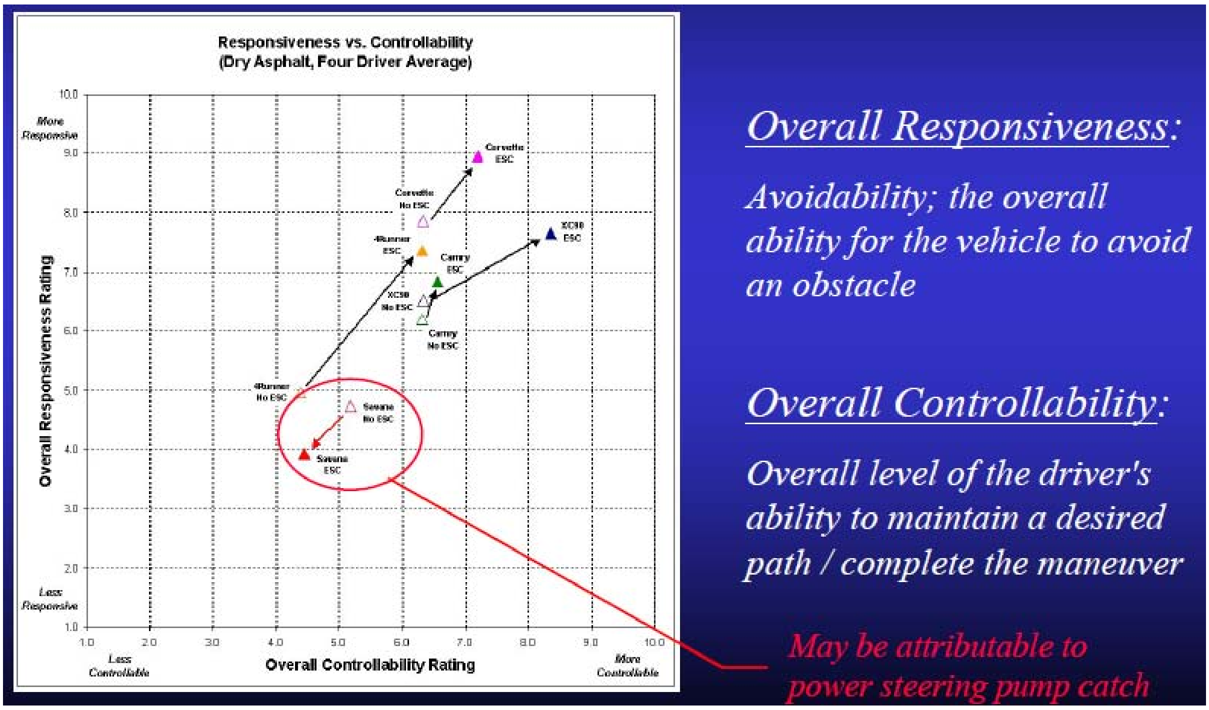

Figure 4.1: NHTSA research into vehicle behaviour with and without ESC (Forckenbrock, 2004)

It can be seen that the magnitude of effect that ESC has on responsiveness and stability varies for different vehicle and that some vehicles without ESC are both more responsive and stable than others with ESC. However, with the exception of one vehicle where a defect was suspected, the effect of ESC was always to improve the performance of a particular model. Thus, although variation in the effectiveness between models would be expected, the results obtained in the STATS19 analysis above cannot be fully explained by this variation because the effect on individual models would always be expected to be positive.

The technical literature has led to a widely held view that ESC is highly effective in avoiding accidents. For example, Frampton and Thomas (2007) report that "ESC effectiveness is 7% in crashes of all severity. Serious crashes are 11% lower compared to non ESC cars and fatalities 25% lower" (based on analyses of STATS19 data for 2002-2005). The Conclusions section of this paper also reports that "Levels of ESC effectiveness in international studies are in many cases different, usually higher, than those seen in this study." Another 2007 study, this time from the USA (Dang, 2007), concluded that ESC "reduced all crash involvements" for cars by 14% (fatal) and 8% (all severities).

Clearly, the technical literature has reported that effectiveness is greater in more severe accidents, which agrees with expectations from simple analyses of STATS19 data. Conversely, this study has found that effectiveness is less in more severe accidents (focussing on the grouped analysis as being more comparable than the single model analyses to the approach typically followed in the literature). The overall level of ESC effectiveness that has been found in this study for the group of 8 models is greater than that reported by these two studies.

Several aspects of these previous studies have been identified in the course of this work as being open to question. A formal review of the technical literature lies outside the scope of this project, but Frampton and Thomas (2007) is the most recent study and represents in many respects the approach followed by the majority of earlier studies. The following observations about this study arose in the course of the analyses reported in section 3.

- The assumption that the distribution of manoeuvres of accident-involved vehicles between 'case' and 'control' manoeuvres is only influenced by the presence ESC (so that differences can be interpreted as evidence of the effectiveness of ESC) is false. Differences have been identified that cannot be attributed to any effect of ESC; these presumably derive from differences in exposure. It is not obvious that these differences necessarily exaggerate the effectiveness of ESC as estimated by the odds ratio approach.
- The odds ratio approach implicitly assumes that ESC-equipped cars are driven in similar circumstances and by similar drivers as cars without ESC. This was seen to be false in the case of the age and sex of the drivers of the group of 8 models, although differences were less for two models. It may be possible to develop the odds ratio approach in line with the proposal in section 3.6, perhaps relying on the contributory factor 'loss of control' in place of the assumption about 'control' and 'other' manoeuvres.
- It seems likely that the odds ratio estimates of the effectiveness of ESC have been exaggerated because of these differences between the driver profiles of cars with and without ESC. ESC first appeared in 'top of the range' models, for financial reasons, and has gradually become available lower down the model range. There are various reasons for expecting that this would skew the odds ratio comparison of 'control' and 'other' manoeuvres. For example, rates of involvement in loss-of-control and single vehicle accidents fall with driver age, so the fact that drivers of cars with ESC tend to be older than other drivers would be expected to lead to relatively few 'other' manoeuvres.
- Considerable effort was required to obtain and link the ESC data to the STATS19 and registration data. The details of which cars are actually equipped with ESC are fundamental to obtaining reliable results, yet the issue tends to be glossed over in other papers. Also, the difficulties caused by the presence of many variants with optional ESC are rarely mentioned, although Farmer (2004) does confront the issue.
- Of the ten models studied in this project, selected as having the highest sales in 2008, eight had only small minorities of cars with ESC as standard and nine had majorities of cars with ESC as optional. In earlier years, the numbers of cars with ESC as standard would have been proportionately less, meaning that the statistical power of earlier studies would have been even lower – at least in respect of mass market models in Great Britain.

5 Conclusions

This project has largely achieved its objectives. It has strengthened TRL's capability in the area of investigating the effectiveness of car primary safety equipment, at a time when progress with the DfT's initiatives in this area appears to have slowed considerably. The development of the STATS19 retrieval software has provided a version with considerable capability which will enhance the ability of TRL researchers to extract and analyse STATS19 accident data.

The basic approach used in this study to assess the effectiveness of ESC has been to compare the accident-involvement rates of cars with and without ESC. Analyses were completed for eight of the most popular models, both individually and collectively. ESC was found to reduce the overall accident-involvement rate by about one fifth, although the effect was less for serious accidents and not significant for fatal accidents. The effects varied widely among car models, and analyses failed to yield satisfactory results for several models because of the low number of cars of these models that had ESC fitted as standard.

Many previous studies of the effectiveness of ESC have used the 'odds ratio' approach. This has been compared carefully with the alternative approach based on accident-involvement rates. While there are strong similarities, there is a key difference. The 'odds ratio' approach requires an assumption about which manoeuvres made by accident-involved vehicles may be susceptible to ESC, and this assumption has been shown to be questionable. The new approach avoids the need for this assumption, so its results should be more reliable.

It was found, however, that a basic assumption of many studies of ESC effectiveness may be violated, invalidating their results. These studies have implicitly assumed that cars with and without ESC are driven in similar circumstances, for similar mileages and with similar drivers, so that any differences in their accident-involvements can be interpreted as the effects of ESC. Analyses of accident data have demonstrated, however, that the driver profiles of the two groups of car can differ in terms of age and sex.

The basic approach of comparing accident-involvement rates has been developed to compensate for the bias introduced by such differences. The suitability of this development has been demonstrated, but there has been insufficient time during this project to complete the development and examine whether other potential confounding factors may need to be treated similarly.

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Feasibility of using various data sources to carry out accident studies into primary safety of cars – phase 2

The development of sophisticated electronic control systems has led in recent years to many new vehicles entering production that are equipped with various new primary safety features designed to avoid accidents. The assessment of the casualty reduction effectiveness of such features can, however, be very difficult. One reason for this is that when a primary safety feature is fully effective, there is no accident and no data for comparison. This project has attempted to assess the effectiveness of Electronic Stability Control (ESC).

The project was carried out in two phases, phase 1 in 2008 and phase 2 in 2009. This is the report of phase 2 which has had three objectives: to develop a user-friendly software interface for the TRL copy of the STATS19 accident database; to obtain details of which car models had been fitted with ESC from the UK Motor Insurance Repair Research Centre; to make a practical assessment of the effectiveness of ESC based on analysis of STATS19 accident data.

Each objective has been achieved. The effectiveness of ESC was analysed for the eight of the most numerous current car models, both individually and as a group.

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