ELECTRONIC STABILITY CONTROL: REVIEW OF RESEARCH AND REGULATIONS

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Electronic Stability Control: Review of Research and Regulations

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Abstract

Recent analysis of real world accidents in the USA suggest that Electronic Stability Control (ESC) can be remarkably effective at preventing loss-of-control accidents. Regulatory authorities and consumer test organisations around the world are therefore actively researching test methods that can be used to assess the performance of ESC. Researchers in the USA, Canada, Europe, Japan and Australia were contacted to establish the status of research and to obtain comments on ways in which ESC can be assessed and encouraged.

Strategies range from "regulation by definition" and defining functional requirements for ESC, to the performance of comparative dynamic tests. At this stage there is no *performance-based* test and assessment protocol that is suitable for use by the Australian New Car Assessment Program or in regulations. However, consideration should be given to regulating functional requirements to ensure there are no unintended adverse effects from ESC. To complement the global research it is recommended that a small research program be undertaken in Australia to evaluate the ability of an Australian-developed test procedure to assess ESC performance.

Keywords

PASSENGER VEHICLE, OCCUPANT, INJURIES, HANDLING, STABILITY
CRASH AVOIDANCE

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Cover illustration from DVExperts (www.dvxexperts.net)

Executive Summary

Recent analysis of real world accidents in the USA, Japan and Europe suggests that Electronic Stability Control (ESC) can be remarkably effective at preventing loss-of-control accidents. Regulatory authorities and consumer test organisations around the world are therefore actively researching test methods that can be used to assess the performance of ESC.

Researchers in the USA, Canada, Europe, Japan and Australia were contacted to establish the status of research and to obtain comments on ways in which ESC can be assessed and encouraged.

Strategies range from "regulation by definition" and defining functional requirements for ESC, to the performance of comparative dynamic tests. At this stage there is no *performance-based* test and assessment protocol that is fully suitable for use by the Australian New Car Assessment Program or in regulations. However, consideration should be given to regulating functional requirements to ensure there are no unintended adverse effects from ESC. This could be implemented with minimal effort. This option relies, in part, on existing provisions in ECE Regulation 13 for complex electronic systems on commercial vehicles.

To complement the current global research it is recommended that a small research program (costing around $50,000) be undertaken in Australia to evaluate the ability of an Australian-developed test procedure to assess ESC performance.

The estimated of the benefit/cost ratio of ESC is similar to that of a driver airbag and ABS brakes, despite the higher initial cost of ESC.

Introduction

Rollover propensity is a concern with high-seat vehicles (seating reference point more than 700mm above the ground). Recent research suggests that electronic stability control (ESC) can be highly effective at reducing rollover and other loss-of-control accidents for these vehicles. Preliminary USA research found that electronic stability control can reduce passenger car single vehicle crashes by 35% and Sports Utility Vehicle (SUV) single vehicle crashes by a remarkable 67% (Dang 2004).

A recent IIHS evaluation supports the NHTSA research: ESC reduced single-vehicle crash involvement risk by approximately 41 percent (95 percent confidence limits 33–48) and single-vehicle injury crash involvement risk by 41 percent (27–52). Based on all fatal crashes in the United States over 3 years, ESC was found to have reduced single-vehicle fatal crash involvement risk by 56 percent (39–68). This translates to an estimated 34 percent reduction in overall fatal crash involvement risk (21–45) (Farmer C 2004).

Authorities in the USA, Canada, Europe and Japan are therefore looking at ways to encourage ESC, particularly on high-seat vehicles such as large four wheel drives.

Availability of ESC

Bosch (2005) prepared the map illustrating the estimated proportion of European cars fitted with ESC as standard.

According to Farmer, ESC first appeared in Europe on prestige cars in 1995 and in the USA a few years later. For the 2004 model year, ESC was on all cars and light trucks manufactured by Audi, BMW, and Mercedes, and on some models produced by just about every other automaker.

In Australia the above makes and an increasing number of local vehicles have ESC. For example, the new Ford Territory has ESC ("Acutrac Plus") as standard on all-wheel-drive models.

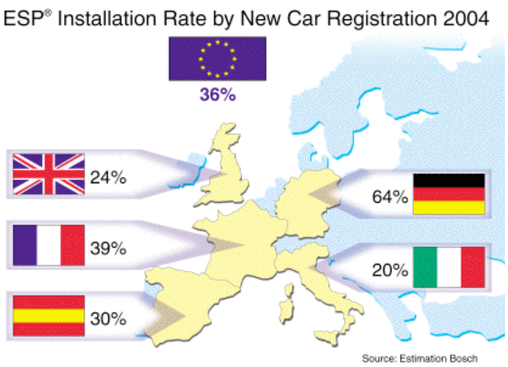

Figure1. ESC installation in Europe (Credit: Bosch)

The Australian New Car Assessment Program (ANCAP) is currently considering an industry proposal to require/encourage ESC on high-seat vehicles as part of its safety rating system. Consumer programs like ANCAP provide an alternative to regulation and can expedite the uptake of important new safety features.

Terminology

The marketing names of ESC systems vary. For example, BMW refers to its system as Dynamic Stability Control (DSC), Mercedes and Bosch calls it Electronic Stability Program (ESP), Toyota calls it Vehicle Stability Control (VSC), Ford (US) calls it AdvanceTrac, and General Motors uses the names StabiliTrak, Active Handling, and Precision Control.

The US Society of Automotive Engineers (SAE) recently revised its Information Report on "Automotive Stability Enhancement Systems" - J2564. The document lists known terms and acronyms for ESC:

ASC (Automotive Stability Control)
ASR (Automatic Stability Regulation)
AH (Active Handling System)
ASMS (Automotive Stability Management System)
CBC (Cornering Brake Control)
DSC (Dynamic Stability Control)
EDS (Electronic Differential-lock System)
DSTC (Dynamic Stability and Traction Control)
ESC (Electronic Stability Control)
ESP (Electronic Stability Program)
ICCS (Integrated Chassis Control System)
IVD (Integrated Vehicle Dynamics)
PCS (Precision Control System)
PSM (Porsche Stability Management)
SCS (Stability Control System)
StabiliTrac
STC (Stability and Traction Control System)
Traxxar
VDC (Vehicle Dynamics Control)
VSA (Vehicle Stability Assist)
VSC (Vehicle Stability Control)
VSES (Vehicle Stability Enhancement System)
YCS (Yaw Control Stability)

The term ESC, as preferred by NHTSA, will be used throughout this report.

Methods of operation

There are potentially many ways that ESC could detect instability and intervene to maintain control. The simplest form detects when the vehicle is failing to follow the intended course, as indicated by the angle of the steering wheel, and applies a small amount of braking to an appropriate road wheel to provide a compensating moment that brings the vehicle back on course. The following diagrams are from a IIHS Status Report.

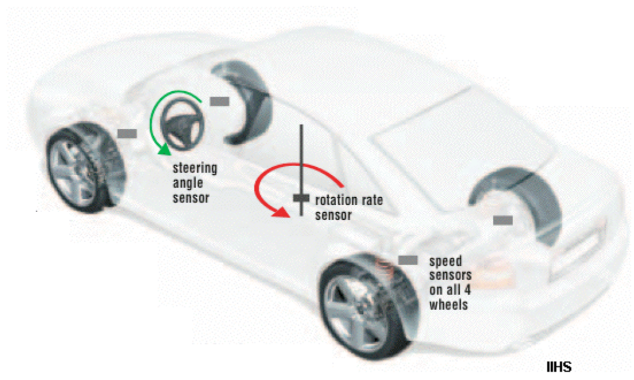

Figure 1. ESC Sensores (credit: IIHS)

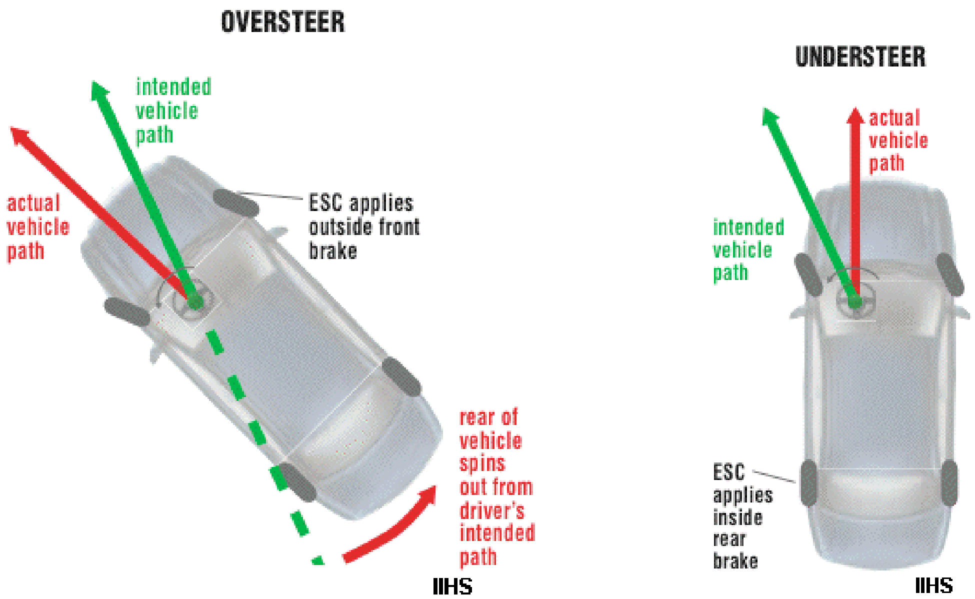

Figure 2. Methods of controlling oversteer and understeer

An SAE paper by van Zanten (2000) contains a detailed description of ESC components and functions. Van Zanten, from Robert Bosch GmbH (the major suppier of ESC) discusses the abnormal conditions for which ESC must be designed and tested: "Changes in the tire and car data such as resulting from usual wear and tear or even from small accidents must not reduce the ESP performance or at least must not result in adverse behaviour. Before the system is released, a catalog of special test manoeuvres must be checked. Flat tires and trailers should be included in the catalog. Also the “Moose Test” has become a part of the catalog. Particularly at low ambient temperatures where fast active braking is hampered by the increasing viscosity of the brake fluid the interventions must be checked to be fast enough to achieve the required yaw moment on the car in time. "

The SAE J2564 defines ESC as having the following functions:

a. Is computer controlled and the computer contains a closed-loop algorithm designed to limit understeer and oversteer of the vehicle.

b. Has a means to determine vehicle yaw velocity and side slip.

c. Has a means to monitor driver steering input.

d. Has a means of applying and adjusting the vehicle brakes to induce correcting yaw torques to the vehicle.

e. Is operational over the full speed range of the vehicle (except below a low-speed threshold where loss of control is unlikely).

The document recognises four types of ESC, as illustrated in the following diagram.

	Systems with Engine Control	Systems without Engine Control
Four Wheel Systems	4-Wheel ESC with Engine Control a) This system must have the means to apply all four brakes individually and a control algorithm which utilizes this capability. b) The system must have an algorithm to determine the need, and a means to modify engine torque, as necessary, to assist the driver in maintaining control of the vehicle. c) The system must be operational during all phases of driving including accelerating, coasting, and decelerating (including braking). d) The system must stay operational when ABS or Traction Control are activated.*	4-Wheel ESC without Engine Control a) This system must have the means to apply all four brakes individually and a control algorithm which utilizes this capability. b) The system must be operational during all phases of driving including acceleration, coasting, and deceleration (including braking). c) The system must stay operational when ABS or Traction Control are activated.*
Two Wheel Systems	2-Wheel ESC with Engine Control a) This system must have the means to apply the brakes individually at the front wheels of the vehicle and a control algorithm that utilizes this capability. b) The system must have an algorithm to determine the need, and a means to modify engine torque, as necessary, to assist the drive in maintaining control of the vehicle. c) The system must be operational during all phases of driving including acceleration, coasting, and deceleration (including braking). d) The system must stay operational when ABS or Traction Control are activated. *	2-Wheel ESC without Engine Control a) This system must have the means to apply the brakes individually at the front wheels of the vehicle and a control algorithm that utilizes this capability. b) The system must be operational during all phases of driving including acceleration, coasting, and decelerating (including braking). c) The system must stay operational when ABS or Traction Control are activated.*

*Some systems may have limited yaw control capability during ABS or Traction Control activation.

Figure 3. Extract from SAE J2564 describing the four types of ESC

It is important to note that ESC is usually integrated with other technologies such as ABS and traction control. SAE J2564 states "all ESC are assumed to include ABS" and "If any of these features [traction control etc] is included on the vehicle, the Electronic Stability Control System must be capable of coordinating their activities to aid the driver in maintaining control of the vehicle and to prevent undesirable interactions."

"The type of Electronic Stability Control used on a specific vehicle is the decision of the vehicle manufacturer. Factors affecting this decision may include handling characteristics of the vehicle, vehicle weight distribution, powertrain size and type, intended vehicle use, size, cost, and customer demographics." (J2564).

SAE J2564 also describes some other electronic methods of improving stability such as active suspension control that actively adjusts damping coefficients, spring rates and anti-roll bar stiffness.

Dynamic tests

This section briefly describes the dynamic tests that are being considered by researchers. Additional Comments on these tests are contained in the next section.

NHTSA Fishhook Test

This was developed for dynamic testing of rollover propensity (Figure 4). It is unlikely to be suitable for assessing ESC.

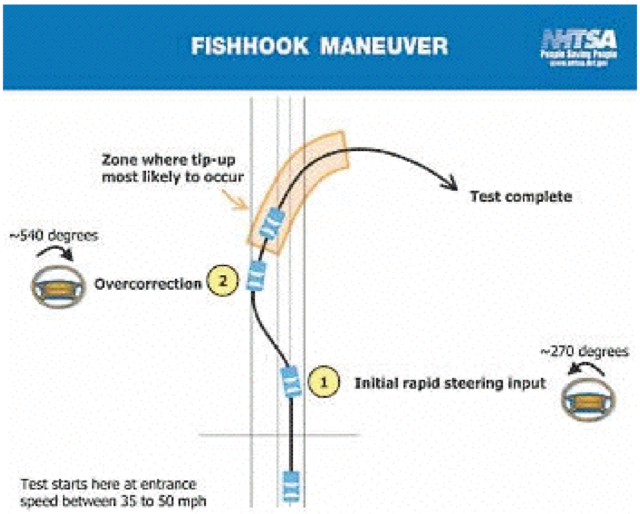

Figure 4. NHTSA Fishhook Test

NHTSA Steering Machine Tests

These tests have been developed to assess ESC. They are performed using a steering machine that delivers a prescribed motion to the steering wheel. Four of the tests are described in more detail in the following section.

A fifth test, that was evaluated for assessing rollover propensity, is the "J-turn" test where a ramped motion is applied to the steering wheel. There are variations to this test such as "pulse braking" (see also ISO 7401).

ISO Lane Change Test

ISO 3888-2 prescribes a severe lane change test with obstacle avoidance. The vehicle enters the course at a particular speed and the throttle is released. The driver then attempts to negotiate the course without striking the cones. The test speed is progressively increased until instability occurs or the course cannot be negotiated. Several manufacturers regard this test as suitable for assessing ESC.

ISO 3888-1 is similar except that the throttle is held at the start position and the course is not quite as demanding.

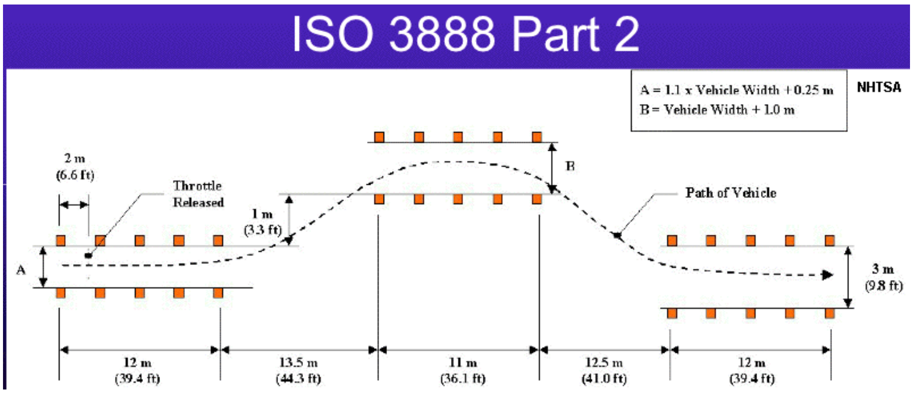

Figure 5. ISO Severe Lane Change with Obstacle Avoidance

ISO 7401 Lateral transient response tests

ISO 7401 specifies a range of tests using specified steering wheel inputs: step input (J-turn), single cycle sinusoidal, pulse steer, continuous sinusoidal and random input. Of these the J-turn test is regarded as more suitable for assessing ESC. It is called the J-turn test because the path of the vehicle is typically similar to letter J (Figure 6).

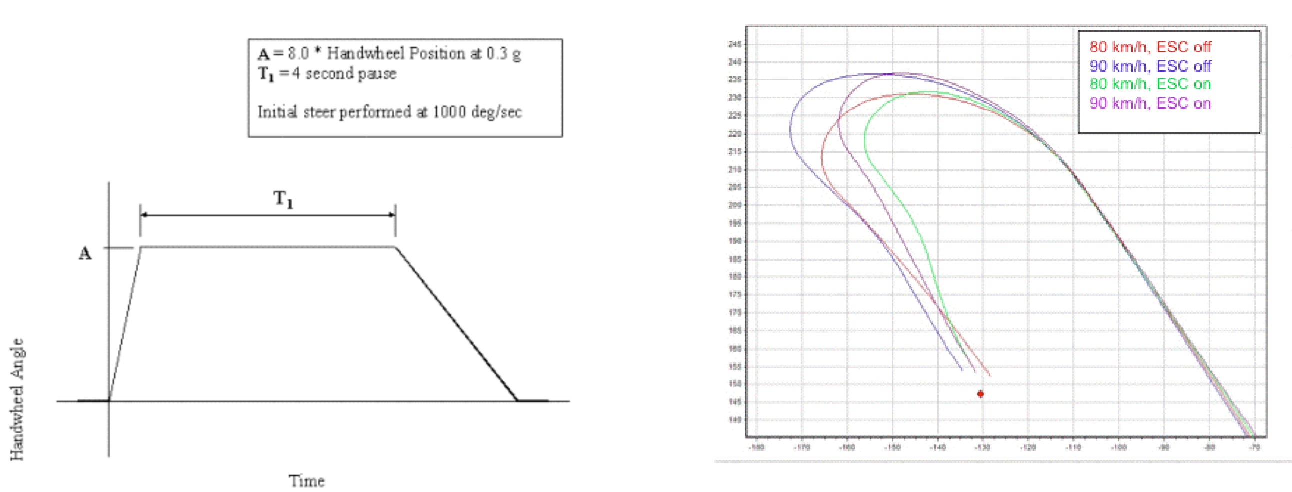

Figure 6. Steering input for J-turn test (ISO 7401) and typical vehicle path (Transport Canada)

Consumer Union Lane Change Test

In the USA, the Consumers Union conducts independent tests of consumer products. The Union has developed a lane change test for assessing vehicle handling. There is concern that the test is too open to variability and depends too much on driver skill.

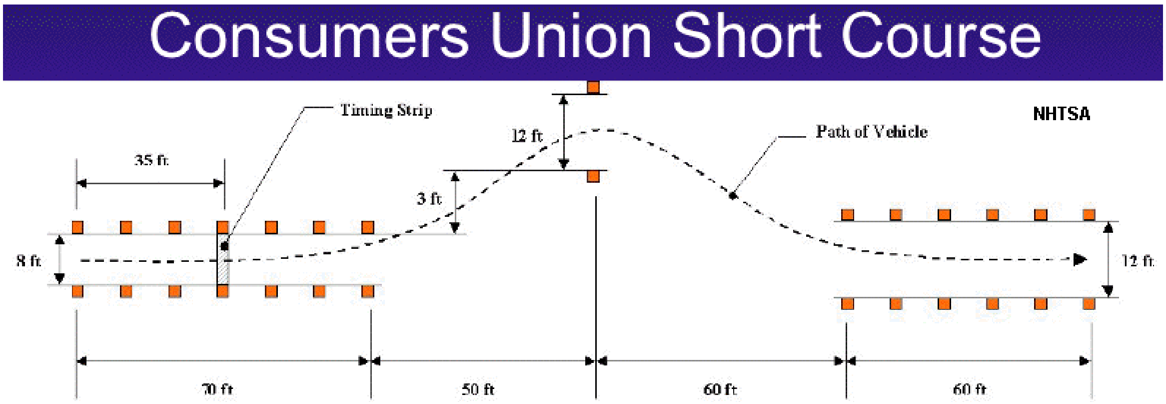

Figure 7. Consumer Union Lane Change Test

Research results

During February and March 2005 key overseas researchers were contacted for advice about the status of research projects on ESC. In brief, the USA, Canada, Europe and Japan are each looking at ways to assess the performance of ESC but development work is still underway.

USA - National Highway Traffic Safety Administration

Early in 2005 NHTSA held meetings with industry representatives to discuss their ESC research program. Industry submissions and NHTSA presentations are available online at: http://dms.dot/gov/ under Docket 19951.

Dr Riley Garrot from NHTSA advises that NHTSA is still investigating possible dynamic tests for "determining whether a vehicle is equipped with ESC". They are focussing on four types of test that each involve applying a set motion to the steering wheel (by machine). Prior to each of these tests a low severity steering motion test is undertaken to establish the limits of the vehicle. In any case outriggers are fitted to high c of g vehicles.

The vehicle is driven on tar up a very slight incline (1%) at 80km/h. The steering wheel is turned through the prescribed motion (see Figures 8 & 9). The test is then repeated at a greater steering wheel angle until the predetermined stability limits are reached, or spin out occurs. The test procedure defines a spin out (loss of control) and a vehicle that does not spin out up to the predetermined limits is deemed to have ESC. It would also be possible to compare vehicles with and without ESC using these tests. For example, NHTSA report that is was possible to cause all test vehicles without ESC to spin. Most with ESC did not spin out.

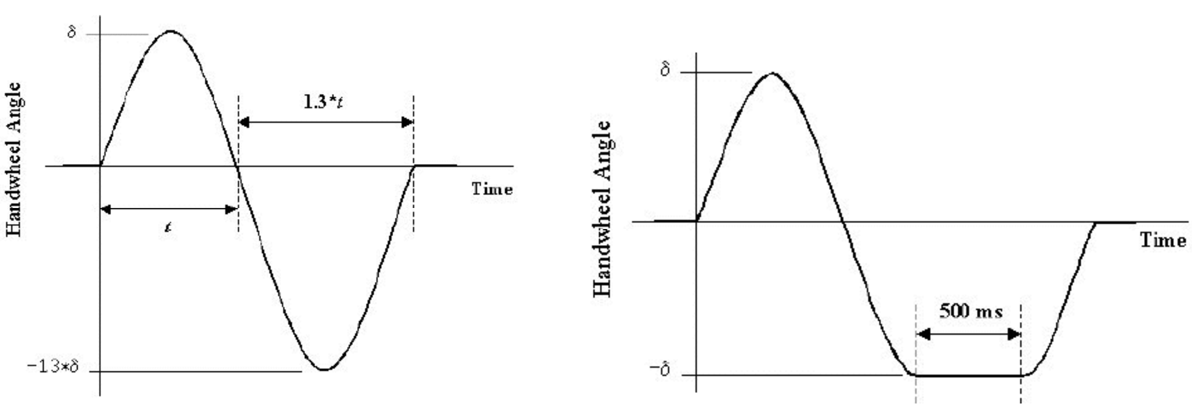

Figure 8. Steering Wheel Motion (0.7Hz Sine tests)

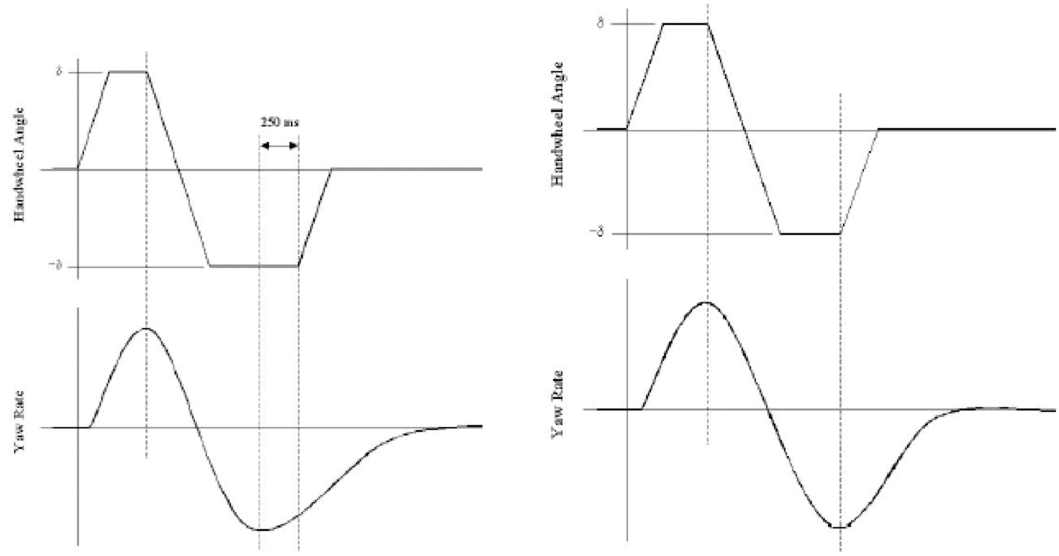

Figure 9. Steering Wheel Motion (Yaw Acceleration Tests)

In correspondence, Dr Garrott points out that this test is separate from NHTSA's rollover research. The planned ESC tests do not attempt to establish the dynamic rollover propensity of vehicles. NHTSA research suggests that less than 4% of all rollovers in the USA are "untripped, on-tar" that could be expected to be directly influenced by ESC. Most rollovers occur when the vehicle leaves the roadway, slews sideways and is tripped (Figure 10). NHTSA's goal is therefore "to keep the vehicle on the road with ESC".

Figure 10. Example of off-road tripped rollover (credit: DV Experts)

In commenting on the NHTSA proposal the Alliance of Automobile Manufacturers (December 2004) provide the results of lane avoidance manoeuvres - regarded as "a typical accident avoidance scenario and yaw stability assessment tool". However, the early test results do not appear to be very conclusive. The Alliance suggest that the performance measures should be able to:

- determine the existence of ESC
- compare basic handling with and without ESC
- discriminate different levels of ESC performance.
- relate to real-world safety

In its comments General Motors provided a detailed description of its StabiliTrak system, including an advanced system with "proactive roll avoidance" that limits manoeuvres that may cause rollover. However the report acknowledges the small proportion of untripped, on-tar rollovers that might be influenced by such a system.

The GM report notes that "the ability to impose forces to the vehicle independent of the driver enables unprecedented capabilities but presents unique challenges is assuring robust system performance". A relatively complicated method of assessing the results of ESC testing - known as Mahalanobis Taguchi System (MTS) is described in the GM report.

In comment on NHTSA's proposed *rollover tests* Daimler-Chrysler caution that the tests should not ignore handling characteristics because vehicles may be optimised to meet the specific rollover test to the detriment of real world safety. They suggest that the test should replicate a somewhat "typical" emergency situation and that ISO 3888 Part 2 (double lane change) fulfils these requirements and is internationally recognised. Three failure modes during this test are spin-out (oversteer), plough-through (under-steer) and rollover. The measure of performance is the maximum entry speed and Daimler-Chrysler recommend that this speed be published, along with the failure mode, rather than a star rating. They support the NHTSA goal of keeping the vehicle on the road and point out that more than 95% of rollover fatalities (in Germany?) occur in off-road tripped events.

Daimler-Chrysler also address NHTSA's criticisms of ISO 3888-2 (NHTSA criticism in italics, paraphrased response non-italics):

- *The entry speed criterion may disproportionately favour ESC that utilize simple brake intervention.* ESC is an integral part of a vehicle's overall stability design and should not be considered in isolation. In any case, the tendency of brake-intervention ESC to slow the vehicle down during the manoeuvre would likely be beneficial in a real world situation by reducing subsequent impact speeds.

- *The narrow lanes may make the course too difficult to follow.* Currently the lane width specified in ISO 3888-2 is determined by the test vehicle width. This was done to minimise driver influence. The lane width requirements may need to be reviewed to provide for large vehicles such as SUVs. Three professional drivers should be used and they must complete the test at the same entry speed without hitting a cone. It is acknowledged that the test does require adequate driving expertise but driver influence can be minimised by having several drivers complete several runs each.
- *The 11m left lane results in the development of less roll momentum than is produced, for example, in the Consumer Union double lane-change (object avoidance) test.* The ISO test is more typical of a manoeuvre drivers are likely to perform in the real world. The CU test is subject to a high degree of variability in steering input.
- *The timing of the steering reversal may result in critical load transfer at peak lateral acceleration in some vehicles, but not in others. This effect is somewhat arbitrary.* The purpose of the test is not to find the most critical conditions specific to each vehicle but to compare relative stability of different vehicles during a typical limit-handling manoeuvre. ISO 3888-2 does represent such typical manoeuvres - it is not ideal but is the least problematic of all available tests.

Daimler-Chrysler points out that the Open Loop Fishhook test addresses the dynamic behaviour of the vehicle, usually at the limit of the particular vehicle's capability. However such situation very rarely occur in the real world, as evidenced by the low rate of on-road, untripped rollovers. "It makes more sense to concentrate on vehicle characteristics that help the driver maintain control of the vehicle in real-world critical manoeuvres." The submission then provides an example of a situation where a vehicle with inferior handling (slower steering response leading to over-correction) can do better in the fishhook test (ie higher speed at which two-wheel lift occurs) than a vehicle with superior handling.

NHTSA's discussion paper on the assessment of *rollover propensity* contains the following criteria for evaluating potential tests:

1. Objectivity and Repeatability, i.e., whether a manoeuvre could be performed objectively with repeatable results for the same vehicle.
2. Discriminatory Capability, i.e., whether a manoeuvre demonstrated poorer performance for vehicles that have less resistance to rollover. Although of obvious importance, a manoeuvre’s ability to discriminate between different levels of vehicle handling was not considered.

3. Performability i.e., how difficult each manoeuvre is to objectively perform while obtaining repeatable results, how well developed are the test procedures for each manoeuvre, and whether the test procedure includes adequate means for adapting to differing vehicle characteristics.
4. Realistic Appearance, i.e., whether a test manoeuvre looks like a manoeuvre consumers might imagine performing in an emergency.

These criteria also apply to a handling test.

USA - Insurance Institute for Highway Safety

IIHS is monitoring the NHTSA research. Chief Operating Officer for the Institute, Dr Adrian Lund advises that IIHS is following up on the apparent real world effectiveness of ESC systems. They were especially surprised by the uniformly high effectiveness across different ESC types - different automakers are specifying different levels of intervention, but IIHS saw no hint of differences in effectiveness (subject to small sample sizes). They aim to better understand the kind of crashes ESC prevents. This would assist in identifying vehicle tests that would assess the real world performance of ESC. He notes that the demonstrations used by suppliers often show how ESC facilitates recovery after serious loss of vehicle control, while the main benefit of ESC for most consumers may be that they don't lose control in the first place. Thus, ESC supplier demonstrations/tests do not translate readily into comparative consumer tests.

The January 2005 issue of Status Report by IIHS was devoted solely to ESC.

Canada - Transport Canada

Denis Boucher (Senior Research Engineer, Ergonomics and Crash Avoidance) advises that Transport Canada is carrying out some evaluations of possible ESC tests. They have conducted a few tests of SUVs and articulated trucks.

For the passenger vehicles, they performed the following tests:

- SAE J266, Steady State Directional Control Test Procedures: Method 2
- ISO 7401, Step Input (J-Turn)
- ISO 3888 Part 1, Double Lane Change
- ISO 3888 Part 2, Obstacle Avoidance

The tests were performed on dry & wet pavement in two loading conditions: nominal load (driver + instrumentation) and "loaded" (driver + instrumentation + three 80-kg water dummies). Two drivers were used for the two ISO 3888 tests. Early results suggest that the only effective test was the J-Turn manoeuvre. The other tests were found to be of limited use, especially for regulatory purposes.

Transport Canada is currently purchasing a programmable steering controller that will be used to perform tests similar to those currently being done at NHTSA (sinusoidal steering manoeuvres and J-turn). An ESC "behavioural adaptation" study is also being planned (to determine if drivers might take additional risks in anticipation of assistance from ESC). Finally, they would like to assess the effectiveness of ESC in reducing the number of collisions and/or injury severity from real-world collision data. However, this is a major challenge given the small number of vehicles fitted with this technology and the difficulty in identifying vehicles with ESC (unless ESC is installed as standard equipment, it appears impossible to determine whether it is installed or not).

Japan - JNCAP

Dr Yuri Ono advises that JNCAP is interested in how to improve active safety of motor vehicles. JNCAP recognises that it is difficult to evaluate the performance of each ESC at present so they conducted research to identify how far ESC is effective in real-world accidents. The results of the research were published in Japanese on 18th of February on the JNCAP website.

Dr Ono stated that JNCAP selected ten models that could be compared with and without ESC. Data for 1,471 ESC-sensitive accidents (single vehicle and frontal collision) in Japan were analysed. According to the research, the number of ESC-sensitive accidents decreased by 36% if equipped with ESC. Single vehicle accidents decreased by about 44% and frontal collisions decreased by about 24%. The improvements are greater for serious accidents and for wet road accidents.

The research aims to inform consumers about the effectiveness of safety equipment. JNCAP publishes lists of safety features on vehicles, including ESC - for example:

http://www.nasva.go.jp/assess/html2004e/as208.html

JNCAP has not yet decided on a test programme to improve active safety. The current research is a first step.

Europe - Euro NCAP

Aled Williams from Euro NCAP advises that Euro NCAP has been looking at ways to promote the broader fitment of ESC systems by manufacturers and to encourage greater uptake by consumers:

"*There is a growing body of evidence that such systems are effective in preventing accidents. However, none of the research that we have seen has been able to identify why such systems are so effective; they simply find good correlation between the fitment of an ESC system and a reduction in the number of accidents. This poses problems when trying to develop a test of ESC, especially one intended to rate and compare cars. If we don't know what makes ESC systems effective, how can we test to demonstrate that one is better than the other?*

Most of the tests I have seen which purport to test ESC systems are actually tests of a car's ability to carry out a handling manoeuvre. Some cars with no ESC may do better in such manoeuvres than others with ESC. In other words, these *tests do not assess the effectiveness of the ESC in correcting the intrinsic instability of the cars. If ESC works by intervening when a driver goes beyond the capability of the car, Euro NCAP doesn't want to base its assessment on the car's road holding. We want to assess the features of an ESC system, as that is what has been shown to influence accidents.*

We could start simply by recommending that consumers buy cars with ESC. A step up from this would be to award points to cars fitted with ESC. We then might want to develop a test which simply checks that the ESC system works.

Beyond that, we might want a test that can distinguish between systems of different "quality," to encourage better systems for the future. Such systems might incorporate active suspension and steering.

Our current thinking is that it may be necessary to have two tests - one with the ESC disengaged, to determine the point at which the car becomes unstable, and one with the ESC on to see how effective it is at correcting that instability. However, there is some concern that rewarding systems that show a great difference between the two tests might encourage manufacturers to "down-rate" the basic performance of the car and to introduce very aggressive ESC systems.

As you can see, a great deal of care is needed before a test and rating system is introduced. Euro NCAP is still some way from having a test procedure that meets its needs, although work is ongoing.

In the short term, it looks as though it might just be best to tell consumers that ESC systems appear to be effective and, if possible, to buy cars with them fitted. Sweden have done this and it has been very effective in increasing the uptake of ESC systems there.

I am not aware of any test methods that would address particular situations like tyre blow-outs. I think the best people to speak to would be the systems' manufacturers, like Bosch, who would know if such work is being done, although they may have problems discussing this in detail if they are developing such systems in conjunction with a vehicle manufacturer."

Europe - TRL Limited

Iain Knight, Senior Research Engineer, Vehicle Safety and Engineering advises that TRL recently completed a project on ESC and the report should be published shortly.

In addition to this research, TRL has been carrying out research for the UK Department for Transport aimed at developing a set of NCAP tests for primary safety. The Euro NCAP Ad-hoc sub group for vehicle dynamics is considering whether Euro NCAP should adopt primary safety tests and, if so, which ones. ESC is certainly a central issue in the discussions.

From the technical level it appears that three options are being considered. Firstly to include ESC as a "tick-box" assessment i.e. the presence of the system attracts a certain fixed number of points. Mr Knight advises that he, and most of his colleagues in the dynamics committee have a number of concerns about this approach. These concerns centre around how to define the presence of an ESC system. In theory, if you have only a tick-box to mark the presence of an ESC a manufacturer could put an empty black box stamped with ESC under the bonnet and attract the marks. Although this is an extreme example the performance of ESC is very much tied to the handling performance of the vehicles steering and suspension systems and the combined performance of car and ESC can be "tuned" to suit the preferences of manufacturers. This means that there is potentially a large difference in handling performance with respect to safety between different cars equipped with different ESC systems. Mr Knight has seen test results that show that one car not equipped with ESC can perform better than another that is equipped with ESC, although the addition of ESC always improved the performance of any particular car.

If there is only a tick-box there is no incentive for manufacturers to invest the money in making the system perform the best it can and hence avoid as many accidents as it could be capable of. The advantages to an assessment body such as NCAP is that it is very cheap to assess in this way.

The second approach is for there to be some sort of "functional" test of the ESC system. It is not clear exactly what this might involve but the suggestion seems to be along the lines of an electronic diagnostic check to show that the system is functioning. His concern is that although this prevents the empty black box potential, it would be very difficult to carry out a "functional" test that guaranteed that the system performed well in combination with the fundamental chassis characteristics and provided incentives to develop the best system.

The third option would be to carry out full scale dynamic handling tests on the vehicle and this is his preferred approach and the preferred approach of the members of the Euro NCAP dynamics sub-group. At present, discussions within that group have been based on an approach where more than one dynamic test should be carried out. This is because, in theory, it is possible for an ESC to be tuned such that it performs well in a particular designated test but not in other situations likely to happen on the road.

At the moment, most of the research carried out on this subject has been in the US where NHTSA have carried out a test programme as have the industry (AAM). The Euro NCAP dynamics group has agreed that whatever test is selected in the US, from candidates such as asymmetric sine steer, is likely to form the basis of our proposal to the higher Euro NCAP committees when combined with a second more general handling test such as braking in a turn.

With respect to unusual events, the study that TRL recently carried out did attempt a very limited assessment of how the system would respond when the physical limits of the vehicle were greatly exceeded and where counter steering from the driver was also applied at the same time as the correction from the ESC. They found no adverse effects. However, the research was limited to two manoeuvres and only one vehicle. Mr Knight has not heard of any research assessing the response when a tyre blow-out occurs but has heard claims that

ESC will be of benefit when the vehicle is attempting to return to the road from the unpaved shoulder. In theory, the ESP should respond to the sudden yaw rate increase and act to stabilise the vehicle, particularly if the driver responds by reducing the steering input. However, he has not seen any research that actually tests in this situation.

Europe - UN/ECE Working Group (Commercial Vehicles)

Prof. Dr. Laszlo Palkovics (Director of Advanced Engineering and Processes, Knorr Bremse Systems for Commercial Vehicles, Hungary) is chairman of the UN-ECE WP29 GRRF working group that has been established to investigate ESC (EVSC) *on commercial vehicles* and develop proposed regulations. He included a recent (2 Feb 2005) report to the GRRF. Extracts are provided below.

> 1. Denmark will mandate stability control system for coaches of class M3 as of 01.05.2005. This welcomed, since the stability control system significantly contributes to the traffic as well as passenger safety. However, there are several problems with the current Danish formulation:
>
> - Definition of the required stability control system is not sufficient
> - There are no clear requirements defined
> - ESC is not readily available on many buses
>
> 2. It is proposed to cover ESC in ECE Regulation 13 (Braking) since almost all of the state-of-the-art EVSC systems are using the brake as intervention actuator
>
> 3. A definition of ESC is proposed: "an electronic control function for a power vehicle which improves the dynamic stability of the vehicle and shall include a directional control and may include a rollover control". A separate definition is provided for trailer systems.
>
> 4. A design requirement is proposed: "In the case of directional control the [vehicle stability] function shall have the ability to automatically control individual wheel speeds by selective braking based on an evaluation of actual vehicle behaviour in comparison with a determination of vehicle behaviour demanded by the driver." Plus the system should have the ability to regulate engine power output and should "determine vehicle behaviour from measured values of yaw rate, lateral acceleration and wheel speeds and from the driver's control input to the braking system, to the steering wheel and to the engine."
>
> 5. At this stage there is no realistically measurable performance test for ESC. In the circumstances it is better to deal with design requirements and not specify performance tests. Existing ISO tests were found to be unsuitable (for commercial vehicles) and manufacturer's in-house tests were considered too complex for regulation.
>
> 6. In the absence of a performance test, manufacturers will be asked to demonstrate the operation of ESC by [unspecified] dynamic test or the

submission of [unspecified] test results for a representative vehicle or by [unspecified] computer simulation.

7. Compatibility and communication between truck and trailer needs to be considered.

In short, the Committee has decided to avoid specifying a performance test and, instead, proposes to set fairly broad design/functional requirements that should be easily demonstrated by manufacturers. Mr Colin Ross, European Technical Manager T/TS6, points out that ESC is regarded as a "complex electronic vehicle control system" and is therefore subject to the provisions of Annex 18 of ECE Regulation 13 (*Commercial Vehicle* Braking). This Annex defines functional requirements, fault strategies and methods of verification of such systems where fitted to commercial vehicles. Manufacturers are required to submit system descriptions and detailed technical information to the approval authority. The Annex was apparently developed to cater for commercial vehicle ABS braking systems in the 1980s but its provisions are considered flexible enough to also cover ESC on cars.

Australia - ANCAP

Government authorities and motoring organisations are understood to be monitoring developments with ESC but no active research programs are underway.

As stated earlier, ANCAP is currently considering an industry proposal to require/encourage ESC on high-seat vehicles as part of its safety rating system. One proposal is to make ESC a requirement before a high-seat vehicle can earn a five star rating. Currently the two high-seat SUVs that have a five star rating already have ESC so the proposal could be implemented without affecting current ANCAP ratings. A second proposal is deduct points from the overall score of high-seat vehicles that do not have ESC - this would have a lead time of several years.

Australia - DV Experts

Shane Richardson from DV Experts in Melbourne has developed stability/rollover performance tests for the Australian army and has also conducted tests for the Victorian Police and Ambulance services (Richardson 2003).

Although the main focus of the research was to prevent rollover accidents, during discussions Mr Richardson has stated that the dynamic tests should also be suitable for assessing ESC systems. First a limit of lateral acceleration (LLA) is determined by observing wheel lift during a static tilt table test. All subsequent dynamic tests are restricted to no more than 70% of this value. This avoids the need for outriggers. Dynamic tests are based on ISO 4138 "Passenger Cars - Steady State Circular Driving Behaviour - Open loop test procedure" and ISO 3888-1 "Passenger Cars - Test Track for a Severe Lane Change Manoeuvre". In the latter test the vehicle was driven through the lane change envelope at progressively higher speeds until 70% of LLA was reached. The speed at which the vehicle was driven was the main output from the test and correlated well with known stability limitations of the tested vehicles.

Further research is needed to determine the ability of these tests to assess the performance of ESC systems but the work with a range of Police vehicles (none of which had ESC) suggests that the tests have good potential to distinguish between similar vehicles with and without ESC. Consideration could be given using the ISO 3888-2 test as it appears to be more demanding of ESC.

Effectiveness of ESC

Global studies of ESC effectiveness

Bosch (2005) provides a review of effectiveness studies of ESC (some have been mentioned previously in this report):

- 1998 RESIKO study GDV (German insurers): 28% of all accidents involve loss of control by the driver. 60% of all fatal accidents involve sideways skidding.
- 2004 University of Iowa driving simulator research: 34% improvement in maintaining control off the vehicle.
- 2004 NHTSA: Single vehicle accidents for cars reduced by 35%. Single vehicle accidents for SUVs reduced by 67%.
- 2004 IIHS: Single vehicle accidents reduced by 41%. Fatal single vehicle accidents reduced by 56%.
- 2002 Daimler-Chrysler: Single vehicle loss-of-control accidents reduced by 42%.
- 2004 Ford (Europe): Single vehicle accidents reduced by 13-35%, depending on accident scenario.
- 2004 LAB (Laboratoire d'Accidentologie, de Biomécanique - Renault and PSA): Single vehicle loss-of-control accidents reduced by 44%.
- 2002 Swedish National Road Administration: All accidents (except rear-end impacts on dry roads) reduced by 22%.
- 2004 Volkswagen: Fatalities reduced by 35%.
- 2003 Toyota: Severe single vehicle accidents reduced by 50%.

Potential effectiveness in Australia

Approximately 30% of Australian light vehicle fatal crashes are single vehicle crashes and the remaining 70% are multi-vehicle fatal crashes. Applying the IIHS estimates of effectiveness gives the following indication of potential savings from ESC.

56% of single vehicle crashes = 56% x 30% = 17% of all light vehicle fatal crashes

17% of multi-vehicle crashes = 17% x 70% = 12% of all light vehicle fatal crashes

Total saving = 17% + 12% = 29% of all light vehicle fatal crashes.

This is substantially greater than earlier estimates for Europe and Japan (Tingvell 2003, Langweider 2003 and Aga 2003), although the proportion of light vehicle fatal crashes, compared with all fatal crashes, does vary substantially between regions.

Cost effectiveness

Glass's Guide provides the following costs for optional installation of ESC in certain vehicle models around 2003. In several cases ESC is now standard on these models.

Table 1: Cost of ESC as an Option (Source: Glass's Guide)

Make and Model	**ESC Option**
Audi A6	$2500
BMW 318 (base variant)	$1500
BMW 318 Exec, 5 Series and Z3	$2550
Ford Focus	$990
Jaguar S-Type	$3475
Jaguar X-Type	$2550
Mini Cooper	$290
Porsche 911 and Boxer	$2990
Volvo S40, V50 and V70	$2190

A reasonable cost of $1000 has been assumed for this analysis, based on the Ford Focus option of $990.

Paine (2003) developed a methodology for comparing the cost-effectiveness of vehicle safety features. Using this method and assuming that ESC can prevent 50% of loss-of-control accidents then it is estimated the ESC has a benefit cost ratio of 0.51 (see figure 11 overleaf). Table 2 compares this outcome with several other safety features. Note that very few safety features have a benefit/cost ratio greater than unity and it is advisable to simply compare features.

SAFETY FEATURE ANALYSIS

FEATURE CODE	VSC	CATEGORY	*HANDLING AND BRAKING*
DESCRIPTION	VEHICLE STABILITY CONTROL		
READINESS	TAKE-OFF	ACCEPTANCE	GOOD
NET COST (1 OFF)	$1,000.00	MAINTENANCE/YR	$0.00
INFLUENCE	LOSS OF CONTROL ACCIDENTS (34% FATALS AND 18% OTHERS ACCORDING TO TINGVELL 2003)		
EFFECTIVENESS	50% OF LOSS OF CONTROL ACCIDENTS (MOSTLY SINGLE VEHICLE) ACCORDING TO IIHS IN 2004		

CRASH SAVING ANALYSIS	FATALS	SERIOUS	MINOR	PROPERTY
CRASH COST/VEHICLE/YEAR	$142.00	$252.00	$136.00	$143.00
% OF CRASHES INFLUENCED	34%	18%	18%	18%
% EFFECTIVENESS	50%	50%	50%	50%
$ SAVED PER VEHICLE/YEAR	$24.14	$22.68	$12.24	$12.87

DISCOUNT RATE 7.00% OVER 10 YEARS

BENEFIT/COST RATIO **0.51**

TOTAL SAVINGS/YR $71.93

NET SAVINGS/YR $71.93

Figure 11. Calculated Benefit/Cost Ratio of ESC

Table 2. Comparison of Benefit Cost Ratios (from Paine 2003)

Safety Feature	Initial Cost	Estimated B/C
Daytime running lights	$50	7.67
Seat belt pretensioner (front)	$100	1.12
ABS brakes	$400	0.83
Driver airbag	$600	0.81
Electronic Stability Control	$1000	0.51 (figure 11)
Side curtain	$400	0.20
Front passenger airbag	$400	0.19 (typical occupancy)
Traction control	$700	0.02

Despite the relatively high initial cost, ESC has a similar benefit/cost ratio to popular safety features such as driver and passenger airbags, side curtains and ABS brakes.

Discussion

Key researchers working in the field of vehicle dynamics have provided valuable advice about the status of research, the likely directions that policy will follow and the advantages and limitations of various tests and strategies. Most of the research is relevant to the encouragement of ESC through regulation or consumer test programs but none is sufficiently progressed to be adopted by ANCAP at this stage.

For the assessment of ESC, there are three main options to consider, as described succinctly by Iain Knight from TRL Limited (but covered in other comments). The first option has two possible levels of evidence and has been split into Options 1a and 1b in the following table.

Table 3. Options for Assessing ESC

Option to assess ESC	Advantages	Disadvantages
1a. Definition - "tick the box" if ESC, as defined, is fitted	• Simple to implement • No test costs	• Might be difficult to define ESC • Relies on manufacturer providing a "black box" that actually provides ESC • Does not assess the combination of ESC and vehicle • Unlikely to encourage ESC that will address real world situations
1b. Definition plus submission of technical information in accordance with Annex 18 of ECE Regulation 13. (preferred option of UN-ECE WP29 GRRF working group)	• Simple to implement • Minimal test costs - ESC should already be part of approval process for Regulation 13. • Addresses most safety concerns about complex electronic systems.	• Might be difficult to define ESC • Relies on manufacturer providing specific technical information (onerous) and the approval authority checking this information (unusual for ADRs). • Does not assess the combination of ESC and vehicle • Unlikely to encourage ESC that will address real world situations

Option to assess ESC	Advantages	Disadvantages
2. Specifying functional requirements - for example, electronic diagnostic checks to show that ESC is present and operational	• Simple to implement • Minimal test costs • A requirement for diagnostics can probably address the problem of truck/trailer combinations	• Difficult to cover a range of systems • Needs to be combined with Option 1b to ensure that system requirements are met. • Does not assess the combination of ESC and vehicle • Unlikely to encourage ESC that will address real world situations
3. Dynamic performance tests (favoured by NHTSA, car manufacturers, Euro NCAP dynamics group, Transport Canada and DV Experts)	• Tests the complete system (ESC and vehicle) • Some tests can relate directly to real world emergency situations • May also provide a test of rollover propensity	• Possible lack of suitable test • Needs to be combined with Option 1b to ensure that system requirements are met. • Cost of testing • Repeatability • Driver influence(unless steering machine used) • Relating test outcomes with real world safety • May not cover unusual events such as tyre blow-outs •

For light passenger vehicles it is considered that dynamic tests are preferable. NHTSA's current research program is the most comprehensive and advanced. However, NHTSA is focussing on tests that are suitable for steering machines. Although this approach has advantages such as good repeatability and no influence from driver skills, there is concern that the test does not relate to real world emergency situations. Daimler-Chrysler considers that the ISO 3888-2 (lane change with obstacle avoidance) is more realistic in this regard. However, preliminary (yet-to-be-published) tests by Transport Canada indicate that ISO 3888-2 is "likely to be unsuitable for regulatory purposes." Furthermore a NHTSA study that looked at tests for rollover propensity rated the ISO 3888-2 test as "bad" for objectivity and repeatability, "good" for performability, "very bad" for discriminatory capability (rollover propensity) and "excellent" for appearance of reality (Forkenbrock 2003).

Less demanding ISO 3888-1 tests have been conducted in Australia by DV Experts. These tests use performance metrics that may not have been considered by overseas researchers. Mr Richardson from DV Experts already has test results for a Ford Territory fitted with ESC (carried out for Victoria Police). Further tests could be conducted on a Ford Territory without ESC and for both vehicles (with and without ESC) using the ISO 3888-2 test. This would enable evaluation of each of the test methods (ISO 3888-1 and 3888-2) and their suitability for assessing ESC. An important feature of the DV Experts test is that lateral acceleration is limited to 70% of the theoretical roll limit. This makes a rollover very unlikely and usually eliminates the need for outriggers that might influence the vehicle handling (Elsasser 2003). On the other hand, the lower severity of the test might make it less able to discriminate vehicles with ESC. Research tests are needed to resolve these questions.

It is estimated that a suitable study, involving Ford Territories with and without ESC and the two ISO 3888 lane change tests, would cost about $50,000. This would include a review of the Transport Canada study that will soon be published and the NHTSA rollover study to determine if the Australian methods overcome difficulties encountered by Canadian and US researchers.

Recommendations

It is recommended that Australian authorities monitor overseas developments concerning the assessment of ESC. At this stage none of the surveyed overseas projects have produced a *performance-based* test protocol and/or rating system that is fully suitable for use in a consumer program (or regulation).

As a first step to regulating ESC, Option 1b from Table 2 could be utilised with minimal implementation effort. Under this option the regulation/protocol defines ESC and sets out functional requirements, including compliance with Annex 18 of ECE Regulation 13. In the case of commercial vehicles, manufacturers should already be providing most of the technical documentation required in the Annex because ESC meets the definition of a "complex electronic vehicle control system" under that regulation. Furthermore, it is expected that most car manufacturers would take Annex 18 into account when designing ESC systems, even though the Annex does not apply to cars. Implementation of this option would help to ensure that ESC did not have unintended adverse effects.

It is also recommended that a short research project be funded to evaluate the potential for an Australian-developed handling test (based on ISO 3888) to be used for assessing ESC. The estimated cost is $50,000.

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Appendix A – Selected Bibliography

Tingvell C, Krafft M, Kullgren A and Lie A, 2003, 'The effectiveness of electronic stability program (ESP) in reducing real life accidents', *Proceedings of 18th ESV,* Nagoya, May 2003.

> Real world accidents of vehicles with and without ESP were compared (with control methods). *Confidence intervals are very large* suggesting that either sample sizes are small or there is a large variation of the population. Subject to this concern, overall effectiveness (in stability-related accidents) was found to be 22%. On wet roads it was 32% and on icy roads it was 38%. Loss of control is a factor in 18% of all accidents and 34% of all fatal accidents. Hence ESP is judged to reduce all accidents by 4% and fatal accidents by 7%.

Kon K, Sekine H, Yano O and Sugishita H, 2003, 'Development of a technology to prevent deviation from an intended lane while turning using vehicle dynamics control', *Proceedings of 18th ESV,* Nagoya, May 2003.

> Experimental system that uses ABS-style sensors plus accelerometers to assess when limits of adhesion are being reached while cornering. Adjusts braking at individual wheels to maintain stability. 18% of Japanese traffic fatalities occur while a vehicle is cornering. In 59% of these driver error in the approach speed is judged to be a factor. One interesting idea is to combine the stability system with a navigation system that can anticipate the appropriate speed for the road ahead. Without this "anticipation" the stability control was found to be only marginally effective.

Langweider K, Gwehenberger J, Hummel T and Bende J, 2003, 'Benefit potential of ESP in real accident situations involving cars and trucks', *Proceedings of 18th ESV,* Nagoya, May 2003.

> Analysis of accident databases to estimate effectiveness of electronic stability programs (ESP). It is estimated that 60% of skidding accidents involve excessive steering input by the driver. These cases could be influenced by ESP. Between 20% and 25% of all German car accidents involve skidding. Therefore about 12% could be influenced by ESP. This suggets similar findings to Sweden – ESP could prevent about 5% of all car accidents. A reduction of up to 9% in truck accidents is possible.

Aga M and Okada A, 2003, 'Analysis of vehicle stability control (VSC) effectiveness for accident data', *Proceedings of 18th ESV,* Nagoya, May 2003.

> In Japan 20% of serious accidents are due to "loss of control". Analysis of cars with and without VSC indicate 35% fewer single car accidents and 30% fewer head-on collisions for cars with VSC. VSC appears to be more effective in high severity accident but sample sizes were too small.

Papelis Y, Brown T, Watson G, Holtz D and Pan, W, 2004, 'Study of ESC Assisted Driver Performance Using a Driving Simulator', University of Iowa, National Advanced Driving Simulator, Document ID: N04-003-PR.

"The goal of this study was to compare driver performance in critical loss of control situations both with and without the aid of Electronic Stability Control (ESC) systems. To accomplish this, an incursion, a tightening-radius curve, and a wind event were developed for use in the National Advanced Driving Simulator (NADS), and the implementation of two ESC systems, one on an Oldsmobile Intrigue and another on a Ford Excursion, was modeled and validated. A total of 120 participants from three age groups balanced by gender completed the study. Each participant experienced all of the events either with or without an ESC system. Results showed an 88% reduction in loss of control with the presence of an ESC system. Overall reductions in loss of control were observed for each of the events across gender and age groups. From this research, it is clear that ESC systems provide a significant safety benefit by helping drivers maintain control of their vehicles during critical steering maneuvers."