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(ECE/TRANS/132 and Corr.1)
Done at Geneva on 25 June 1998

Addendum

## Global technical regulation No. 8

ELECTRONIC STABILITY CONTROL SYSTEMS

(Established in the Global Registry on 26 June 2008)

**UNITED NATIONS**

GE.08-

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## A. STATEMENT OF TECHNICAL RATIONALE AND JUSTIFICATION

### 1. INTRODUCTION

1. In spite of the technological advances and regulatory efforts of the past few decades, the global burden to society associated with motor vehicle crashes remains considerable. According to the World Health Organization (WHO), each year there are more than one million fatalities and two million injuries in traffic crashes worldwide, and the global annual economic cost of road crashes is nearly $600 billion. These human and economic losses are distributed across regions, including approximately 40,000 fatalities annually in Europe, over 40,000 in the United States, over 90,000 in India, and over 100,000 in China. Therefore, regulators and others with an interest in vehicle safety and public health shall carefully monitor the development of new technologies, which may offer the potential to reduce the mortality, morbidity, and economic burdens associated with vehicle crashes. Current research demonstrates that electronic stability control (ESC) systems represent a mature technology, which could have the most significant life-saving potential since the advent of the seat belt. ESC systems are particularly effective in preventing single-vehicle, run-off-road crashes (many of which result in rollover).

2. Crash data studies conducted in the United States of America (U.S.), Europe, and Japan indicate that ESC is very effective in reducing single-vehicle crashes. Studies of the behaviour of ordinary drivers in critical driving situations (using a driving simulator) show a very large reduction in instances of loss of control when the vehicle is equipped with ESC, with estimates that ESC reduces single-vehicle crashes of passenger cars by 34 per cent and single-vehicle crashes of sport utility vehicles (SUVs) by 59 per cent. The same recent U.S. study showed that ESC prevents an estimated 71 per cent of passenger car rollovers and 84 per cent of SUV rollovers in single-vehicle crashes. ESC is also estimated to reduce some multi-vehicle crashes, but at a much lower rate than its effect on single-vehicle crashes. It is evident that the most effective way to reduce deaths and injuries in rollover crashes is to prevent the rollover crash from occurring, something which ESC can help accomplish by increasing the chances for the driver to maintain control and to keep the vehicle on the roadway. It is expected that potential benefits would be maximized by fleet-wide installation of ESC systems meeting the requirements of this gtr. The following discussion explains in further detail the nature of the identified safety problem and how ESC systems can act to mitigate that problem.

### 2. TARGET POPULATION: SINGLE-VEHICLE CRASH AND ROLLOVER STATISTICS

3. Although vehicle and road conditions may vary in different countries and regions, it is anticipated that the experience with ESC, as reported in European, U.S., and Japanese research studies, would be generally applicable across a range of driving environments. The following information, based upon statistical analyses of U.S. data is illustrative of the types of crashes that could potentially be impacted by a global technical regulation for ESC.

4. In the U.S., about one in seven light vehicles involved in police-reported crashes collide with something other than another vehicle. However, the proportion of these single-vehicle crashes increases steadily with increasing crash severity, and almost half of serious and fatal injuries occur in single-vehicle crashes. Of the 28,252 people who were killed as occupants of

light vehicles in the U.S., over half of these (15,007) occurred in single-vehicle crashes. Of these, 8,460 occurred in rollovers. About 1.1 million injuries (AIS 1-5) occurred in crashes that could be affected by ESC, almost 500,000 in single vehicle crashes (of which almost half were in rollovers). Multi-vehicle crashes that could be affected by ESC accounted for 13,245 fatalities and almost 600,000 injuries.

5. Rollover crashes are complex events that reflect the interaction of driver, road, vehicle, and environmental factors. The relationship between these factors and the risk of rollover can be described by using information from available crash data programs. According to 2004 U.S. data, 10,555 people were killed as occupants in light vehicle rollover crashes, which represents 33 per cent of all occupants killed that year in crashes in the U.S. Of those, 8,567 were killed in single-vehicle rollover crashes. Seventy-four per cent of the people who died in those single-vehicle rollover crashes were not using a seat belt, and 61 per cent were partially or completely ejected from the vehicle (including 50 per cent who were completely ejected). These data also show that 55 per cent of light vehicle occupant fatalities in single-vehicle crashes involved a rollover event.

6. Using U.S. data from 2000-2004, estimates show that 280,000 light vehicles were towed from a police-reported rollover crash each year (on average), and that 29,000 occupants of these vehicles were seriously injured. Of these 280,000 light vehicle rollover crashes, 230,000 were single-vehicle crashes. Sixty-two per cent of those people who suffered a serious injury in a single-vehicle tow-away rollover crash were not using a seat belt, and 52 per cent were partially or completely ejected (including 41 per cent who were completely ejected). Estimates from the data indicate that 82 per cent of tow-away rollovers were single-vehicle crashes, and that 88 per cent (202,000) of the single-vehicle rollover crashes occurred after the vehicle left the roadway. An audit of 1992-1996 U.S. data showed that about 95 per cent of rollovers in single-vehicle crashes were tripped by mechanisms such as curbs, soft soil, pot holes, guard rails, and wheel rims digging into the pavement, rather than by tyre/road interface friction as in the case of untripped rollover events.

## 3. OPERATION OF ESC SYSTEMS

7. Although ESC systems are currently known by many different trade names, their function and performance are similar. These systems use computer control of individual wheel brakes to help the driver maintain control of the vehicle during extreme manoeuvres by keeping the vehicle headed in the direction the driver is steering even when the vehicle nears or reaches the limits of road traction.

8. When a driver attempts an "extreme manoeuvre" (e.g., one initiated to avoid a crash or due to misjudgement of the severity of a curve), the driver may lose control if the vehicle responds differently as it nears the limits of road traction than it does during ordinary driving. The driver's loss of control can result in either the rear of the vehicle "spinning out" or the front of the vehicle "plowing out". As long as there is sufficient road traction, a highly skilled driver may be able to maintain control in many extreme manoeuvres using counter steering (i.e. momentarily turning away from the intended direction) and other techniques. However, average drivers in a panic situation in which the vehicle begins to spin out would be unlikely to counter steer to regain control.

9. In order to counter such situations in which loss of control may be imminent, ESC uses automatic braking of individual wheels to adjust the vehicle's heading if it departs from the direction the driver is steering. Thus, it prevents the heading from changing too quickly (spinning out) or not quickly enough (plowing out). Although it cannot increase the available traction, ESC affords the driver the maximum possibility of keeping the vehicle under control and on the road in an emergency manoeuvre using just the natural reaction of steering in the intended direction. Keeping the vehicle on the road prevents single-vehicle crashes, which are the circumstances that lead to most rollovers. However, there are limits to an ESC system's ability to intervene effectively in such situations. For example, if the speed is simply too great for the available road traction, even a vehicle with ESC will unavoidably drift off the road (but not spin out). Furthermore, ESC cannot prevent road departures due to driver inattention or drowsiness rather than loss of control. Nevertheless, available research from around the world has shown that given their high effectiveness rate, ESC systems would have a major life-saving impact, particularly once there is wide fleet penetration.

### (a) Mechanism of Action by Which ESC Prevents Loss of Vehicle Control

10. The following explanation of ESC operation illustrates the basic principle of yaw stability control. An ESC system maintains "yaw" (or heading) control by comparing the driver's intended heading with the vehicle's actual response, and automatically turning the vehicle if its response does not match the driver's intention. However, with ESC, turning is accomplished by applying counter torques from the braking system rather than from steering input. Speed and steering angle are used to determine the driver's intended heading. The vehicle response is determined in terms of lateral acceleration and yaw rate by onboard sensors. If the vehicle is responding in a manner corresponding to driver input, the yaw rate will be in balance with the speed and lateral acceleration.

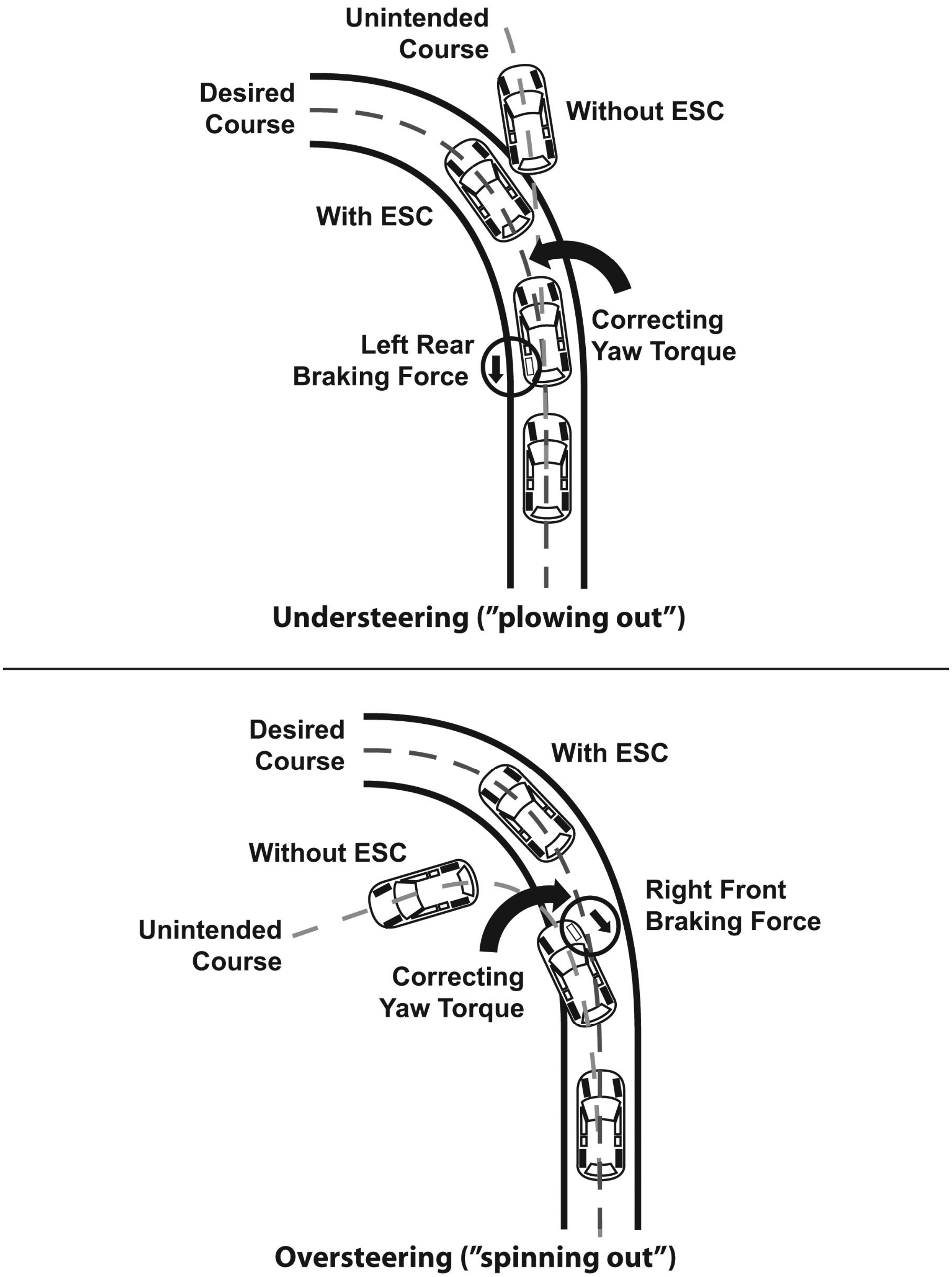
11. The concept of "yaw rate" can be illustrated by imagining the view from above a car following a large circle painted on a parking lot. One is looking at the top of the roof of the vehicle and seeing the circle. If the car starts in a heading pointed north and drives half way around the circle, its new heading is south. Its yaw angle has changed 180 degrees. If it takes 10 seconds to go half way around the circle, the "yaw rate" is 180 degrees per 10 seconds or 18 deg/sec. If the speed stays the same, the car is constantly rotating at a rate of 18 deg/sec around a vertical axis that can be imagined as piercing its roof. If the speed is doubled, the yaw rate increases to 36 deg/sec.

12. While driving in a circle, the driver notices that he shall hold the steering wheel tightly to avoid sliding laterally. The braking force is necessary to overcome the lateral acceleration that is caused by the car following the curve. The lateral acceleration is also measured by the ESC system. When the speed is doubled, the lateral acceleration increases by a factor of four if the vehicle follows the same circle. There is a fixed physical relationship between the car's speed, the radius of its circular path, and its lateral acceleration.

13. The ESC system uses this information as follows: Since the ESC system measures the car's speed and its lateral acceleration, it can compute the radius of the circle. Since it then has the radius of the circle and the car's speed, the ESC system can compute the correct yaw rate for

a car following the path. The system includes a yaw rate sensor, and it compares the actual measured yaw rate of the car to that computed for the path the car is following. If the computed and measured yaw rates begin to diverge as the car that is trying to follow the circle speeds up, it means the driver is beginning to lose control, even if the driver cannot yet sense it. Soon, an unassisted vehicle would have a heading significantly different from the desired path and would be out of control either by oversteering (spinning out) or understeering.

14. When the ESC system detects an imbalance between the measured yaw rate of a vehicle and the path defined by the vehicle's speed and lateral acceleration, the ESC system automatically intervenes to turn the vehicle. The automatic turning of the vehicle is accomplished by uneven brake application rather than by steering wheel movement. If only one wheel is braked, the uneven brake force will cause the vehicle's heading to change. Figure 1 below shows the action of ESC using single-wheel braking to correct the onset of oversteering or understeering.




<u>Figure 1</u>: ESC Interventions for Understeering and Oversteering

(i) <u>Oversteering</u>. In Figure 1 (bottom panel), the vehicle has entered a left curve that is extreme for the speed it is travelling. The rear of the vehicle begins to slide which would lead to a vehicle without ESC turning sideways (or "spinning out") unless the driver expertly countersteers. In a vehicle equipped with ESC, the system immediately detects that the vehicle's heading is changing more quickly than appropriate for the driver's intended path (i.e. the yaw rate is too high). It momentarily applies the right front brake to turn the heading of the vehicle back to the correct path. The action happens quickly so that the driver does not perceive the need for steering corrections. Even if the driver brakes because the curve is sharper than anticipated, the system is still capable of generating uneven braking if necessary to correct the heading.

(ii) Understeering. Figure 1 (top panel) shows a similar situation faced by a vehicle whose response as it nears the limits of road traction is to slide at the front ("plowing out" or understeering) rather than oversteering. In this situation, the ESC system rapidly detects that the vehicle's heading is changing less quickly than appropriate for the driver's intended path (i.e. the yaw rate is too low). It momentarily applies the left rear brake to turn the heading of the vehicle back to the correct path.

15. While Figure 1 may suggest that particular vehicles go out of control as either vehicles strictly prone to oversteer or vehicles strictly prone to understeer, it is just as likely that a given vehicle could require both understeer and oversteer interventions during progressive phases of a complex avoidance manoeuvre such as a double lane change.

16. Although ESC cannot change the tyre/road friction conditions the driver is confronted with in a critical situation, there are clear reasons to expect it to reduce loss-of-control crashes, as discussed below.

17. In vehicles without ESC, the response of the vehicle to steering inputs changes as the vehicle nears the limits of road traction. All the experience of the average driver is in operating the vehicle in its "linear range" (i.e. the range of lateral acceleration in which a given steering wheel movement produces a proportional change in the vehicle's heading). The driver merely turns the wheel the expected amount to produce the desired heading. Adjustments in heading are easy to achieve because the vehicle's response is proportional to the driver's steering input, and there is very little lag time between input and response. The car is traveling in the direction it is pointed, and the driver feels in control. However, at lateral accelerations above about one-half "g" on dry pavement for ordinary vehicles, the relationship between the driver's steering input and the vehicle's response changes (toward oversteer or understeer), and the lag time of the vehicle response can lengthen. When a driver encounters these changes during a panic situation, it adds to the likelihood that the driver will lose control and crash because the familiar actions learned by driving in the linear range would not be the correct steering actions.

18. However, ordinary linear range driving skills are much more likely to be adequate for a driver of an ESC-equipped vehicle to avoid loss of control in a panic situation. By monitoring yaw rate and sideslip, ESC can intervene early in the impending loss-of–control situation with the appropriate brake forces necessary to restore yaw stability before the driver would attempt an over-correction or other error. The net effect of ESC is that the driver's ordinary driving actions learned in linear range driving are the correct actions to control the vehicle in an emergency.

Also, the vehicle will not change its heading from the desired path in a way that would induce further panic in a driver facing a critical situation.

19. Besides allowing drivers to cope with emergency manoeuvres and slippery pavement using only "linear range" skills, ESC provides more powerful control interventions than those available to even expert drivers of non-ESC vehicles. For all practical purposes, the yaw control actions with non-ESC vehicles are limited to steering. However, as the tyres approach the maximum lateral force sustainable under the available pavement friction, the yaw moment generated by a given increment of steering angle is much less than at the low lateral forces occurring in regular driving. 1/ This means that as the vehicle approaches its maximum cornering capability, the ability of the steering system to turn the vehicle is greatly diminished, even in the hands of an expert driver. ESC creates the yaw moment to turn the vehicle using braking at an individual wheel rather than the steering system. This intervention remains powerful even at limits of tyre traction because both the braking force of the individual tyre and the reduction of lateral force that accompanies the braking force act to create the desired yaw moment. Therefore, ESC can be especially beneficial on slippery surfaces. While a vehicle's possibility of staying on the road in a critical manoeuvre ultimately is limited by the tyre/pavement friction, ESC maximizes an ordinary driver's ability to use the available friction.

(b) Additional Features of Some ESC Systems

20. In addition to the basic operation of "yaw stability control," many ESC systems include additional features. For example, most systems also reduce engine power during intervention to slow the vehicle and give it a better chance of being able to stay on the intended path after its heading has been corrected.

21. Other ESC systems may go further by performing high deceleration automatic braking at all four wheels. Of course, such braking would be performed unevenly side to side so that the same net yaw torque or "turning force" would be applied to the vehicle as in the basic case of single-wheel braking.

22. ESC systems used on vehicles with a high centre of gravity (c.g.), such as SUVs, are often programmed to perform an additional function known as "roll stability control". Roll stability control (RSC) is a direct countermeasure for on-pavement rollover crashes of high c.g. vehicles. Some RSC systems measure the roll angle of the vehicle using an additional roll rate sensor to determine if the vehicle is in danger of tipping up. Other systems rely on the existing ESC sensors for steering angle, speed, and lateral acceleration, along with knowledge of vehicle-specific characteristics to estimate whether the vehicle is in danger of tipping up.

23. Regardless of the method used to detect the risk of tip-up, the various types of roll stability control intervene in the same way. Specifically, they intervene by reducing lateral acceleration which is the cause of the roll motion of the vehicle on its suspension, thus preventing the possibility of it rolling so much that the inside wheels may lift off the pavement. The intervention is performed the same way as the oversteer intervention shown in the Figure 1.

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1/ Liebemann et al, (2005) Safety and Performance Enhancement: The Bosch Electronic Stability Control (ESP), 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Washington, DC.

The outside front brake is applied heavily to turn the vehicle toward a path of less curvature and, therefore, less lateral acceleration.

24. The difference between a roll stability control intervention and an oversteer intervention by the ESC system operating in the basic yaw stability control mode is the triggering circumstance. The oversteer intervention occurs when the vehicle's excessive yaw rate indicates that its heading is departing from the driver's intended path, but the roll stability control intervention occurs when there is a risk the vehicle could roll over. Thus, the roll stability control intervention occurs when the vehicle is still following the driver's intended path. The obvious trade-off of roll stability control is that the vehicle shall depart to some extent from the driver's intended path in order to reduce the lateral acceleration from the level that could cause tip-up.

25. If the determination of impending rollover that triggers the roll stability intervention is very certain, then the possibility of the vehicle leaving the roadway as a result of the roll stability intervention represents a lower relative risk to the driver. Obviously, the most effective systems are ones that intervene only when absolutely necessary and then with the minimum loss of lateral acceleration to prevent rollover. However, roll stability control is a new technology that is still evolving.

26. Furthermore, there is currently insufficient data to evaluate the effectiveness of many of these additional features, including roll stability control, either because their implementation is not widespread or because it is too soon for actual crash statistics to illuminate its practical effect on crash reduction. This is in contrast to the fundamental ESC system described above for which a substantial amount of data exists.

## 4. EFFECTIVENESS OF ESC SYSTEMS

### (a) Overview of ESC Effectiveness in Preventing Single-Vehicle and Rollover Crashes

27. The following discussion explains in detail relevant research findings related to the anticipated effectiveness of ESC systems. Electronic stability control can directly reduce a vehicle's susceptibility to on-road untripped rollovers as measured by the "fishhook" test. The direct effect is mostly limited to untripped rollovers on paved surfaces. However, untripped on-road rollovers are a relatively infrequent type of rollover crash.

28. In contrast, the vast majority of rollover crashes occur when a vehicle runs off the road and strikes a tripping mechanism such as soft soil, a ditch, a curb or a guardrail. The purpose of ESC is to assist the driver in keeping the vehicle on the road during impending loss-of-control situations. In this way, it can prevent the exposure of vehicles to off-road tripping mechanisms.

29. Although ESC is an indirect countermeasure to prevent rollover crashes, it is anticipated to be the most powerful countermeasure available to address this serious risk. Effectiveness studies worldwide 2/ estimate that ESC can reduce single-vehicle crashes by at least one-third in passenger cars and perhaps reduce loss-of-control crashes (e.g., road departures leading to rollovers) by an even greater amount. Thus, it is estimated that ESC can reduce the numbers of rollovers of all vehicles, including lower centre of gravity vehicles (e.g., passenger cars, minivans and two-wheel-drive pickup trucks), as well as of the higher centre of gravity vehicle types (e.g., SUVs and four-wheel-drive pickup trucks). ESC can affect both crashes that would have resulted in rollover as well as other types of crashes (e.g., road departures resulting in impacts) that result in deaths and injuries.

(b) Human Factors Study on ESC Effectiveness

30. A U.S. study conducted in 2004 demonstrated the effect of ESC on the ability of ordinary drivers to maintain control in critical situations.3/ In that study, a sample of 120 drivers equally divided between men and women and between three age groups (18-25, 30-40, and 55-65) was subjected to the following three critical driving scenarios. The "Incursion Scenario" forced drivers to attempt a double lane change at high speed (65 mph speed limit signs) by presenting them first with a vehicle that suddenly backs into their lane from a driveway and then with another vehicle driving toward them in the left lane. The "Curve Departure Scenario" presented drivers with a constant radius curve that was uneventful at the posted speed limit of 65 mph (105 km/h) followed by another curve that appeared to be similar but that had a decreasing radius that was not evident upon entry.

31. The "Wind Gust Scenario" presented drivers with a sudden lateral wind gust of short duration that pushed the drivers toward a lane of oncoming traffic. The 120 drivers were further divided evenly between two vehicles; a SUV and a midsize sedan. Half the drivers of each vehicle drove with ESC enabled, and half drove with ESC disabled.

32. In 50 of the 179 test runs performed in a vehicle without ESC, the driver lost control. In contrast, in only six of the 179 test runs performed in a vehicle with ESC did the driver lose control. One test run in each ESC operating status had to be aborted. These results demonstrate an 88 per cent reduction in loss-of-control crashes when ESC was engaged. The study also concluded that the presence of an ESC system helped reduce loss of control regardless of age or gender, and that the benefit was substantially the same for the different driver subgroups in the study.

2/ See Aga M, Okada A. (2003) Analysis of Vehicle Stability Control (VSC)'s Effectiveness from Accident Data, 18th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Nagoya. See also Dang, J. (2004) Preliminary Results Analyzing Effectiveness of Electronic Stability Control (ESC) Systems, Report No. DOT HS 809 790. U.S. Dept. of Transportation, Washington, DC; Farmer, C. (2004) Effect of Electronic Stability Control on Automobile Crash Risk, Traffic Injury Prevention, Vol. 5:317-325; Kreiss J-P, et al. (2005) The Effectiveness of Primary Safety Features in Passenger Cars in Germany, 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Washington, DC; and Lie A., et al. (2005) The Effectiveness of ESC (Electronic Stability Control) in Reducing Real Life Crashes and Injuries, 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Washington, DC.

3/ Papelis et al. (2004) Study of ESC Assisted Driver Performance Using a Driving Simulator, Report No. N04-003-PR, University of Iowa.

(c) Crash Data Studies of ESC Effectiveness

33. There have been a number of studies of ESC effectiveness in Europe and Japan beginning in 2003. 4/ All of them have shown large potential reductions in single-vehicle crashes as a result of ESC. Additionally, a preliminary U.S. study published in September 2004 5/ of crash data from 1997-2003 found ESC to be effective in reducing single-vehicle crashes, including rollover. Among vehicles in the study, the results suggested that ESC reduced single-vehicle crashes in passenger cars by 35 per cent and in SUVs by 67 per cent.

34. A later peer-reviewed study 6/ of ESC effectiveness found that ESC reduced single-vehicle crashes in passenger cars by 34 per cent and in SUVs by 59 per cent, and that its effectiveness was greatest in reducing single-vehicle crashes resulting in rollover (71 per cent reduction for passenger cars and an 84 per cent reduction for SUVs). It also found reductions in fatal single-vehicle crashes and fatal single-vehicle rollover crashes that were commensurate with the overall crash reductions cited. ESC reduced fatal single-vehicle crashes in passenger cars by 35 per cent and in SUVs by 67 per cent and reduced fatal single-vehicle crashes involving rollover by 69 per cent in passenger cars and 88 per cent in SUVs.

5. INPUT ON THE SUBSTANCE OF THE ESC GTR

35. The substantive content of this global technical regulation for ESC was developed with the input of a variety of interested parties, including the Contracting Parties to the 1998 Agreement, other governmental representatives, automobile manufacturers and trade associations, the automobile equipment trade association, and safety advocacy organizations. In addition, international automobile manufacturers conducted testing with a broad array of ESC-equipped vehicles in order to assess potential performance criteria for evaluating ESC systems. Thus, the ESC gtr has undergone a thorough vetting by not only government regulators from the Contracting Parties, but also from the automotive industry and the safety community.

36. The overwhelming majority of these participants supported establishing a technical regulation for ESC systems installed on new light vehicles. Indeed, the difference of opinion among the participants involved the stringency of the standard and the test procedures. Other topics included making the "ESC System" definition more performance-based, lateral responsiveness criteria, ESC performance requirements, ESC malfunction detection requirements, ESC tell-tale requirements, system disablement and the "ESC Off" switch, test procedures, and impacts on the aftermarket, among other things. In discussing the provisions set forth as part of this gtr, this document addresses the issues raised by these participants and the positions expressed on these topics.

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4/ See Footnote 3.
5/ Dang, J. (2004) Preliminary results analyzing effectiveness of Electronic Stability Control (ESC) Systems, Report DOT HS 809 790, U.S. Department of Transportation, Washington, DC.
6/ Dang, J., Statistical Analysis of the Effectiveness of Electronic Stability Control (ESC) Systems, Final Report DOT HS 810 794, U.S. Department of Transportation, Washington, DC.

## 6. DISCUSSION OF KEY ISSUES

37. The proposed gtr provides performance requirements (established through a combination of the definition of "Electronic Stability Control System" and specified dynamic tests) that ESC-equipped vehicles shall meet in order to comply with the requirements of the gtr. This gtr applies to all Category 1-1, 1-2, and 2 vehicles with a gross vehicle mass (GVM) of 4,536 kg or less.

### (a) Applicability

38. As noted above, this gtr applies to all Category 1-1, 1-2, and 2 vehicles with a GVM of 4,536 kg or less.

39. The gtr excludes heavier vehicles because the different structural and handling characteristics of those vehicle may necessitate different ESC system designs and entirely new test procedures. Thus, ESC systems for heavier vehicles would not be regulated by the gtr at this time.

40. Furthermore, if a jurisdiction determines that its domestic regulatory scheme is such that full applicability is inappropriate, it may limit domestic regulation to a narrower group of vehicles. The jurisdiction could also decide to phase-in the ESC requirements or delay implementation for a few years.

#### (i) Vehicles with dual wheels on the rear axle and vehicles with double rear axles

41. According to the automobile industry, there are a small number (unspecified) of incomplete vehicles with a GVM of 4,536 kg or less that are equipped with dual wheels on the rear axle ("dualies", typically completed as commercial vehicles), as well as vehicles with double or multiple rear axles, which require their own unique ESC calibration. Based upon their small number and unusual calibration needs, the industry recommended that these vehicles be excluded from the gtr's applicability.

42. Although "dualies" and vehicles with double rear axles may require manufacturers to make certain technical adjustments in their ESC systems, to the extent that such vehicles fall within the scope of applicable vehicles, they are subject to the requirements of this gtr.

(b) Definitions

43. One of the key elements of the gtr is the definition of "Electronic Stability Control System". The definitional requirements specify the necessary elements of a stability control system that is capable of both effective oversteer and understeer intervention. These requirements are necessary due to the extreme difficulty in establishing tests adequate, by themselves, to ensure the desired level of ESC functionality in a variety of circumstances. **7**/ The test that is being adopted is necessary to ensure that the ESC system is robust and meets a level of performance at least comparable to that of current production ESC systems.

44. Consistent with the definition of ESC contained in a voluntary consensus standard, the Society of Automotive Engineers (SAE) 8/ Surface Vehicle Information Report J2564 (rev. June 2004), vehicles covered under the standard are required to be equipped with an ESC system:

(i) That improves vehicle directional stability by at least having the ability to automatically control individually the vehicle braking torques of the left and right wheels on each axle or an axle of each axle group 9/ to induce a correcting yaw moment based on the evaluation of actual vehicle behaviour in comparison with a determination of vehicle behaviour demanded by the driver;

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**7**/ An equipment requirement is necessary because it would be almost impossible to devise a single performance test that could not be met through some action by the manufacturer other than providing an ESC system. Establishing a battery of performance tests to achieve the intended results is not possible at this time because it has not been possible to develop a practical, repeatable limit-understeer test, and there are no applicable tests in vehicle dynamics literature. Although preliminary research efforts were undertaken in the United Stated related to understeer, it was determined that the complexity of such research would require several years of additional work before any conclusions could be reached regarding an ESC understeer performance test.

Given this, three available options were identified: (1) delay the ESC gtr and conduct research and development; (2) drop the understeer requirement and amend the gtr once an ESC performance test is developed; or (3) include a requirement for understeer as part of the definition of "ESC System," along with requiring specific components that will permit the system to intervene in excessive understeer situations.

The first and second options were eliminated on the grounds of safety.

The third option, adopting an understeer requirement as part of the definition of "ESC System," along with a requirement for specific equipment suitable for that purpose, was determined to be most appropriate for accomplishing the safety purposes and related benefits of the gtr. Such a requirement is objective in terms of explaining to manufacturers what type of performance is required and the minimal equipment necessary for that purpose. Contracting Parties can verify that the system has the necessary hardware and logic for understeer mitigation. Since the necessary components for effective understeer intervention are already present on all ESC systems, it is anticipated that manufacturers are highly unlikely to decrease their ESC systems' understeer capabilities simply because the regulation does not currently have a specific test for understeer. It is expected that this approach will ensure that vehicle manufacturers maintain understeer intervention as a feature of the ESC system, without delaying the life-saving benefits of the ESC gtr. In the meantime, additional research may be undertaken in the area of ESC understeer intervention and additional action may be taken, as appropriate.

Even with an understeer test, the ultimate practicability of a standard without an equipment requirement remains in doubt because of the possible large number of test conditions that would be required.

8/ The Society of Automotive Engineers is an association of engineers, business executives, educators, and students who share information and exchange ideas for advancing the engineering of mobility systems. SAE currently has over 90,000 members in approximately 97 countries. The organization's activities include development of standards, events, and technical information and expertise used in designing, building, maintaining, and operating self-propelled vehicles for use on land or sea, in air or space. See <http://www.sae.org>.

9/ An axle group shall be treated as a single axle and dual wheels shall be treated as a single wheel.

(ii) That is computer-controlled with the computer using a closed-loop algorithm to limit vehicle oversteer and to limit vehicle understeer based on the evaluation of actual vehicle behaviour in comparison with a determination of vehicle behaviour demanded by the driver;

(iii That has a means to directly determine the value of the vehicle's yaw rate 10/ and to estimate its sideslip 11/ or sideslip derivative 12/ with respect to time;

(iv) That has a means to monitor driver steering inputs; and

(v) That has an algorithm to determine the need, and a means to modify propulsion torque as necessary, to assist the driver in maintaining control of the vehicle.

The ESC system shall meet additional specific functional requirements besides the definition, as follows:

(i) Be capable of applying braking torques individually to all four wheels 13/ and have a control algorithm that utilizes this capability;

(ii) Be operational over the full speed range of the vehicle, during all phases of driving including acceleration, coasting, and deceleration (including braking), except:

a. When the driver has disabled ESC;

b. When the vehicle speed is below 20 km/h;

c. While the initial start-up self-test and plausibility checks are completed, not to exceed 2 minutes when driven under the conditions of paragraph 7.10.2.; and

d. When the vehicle is being driven in reverse.

(iii) Remain capable of activation even if the antilock brake system or traction control system is also activated.

45. The gtr also specifies a number of other definitions intended to clarify the operation of ESC systems or related performance testing. Specifically, definitions are provided for the following terms: (1) "Ackerman Steer Angle"; (2) "Lateral Acceleration"; (3) "Oversteer"; (4) "Sideslip or side slip angle"; (5) "Understeer"; (6) "Yaw rate"; and "SSF".

46. The gtr does not require the ESC system to be operable when the vehicle is being driven in reverse, because such provision would necessitate costly changes to current ESC systems with no anticipated safety benefit. The main safety problems associated with the vehicle operating in reverse are backing into/over pedestrians, backing over edges (drop-offs), and backing into inanimate objects (e.g., other vehicles, buildings). ESC is not expected to help prevent any of these types of crashes. Furthermore, vehicles are rarely driven rapidly in reverse, so the provision that ESC need not function when "the vehicle speed is below 20 km/h" means that ESC would typically not have to be active when the vehicle is in reverse.

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10/ "Yaw rate" means the rate of change of the vehicle's heading angle (measured in degrees/second) of rotation about a vertical axis through the vehicle's center of gravity.

11/ "Sideslip" means the arctangent of the lateral velocity of the center of gravity of the vehicle, divided by the longitudinal velocity of the center of gravity.

12/ Because sideslip and the time derivative of sideslip are intimately mathematically related, when one of these values is known, it is then possible to determine the other. This global technical regulation permits this key value for ESC operation to be determined by either means.

13/ Dual wheels shall be treated as a single wheel, and a twin axle group shall be treated as a single axle.

47. The gtr acknowledges that the ESC system, the antilock brake system, and any traction control system on current vehicles tend not to be functionally separate but instead to be integrated into a single system, all of which utilize the vehicle's brake control system to accomplish their intended stability enhancement goals. In order to allow subsystem arbitration to occur as needed to optimize ESC performance, the regulation makes clear that the vehicle's design logic for activation of these systems may be integrated so that these systems can work in unison to address vehicle instabilities.

48. When defining the ESC hardware and software requirements for the gtr, the focus was on specific technologies known to be effective in reducing real world crashes, rather than systems or features that only theoretically might have a safety impact. For example, inclusion of a provision related to sideslip of the tyre contact patch was recommended. However, although contemporary ESC systems meet the definitional requirements of this regulation, they do not necessarily estimate the sideslip of the tyre contact patch, and an effective technology for measuring the sideslip of the tyre contact patch has not been demonstrated. While it is encouraging to learn of new technologies that may improve vehicle safety, quantifying their effectiveness is not possible until crash data become available, even if one would theoretically expect the alternative technology to affect vehicle performance in a similar manner as the proven technology. Therefore, absent such effectiveness data for ESC-type systems that estimate the sideslip of the tyre contact patch (instead of determining the vehicle's yaw rate, or estimating the vehicle's sideslip, and monitoring the driver's steering inputs), it is not reasonable to treat them as equivalent to those ESC systems which have demonstrated that they can save thousands of lives each year.

(c) General Requirements

49. In addition to the definitional requirements discussed above, ESC systems shall also meet the following additional requirements of the gtr.

(i) Basic System Operation

50. The ESC system, as defined above, is required to be capable of applying braking torques individually at all four wheels and to have an algorithm that utilizes this capability. 14/ Except for the situations specifically set forth in part (b) of the definition of "ESC System" above, the system is also required to be operational during all phases of driving, including acceleration, coasting, and deceleration (including braking). The ESC system is required to be capable of activation even if the anti-lock brake system or traction control system is also activated.

51. In adopting the combination of ESC definitional and performance requirements set forth in this gtr, the Contracting Parties express their intention to spread the proven safety benefits of current ESC systems across the global light vehicle fleet as rapidly as possible. Available information shows that current brake-based ESC systems are effective and meet the need for motor vehicle safety. There is currently no information to demonstrate the efficacy of the ESC-

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14/ The gtr was developed based on new vehicles produced in 2005 and 2006. The definition of ESC is limited to four-wheel ESC systems because existing two-wheel ESC systems are not capable of understeer intervention or four-wheel automatic braking during an intervention, even though these systems also produced substantial (but lesser) benefits.

related technologies which some stakeholders have suggested as alternatives to brake-based ESC systems (e.g., active steering systems (Active Front Steer, Active Rear Steer, Steer by Wire, Electric Power Steering), active drivetrains (Active Differentials, Electronic Limited Slip Differentials, Electric Motor/Generator Devices for Propulsion/Braking), and active suspensions (Active Stabilizer Bars, Active Dampers, Active Springs), automatic braking, traction control, brake assist and roll stability control).

52. Furthermore, it is possible for a vehicle without ESC to be optimized to avoid spin-out in the narrowly defined conditions of the ESC oversteer intervention test (especially if the regulation is silent on understeer) but to lack the advantages of ESC under other conditions. It has been determined that it is not currently feasible to develop a comprehensive battery of tests that could substitute for the knowledge of what equipment constitutes ESC, and it remains to be seen if such an approach would ever be practical to set a purely performance-based standard that would ensure that manufacturers provide at least current ESC systems. Therefore, the gtr's definition of "ESC System" is necessary in order to ensure that vehicles subject to this regulation have the attributes of ESC systems that produced the large reduction of single-vehicle crashes and rollovers in recent crash data studies. The following discussion explains the identified obstacles to a strictly performance-based approach.

53. Among the challenges associated with developing a performance test for ESC, it should be noted that manufacturers develop ESC algorithms using tests whose conditions are generally not repeatable (e.g., icy surfaces which change by the minute, wet/slippery surfaces which are not repeatable day-to-day) and through simulation. Manufacturers also use hundreds of conditions requiring weeks of testing for a given vehicle. However, it is not practicable to use these approaches as part of a safety regulation. In contrast, this gtr is objective and is expected to generate repeatable results.

54. It is possible to overcome these limitations through the gtr's use of a definition of "ESC System," which is based on a Society of Automotive Engineers definition of what ESC is, and which includes those elements that account for the cost of those systems. There is no reason to believe that manufacturers will incur all the costs of the ESC equipment and capabilities required by the regulation's definition and then just program the system to achieve limited operation restricted to the test conditions of the gtr. The regulation's definitional requirement for "ESC System" requires, at a minimum, the equipment and capabilities of existing ESC system designs. This translates into the substantial fatality and injury benefits provided by existing ESC systems.

55. Without the definition of "ESC System," it would not be feasible to assess comprehensively the operating range of resulting devices, particularly for understeer intervention, that might be installed in compliance with the safety standards. If manufacturers were to optimize the vehicle so as to pass only a few highly-defined tests, the public would not receive the full safety benefits provided by current ESC systems. 15/

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15/ The U.S. Environmental Protection Agency (EPA) experienced problems with heavy duty diesel manufacturers' production of engines that met EPA standards during laboratory testing under EPA procedures but were turned off under highway driving conditions. On 22 October 1998, the U.S. Department of Justice and EPA announced a settlement with seven major diesel engine manufacturers. Accordingly, it is not believed that the industry's ability to circumvent the requirements of the standard is a theoretical one, as would permit us to forgo a definition for "ESC System".

56. Some participants listed a number of systems and components that can influence wheel forces and suggested that it should be permissible for the definition of ESC to be satisfied by systems that can generate wheel force (i.e. a requirement more open than compelling a system that shall operate through brake forces). However, data were not provided to show the effectiveness of such systems, as would demonstrate that they meet the need for motor vehicle safety and that it would be appropriate to substitute them for proven brake-based ESC systems. Instead, there are good reasons for the gtr, at least initially, to be based on braking forces. While some of the devices mentioned could create yaw moments (for ESC interventions) by driving torques 16/, yaw moments created by braking torques have an advantage in critical situations because they also cause the vehicle to slow down.

57. Some participants mentioned a number of steering-related concepts for consideration as performance requirements that could be used as part of the gtr. One specific example included using active steering interventions (in a vehicle that combines steering and braking in its ESC). However, while active steering may be useful in certain situations, the steering interventions may not be very helpful at or near the limit of traction, which is arguably the critical situation to be addressed by the gtr. Again, braking forces have an advantage over steering forces because they can create a more powerful yaw intervention when the vehicle is at the limit of traction. 17/

58. To clarify, the gtr in no way prohibits the addition of refinements (e.g., active steering) to vehicles that retain the ability to create yaw moments with brake torques when necessary. The vehicles in question retain the brake-based ESC as the backstop for stability, because the brake interventions which are more noticeable to drivers retain their power in situations where the transparent steering interventions might not be powerful enough. Without data to assess the effectiveness of these potential alternative operating features for ESC, it would not be appropriate at this time to abandon the requirement for brake torque-based systems which have proven benefits, in favour of concepts that have not yet demonstrated any safety benefits, much less the enormous benefits associated with current brake torque-based ESC systems.

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16/ "Driving torque" is a force applied by the engine through the drive train in order to make a particular wheel turn faster than the others—similar to "braking torque" which brakes one wheel to make it turn slower than the others. Either force can be utilized by an ESC system to change the heading of the vehicle, although braking torque has the added benefit of helping slow the vehicle down.

17/ Liebemann et al, Safety and Performance Enhancement: The Bosch Electronic Stability Control (ESP), 2005 ESC Conference.

59. Furthermore, all of these other ESC-related components (including roll stability control 18/) lack supporting data to assess their effectiveness and to determine whether such technologies meet the need for safety. The commonality of design for ESC systems in the studies used to develop this regulation focused on individual brake application and engine control, and at least one industry association (the 'Verband der Automobilindustrie') stated that the definition for "ESC system" captures the state-of-the-art. Again, even though certain later ESC designs incorporate some additional features, it was not possible to determine the safety benefits, if any, of these features because these features were not available on any of the ESC-equipped vehicles in the crash data study. Also, some of those features are directed at comfort and convenience rather than safety.

60. Based upon the above consideration, it was concluded that there is no good reason to postpone the proven life-saving benefits of basic ESC systems until such time as necessary research could be conducted to assess the panoply of related components. Thus, instead of specifying additional components as part of the regulation's definition for "ESC system," it is left to the discretion of vehicle manufacturers to tailor the features of their individual ESC systems to the needs of a given vehicle. The gtr does not limit manufacturers' ability to develop, install, and advertise stability control systems that go beyond its requirements.

61. It is acknowledged that in requiring ESC as it now exists and has proven to be beneficial, the gtr may be indirectly impacting hypothetical future technological innovations. Should new advances lead to forms of ESC different than those currently required by this regulation, Contracting Parties may seek to modify this gtr. It is also noted that the vehicle manufacturers who are the directly regulated parties have not opposed using the definition for "ESC System" as the primary requirement of the gtr, and some have actively supported it.

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18/ "Roll stability control" senses the vehicle's body roll angle and applies high brake force to the outside front wheel to straighten the vehicle's path and reduce lateral acceleration if the roll angle indicates probable tip-up.

However, roll stability control was not responsible for the huge reduction in rollovers in single-vehicle crashes of 71 per cent for cars and 84 per cent for SUVs. None of the vehicles in the U.S. crash data study had roll stability control. The crash data study was a study of the benefits of yaw stability control. The first light vehicle with roll stability control was the 2003 Volvo XC90 which was not in the data study because it was a new vehicle without a non-ESC version that could serve as a control vehicle. It is also a low-production-volume vehicle that would have produced very few crash counts in the 1997-2003 crash data of the study. A similar roll stability control system was used on high-volume Ford Explorers starting in 2005, and eventually there should be enough Explorer data to evaluate the effectiveness of roll stability control through analysis of crash data (i.e. in approximately three to four years).

However, because the data study showed yaw stability control reducing rollovers of SUVs by 84 per cent by reducing and mitigating road departures, and because on-road untripped rollovers are much less common events, the target population of crashes that roll stability control could possibly prevent may be very small. If and when roll stability control can be shown to be cost-effective, then it could be a candidate for inclusion in the gtr.

In addition, the countermeasure of roll stability control systems is at least theoretically not benign. It reduces lateral acceleration by turning the vehicle away from the direction the driver is steering for at least a short distance. Several participants expressed strong dissatisfaction with a mandatory safety device in which the driver yields at least some measure of vehicle control to a computer (e.g., ESC engine control causing the system to override the driver's throttle control). This was an inaccurate criticism of a pure yaw stability control system, because such a system would help the vehicle go in the direction the driver is steering. However, requiring systems that actually countermand the driver's steering control requires a high level of justification, a hurdle which roll stability control cannot yet surmount due to the newness of the technology and the corresponding lack of available data.

a. ESC Initialization Period

62. Most ESC systems typically require a short initialization period after the start of each new ignition cycle, during which time the ESC system is not operational because it is performing diagnostic checks and sensor signal correlation updates. According to ESC manufacturers, the duration of this ESC initialization interval may depend upon several factors, including distance travelled, speed, and/or signal magnitudes. In order to account for such initialization periods, the regulation makes clear that ESC does not need to be active when the vehicle speed is below 20 km/h. Therefore, the ESC manufacturer has a short period of time, from the time the vehicle's ignition is turned on to the time when the vehicle speed first exceeds 20 km/h to initialize ESC. The process of initializing ESC is, in many ways, similar to the process of initializing ABS. ABS systems typically have completed their initialization by the time the vehicle reaches speeds of 5 km/h to 9 km/h. Therefore, it is anticipated that allowing up to a speed of 20km/h should be adequate to initialize ESC.

63. Industry participants pointed out that some types of diagnostic checks cannot be performed unless the vehicle is making turns or travelling at relatively high speeds. Accordingly, the regulation's test procedure accommodates these types of diagnostic checks. ESC manufacturers can assume that the ESC has not malfunctioned and make the system operational once driving situations occur that permit these diagnostic checks to be performed.

b. ESC Calibration

64. Determining when ESC intervention shall occur is a complicated balance of effectiveness and intrusiveness. As such, one of the challenges of designing ESC control algorithms is how to anticipate when a loss-of-control situation may occur. The Sine with Dwell manoeuvre, and the lateral stability and responsiveness performance criteria that evaluate the test output, provide an excellent way of assessing ESC system performance for all light vehicles. By successfully satisfying these minimum performance requirements, it is anticipated that the ESC system will perform in an effective manner.

(ii) <u>Malfunction Detection</u>

65. Because the benefits of the ESC system can only be realized if the system is functioning properly, the system shall be able to detect and alert the driver of ESC system malfunctions (through illumination of a tell-tale described below). The regulation requires that the vehicle shall be equipped with a tell-tale that provides a warning to the driver not more than two minutes after the occurrence of one or more malfunctions that affect the generation or transmission of control or response signals in the vehicle's ESC system. The regulation also sets forth the following additional requirement related to ESC malfunction detection.

66. Specifically, the ESC malfunction tell-tale shall be mounted inside the occupant compartment in front of and in clear view of the driver and be identified by the symbol shown for "ESC Malfunction Tell-tale" as described in this regulation. The ESC malfunction tell-tale shall remain continuously illuminated under the conditions specified in the regulation for as long as the malfunction(s) exists, whenever the ignition locking system is in the "On" ("Run") position, and except as otherwise provided, each ESC malfunction tell-tale shall be activated as a

check of lamp function either when the ignition locking system is turned to the "On" ("Run") position when the engine is not running, or when the ignition locking system is in a position between "On" ("Run") and "Start" that is designated by the manufacturer as a check position. The ESC malfunction tell-tale need not be activated when a starter interlock is in operation. The ESC malfunction tell-tale shall extinguish after the malfunction has been corrected. Manufacturers may use the ESC malfunction tell-tale in a flashing mode to indicate ESC operation.

a. Types of Malfunctions to be detected

67. Regarding the issue of which vehicle components are subject to ESC malfunction testing, a rule of reason applies. Simply stated, if a vehicle malfunction was to affect the generation or transmission of control or response signals in the vehicle's electronic stability control system, it shall be detectable by the ESC system. In other words, if the malfunction impacts the functionality of the ESC system, the ESC system shall be capable of detecting it. For shared or connected components, a malfunction need only be detected to the extent it may impact the ESC system's operation. Manufacturers are in the best position to know the vehicle components involved in ESC operation.

b. Practicability Issues with ESC Malfunction Detection

68. The regulation specifies that disconnections and connections of ESC components are to be made with the power turned off, in order to prevent the risk of harm to technicians.

69. The gtr intends to ensure that ESC malfunctions are detected within a reasonable time after the start of driving. The language adopted specifically provides that the vehicle should be driven during the proposed two-minute period so that the parts of its malfunction detection capability which depend on vehicle motion can operate.

70. Furthermore, in response to industry input, the gtr clarifies that the ESC system is not expected to maintain its monitoring capability with ignition turned off and that it is not necessary to restrict the extinguishment of the tell-tale to the exact instant of the initiation of the next ignition cycle.

c. Use of ESC Malfunction Indicator to Indicate Malfunctions of Related Systems/Functions

71. Industry stakeholders suggested that manufacturers should be allowed to use the ESC malfunction indicator to indicate the malfunction of any ESC-related system, including traction control, trailer stability assist, corner brake control, and other similar functions that use throttle and/or individual wheel torque control to operate and which share common components with the ESC system (arguing that the dealer or repair business can inform the owner precisely which system is malfunctioning). Particularly in light of space limitations in the instrument panel for incorporation of additional tell-tales, it has been decided that a single malfunction tell-tale that relates to a vehicle's stability-related safety systems generally is sufficiently informative for the driver, and it should be effective in conveying to the driver that a malfunction has occurred which may require diagnosis and service by a repair facility. Accordingly, the ESC malfunction

symbol may also be used to indicate the malfunction of related systems/functions including traction control, trailer stability assist, corner brake control, and other similar functions that use throttle and/or individual torque control to operate and share common components with the ESC system.

(iii) Tell-tale Specifications

a. ESC Malfunction Tell-tale

72. Because the benefits of the ESC system can only be realized if the system is functioning properly, a tell-tale is required to be mounted inside the occupant compartment in front of and in clear view of the driver. The ESC malfunction tell-tale shall be identified by the following International Standards Organization (ISO) symbol or text:

| Symbol | Word or Abbreviation | control | Colour |
|---|---|---|---|
|  | ESC | Tell-tale | Yellow |

73. The ESC malfunction tell-tale is required to illuminate after the occurrence of one or more malfunctions that affect the generation or transmission of control or response signals in the vehicle's ESC system. When illuminated, the telltale shall be sufficiently bright to be visible to the driver under both daylight and night time driving conditions, when the driver has adapted to the ambient roadway light conditions. Such tell-tale shall remain continuously illuminated for as long as the malfunction(s) exists, whenever the ignition locking system is in the "On" ("Run") position. The ESC malfunction tell-tale shall extinguish at the next ignition cycle after the malfunction has been corrected.

74. Except as provided in the regulation, each ESC malfunction tell-tale shall be activated as a check of lamp function either when the ignition locking system is turned to the "On" ("Run") position when the engine is not running, or when the ignition locking system is in a position between "On" ("Run") and "Start" that is designated by the manufacturer as a check position. (The check of lamp requirement does not apply to tell-tales shown in a common space.) In addition, the ESC malfunction tell-tale need not be activated when a starter interlock is in operation.

75. Vehicle manufacturers are permitted to use the ESC malfunction tell-tale in a flashing mode to indicate operation of the ESC system.

b. Tell-tale Labelling

76. In terms of how to label the ESC malfunction tell-tale, it is the gtr's intention to provide flexibility to vehicle manufacturers via alternative text terms for tell-tales, while at the same time promoting consistency of message. As the concept of ESC becomes more widely understood by drivers, it is expected that offering the option of using the text term "ESC," as opposed to manufacturer-specific ESC system acronyms, will facilitate driver recognition of the tell-tale.

Therefore, the regulation permits use of the term "ESC" at the manufacturer's discretion instead of the ISO symbol.

77. In light of the importance of promoting drivers' understanding of ESC and whether or not their vehicle is equipped with ESC, industry recommended combining the ISO symbol with the acronym "ESC". Insofar as drivers will have to learn the precise meaning of any tell-tale offered by manufacturers to convey the idea of ESC, it is not necessary at this time to specifically require a tell-tale that includes both the symbol and the acronym, and there is no evidence that both together will convey a greater benefit than either alone. It is expected that most drivers become increasingly familiar with the meaning of instrument panel tell-tales over time, and that the ESC malfunction tell-tale symbol and substitute "ESC" text can effectively be used interchangeably. However, given vehicle manufacturers' stated concern that limited instrument panel area is available for locating tell-tales, it is noted that it is permissible to augment the ISO symbol with the text "ESC".

c. Use of Message Centers

78. It should be noted that in the event that the text alternative for the ESC malfunction tell-tale is presented via the vehicle's message/information centre (sometimes referred to as a "common space"), the regulation's tell-tale requirements shall continue to be met and the warning shall not be displaced by a subsequent warning until such time as the malfunction condition has been corrected.

d. Color Requirement

79. The use of message/information centres for presentation of ESC malfunction information is permissible to the extent that the relevant requirements of the regulation are met, including the yellow colour requirement. The intent of the colour requirement is that the colour yellow be used to communicate to the driver a condition of compromised performance of a vehicle system that does not require immediate correction. The International Standards Organization in its standard titled, "Road Vehicles – Symbols for controls, indicators, and tell-tales" (ISO 2575:2004(E)), agrees with this practice through its statement of the meaning of the colour yellow as "yellow or amber: caution, outside normal operating limits, vehicle system malfunction, damage to vehicle likely, or other condition which may produce hazard in the longer term". In the context of ESC, a yellow, cautionary warning to the driver was purposely chosen to indicate an ESC system malfunction. This requirement shall be maintained in order to communicate properly the level of urgency with which the driver shall seek to remedy the malfunction of this important safety system.

e. Illumination Strategy

80. Some current ESC systems utilize a tell-tale control logic that illuminates the "ESC Off" tell-tale every time the ESC malfunction tell-tale is illuminated. When an ESC malfunction situation exists, this gtr permits manufacturers to illuminate the "ESC Off" tell-tale or display "ESC Off" text in a message/information centre in addition to illuminating the separate ESC malfunction tell-tale to emphasize to the driver that ESC functionality has been reduced due to

the failure of one or more ESC components. However, when ESC has been manually disabled by the driver, the ESC malfunction telltale may not be illuminated along with the "ESC Off" telltale unless an actual ESC malfunction condition exists. There is an exception related to two part tell-tales as described in section titled: "use of two part tell-tales". In such situations, an ESC system actively disengaged by the driver through an appropriate control is not malfunctioning, but is instead functioning properly. Such an illumination strategy could cause driver confusion, which may in turn decrease confidence in the ESC system.

f. Tell-tale Extinguishment

81. In terms of tell-tale extinguishment, the gtr should not be interpreted as implying that all ESC malfunctions will require corrective action by a third party (e.g., dealership, repair shop). Instead, there are numerous examples of situations in which outside intervention is not required to return the ESC system to normal operation, such as where a sensor may be become temporarily inactive but subsequently return to service.

g. Tell-tale Location

82. Although some participants suggested that the regulation should require an appropriate tell-tale in that vehicle's "instrument cluster" where its message would be more prominent, rather than in the vehicle's centre console (i.e. where the radio and climate control mechanisms are normally located), such a narrow locational requirement is not necessary. Instead, the regulation's requirement that the ESC malfunction tell-tale "shall be displayed in direct and clear view of the driver while in the driver's designated seating position with the driver's seat belt fastened" should be sufficiently stringent to ensure that vehicle manufacturers will locate the ESC malfunction tell-tale in a reasonable location.

(iv) Optional "ESC Off" Switch and Tell-tale

83. In certain circumstances, drivers may have legitimate reasons to disengage the ESC system or limit its ability to intervene, such as when the vehicle is stuck in sand/gravel, is being used while equipped with snow chains, or is being run on a track for maximum performance. Accordingly, under this gtr, vehicle manufacturers may include a driver-selectable switch that places the ESC system in a mode in which it does not satisfy the performance requirements of the standard (e.g., during the use of snow chains, attempting to "rock" a vehicle stuck in a deformable surface such as snow or mud, attempting to initiate movement on deep snow or ice, driving through a deep, deformable surface such as mud or sand, driving with a compact spare tyre, tyre of mismatched sizes or tyres with chains or driving in full-off mode). However, if the vehicle manufacturer chooses this option, it shall ensure that the ESC system always returns to the manufacturer's default mode at the initiation of each new ignition cycle, regardless of the mode the driver had previously selected (with certain exceptions such as for low range off-road operation).

84. If the vehicle manufacturer chooses this option, it shall also provide an "ESC Off" control and a tell-tale that is mounted inside the occupant compartment in front of and in clear view of the driver. The purpose of this tell-tale is to indicate to the driver that the vehicle has been put into a mode that renders it unable to satisfy the requirements of the gtr. The ESC Off tell-tale

shall be identified by the following symbol (the ISO symbol J.14 with the English word "OFF") or text:

| SYMBOL | WORD OR ABBREVIATION | CONTROL | COLOUR |
|---|---|---|---|
|  | ESC OFF | Tell-tale | Yellow |
| | | Control (Illuminated) | -- |

85. Such tell-tale shall remain continuously illuminated for as long as the ESC is in a mode that renders it unable to meet the performance requirements of the gtr, whenever the ignition locking system is in the "On" ("Run") position. Except as provided in this regulation, each "ESC Off" tell-tale shall be activated as a check of lamp function either when the ignition locking system is turned to the "On" ("Run") position when the engine is not running, or when the ignition locking system is in a position between "On" ("Run") and "Start" that is designated by the manufacturer as a check position. The "ESC Off" tell-tale need not be activated when a starter interlock is in operation. The "ESC Off" tell-tale shall extinguish after the ESC system has been returned to its fully functional default mode.

86. Several participants raised specific issues pertaining to the ESC Off control and tell-tale, which are set forth and addressed below.

### h. System Disablement and the "ESC Off" Control

87. Most participants expressed support for the decision to permit vehicle manufacturers to install ESC Off controls, stating that a driver may need to disable the ESC system in certain situations such as when a vehicle is stuck in a deformable surface such as mud or snow, or when a compact spare tyre, tyres of mismatched sizes, or tyres with chains are installed on the vehicle.

88. In contrast, some safety advocacy organizations have expressed concern that ESC on-off controls may place motorists at unnecessary risk, particularly where de-activation occurs for "driving enjoyment" or racing purposes; this small minority of drivers could disable their ESC systems by other (unspecified) means. Concern was expressed that permitting ESC disablement could result in the loss of benefits of an active ESC system for long distances or considerable periods of time until the start of the next ignition cycle and that turning off the ESC system could also disable ABS operation, thereby negatively impacting vehicle safety. Alternatively, it was suggested that it may be unnecessary to permit ESC de-activation, if ESC systems can operate in conjunction with vehicle traction control systems or that the gtr permits ESC disablement controls, de-activation should require either: (1) a long control engagement period, or (2) sequential control engagement actions.

89. After considering these observations, it was nevertheless decided that provision in the gtr for a control to disable the ESC system temporarily will enhance safety. The rationale for this position is detailed below.

90. Driving situations exist in which ESC operation may not be helpful, most notably in conditions of winter travel (e.g., driving with snow chains, initiating movement in deep snow). ESC determines the speed at which the vehicle is travelling via the wheel speeds, rather than using an accelerometer or other sensor. While the gtr only requires ESC to operate at travel speeds of 20 km/h and greater, some manufacturers may choose to design their ESC systems to operate at lower speeds. Thus, drivers trying to work their way out of being stuck in deep snow may induce wheel spinning that implies a high enough travel speed to engage the ESC to intervene, thereby hindering the driver's ability to free the vehicle.

91. Second, there is the concern that if a control is not provided to permit drivers to disable ESC when they choose to, some drivers may find their own, permanent way to disable ESC completely. This permanent elimination of this important safety system would likely result in the driver losing the benefit of ESC for the life of the vehicle. However, as currently designed, ESC systems retain some residual safety benefits when they are "switched off," and they also become operational again at the next ignition cycle of the vehicle. Accordingly, it was decided that provision of this type of temporary "ESC Off" control is the best strategy for dealing with such situations.

92. In response to the idea that it may be unnecessary to permit ESC disablement, if ESC systems can operate in conjunction with traction control, it was not thought that ESC disablement should be prohibited on this basis. This gtr sets forth requirements for ESC, not traction control, for new vehicles. For vehicles equipped with ESC but not with traction control, ESC disablement may be necessary in certain situations, as described above.

i. Control for Complete ESC Deactivation

93. Some participants suggested that for certain sporty models, the regulations should provide for a separate mode (perhaps activated with a control) which would give the driver discretion to disable the ESC completely for race track use. As described, such a disablement mechanism would fully and permanently disable the vehicle's ESC system, shutting down any vehicle subsystem that intervenes in the vehicle's performance (with some exceptions, such as where the driver wishes to keep ABS operative).

94. Because the gtr permits, rather than requires, an ESC Off control and is not specifying the extent to which ESC function shall be reduced via the control, manufacturers have the freedom to provide drivers with a control that has the ability to disable ESC completely. Of course, this does not obviate the necessity for the vehicle's ESC system to return to the default mode at the initiation of each new ignition cycle, as required by paragraph 5.5.1. If the manufacturer chooses this option, three cases can be possible: (1) one single control whose only purpose is to switch on and off the ESC function; (2) a control (e.g. a rotary control) whose purpose is to place the ESC system in different modes, at least one of which may no longer satisfy the performance requirements; (3) a control for another system that has the ancillary effect of placing the ESC system in a mode in which it no longer satisfies the performance requirements.

### j. ESC Operation After Malfunction and "ESC Off" Control Override

95. In discussions, concern was expressed that when an ESC malfunction is detected, some drivers may respond by pressing the ESC Off control (if one is provided). However, not all ESC malfunctions may render the system totally inoperable, so there may be benefits to ensuring that the system remains active in those cases. Thus, it was suggested that manufacturers should be permitted to disable the "ESC Off" control in those instances where an ESC malfunction has been indicated or override the "ESC Off" control in other appropriate situations. It was argued that at such times, the benefits of ESC operational availability are more important than the ability to disable the system, and it was further argued that because the "ESC Off" control is permitted at the vehicle manufacturer's option, the manufacturer should be accorded discretion to appropriately limit the operation of that off control.

96. It is logical to conclude that just because the manufacturer permits the ESC system to be disabled under some circumstances, that does not mean that the manufacturer shall allow it to be disabled at all times. If the vehicle manufacturer believes a situation has occurred in which it should not be possible to turn ESC off, then the manufacturer should be permitted to override the operation of the "ESC Off" control. The example of an ESC system malfunction after which the driver triggers the "ESC Off" control is illustrative of such a situation; in such cases, the vehicle operator presumably had desired to maintain ESC functionality while driving, so the driver's action to turn the system off arguably reflects a reflex reaction that the system is unavailable and shall be shut down, rather than a reasoned decision to forgo any residual ESC benefits that might remain in spite of the malfunction. Similarly, it makes little sense to require the ESC system to remain disabled if the vehicle manufacturer believes a situation has occurred in which ESC should again become functional. The gtr's regulatory text has been drafted in a manner which reflects these principles.

### k. Default to "ESC On" Status

97. This gtr recognizes that there may be certain situations in which ESC disablement may be appropriate (e.g., vehicles stuck in snow or mud), but considered the fact that permitting the ESC system to remain disabled until the next ignition cycle (i.e. default mode upon vehicle start-up be ESC "full-on") could be problematic. It was argued that the driver may inadvertently forget to reengage the ESC for the remainder of the current trip by turning the ignition off and then on again, and that waiting for the next ignition cycle to require reengagement of the ESC system needlessly compromises potential safety benefits. One suggestion was to have the gtr require that, once disabled, the ESC system shall again become operational when the vehicle reaches a speed of 40 km/h (or develop some other alternative, such as a time-delay reminder to re-enable the system or some other means of automatic re-enablement).

98. In response, it is noted that although ESC systems shall always return to the manufacturer's original default mode that satisfies the regulatory requirements at the initiation of each new ignition cycle, manufacturers have the freedom to equip their vehicles with ESC systems that return to a compliant mode sooner, based upon an automatic speed trigger or timeout.

l. Operation of Vehicle in 4WD Modes

99. Several industry stakeholders stated that there are certain situations in which the ESC system would not be able to default to "on" status at the start of a new ignition cycle. As an example, it was noted that there are certain vehicle operational modes in which the driver intends to optimize traction, not stability (e.g., 4WD-locked high, 4WD-locked low, locking front/rear differentials). These industry participants argued that an exception should be made in the gtr for the cases when the driver's ESC modes selection for four-wheel drive low has locked the vehicle's differentials, or has placed the vehicle in other special off-road chassis modes. According to the industry, transition to one of these modes is mechanical and cannot be automatically reverted to "on" status at the start of each new ignition cycle. These industry stakeholders further suggested that this approach would be consistent with safety because the operating conditions for these vehicle modes tend to involve low speed. It was added that in those cases, the ESC "Off" tell-tale should be illuminated, in order to remind the driver of the ESC system's status as being unavailable. Industry stakeholders also argued that when a driver has placed a vehicle into a 4WD-locked high mode (i.e. when the vehicle is in 4WD-high with the front and rear axles locked together, which can be useful in improving stability on snow-, sand-, or dirt-packed roads), the vehicle should not be subject to the stability and responsiveness performance requirements in paragraphs 5.1. and 5.2., because the vehicle's ESC system has been "optimized" for that driving configuration and reverting to "full on" with subsequent ignition cycles would serve no safety benefit under the driving conditions in which 4WD-locked high would be appropriate.

100. It makes sense that when a vehicle has been intentionally placed in a mode specifically intended for enhanced traction during low-speed, off-road driving via mechanical means (e.g., levers, switches) and in this mode ESC is always disabled, it is not sensible to require the ESC system to be returned to "full on" status just because the ignition has been cycled. In these situations, keeping the ESC disabled makes more sense. It is thought that this approach should have no substantial effect on safety because the operating conditions for these vehicle modes tend to involve low-speed driving. Additionally, we agree that when driving conditions are appropriate for a driver to use 4WD-locked high if their vehicle is equipped with it, there is little safety benefit likely from requiring the ESC system to revert to "full on" with the next ignition cycle. However, we believe that an ESC system optimized for 4WD-locked high should be able to meet the stability performance requirements if not the responsiveness requirements, since 4WD-locked high is designed to improve stability and reduce responsiveness for purposes of improving safety under the relevant driving conditions. Thus, the regulatory text now states that "…the vehicle's ESC system need not return to a mode that satisfies the requirements of paragraphs 5. through 5.3. at the initiation of each new ignition cycle if: (a) the driver-selected mode is designed for low-speed, off-road driving and vehicle speed is limited in this mode by transmission gear reduction; or (b) the driver-selected mode is designed for operation at higher speeds on snow-, sand-, or dirt-packed roads and has the effect of locking the front and rear axles together, provided that in this mode the vehicle meets the stability performance requirements of paragraphs 5.1. and 5.2. under the test conditions specified in paragraph 6."

### m. Labelling of the "ESC Off" Control

101. Industry stakeholders agreed that the "ESC Off" control should be identified, but they argued that vehicle manufacturers should be granted flexibility in terms of how to identify the "ESC Off" control. The industry stated that it is not necessary to standardize the identification of the control because vehicle manufacturers have been providing drivers with more detailed feedback on the ESC operating mode when the system is in other than the default "full on" mode. In other words, the argument is that because vehicle manufacturers are providing a tell-tale that would illuminate whenever the system is in a mode other than "full on," they should be permitted discretion to optimize control labelling in ways that would facilitate driver understanding of variable ESC modes (i.e. permitting an identification other than "ESC Off").

102. There is a legitimate concern for ensuring driver understanding of ESC status. Therefore, it would be beneficial to encourage drivers to select ESC modes other than "full on" only when driving conditions warrant. However, standardized control labelling of an "ESC Off" control shall be maintained, and, therefore, manufacturers shall identify an actual "ESC Off" control using the specified "ESC Off" symbol or "ESC Off" text (which may be supplemented with other text and symbols). However, there is a difference between a dedicated "ESC Off" control (i.e. one whose sole function is to put the ESC system in a mode in which it no longer satisfies the requirements of an ESC system, and which accordingly shall bear the required "ESC Off" labelling) and other types of controls.

103. One type of control to be clarified as excluded is one which has a different primary purpose (e.g., a control for the selection of low-range 4WD that locks the axles), but which shall turn off the ESC system as an ancillary consequence of an operational conflict with the function that it controls. In this case, such a control would be made confusing by adding "ESC Off" to its functional label. Nevertheless, in such situations, the "ESC Off" tell-tale shall illuminate to inform the driver of ESC system status.

104. Another type of control to be clarified as excluded is one that changes the mode of ESC to a less aggressive mode than the default mode but which still satisfies the performance criteria of this gtr. In such cases, the manufacturer may label such a control with an identifier other than "ESC Off," and the manufacturer is permitted, but not required, to use the "ESC Off" tell-tale beyond the default mode to signify lesser modes that still satisfy the test criteria. If this control is combined with a control that puts ESC in a mode in which it no longer satisfies the test criteria (a "dedicated" ESC Off control), as on a multi-mode switch or button, the multi-mode control shall be labelled with either the words "ESC OFF" or the symbol word combination for "ESC Off".

### n. Location of the "ESC Off" Control

105. Certain industry participants requested that vehicle manufacturers be provided flexibility in the placement of the ESC Off control for the following reasons. First, it was argued that the ESC Off control would be infrequently used during normal driving. Second, it was argued that the location of the ESC Off control would help ensure that disabling of the ESC reflects a deliberate act by the driver.

106. For the reasons that follow, the "ESC Off" control location shall be visible to and operable by the driver while properly restrained by the seat belt. Hand-operated controls should be mounted where they are easily visible to the driver so as to minimize visual search time, because safety may be diminished the longer a driver's vision and attention are diverted from the roadway. Furthermore, relative consistency of location across vehicle platforms will promote easy identification of the control when drivers encounter a new vehicle.

o. ESC Off Controls for Vehicles with Towed Trailers

107. This gtr does not require an ESC Off control for vehicles capable of towing a trailer, although it permits them at the manufacturer's discretion. However, tow vehicle/trailer safety is an area of ongoing interest, and additional information is always welcome on ways new technology can improve it. For example, some ESC systems are now being offered with trailer stabilization assist (TSA) control algorithms. These algorithms are specifically designed to help mitigate yaw oscillations that can occur when the vehicle/trailer system is being operated in certain driving situations. These systems operate by using the tow vehicle ESC system to automatically brake the tow vehicle in a way that suppresses the trailer yaw oscillations before they become so large that a loss of control is evident. Evaluating TSA effectiveness is an area of research presently under consideration in the U.S.

p. Tell-tale Labelling

108. Similar to the above reasoning of how to label the ESC malfunction tell-tale, the intention is to provide flexibility to vehicle manufacturers via alternative text terms for tell-tales, while at the same time promoting consistency of message. Therefore, the regulation permits use of the term "ESC OFF" at the manufacturer's discretion instead of the modified ISO symbol.

q. Colour Requirement

109. Similar to the above reasoning for the yellow colour requirement for the ESC malfunction tell-tale, the use of message/information centres for presentation of required ESC information is permissible to the extent that the requirements of the regulation (including the yellow colour requirement) are met. As operating ESC in a mode other than "full on" qualifies as a condition of "compromised performance," the yellow colour requirement shall be maintained in order to communicate properly the condition of potentially decreased safety to the driver.

r. "ESC Off" Tell-tale Clarification

110. In response to industry request, it should be clarified that it is permissible under this gtr to illuminate the "ESC Off" tell-tale whenever the ESC system is in a mode other than the fully active system, even if, at that level, the system would meet the requirements of the regulation. Permitting such an illumination strategy may help to remind drivers when their vehicle's ESC system has been placed in a mode of less than maximal effectiveness and to encourage them to rapidly return the system to fully-functional status.

s. "ESC Off" Tell-tale Strategy

111. In developing the provisions for the ESC Off tell-tale, vehicle manufacturers sought clarification on whether the following ESC tell-tale illumination strategy would be permissible: If the ESC is deactivated by the driver, illuminate the ESC symbol in the instrument panel (presumed to mean the ESC malfunction symbol and not the "ESC Off" symbol), provide a "ESC OFF" message in the message/information centre, and illuminate a yellow light-emitting diode (LED) in the "ESC Off" control which is in clear view of the driver. Such a strategy is not permissible under this gtr for the reasons that follow.

112. The regulation provides that the ESC malfunction tell-tale shall be illuminated "…after the occurrence of any malfunction". Manual disablement of the ESC by the driver does not constitute an ESC malfunction. In order to prevent confusion on the part of the driver, it has been decided that the ESC malfunction tell-tale can only be used when a malfunction exists. Specifically, if the ESC malfunction tell-tale were permitted to be presented simultaneously with the "ESC Off" tell-tale, drivers would be unable to distinguish whether the system had been switched off or whether a malfunction had occurred. Therefore, presentation of the ESC malfunction tell-tale in addition to an "ESC OFF" indication when ESC has been disabled via the driver-selectable control and no system malfunction exists is prohibited.

t. Use of Two-Part Tell-tales

113. Some industry stakeholders stated that vehicle manufacturers should be permitted the flexibility to use two adjacent tell-tales, one containing the ISO symbol for the proposed yellow ESC malfunction indicator and another yellow tell-tale with the word "Off". It was argued that, given the limited space available on vehicle instrument clusters, this dual-purpose combination would increase efficiency by allowing one lamp to be illuminated to indicate ESC malfunction and both to be illuminated to indicate that the system has been turned off or placed in a mode other than the "full on" mode.

114. This gtr would permit the tell-tale configuration described above. Indication of a malfunction condition generally shall always be the predominant visual indication provided to the driver by a tell-tale. As a result, if a two-part ESC tell-tale was used and an ESC malfunction occurred, only the malfunction portion of the tell-tale could be illuminated. However, other provisions in the regulation state that a tell-tale consisting of the symbol for "ESC Off" or substitute text shall be illuminated when a control input to the ESC switch (i.e. control) has been made by the driver to put the vehicle into a non-compliant mode. Thus, both parts of the two-part tell-tale would be required to illuminate. In the rare event that an ESC malfunction occurs while the ESC has been manually disabled, this gtr would allow the ESC Off message to remain (i.e. both parts of the two-part tell-tale to remain illuminated) until the next ignition cycle (at which point the ESC shall revert to "full on" mode regardless), at which point the ESC malfunction part of the two-part tell-tale shall be illuminated.

u. Conditions for Illumination of the "ESC Off" Tell-tale: Speed

115. The automobile industry sought clarification that the "ESC Off" tell-tale (if an "ESC Off" control is provided) need not illuminate when the vehicle is travelling below the low-speed threshold at which the ESC system becomes operational. That understanding is correct. The regulation requires that the ESC system shall be "…operational during all phases of driving including acceleration, coasting, and deceleration (including braking), except when the driver has disabled ESC or when the vehicle is below a speed threshold where loss of control is unlikely". Thus, the ESC system need not be functional when the vehicle is travelling at a speed below the low-speed threshold. Furthermore, the regulation requires the vehicle manufacturer to illuminate the "ESC Off" tell-tale when the vehicle has been put into a mode that renders it unable to satisfy the gtr's performance requirements. Driving a vehicle at low speeds does not equate with the vehicle operator actively using a driver-selectable control that places the ESC system into a mode in which it will not satisfy these performance requirements. Therefore, the regulation should not be read to imply that the "ESC Off" tell-tale shall be illuminated when the vehicle is travelling at low speeds, and it is sufficiently clear in defining the conditions under which the "ESC Off" tell-tale shall be illuminated.

v. Conditions for Illumination of the "ESC Off" Tell-tale: Direction

116. Participants sought confirmation that there is no need to illuminate the "ESC Off" tell-tale when the vehicle is driven in reverse, arguing that triggering the tell-tale under those circumstances could result in driver confusion. That understanding is correct.

117. In developing this gtr, it was not intended that the ESC system be required to be operable when the vehicle is driven in reverse, because such a requirement would necessitate costly changes to current ESC systems with no anticipated safety benefit. Furthermore, the regulatory language states that ESC is intended to function over the full speed range of the vehicle (except at vehicle speeds less than 20 km/h or when being driven in reverse). In such instances, the ESC system has not been turned off, but instead, it has encountered a situation in which, by regulation, the ESC system need not operate; once the vehicle is returned to forward motion at a speed above the minimum threshold, one would presume that the ESC system would return to normal operation automatically. Requiring the "ESC Off" tell-tale to illuminate frequently (given that reversing the vehicle and low-speed driving are routine occurrences) would certainly be perceived as a nuisance by drivers and might even be mistaken for a system malfunction. Furthermore, the regulatory provisions already stated that the "ESC Off" indicator shall be illuminated when the ESC system is manually disabled (i.e. placed in a non-compliant mode) by the driver via the "ESC Off" control, a very different situation from a vehicle being placed in reverse.

w. Alerting the Driver of ESC Activation - Visual and Auditory Indications of ESC Activation

118. Participants offered a variety of viewpoints regarding provision of an indication of ESC activation to the driver. Some supported a visual tell-tale; others supported both visual and

auditory indications (e.g., suggesting that such warnings are helpful, in that they may alert drivers earlier regarding slippery road conditions, thereby causing the driver to slow down in anticipation of a potential hazard). Some supported a steady-burning activation indicator (citing one study, which was interpreted as suggesting that flashing illumination increases driver distraction, or even suggesting that a flashing tell-tale could elicit a panic reaction in which the driver fails to even attempt to steer the vehicle), whereas others argued that such indicator should be permitted to flash. Still others stated that an activation tell-tale is unnecessary and potentially distracting to the driver or could lead to annoyance, which may cause drivers to deactivate the ESC system.

119. After careful consideration of the substantial input on this issue, the gtr provides that manufacturers may use the ESC malfunction tell-tale in a flashing mode to indicate ESC operation. However, no safety need has been identified that would justify a requirement for provision of an ESC activation indicator to alert the driver that the ESC system is intervening during a loss-of-control situation.

120. In a U.S. survey conducted as part of relevant human factors research relating to ESC, 28 vehicles equipped with ESC systems were examined and it was found that all manufacturers appeared to provide a visual indication of ESC activation. The study found that a majority of vehicle manufacturers provided such indication using a symbol, while a few indicated ESC activation using text. Each vehicle examined that used a symbol to indicate ESC activation did so by flashing the tell-tale. Owners' manuals examined typically indicated that the purpose of the flashing tell-tale was to inform the driver that the ESC was "active" or "working".

121. However, the safety need for an ESC activation indicator to alert the driver during an emergency situation that ESC is intervening is not obvious. It would seem that with ESC, as with anti-lock brake systems, vehicle stability would be increased regardless of whether feedback was provided to inform the driver that a safety system had intervened. No data have been provided to suggest that safety benefits are enhanced by alerting the driver of ESC activations. Nevertheless, current research on the topic of ESC activation warnings supports this gtr's current approach that an ESC activation indication should neither be prohibited nor required, as explained below.

122. The results of recent research neither show that alerting a driver to ESC activation provides a safety benefit, nor that it may prove to be a source of distraction that could lead to adverse safety consequences. Research shows that drivers presented with the flashing tell-tale were more likely to glance at the instrument panel and that these drivers typically glanced at the panel twice, rather than just once as for the steady-burning tell-tale or no tell-tale. Insofar as a flashing tell-tale draws a driver's attention away from the road, where it should be during an emergency loss-of-control situation, requiring it is not logical. It makes sense to alert drivers to slick road conditions, when the driver is operating the vehicle on the roadway in a generally straight path, but it would not make sense to draw the driver's attention away from the road when they are in the midst of assessing a crash-imminent situation and attempting to avoid a collision.

123. While research to date shows that drivers looked at a flashing tell-tale twice as often, this did not result in significantly different rates for loss of control, road departures, and collisions than with steady-burning tell-tales or no tell-tales. Thus, despite the logical risk of looking away

from the road during an ESC-worthy manoeuvre, there is no apparent detriment from the increased glances at a flashing tell-tale. Currently available research results are insufficient to support prohibition of the existing practice of providing a visual indication of ESC activation, but neither do they support requiring it.

124. Once additional data from relevant research become available and are analyzed, it may be possible to clarify further which strategy for notifying the driver of ESC activation is least likely to negatively impact the driver's response to a loss-of-control situation. However, unless additional research provides strong, statistically-valid evidence of a benefit or detriment associated with presentation of an ESC activation indication, no requirement or prohibition for such an indication will be made.

125. Consistent with available research, auditory indications of ESC activation are not necessary and provide no apparent safety benefit. However, while research suggests that an auditory indication of ESC activation elicits longer instrument panel glances and may be associated with an increase in road departures, it is not considered that these results from a single simulator study provide sufficient justification to prohibit use of an auditory ESC indicator. Therefore, while an auditory ESC activation warning would be discouraged, even when combined with a visual indication, current data do not justify a prohibition of such approach.

#### x. Flashing Tell-tale as Indication of Intervention by Related Systems/Functions

126. The automobile industry requested that it be permitted to flash the ESC malfunction tell-tale to indicate the intervention of other related systems, including traction control and trailer stability assist function. The industry reasoned that these functions are directly related to the ESC system and that the driver would experience the same sensations from the braking system actuator and throttle control triggered by operation of these related systems, as they would in the event of ESC activation. In addition to keeping the driver informed, it also reasoned that this strategy would aid in minimizing the number of tell-tales used for related functions.

127. Because this gtr does not require an ESC activation indication, if vehicle manufacturers choose to provide one, they may use it to indicate interventions by additional related systems at their discretion. It is expected that manufacturers would explain the meaning and scope of the activation indication in the vehicle owner's manual, consistent with facilitating consumer understanding of important vehicle safety features.

#### y. Bulb Check - Waiver of Bulb Check for Message/Information Centers

128. Except when a starter interlock is in operation, the gtr requires that each ESC malfunction tell-tale and each "ESC Off" tell-tale shall be activated as a check of lamp function either when the ignition locking system is turned to the "On" ("Run") position when the engine is not running, or when the ignition locking system is in a position between "On" ("Run") and "Start" that is designated by the manufacturer as a check position.

129. Industry participants stated that while such requirements are appropriate for traditional tell-tales, those requirements are not appropriate for vehicle message/information centres which do not use bulbs and are illuminated whenever the vehicle is operating. According to the industry, if there were a problem of this type, it would be readily apparent because the entire message/information centre would be blank. Therefore, it was requested that ESC system status indications provided through a message/information centre be excluded from the regulation's bulb check requirements.

130. In response, it seems logical that a bulb check is not relevant or necessary for the type of display technology utilized for information/message centres. Presumably, if an information/message centre experiences a problem analogous to one which would be found by a tell-tale's bulb check, the entire message centre would be non-operational, a situation likely to be rapidly discovered by the driver. Therefore, it was decided to waive the bulb check requirement for ESC system status indications provided via a message/information centre.

z. Clarification Regarding Bulb Check

131. Clarification was sought that the bulb check for the ESC malfunction tell-tale and ESC Off tell-tale (if provided) may be performed by any vehicle system and is not required to be conducted by the ESC system itself. It was asserted that many vehicle systems are able to perform this function, and most current vehicles are designed such that the instrument panel controls the tell-tales. Because it is not important how precisely the bulb check for an ESC-related tell-tale is accomplished (provided that this performance requirement is met), this request was accommodated in this regulation.

(v) Technical Documentation

132. In addition, the regulation requires vehicle manufacturers to supply additional documentation in order to ensure that a vehicle is equipped with an ESC system that meets the definition of "ESC System". For example, vehicle manufacturers shall submit, upon request, ESC system technical documentation as to when understeer intervention is appropriate for a given vehicle (e.g., information such as a system diagram that identifies all ESC components, a written explanation sufficient to describe the ESC system's basic operational characteristics, a logic diagram supporting the explanation of system operations, and an outline description of the pertinent inputs to the vehicle computer or calculations within the computer and how its algorithm uses that information and controls ESC system hardware to limit vehicle understeer).

(d) Performance Requirements

133. ESC-equipped vehicles covered under this gtr are also required to meet performance tests. Specifically, such vehicles shall satisfy the gtr's stability criteria and responsiveness criteria when subjected to the Sine with Dwell steering manoeuvre test. This test involves a vehicle coasting at an initial speed of 80 km/h while a steering machine steers the vehicle with a steering wheel pattern as shown in Figure 2 of the regulatory text. The test manoeuvre is then repeated over a series of increasing maximum steering angles. This test manoeuvre was selected over a number of other alternatives, because it was decided that it has the most optimal set of

characteristics, including severity of the test, repeatability and reproducibility of results, and the ability to address lateral stability and responsiveness.

134. The manoeuvre is severe enough to produce spinout for most vehicles without ESC. The stability criterion for the test measure is how quickly the vehicle stops turning after the steering wheel is returned to the straight-ahead position. A vehicle that continues to turn for an extended period after the driver steers straight is out of control, which is what ESC is designed to prevent.

(i) Lateral Stability Criterion

135. The quantitative stability criteria are expressed in terms of the per cent of the peak yaw rate after maximum steering that persists at a period of time after the steering wheel has been returned to straight ahead. The criteria require that the vehicle yaw rate decrease to no more than 35 per cent of the peak value after one second and that it continues to drop to no more than 20 per cent after 1.75 seconds.

(ii) Lateral Responsiveness Criterion

136. Since a vehicle that simply responds very little to steering commands could meet the stability criteria, a minimum responsiveness criterion is applied to the same test. It requires that an ESC-equipped vehicle with a GVM of 3,500 kg or less shall move laterally at least 1.83 m during the first 1.07 seconds after the Beginning of Steer (BOS); (Initiation of steering marks a discontinuity in the steering pattern that is a convenient point for timing a measurement. BOS is defined in the regulation at paragraph 7.11.6.). It also requires that a heavier vehicle with a GVM greater than 3,500 kg shall move at least 1.52 m laterally in the same manoeuvre for specified steering angles (i.e. conducted with a commanded steering wheel angle of 5A or greater). These computations are for the lateral displacement of the vehicle centre of gravity with respect to its initial straight path.

137. After considering industry input, it was decided to use a normalized steering wheel angle of 5.0 as the minimum steering input for applying the responsiveness test criteria. A normalized steering wheel angle accounts for differences in steering ratios between vehicles by dividing the first peak steering wheel angle by the steering wheel angle at 0.3g determined by the slowly-increasing steer test. It thus expresses the amount of steering as a unitless number or scalar, rather than in degrees. The performance test includes the procedure for normalizing the steering wheel angle and calls for performing the Sine with Dwell manoeuvre at normalized steering wheel angles including 5.0, 5.5, 6.0, and 6.5, at which points responsiveness would be measured. For contemporary light vehicles, data indicate that, on average, a normalized steering wheel angle of 5.0 is about 180 degrees. However, the heavier vehicles in the mass class with a GVM up to 4,536 kg tend to have slower steering ratios, which means that 180 degrees of rotation for those vehicles produces less steering motion of the front wheels than for cars (e.g. a normalized steering wheel angle of 5.0 averages approximately 147 degrees for passenger cars, 195 degrees for SUVs, and 230 degrees for pickups). Since these are the vehicles whose inherent chassis properties limit responsiveness, the test becomes very difficult to pass if they are also tested at lower effective steering angles at the front wheels. Thus, the use of normalized steering wheel angles will remove a systematic disadvantage for certain vehicles in the test procedure.

138. Regarding the industry's suggestion for applying the normalized steering angles to the first actual peak steering wheel angles measured during the test, problems were identified with such an approach. Figure 2 of the regulatory text shows the ideal steering profile of the Sine with Dwell Manoeuvre used to command the steering machine. A steering machine is utilized because it turns the steering wheel in the test vehicles with far greater precision and repeatability than is possible for a human driver. However, the power steering systems of some vehicles do not permit the steering machines to accomplish the desired steering profile. For the reasons discussed below, it was determined that the normalized steering angle should be based on the commanded angle of a steering machine (which replaces driver input during the test) with a high steering effort capacity rather than on the measured maximum steering angle achieved by the machine.

139. The industry also suggested specifying a maximum steering torque capacity of 50 to 60 Nm for steering machines to reduce the variability caused by the choice of steering machine and to assure manufacturers that the tests would be carried out with powerful machines to maximize the steering input during the responsiveness test. Accordingly, this gtr specifies that the steering machine used for the Sine with Dwell manoeuvre shall be capable of applying steering torques between 40 and 60 Nm at steering wheel velocities up to 1,200 degrees per second. This is a more rigorous specification than simply a maximum torque range that does not include speed capability, and it prevents testing with some of the less powerful machines in use by many test facilities.

140. However, even a robust steering machine cannot maintain the commanded steering profile with some vehicle power steering systems. Some of the electric power steering systems are especially marginal in that their power assistance diminishes at high steering wheel velocities. In the case of vehicle power steering limitations, the first steering angle peak in Figure 2 cannot be met, but the second peak as well as the frequency of the wave form are usually achieved. Thus, marginal vehicle power steering does not likely reduce the severity of the oversteer intervention part of the test, but it will reduce the steering input that helps the vehicle satisfy the responsiveness criteria. If the regulation were to use the actual steering angle rather than the commanded steering angle as the normalized steering angle for the responsiveness test, it could create the unacceptable situation of vehicles that could not be tested for compliance, because the test would not allow for their evaluation. For example, if the steering machine could not achieve a normalized steering wheel angle of 5.0 even when commanded to a normalized angle of 6.5 because of vehicle limitations, the vehicle could not be said to fail, no matter how poor its performance.

141. Therefore, the gtr uses the commanded steering profile (using an assuredly robust steering machine), rather than the measured steering profile, to calculate the normalized steering wheel angle used to assess compliance with our lateral displacement requirement. This should not create a practical problem. At this time, the larger vehicles have reasonably powerful steering systems that should enable them to achieve actual peak steering angles within at least 10 degrees of the commanded peak. Furthermore, under this approach to defining the steering input, the lateral displacement required for large vehicles would be reduced to 1.52 m rather than the 1.68 m requested by the industry (with its somewhat higher measured steering angle). The weaker electric power steering systems discussed above are typically found on cars, and cars

tend to be responsive enough to pass the 1.83 m lateral displacement criterion at normalized steering wheel angles of less than 5.0.

142. As noted above, the gtr includes a responsiveness criterion that specifies a minimum lateral movement of 1.83 m during the first 1.07 seconds of steering during the Sine with Dwell manoeuvre. The purpose of the criterion is to limit the loss of responsiveness that could occur with unnecessarily aggressive roll stability measures incorporated into the ESC systems of SUVs. This is a real concern, as research has demonstrated that one such system reduced the lateral displacement capability of a mid-sized SUV below that attainable with a 15-passenger van, multiple unloaded long wheelbase diesel pickups, and even a stretched wheelbase limousine.

143. A heavy-duty pickup truck understeers strongly in this test because of its long wheelbase and because it is so front-heavy under the test condition. The ESC standard is not intended to influence the inherent chassis properties of these vehicles (which were tested without ESC), because low responsiveness in the unloaded state is the consequence of a chassis with reasonable inherent stability in the loaded state. The gtr shall avoid causing any vehicle to be designed with a chassis that is unstable at GVM and relies on ESC in normal operation. In addition, some very large vans with a high centre of gravity, such as 15-passenger vans, rely on their ESC system to reduce responsiveness because of special concerns for loss of control and rollover. While it is necessary to respect the responsiveness limitations appropriate to large vehicles with commercial purposes, there is no need for lighter vehicles designed for personal transportation, including SUVs, to give up so much of the object avoidance capability of their chassis when tuning the ESC system.

144. While the industry's suggestion that a lower responsiveness criterion for vehicles with higher GVMs is appropriate, the recommended 2,495 kg GVM break point is not appropriate. Some large passenger cars have GVMs near this level. With this break point, some minivans and midsize SUVs would be considered to have the same limitations as 15-passenger vans and trucks with a GVM of 4,536 kg. Thus, the gtr establishes a more representative break point at a GVM of 3,500 kg.

145. Regarding calculation of lateral displacement, such calculations use double integration with respect to time of the measurement of lateral acceleration at the vehicle centre of gravity (where time, t = 0, for the integration operation is the instant of steering initiation), as expressed by the following formula:

$$\text{Lateral displacement} = \iint A_{yC.G.} dt$$

146. Participants stated that, given the short interval of time in the initial phase of the lane change manoeuvre, it is reasonable to use double integration of measured lateral acceleration to approximate the vehicle's actual lateral displacement. Still, the two are technically not exactly equivalent, because lateral acceleration is measured in the coordinate frame of the vehicle, whereas lateral displacement is in the fixed reference frame of the road (i.e. the surface of the earth). Theoretically, the vehicle frame can rotate with respect to the earth frame, leading to an error in the double integration method (i.e. a small error in calculation of a vehicle's lateral displacement due to coordinate system differences). However, because the integration interval is

short (since lateral displacement is assessed 1.07 seconds after initiation of the manoeuvre's steering inputs), the integration errors are expected to be so small as to be negligible. In the alternative, this gtr permits a method of measuring lateral displacement based on GPS data to be used.

147. Regarding the yaw rate ratio calculation methodology, the gtr acknowledges that first peak value of yaw velocity may occur near (or even before) the start of the dwell. In order to account for this possibility and to ensure that the calculation is correct and consistent in all cases, the regulation specifies that the first peak value of yaw velocity is to be recorded after the steering wheel angle changes sign (between first and second peaks). However, the gtr does not adopt the recommendation of some participants that the regulation should specify that the measurement is for the "absolute value of yaw rate," in order to ensure that any negative yaw rate is included in the standard's yaw rate calculation. A negative yaw rate ratio can only be achieved when the yaw rate measured at a given instant in time is in an opposite direction of the second yaw rate peak, which can have a much different meaning than the absolute value of identical magnitude. Although it is very unlikely, taking the absolute value of the yaw rate at 1.0 or 1.75 seconds after completion of steer could cause a compliant vehicle to be deemed non-complaint if the respective yaw rate ratios are large enough. For example, if at 1.75 seconds after completion of steer a vehicle produces a yaw rate ratio of -21 per cent, the vehicle would be in compliance with the regulation's lateral stability criteria. However, if the absolute value of the yaw rate ratio were used (21 per cent), the vehicle's performance would be non-compliant. Requiring a provision that prevents a negative yaw rate ratio does not simplify the data analysis process, and can only confound interpretation of the test data.

(iii) The Issue of Understeer Performance

148. The following discussion explains the concept of vehicle understeer, how ESC systems operate to control excessive understeer, and why it was not possible to develop and incorporate an understeer performance test as part of this gtr.

149. As background, all light vehicles (including passenger cars, pickups, vans, minivans, crossovers, and sport utility vehicles) are designed to understeer 19/ in the linear range of lateral acceleration, 20/ although operational factors such as loading, tyre inflation pressure, and so forth can in rare situations make them oversteer in use. This is a fundamental design characteristic. Understeer provides a valuable, and benign, way for the vehicle to inform the driver of how the available roadway friction is being utilized, insofar as the driver can 'feel' the response of the

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19/ In lay terms, the term "understeer" is probably best described as the normal condition of most cars for everyday driving. Light vehicles are designed to be slightly understeer in normal driving situations, because being understeer provides both stability (e.g., the vehicle is not hugely affected by common factors such as small gusts of wind) and lateral responsiveness (e.g., the vehicle is able to respond to the driver's sudden decision to avoid an obstruction in the roadway by turning the wheel quickly).

20/ The "linear range of lateral acceleration" is often referred to as "linear-handling" and "linear range," and in very basic terms describes the normal situation of everyday driving, where a given turn by the driver of the steering wheel causes an expected amount of turn of the vehicle itself, because the vehicle is operating at the traction levels to which most drivers are accustomed. As the limits of the accustomed traction levels are approached, the vehicle begins to enter non-linear range, in which the driver cannot predict the movement of the vehicle given a particular turn of the steering wheel, as on a slippery road or a sharp curve, where the driver can turn the wheel a great deal and get little response from the skidding vehicle.

vehicle to the road as the driver turns the steering wheel. Multiple tests have been developed to quantify linear-range understeer objectively, including SAE J266, "Steady-State Directional Control Test Procedures for Passenger Cars and Light Trucks," and ISO 4138, "Road vehicles – Steady state circular test procedure". These tests help vehicle manufacturers design their vehicles with an appropriate amount of understeer for normal linear-range driving conditions. Tests such SAE J266 and ISO 4138 simply measure the small constant reduction in vehicle turning (in comparison to the geometric ideal for a given steering angle and wheelbase) that characterizes linear range understeer at relatively low levels of lateral acceleration. This is much different from limit understeer in loss-of-control situations where even large increases in steering to avoid an obstacle create little or no effect on vehicle turning.

150. In the linear range of handling, ESC should never activate. ESC interventions occur when the driver's intended path (calculated by the ESC control algorithms using a constant linear range understeer gradient) differs from the actual path of the vehicle as measured by ESC sensors. Since this does not occur while driving in the linear range, ESC intervention will not occur. Therefore, ESC has no effect upon the linear-range understeer of a vehicle.

151. In overview, understeer intervention is one of the core functions of an ESC system, a feature common to all current production systems. A literature search of the available research was conducted in the U.S. in order to identify a potential ESC understeer test for loss-of-control situations. However, no such tests were found. Understeer tests in the literature (such as SAE J266 and ISO 4138) focus on linear range understeer properties and are not relevant to the operation of ESC, as explained above.

152. Because there are no suitable tests of limit understeer performance in existence and because of the complexity of undertaking new research in this area, several years of additional work would be required before any conclusions could be reached regarding an ESC understeer performance test. A principal complication is that manufacturers often program ESC systems for SUVs to avoid understeer intervention altogether on dry roads because of concern that the intervention could trigger tip-up or make the oversteer control of some vehicles less certain in high-speed situations.

153. It would be unwise to disregard manufacturers' exercise of caution in this circumstance, particularly in view of the remarkable reduction in rollover crashes of SUVs that manufacturers have achieved with current ESC strategies. As a result, tests of understeer intervention would have to be conducted on low-coefficient of friction ("low-coefficient") surfaces. There are two kinds of low-coefficient test surfaces: (1) those involving water delivery to the pavement and pavement sealing compounds such as Jennite to reduce the friction of wet asphalt, and (2) those involving water delivery to inherently slick surfaces such as basalt tile pads. Repeatable pavement watering is confounded by factors like time between runs, wind, slope, temperature, and sunlight. Jennite itself is not very durable, resulting in the coefficient changing with wear. Simply wetting the same surface used for the oversteer test would not produce a surface slippery enough to ensure that SUVs would intervene in understeer. Basalt tile is extremely expensive. Moreover, the coefficient of friction of basalt pads is extremely low, almost as low as glare ice. Causing manufacturers to optimize understeer intervention at extremely low coefficients like this may create overly-aggressive systems that compromise oversteer control on more moderate low-

coefficient surfaces. Given the practicability problems of repeatable low-coefficient testing, the need for compliance margins expressed by the industry would likely result in very low criteria.

154. Development of specific performance criteria is also problematic. In the oversteer performance test, the difference between the maximum yaw rate achieved and the zero when the vehicle is steered straight at the end of the manoeuvre is large and readily obvious. In contrast, the difference between understeer and the ultimate controlled drift, which is the most any ESC system can deliver when there is simply not enough traction for the steering manoeuvre, is difficult to differentiate. Also, the kind of optical instrumentation that a test would use to measure possible metrics in an understeer test such as body and wheel slip angles does not function reliably for tests on wet surfaces. There is a real question of whether it would ever be possible to create criteria for understeer intervention that would be both stringent enough for testing and universal enough to be applied on cars and SUVs without upsetting legitimate design compromises.

155. Despite these limitations surrounding development of a performance test for excessive understeer in loss-of-control situations, it was not deemed reasonable to delay issuance of the gtr, given the significant life-saving potential of ESC systems. Similarly, it was decided that eliminating the understeer requirement from the gtr and deferring its adoption until the completion of future research would also run counter to safety, given that understeer intervention is one of the key beneficial features in current ESC systems. Thus, it was decided that the only suitable option for the gtr was to adopt an understeer requirement as part of the definition of "ESC System," along with a requirement for specific equipment suitable for that purpose. Such a requirement is objective in terms of explaining to manufacturers what type of performance is required and the minimal equipment necessary for that purpose. The gtr also provides that Contracting Parties may require the manufacturers to submit, upon request, the engineering documentation necessary to demonstrate the system's understeer capability.

156. Specifically, in order to ensure that a vehicle is equipped with an ESC system that meets the definition of "ESC System," the Contracting Party may ask the vehicle manufacturer to provide a system diagram that identifies all ESC components, a written explanation describing the ESC system's basic operational characteristics, and a logic diagram supporting the explanation of system operations. In addition, regarding mitigation of understeer, the Contracting Party may request an outline description of the pertinent inputs to the computer that control ESC system hardware and how they are used to limit vehicle understeer. It is understood that much of the above information may be proprietary and would be submitted under a request for confidential treatment.

157. In sum, the above information would be expected to allow the Contracting Party to understand the operation of the ESC system and to verify that the system has the necessary hardware and logic for mitigating excessive understeer. This ensures that vehicle manufacturers are required to provide understeer intervention as a feature of the ESC systems, without delaying the life-saving benefits of the ESC gtr (including those attributable to understeer intervention). In the meantime, the Contracting Parties will monitor the progress of any additional research in the area of ESC understeer intervention and consider taking further action, as appropriate.

158. It is further noted that the understeer requirement is objective, even without a specific performance test. The definition of "ESC System" requires not only an understeer capability (part (2) of the definition), but also specific physical components that allow excessive understeer mitigation (part (1) of the definition).

#### (iv) Other Test Requirement Issues (Post Data Processing Calculations)

159. Participants raised numerous issues related to the appropriateness and technical details of the ESC requirements and test procedures. These issues were carefully considered in developing this gtr. Additional details regarding these issues are provided below.

##### a. Determining the Beginning of Steering

160. In order to ensure consistent calculation of lateral displacement, careful consideration was given to the gtr's data processing specifications. One topic included determining the start of steering, which the regulation ultimately defined as the moment when the "zeroed" steering wheel angle (SWA) passes through 5 degrees.

161. The process to identify "beginning of steering" uses three steps. In the first step, the time when steering wheel velocity that exceeds 75 deg/sec is identified. From this point, steering wheel velocity shall remain greater than 75 deg/sec for at least 200 ms. If the condition is not met, the 200 ms validity check is applied the next time steering wheel velocity that exceeds 75 deg/sec is identified. This iterative process continues until the conditions are satisfied. In the second step, a zeroing range defined as the 1.0 second time period prior to the instant the steering wheel velocity exceeds 75 deg/sec (i.e. the instant the steering wheel velocity exceeds 75 deg/sec defines the end of the "zeroing range") is used to zero steering wheel angle data. In the third step, the first instance the filtered and zeroed steering wheel angle data reaches -5 degrees (when the initial steering input is counter clockwise) or +5 degrees (when the initial steering input is clockwise) after the end of the zeroing range is identified. The time identified in Step 3 is taken to be the beginning of steer.

162. It was decided that an unambiguous reference point to define the start of steering is necessary in order to ensure consistency when computing the performance metrics measured during testing. The practical problem is that typical "noise" in the steering measurement channel causes continual small fluctuations of the signal about the zero point, so departure from zero or very small steering angles does not indicate reliably that the steering machine has started the test manoeuvre. Extensive evaluation of zeroing range criteria (i.e. that based on the instant a steering wheel rate of 75 deg/sec occurs) has confirmed that the method successfully and robustly distinguishes the initiation of the Sine with Dwell steering inputs from the inherent noise present in the steering wheel angle data channel. As such, the regulation incorporates the 75 deg/sec criterion described above plus a 5 degree steering measurement. The value for time at the start of steering, used for calculating the lateral responsiveness metrics, is interpolated.

b. Determining the End of Steering

163. Similarly, it was decided that an unambiguous point to define the end of steering is also necessary for consistency in computing the performance metrics measured during compliance testing. Accordingly, the regulation incorporates the suggestion of defining the end of steering as the first occurrence of the "zeroed" steering wheel angle crossing zero degrees after the second peak of steering wheel angle.

c. Removing Offsets

164. Given the potential for the accelerometers used in the measurement of lateral displacement to drift over time, it was argued that the regulation should use the data one second before the start of steering to "zero" the accelerometers and roll signal. This recommendation was adopted for the following reasons. Prior to the test manoeuvre, the driver shall orient the vehicle to the desired heading, position the steering wheel angle to zero, and be coasting down (i.e. not using throttle inputs) to the target test speed of 80 km/h. This process, known as achieving a "quasi-steady state," typically occurs a few seconds prior to initiation of the manoeuvre, but can be influenced by external factors such as test track traffic, differences in vehicle deceleration rates, etc. A zeroing duration of one second provides a good combination of sufficient time (i.e. enough data is present so as to facilitate accurate zeroing of the test data) and performability (i.e. the duration is not so long that it imposes an unreasonable burden on the driver). Experience has shown that the use of a 0.5 second interval is usually sufficient; however, the 1.0 second is more conservative and, therefore, preferred. Conversely, it is not expected that zeroing intervals longer than one second would improve the zeroing accuracy.

d. Use of Interpolation

165. There are several events in the calculation of performance metrics that require determining the time and/or level of an event, including: (1) start of steering; (2) 1.07 or 1.32 seconds after the start of steering; (3) end of steering; (4) 1 second after the end of steering, and (5) 1.75 seconds after the end of steering. In developing this gtr, it was decided that in determining specific timed and measured data points, interpolation provides more consistent results and is less sensitive to differing sampling rates than other approaches (e.g., choosing the sample that is closest in time to the desired event). Therefore, the regulation uses this method during post data processing.

e. Method for Determining Peak Steering Wheel Angle

166. It was asserted that because metrics for responsiveness are specified by steering wheel angle (SWA), a method for determining the actual SWA needs to be specified. The first measured peak SWA was suggested because it is the peak that directly influences the responsiveness measurement. However, as discussed above, this regulation defines the torque capacity of the steering machine used in the responsiveness test and uses the commanded peak steering angle, rather than the measured peak steering angle, as the indication of tests in which the vehicle shall meet the responsiveness criteria.

f. Need for a Common Data Processing Kernel

167. Because data processing methods can have a significant impact on the results generated, necessary data processing details are included in the regulatory text.

(e) Test Conditions

(i) Ambient Conditions

a. Ambient Temperature Range

168. The regulation states that testing will be conducted when the ambient temperature is between 0 ºC and 45 ºC. It was originally decided, based upon participant input, that the temperature value should be 7 °C. The reason is that research demonstrates that responsiveness is reduced at higher temperatures, which is typical of vehicles with all-season tyres. The temperature values reflect the general desirability of reducing sources of variability in vehicle testing, in order to prevent testing at temperatures that favour a vehicle's chance of passing the test. Higher minimum temperature values were considered (e.g., 10 ºC), but such temperature has the disadvantage of reducing the length of the testing season for potential test facilities in colder regions. Thus, the value selected reflects the dual goals of better repeatability but also practicability. The following provides additional detail on how these ambient temperature requirements were determined.

169. Industry participants stated that their analysis had demonstrated ESC test variability due to temperature. It was suggested that, at near-freezing temperatures, certain high performance tyres could enter their "glass transition range," 21/ which could introduce further test variability. Accordingly, it was recommended that the lower bound of the temperature range should be 10 °C. In addition to reducing test variability, it was asserted that such an approach to the temperature portion of the test procedures would permit virtually year-round testing at many facilities, reduce burdens associated with confirming compliance at low temperatures, and avoid complications of snow and ice during testing.

170. A vehicle's ESC system is designed for and expected to address stability issues over a wide range of various environmental conditions. Testing conducted indicates that lateral displacement for vehicles equipped with all-season tyres varies with fluctuating ambient temperatures. According to the industry, the data indicate that lateral displacement for test vehicles equipped with all-season tyres increases as the ambient temperature decreases, suggesting that the displacement requirement could be met more easily at lower ambient temperatures. However, this same relationship was not manifested in test vehicles equipped with high performance tyres (some high-performance tyres are not designed for operation under freezing conditions, and the performance variability of these tyres under cold ambient temperatures is unknown, because in repeatability studies considered, tyres are tested in the

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21/ Note that this is the industry's term. They are referring to a rubber chemistry issue (i.e. that all rubbery polymers turn into glassy solids at characteristic low temperatures, which vary depending on the polymer composition of the tyres). The industry seems to assert that because of their composition, for certain high performance tyres, the "glass transition range" (i.e. the temperature range between the glass temperature and the onset of fully rubber-like response) may include some of the lower bound of the proposed ambient test range.

temperature ranges in which they are designed to operate). The industry recommended minimizing potential test variability by reducing the specified test condition ambient temperature range. To minimize test variability, the lower bound of the temperature range was set for ESC testing to 7 °C. It was believed that 7 °C is appropriate because it is low enough to increase the length of the testing season at multiple testing sites, and also represents the low end of the relevant temperature range for some brands of high performance tyres. However, because certain Contracting Parties requested a lower bound of the temperature range of 0 °C and because there may be certain tyre/vehicle combinations that perform acceptably under such conditions, this gtr will allow testing down to 0 °C.

b. Wind Speed

171. Industry participants expressed concern that a maximum wind speed for testing of 10 m/s could impact the performance of certain vehicle configurations (e.g., cube vans, 15-passenger vans, vehicles built in two or more stages). It was estimated that a cross wind at 10 m/s could reduce lateral displacement at 1.07 s by 0.15 m, compared to the same test conducted under calm conditions. Accordingly, industry participants recommended a maximum allowable wind speed of 5 m/s, a figure consistent with ISO 7401.

172. Wind speed could have some impact on the lateral displacement for certain vehicle configurations, including large sport utility vehicles and vans. However, a maximum wind speed of 5 m/s can impose additional burdens by restricting the environmental conditions under which testing can be conducted. With these considerations in mind, the wind speed requirement is set at 5 m/s for vehicles with a static stability factor (SSF) less than or equal to 1.25, but the wind speed for vehicles with a SSF greater than 1.25 is set at 10 m/s. This approach will reduce test variability for those vehicles expected to be most affected by wind speed and minimize any additional burdens on test laboratories.

173. It is noted that if the wind speed requirement is set at 5 m/s for all light vehicles, that would unduly limit the number of days on which testing could be performed, and wind speed up to 10 m/s would not have an appreciable impact on the testing of high-SSF vehicles like passenger cars due to their smaller side dimensions.

(ii) Road Test Surface

174. The regulation states that tests are conducted on a dry, uniform, solid-paved surface; surfaces with irregularities and undulations, such as dips and large cracks, are unsuitable. The gtr also states that the test surface has a consistent slope between level and 1 per cent. Although consideration was given in the U.S. to requiring a test surface with a slope up to 2 per cent (with test initiated in the direction of positive slope (i.e. uphill)), this alternative was rejected because most test tracks have a slope of 1 per cent or less, which is so slight that a directional specification is unnecessary.

175. The gtr also provides that the road test surface shall have a nominal peak braking coefficient (PBC) of 0.9, unless otherwise specified, when measured using one of two methods as specified by the respective Contracting Parties.

a. Using an American Society for Testing and Materials (ASTM) E1136-93 (1993) standard reference test tyre, in accordance with ASTM Method E 1337-90 (reapproved 1996), at a speed of 64.4 km/h, without water delivery.
b. The method specified in the Annex 6 Appendix 2 of UNECE Regulation No. 13-H.

176. The intention in specifying a nominal PBC of 0.9 is not to preclude the use of real world test tracks, which may or may not have this exact PBC but rather to permit Contracting Parties to use a high adhesion surface available to them. In practical terms, when testing for conformity to the requirements, manufacturers may test on a surface with a lower PBC, to test for a worse-case scenario. This would assure positive results when verification for compliance testing is conducted by the administrations on a surface with a PBC of 0.9 or higher. In other words, if the vehicle is able to meet the requirements at a PBC below 0.9, it is considered to be compliant with a PBC of 0.9.

(iii) Vehicle Conditions

a. Vehicle Test Mass

177. In the test procedures, the gtr specifies that the vehicle is loaded with the fuel tank filled to at least 90 per cent of capacity, and total interior load of 168 kg comprised of the test driver, approximately 59 kg of test equipment (automated steering machine, data acquisition system and power supply for the steering machine), and ballast as required by differences in the mass of test drivers and test equipment. Where required, ballast shall be placed on the floor behind the passenger front seat or if necessary in the front passenger foot well area. All ballast shall be secured in a way that prevents it from becoming dislodged during test conduct.

178. Given that the mass of a 95$^{th}$ percentile male is 102 kg, 22/ it is believed that the maximum allowable mass allocated for the test driver (109 kg) is conservative and should not impose an unreasonable testing burden on parties performing ESC testing.

179. In the U.S., some participants recommended clarifying the location where ballast (if required) is to be placed in the vehicle to account for varying mass of test drivers and test equipment. As a result, specifications have been incorporated in the regulation as to where the ballast shall be positioned. Such specification serves not only to ensure even distribution of the load of the driver, steering machine, and test equipment, but it also acknowledges the potential for the very abrupt vehicle motions imposed by the Sine with Dwell manoeuvre to dislodge and/or relocate unsecured ballast during testing. Contracting Parties may provide further direction in any accompanying laboratory test procedure, as appropriate.

b. Outriggers

180. Industry participants conceded that the use of outriggers may be appropriate during testing, but recommended that the regulation should explicitly clarify the vehicle class's

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22/ Schneider, L.W., Robbins, D.H., Pflug, M.A., and Synder, R.G., Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family, Volume 1 - Procedures, Summary Findings, and Appendices, The University of Michigan Transportation Research Institute Report UMTRI-83-53-1, December 1983, Table 2-5 at page 20.

properties that are to be equipped with outriggers (e.g., trucks, multipurpose vehicles, and buses) and set forth the design specifications for those devices. Concern was expressed that without such clarification, outriggers can influence vehicle dynamics in the subject tests. Therefore, in order to reduce test variability and increase the repeatability of test results, the gtr specifies that outriggers may be used if deemed necessary for test driver safety. For vehicles with a SSF less than or greater than 1.25, the gtr also specifies maximum mass and roll moment of inertia specifications for outriggers.

(f) Test Procedure

(i) Accuracy Requirements

181. Specification of accuracy requirements for the following measurement instruments used in the ESC test procedures was also considered, for: (1) the yaw rate sensor; (2) the steering machine, and (3) the lateral acceleration sensor. However, it was decided that it is not necessary to include sensor specifications as part of the regulatory text of the gtr. Instead, Contracting Parties may wish to include these sensor specifications in related Laboratory Test Procedures in order to provide detailed instructions to personnel conducting testing (e.g., test equipment to be used, limitations on equipment output variability). Typical sensor specifications of the instrumentation used in research and testing are as follows:

(ii) Tolerances

182. The gtr's test procedures contain a provision for brake conditioning as part of ESC testing. Specifically, the test procedures call for the vehicle to undertake a series of stops from either 56 km/h or 72 km/h in order to condition the brakes prior to further testing under the standard. In addition, the vehicle is to undertake several passes with sinusoidal steering at 56 km/h to condition the tyres.

183. Some participants recommended that the gtr should outline specific tolerances for vehicle speed and deceleration to condition the tyres and brakes prior to compliance testing, thereby helping to ensure consistent test conditions.

184. It was decided that it is not necessary to make additional changes to the tyre and brake-conditioning provisions of the regulatory text based on these recommendations for tolerances for vehicle speed and deceleration. The intent of tyre conditioning is to wear away mold sheen and to help bring the tyres up to test temperature. Minor fluctuations in the vehicle speeds specified in the regulation should not have any measurable affect on these objectives. Similarly, minor fluctuations in the manoeuvre entrance speeds and deceleration specifications provided in the regulation will not adversely affect the brake conditioning process.

(iii) Location of Lateral Accelerometer

185. It was recommended that the test procedures should include detailed specifications on how to calculate lateral acceleration. For example, for some vehicles, it may not be possible to install a lateral acceleration sensor at the location of the vehicle's actual centre of gravity; in

those cases, a correction factor would be necessary to accommodate this different sensor positioning.

186. It may not always be possible to install a lateral acceleration sensor at the location of the vehicle's actual centre of gravity. For this reason, it is important to provide a coordinate transformation to resolve the measured lateral acceleration values to the vehicle's centre of gravity location. The specific equations used to perform this operation, as well as those used to correct lateral acceleration data for the effect of chassis roll angle, are suitable for being incorporated into a laboratory test procedure prepared by Contracting Parties to this gtr.

(iv) Calculation of Lateral Displacement

187. One participant expressed concern with an ESC test procedure that would compute lateral displacement by using double integration with respect to time of the measurement of lateral acceleration at the vehicle centre of gravity (with time t=0 for the integration operation is the instant of steering initiation), because it believes that the same vehicle, when tested at different facilities and by different engineers, may experience differences in lateral displacement of up to 60 cm. Specifically, it suggested that problems could arise from the test procedures' computation of lateral displacement and also the repeatability of those procedures. 23/ This participant also suggested that the test should be based upon "spin velocity" rather than "spin displacement;" the reasoning was that this approach would render timing less important, because spin velocity at 1.071 seconds is roughly constant, and it argued that measurements of "spin velocity" would be easier to repeat.

188. Technically speaking, the lateral displacement evaluated under the regulation is not the "lateral displacement of the vehicle's centre of gravity," but an approximation of this displacement. In the present context, the location of the vehicle's centre of gravity corresponds to the longitudinal centre of gravity, measured when the vehicle is at rest on a flat, uniform surface. The lateral displacement metric, as defined, is based on the double integration of accurate lateral acceleration data. Lateral acceleration data are collected from an accelerometer, corrected for roll angle effects, and resolved to the vehicle's centre of gravity using coordinate transformation equations. The use of accelerometers is commonplace in the vehicle testing

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23/ Regarding lateral displacement computation, it was argued that integrating the accelerometer into a rotating reference frame does not compute actual lateral displacement, because with this technique, a vehicle that rotates more (i.e. achieves a higher yaw angle compared to the original straight driving line) will yield a different result, even if the displacement is the same. Although acknowledging the need to set some value as part of the test (e.g. 1.83 meters, as proposed), it was suggested to use some term to prevent confusion, such as "ESC Displacement" or "Spin Displacement". Regarding repeatability, it was argued that up to 60 cm of difference in lateral displacement could result from small differences in the conduct of testing, including: (1) use of a true lateral displacement measurement (i.e. GPS), as opposed to the proposed accelerometer technique; (2) failure to do a roll correction for the acceleration; (3) variation for the linearity error of a low-cost accelerometer; (4) rainwater run-off angle of the road; (5) variations in the mounting angle of the accelerometer in the vehicle; (6) timing errors in acquisition; (7) differences due to use of accelerometers with a 10 Hz bandwidth, as compared to a wide bandwidth; (8) variation in the natural drift of vehicles.

community, and installation is simple and well understood. However, this gtr also permits use of GPS-based data for calculation of lateral displacement if a Contracting Party determines that the GPS-based calculation method is equivalent or better in accuracy than the double integration method.

189. Therefore, for the purposes of the ESC performance criteria, use of a calculated lateral displacement metric provides a simple, reasonably accurate, and cost-effective way to evaluate vehicle responsiveness. Since the integration interval is short (recall that lateral displacement is assessed 1.07 seconds after initiation of the manoeuvre's steering inputs), integration errors are expected to be small. Data processing routines including refined signal offset and zeroing strategies should minimize the confounding effects these factors may have on the test output, thereby ensuring repeatable results. Contracting Parties are encouraged to make publicly available these routines used to calculate lateral displacement during data post-processing, in order to ensure that vehicle manufacturers and ESC suppliers know exactly how the responsiveness of their vehicles (or customer's vehicles) will be evaluated. If the sensors used to measure the vehicle responses are of sufficient accuracy, and have been installed and configured correctly, use of the analysis routines for this gtr are expected to minimize the potential for performance discrepancies in test efforts by different parties. Suitable specifications of the accelerometers include: (1) bandwidth > 300 Hz, (2) non-linearity < 50 $\mu g/g^2$, (3) resolution ≤ 10 µg, and (4) output noise ≤ 7.0 mV. An overview of suitable instrumentation for use during Sine with Dwell tests is provided in the table below.

| Data Measured | Type | Range | Accuracy |
|---|---|---|---|
| Steering wheel angle | Angle encoder | ±720 degrees | ±0.10 degrees (1) |
| Longitudinal, lateral and vertical acceleration; Roll, yaw and pitch rate | Multi-axis inertial sensing system | Accelerometers: ±2g<br>Angular rate sensors: ±100°/s | Accelerometers: < 50 $\mu g/g^2$ (2)<br>Angular rate sensors: ≤ 0.05% of full scale (2) |
| Left and right side vehicle ride height | Ultrasonic distance measuring system | 10-102 cm | 0.25% of maximum distance |
| Vehicle speed | Radar speed sensor | 0.16-201 km/h | 0.16 km/h |

(1) Combined resolution of the encoder and D/A converter.
(2) Non-linearity specifications.

(v) Maximum Steering Angle

190. In the U.S. rulemaking, concern was expressed that steering angles under the test procedure not be too large for vehicles that have a large steering gear ratio. It was argued that the upper limit of an average driver's steering velocity is approximately 1000°/sec; thus, the steering angle is 227° under a Sine with Dwell condition with a frequency of 0.7 Hz. Similarly,

it stated that the steering angle of 270º is equal to the steering velocity of 1188º/sec, a value that exceeds the average driver's steering velocity.

191. However, studies have shown that human drivers can sustain handwheel rates of up to 1189 degrees per second for 750 milliseconds, a steering rate which corresponds to a steering angle magnitude of approximately 303 degrees. 24 It is conceded that the method used to determine maximum Sine with Dwell steering angles can produce very large steering angles. Of the 62 vehicles used to develop the Sine with Dwell performance criteria, the vehicle requiring the most steering required a maximum steering angle of 371 degrees (calculated by multiplying the average steering angle capable of producing a lateral acceleration of 0.3g in the Slowly Increasing Steer manoeuvre times a steering scalar of 6.5). Use of this steering wheel angle required an effective steering wheel rate of 1454 degrees per second, a magnitude well beyond the steering capability of a human driver.

192. In order to ensure that the maximum steering angle in the regulation does not surpass the steering capability of a human driver, the regulation provides that the steering amplitude of the final run in each series is the greater of 6.5A or 270 degrees, provided the calculated magnitude of 6.5A is less than or equal to 300 degrees. If any 0.5A increment, up to 6.5A, is greater than 300 degrees, the steering amplitude of the final run shall be 300 degrees.

(vi) Data Filtering

193. It was recommended that the gtr should include specifications for data filtering methods directly in its regulatory text, given the potential for different filtering methods to significantly influence final results. Specifically, the following filtering protocol was recommended for all channels (except steering wheel angle and steering wheel velocity): (a) create a six-pole, low-pass Butterworth filter with a 6 Hz cut-off frequency, and (b) filter the data forwards and backwards so that no phase shift is induced. For the steering wheel angle channel, use of the same protocol was recommended, but with a 10 Hz cut-off frequency. For steering wheel velocity, adoption of a specific calculation was also recommended.

194. Data filtering methods can have a significant impact on final test results used for determining vehicle compliance with this regulation, and the same filtering and processing protocols shall be followed in order to ensure consistent and repeatable test results. Accordingly, the test procedures section of the gtr's regulatory text now specifies critical test filtering protocols and techniques to be used for test data processing.

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24/ As background, the frequency of the sinusoidal curve used to command the Sine with Dwell manoeuvre steering input is 0.7 Hz. Use of this frequency causes the time from the completion of the initial steering input (the first peak) to the completion of the steering reversal (the second peak) to take approximately 714 ms, regardless of the commanded steering angle magnitude. Multiple studies using double-lane change manoeuvres have been performed to evaluate the upper limit of human driver steering capability, generating results consistent with those listed above. See Forkenbrock, Garrick J. and Devin Elsasser, An Assessment of Human Driver Steering Capability, NHTSA Technical Report, DOT HS 809 875, October 2005. Available at <http://www-nrd.nhtsa.dot.gov/vrtc/ca/capubs/NHTSA_forkenbrock_driversteeringcapabilityrpt.pdf>.

(vii) Brake Temperatures

195. Industry participants provided their assessment of the effect of brake pad temperatures on ESC test results, particularly given the potential for drivers to use heavy braking between test runs. Charts were provided based upon research that purported to demonstrate variance in testing due to brake pad temperature, which would be an artefact of the test methodology, not a reflection of expected ESC performance in the real world. Therefore, in order to minimize non-representative test results, a recommendation was made that the ESC test procedures should specify a minimum of 90 seconds between test runs in order to allow sufficient time for cooling of the brake pads.

196. Because excessive brake temperatures may have an effect on ESC test results, a minimum wait time between test runs has been incorporated into the test procedure to ensure brake temperatures are not excessive. Ninety seconds, as recommended by the industry, is a reasonable lower bound for the allowable time between runs. The regulation also specifies a maximum wait time of 5 minutes between test runs to ensure that the brakes and tyres remain at operating temperatures, an important feature since test procedures endeavour to simulate real world driving conditions. For these reasons, the regulation provides that the allowable range of time between Sine with Dwell tests is 90 seconds to 5 minutes.

(viii) Rounding of Steering Wheel Angle at 0.3g

197. During the development process for this gtr, consideration was given to the following approach, which provided that from the Slowly Increasing Steer tests, the quantity "A" is determined. "A" is the steering wheel angle in degrees that produces a steady state lateral acceleration of 0.3g for the test vehicle at 80 km/h. Utilizing linear regression, A is calculated, to the nearest 0.1 degrees, from each of the six Slowly Increasing Steer tests. The absolute value of the six A's calculated is averaged and rounded to the nearest degree to produce the final quantity, A.

198. Industry participants recommended against rounding the steering wheel angle measurement at 0.3g to the nearest whole number, because such methodology potentially increases variability across test runs. It was argued that such an approach could also increase steering wheel angle variability at a scalar of 5.0 (where the proposed responsiveness metric starts) by a factor of five. According to the industry, rounding to a whole-number level of precision does not simplify programming or control of the steering robot. Therefore, the participants recommended rounding steering wheel angle at 0.3g to the nearest 0.1 degrees, so as to eliminate this source of test variability.

199. The recommendation to round the steering wheel angle at 0.3g to the nearest 0.1 degree was adopted as part of this gtr. Rounding to this level is not expected to complicate programming of the automated steering controller and will decrease the variability in the number of required test runs.

(ix) Alternative Test Procedures

200. While acknowledging that there is a trade-off between lateral stability and intervention magnitude, some participants stated that an assessment should be provided of other available alternative test procedures and the rationale for not adopting those procedures. Furthermore, concern was expressed that the test procedures not allow for errors in measurement that would allow vehicles to pass the performance test on that basis.

201. An appropriate balance between lateral stability and intervention magnitude is one in which a light vehicle is in compliance with the evaluation criteria of this gtr, both in terms of lateral stability and responsiveness. Development of these criteria was the result of hundreds of hours of testing and data analysis. These criteria provide an extremely effective way of objectively assessing whether the lateral stability of an ESC-equipped vehicle is adequate.

202. The responsiveness criteria proposed for use in this gtr, that a vehicle with a GVM of greater than 3,500 kilograms shall achieve at least 1.83 m (1.52 feet) of lateral displacement when the Sine with Dwell manoeuvre is performed with normalized steering angles greater than 5.0, adequately safeguards against implementation of overly aggressive ESC systems, even those specifically designed to mitigate on-road untripped rollover (i.e. systems that may consider stability more important than path-following capability). Achieving acceptable lateral stability is very important, but should not be accomplished by grossly diminishing a driver's crash avoidance capability.

203. Intervention intrusiveness can refer to how the vehicle manufacturer and its ESC vendor "tune" an ESC system for a particular vehicle make/model, specifically how apparent the intervention is to the driver. It is not believed that it is appropriate to dictate this form of intervention magnitude, as it can be an extremely subjective specification. As long as a vehicle's ESC (1) satisfies the regulation's hardware and software definitions, and (2) allows the vehicle to comply with the lateral stability and responsiveness performance criteria, intervention intrusiveness should be a tuning characteristic best specified by the vehicle/ESC manufacturers.

204. In response to the issue of manoeuvre selection, twelve test manoeuvres were evaluated in the U.S. before ultimately selecting the Sine with Dwell manoeuvre to assess ESC performance. As explained below, this U.S. evaluation was performed in two stages, an initial reduction from twelve manoeuvres to four, then from four to one.

205. The first stage began with identification of three important attributes: (1) high manoeuvre severity ("manoeuvre severity"); (2) capability to produce highly repeatable and reproducible results using inputs relevant to real-world driving scenarios ("face validity"); and (3) ability to effectively evaluate both lateral stability and responsiveness ("performability"). To quantify the extent to which each manoeuvre possessed these attributes, adjectival ratings ranging from "Excellent" to "Fair" were assigned to each of the twelve manoeuvres, for each of the three manoeuvre evaluation criteria. Of the twelve test manoeuvres, only four received "Excellent" ratings 25/ for each of the manoeuvre evaluation criteria - the Increasing Amplitude Sine (0.7 Hz), Sine with Dwell (0.7 Hz), Yaw Acceleration Steering Reversal (YASR; 500 deg/sec), and Yaw Acceleration Steering Reversal with Pause (YASR with Pause; 500 deg/sec steering rate).

206. Stage two of the manoeuvre reduction process used data from 24 vehicles (a sampling of sports cars, sedans, minivans, small and large pickup trucks, and sport utility vehicles) to compare the manoeuvre severity, face validity, and performability of the four manoeuvres selected in the first stage. The ability of the four manoeuvres to satisfy these three evaluation criteria were compared and rank ordered.

207. Of the four candidate manoeuvres, the Sine with Dwell and YASR with Pause were the top performers in terms of evaluating the lateral stability component of ESC functionality. However, due to the fact that the Sine with Dwell manoeuvre required smaller steering angles to produce spinouts for five of the ten vehicles evaluated with left-right steering, and for two of the ten vehicles with right-left steering (with the remaining thirteen tests using the same steering angles), the Sine with Dwell manoeuvre was assigned a higher manoeuvre severity ranking than that assigned to the YASR with Pause manoeuvre.

208. Generally speaking, the Increasing Amplitude Sine and YASR manoeuvres required the most steering to produce spinouts, regardless of direction of steer. However, the Increasing Amplitude Sine manoeuvre also produced the lowest normalized second yaw rate peak magnitudes, implying the manoeuvre was the least severe for most of the 24 test vehicles used for manoeuvre comparison. For this reason, the worst severity ranking was assigned to the Increasing Amplitude Sine manoeuvre.

209. Each of the four candidate manoeuvres possessed inherently high face validity since they were each comprised of steering inputs similar to those capable of being produced by a human driver in an emergency obstacle avoidance manoeuvre. However, of the four manoeuvres, the Increasing Amplitude Sine manoeuvre possessed the best face validity. Conceptually, the steering profile of this manoeuvre was the most similar to that expected to be used by real drivers, 26/ and even with steering wheel angles as large as 300 degrees, the manoeuvre's

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25/ The adjectival ratings used to rate the test manoeuvres were "Excellent," "Good," and "Fair," with "Excellent" being the best and "Fair" being the worst. An "Excellent" manoeuvre was one capable of adequately demonstrating whether a vehicle was, or was not, equipped with an ESC system that satisfied a preliminary version of our minimum performance criteria. Conversely, a manoeuvre assigned a "Fair" rating was unable to adequately demonstrate whether these vehicles were, or were not, equipped with ESC systems capable of satisfying the preliminary minimum performance criteria.

26/ In an obstacle avoidance scenario, it is clearly conceivable that the second steering input may be larger than the first input. If the first steering input induces overshoot, the driver's reversal will need to be equal to the first steering input plus enough steering to combat the yaw overshoot.

maximum effective steering rate was a very reasonable 650 deg/sec. For these reasons, the Increasing Amplitude Sine manoeuvre received the top face validity rating.

210. The two YASR manoeuvres received the same face validity ratings, just lower than that assigned to the Increasing Amplitude Sine. The YASR steering profiles were comprised of very reasonable 500 deg/sec steering rates; however, their sharply defined, trapezoidal shapes reduce their similarity to inputs actually used by drivers in real world driving situations. The steering profile of the Sine with Dwell was deemed very reasonable; however, the manoeuvre can require steering rates very near the maximum capability of a human driver.

211. The performability of the Sine with Dwell and the Increasing Amplitude Sine manoeuvres were deemed to be excellent. These manoeuvres are very easy to program into the steering machine, and their lack of rate or acceleration feedback loops simplifies the instrumentation required to perform the tests. Conversely, the YASR manoeuvres require the use of specialized equipment (an angular accelerometer), and these manoeuvres required an acceleration-based feedback loop that was sensitive to the accelerometer's signal-to-noise ratio near peak yaw rate. Testing demonstrated that large steering angles can introduce dwell time variability capable of adversely reducing manoeuvre severity and test outcome.

212. After considering the totality of the test result from the U.S. evaluation of the candidate manoeuvres and for the reasons stated above, the conclusion was that the Sine with Dwell manoeuvre offers the best combination of manoeuvre severity, face validity, and performability. Additional details of the manoeuvre selection process are available in an Enhanced Safety of Vehicles (ESV) technical paper 27/ and a related technical report 28/.

213. Regarding the implication of measurement errors, it is noted that many of these potential errors have already been addressed by the regulation, given the accuracy of the accelerometers for ESC testing and post-processing routines which already contain algorithms to resolve such concerns.

214. Note that all test track evaluations inherently contain some degree of output variability, regardless of what aspect of vehicle performance they are being used to evaluate. In the context of ESC testing, it is conceded that this variability could result in a marginally non-compliant vehicle passing the test, but it is important to recognize these situations would only affect a very small population of vehicles, and that the effect of instrumentation and/or calculation errors is likewise believed to be very small. Since the performance of most contemporary target vehicles resides far enough away from the regulation's performance thresholds, it is extremely unlikely that measurement complications will be solely responsible for having the performance of a non-compliant vehicle being deemed acceptable.

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27/ Forkenbrock, Garrick J., Elsasser, Devin, O'Harra, Bryan C., NHTSA's Light Vehicle Handling and ESC Effectiveness Research Program, ESV Paper Number 05-0221, June 2005, (Docket No. NHTSA-2006-25801-5).

28/ Forkenbrock, Garrick J., Elsasser, Devin, O'Harra, Bryan C., Jones, Robert E., Development of Electronic Stability Control (ESC) performance criteria, NHTSA Technical Report, DOT HS 809 974, September 2006. Available at: www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv19/05-0221-O.pdf.

(x) Representativeness of Real World Conditions

215. A few participants in the U.S. questioned how many tests are necessary to ensure that the ESC system is robust, and how many different configurations of tyres, loading, and trailering are needed to be representative of real world driving. Concerns were also expressed that even though an ESC system may increase safety under certain conditions, in other cases, it may add unpredictable and unusual characteristics to the vehicle.

216. Many crash data studies quantifying real world ESC effectiveness were reviewed. 29/ Regardless of the origin of the data used for these studies (i.e. whether from France, Germany, Japan, Sweden, the United States, etc.), all reported or estimated that ESC systems provide substantial benefits in "loss of control" situations. These studies reported that ESC is expected to be particularly effective in situations involving excessive oversteer, such as "fishtailing" or "spinout" which may result from sudden collision avoidance manoeuvres (e.g., lane changes or off-road recovery manoeuvres).

217. The Sine with Dwell manoeuvre is specifically designed to excite an oversteer response from the vehicle being evaluated. While this manoeuvre has been optimized for the test track (because objectivity, repeatability, and reproducibility are necessary elements of a regulatory compliance test), it is important to recognize that multiple studies have indicated that the steering angles and rates associated with the Sine with Dwell manoeuvre are within the capabilities of actual drivers, not just highly trained professional test drivers.

218. It is noted that there is no evidence of any "unpredictable and unusual characteristics" imparted by any ESC system on the vehicle in which it is installed. ESC interventions occur in extreme driving situations where the driver risks losing control of the vehicle, not during "normal" day-to-day driving comprised of relatively small, slow, and deliberate steering inputs. In these extreme situations, the driver shall still operate the vehicle by conventional means (i.e. use of steering and/or brake inputs are still required to direct the vehicle where the driver wants it to go); however, the mitigation strategies used by ESC to suppress excessive oversteer and understeer help improve the driver's ability to successfully retain control of the vehicle under a broad range of operating conditions.

219. The load configuration used during the conduct of our ESC performance tests is known as the "nominal" load configuration, consisting of a driver and test equipment. This configuration approximates a driver and one front seat occupant. This configuration is highly representative of how the majority of vehicles are loaded. U.S. analyses, based on results from a database 30/ comprised of 293,000 single-vehicle crashes, indicate that the average number of passenger car occupants involved in a single-vehicle crash was 1.48 occupants per vehicle. Results for pickups, sport utility vehicles, and vans were similar (1.35, 1.54, and 1.81 occupants per vehicle, respectively).

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29/ See 71 FR 54712, 54718 (September 18, 2006), footnote 11.

30/ Data were analyzed for the development of the rollover NCAP star ratings criteria. It is data for six U.S. States: Florida (1994-2001), Maryland (1994-2000), Missouri (1994-2000), North Carolina (1994-1999), Pennsylvania (1994-1997), and Utah (1994-2000). Only single-vehicle crashes for 100 make-models were included. Please consult the Rollover NCAP portion of the NHTSA website for further information (<http://www.nhtsa.dot.gov>).

220. It is important for an objective test procedure to be applicable to all light vehicles. The use of multiple load configurations was considered, but there are an infinite number of ways drivers can potentially load their vehicles, and not all vehicles can be subjected to the same load configurations.

221. Although it is important to understand how vehicle loading can influence ESC effectiveness and presently have research programs designed to objectively quantify those effects, requiring ESC on all light vehicles will save thousands of lives per year. Accordingly, it is not appropriate to delay the present gtr for ESC, and to thereby fail to maximize the benefits of this technology, pending the outcome of this additional research. In sum, it is believed that the available data strongly support the decision to adopt this gtr for ESC at this time.

## 7. BENEFITS AND COSTS

### (a) Summary

222. This section summarizes the anticipated benefits, costs, and cost per equivalent life saved as a result of installation of ESC systems consistent with the requirements contained in this gtr. Specific benefit estimates are available for the U.S., which recently adopted a regulation requiring installation of ESC systems in all new light vehicles beginning September 1, 2011. Similarly, cost estimates are available from the United States, which provide a basis for understanding the economic impacts of the gtr for ESC. However, a detailed cost-benefits analysis would be necessary to properly estimate the impact of the gtr on each Contracting Party, with changes in these variables obviously affecting the cost-effectiveness calculation for ESC. Nevertheless, it is anticipated that the U.S. experience may serve as a case study, which can be extrapolated, to other Contracting Parties.

223. In overview, the life- and injury-saving potential of ESC is very significant, both in absolute terms and when compared to prior U.S. automobile safety rulemakings. In the U.S. context, compared to a baseline of manufacturers' plans of having 71 per cent of the light vehicle fleet with ESC by Model Year (MY) 2011, it was estimated that the final regulation for ESC will save 1,547 to 2,534 lives and cause a reduction of 46,896 to 65,801 MAIS 1-5 injuries (Maximum Abbreviated Injury Scale) annually once all passenger vehicles have ESC. The ESC regulation in the U.S. is also expected to save $376 to $535 million annually in property damage and travel delay (undiscounted). The total cost of this U.S. rule is estimated to be $985 million. Based upon these figures, the ESC final rule in the U.S. was determined to be extremely cost-effective, with the cost per equivalent life saved expected to range from $0.18 to $0.33 million at a 3 per cent discount and $0.26 to $0.45 million at a 7 per cent discount.

### (b) Benefits

224. It is anticipated that, when all U.S. light vehicles are equipped with ESC, the regulation would prevent 67,466 to 90,807 crashes (1,430 to 2,354 fatal crashes and 66,036 to 88,453 non-fatal crashes). Preventing these crashes entirely is the ideal safety outcome and would translate into 1,547 to 2,534 lives saved and 46,896 to 65,801 MAIS 1-5 injuries prevented.

225. The above figures include benefits related to rollover crashes, a subset of all crashes. However, in light of the relatively severe nature of crashes involving rollover, ESC's contribution toward mitigating the problem associated with this subset of crashes should be noted. It is anticipated that the regulation would prevent 35,680 to 39,387 rollover crashes (1,076 to 1,347 fatal crashes and 34,604 to 38,040 non-fatal crashes). This would translate into 1,171 to 1,465 lives saved and 33,001 to 36,420 MAIS 1-5 injuries prevented in rollovers.

226. In addition, preventing crashes would also result in benefits in terms of travel delay savings and property damage savings. It is estimated that the regulation would save $376 to $535 million, undiscounted 31/, in these two categories ($240 to $269 million of this savings is attributable to prevented rollover crashes).

227. In addition, the ESC gtr will also have the effect of causing all light vehicles to be equipped with anti-lock braking systems (ABS) as a foundation for ESC. It is anticipated that some level of benefits will result from improved brake performance on vehicles not currently equipped with ABS, but it has not been possible to quantify them. However, it should be noted that the potential benefits of ABS did not influence the above-discussed effectiveness estimates for ESC, because all of the non-ESC control vehicles in the study already had ABS. The measure of unquantified benefits relates to situations where the ABS system activates (but the ESC system does not need to) on vehicles that were not previously equipped with ABS.

(c) Costs

228. The cost of this gtr will need to be calculated for each individual Contracting Party. In the case of the U.S. (for which an estimate is already available), in order to estimate the cost of the additional components required to equip every vehicle in future model years with an ESC system, assumptions were made about future production volume and the relationship between equipment found in anti-lock brake systems (ABS), traction control (TC), and ESC systems. It was assumed that in an ESC system, the equipment of ABS is a prerequisite. Thus, if a passenger car did not have ABS, it would require the cost of an ABS system plus the additional incremental costs of the ESC system to comply with an ESC standard. It was assumed that traction control (TC) was not required to achieve the safety benefits found with ESC. Future annual U.S. production of 17 million light vehicles was estimated (consisting of nine million light trucks and eight million passenger cars).

229. In addition, an estimate was made of the MY 2011 installation rates of ABS and ESC. It served as the baseline against which both costs and benefits were measured. Thus, the cost of the U.S. regulation was determined to be the incremental cost of going from the estimated MY 2011 installations to 100 per cent installation of ABS and ESC. The estimated MY 2011 installation rates are presented in Table 1.

31/ The present discounted value of these savings ranges from $247 to $436 million (based on 3 per cent and 7 per cent discount rates).

Table 1. MY 2011 Predicted installations (per cent of the light vehicle fleet)

| | ABS | ABS + ESC |
|---|---|---|
| Passenger Cars | 86 | 65 |
| Light Trucks | 99 | 77 |

230. Based on the assumptions above and the data provided in Table 1, Table 2 presents the per cent of the MY 2011 fleet that would need these specific technologies in order to equip all light vehicles with ESC.

Table 2. Per cent of the light vehicle fleet requiring technology to achieve 100 per cent ESC installation

| | None | ABS + ESC | ESC only |
|---|---|---|---|
| Passenger Cars | 65 | 14 | 21 |
| Light Trucks | 77 | 1 | 22 |

231. The cost estimates developed for this analysis were taken from tear down studies. This process resulted in estimates of the consumer cost of ABS at $368 and the incremental cost of ESC at $111. Thus, it would cost a vehicle that does not currently have ABS, $479 to meet the regulatory requirements for ESC. Combining the technology needs in Table 2 with the cost above and assumed production volumes yields the cost estimate in Table 3 for the ESC regulation. Thus, for example, the average cost for passenger cars, including both those that require installation of an ESC system and those that already have it, is $90.

Table 3. Summary of Vehicle Costs for the ESC Standard (2005$)

| | Average Vehicle Costs | Total Costs |
|---|---|---|
| Passenger Cars | $90.3 | $722.5 million |
| Light Trucks | $29.2 | $262.7 million |
| Total | $58.0 | $985.2 million |

232. In summary, Table 3 shows that requiring electronic stability control and anti-lock brakes will increase the cost of new light vehicles on average by $58, totalling $985 million annually across the new U.S. light vehicle fleet.

233. In addition, this regulation is expected to add mass to vehicles and consequently to increase their lifetime use of fuel. Most of the added mass is for ABS components and very little is for the ESC components. Since 99 per cent of light trucks in the U.S. are predicted to have ABS in MY 2011, the mass increase for light trucks is less than one pound and is considered negligible. The average mass gain for passenger cars is estimated to be 0.97 kg, resulting in 9.8 litres more of fuel being used over the lifetime of these vehicles. The present discounted value of the added fuel cost over the lifetime of the average passenger car is estimated to be $2.73 at a 7 per cent discount rate and $3.35 at a 3 per cent discount rate.

234. These cost estimates do not include allowances for ESC system maintenance and repair. Although all complex electronic systems will experience component failures from time to time necessitating repair, experience to date with existing systems is that their failure rate is not outside the norm. Also, there are no routine maintenance requirements for ESC systems.

B. Text of the Regulation

1. Purpose. This regulation specifies performance and equipment requirements for electronic stability control (ESC) systems. The purpose of this regulation is to reduce the number of deaths and injuries that result from crashes in which the driver loses directional control of the vehicle, including those resulting in vehicle rollover.

2. Application. This regulation applies to all vehicles of Category 1-1, 1-2 and 2, with a gross vehicle mass (GVM) of 4,536 kilograms or less.

3. Definitions. For the purpose of this gtr, vehicle categories, listed in paragraph 2., are defined in Special Resolution No. 1, Concerning the Common Definitions of Vehicle Categories, Masses and Dimensions (S.R. 1) (ECE/TRANS/WP.29/1045 and Amend.1). Other relevant definitions are provided in paragraphs 3.1. through 3.7. below.

3.1. "Ackerman Steer Angle" means the angle whose tangent is the wheelbase divided by the radius of the turn at a very low speed.

3.2. "Electronic Stability Control System" or "ESC System" means a system that has all of the following attributes:

(a) That improves vehicle directional stability by at least having the ability to automatically control individually the braking torques of the left and right wheels on each axle or an axle of each axle group 1/ to induce a correcting yaw moment based on the evaluation of actual vehicle behaviour in comparison with a determination of vehicle behaviour demanded by the driver;

(b) That is computer-controlled with the computer using a closed-loop algorithm to limit vehicle oversteer and to limit vehicle understeer based on the evaluation of actual vehicle behaviour in comparison with a determination of vehicle behaviour demanded by the driver;

(c) That has a means to determine directly the value of vehicle's yaw rate and to estimate its side slip or side slip derivative with respect to time;

(d) That has a means to monitor driver steering inputs; and

(e) That has an algorithm to determine the need, and a means to modify propulsion torque, as necessary, to assist the driver in maintaining control of the vehicle.

3.3. "Lateral Acceleration" means the component of the vector acceleration of a point in the vehicle perpendicular to the vehicle x axis (longitudinal) and parallel to the road plane.

3.4. "Oversteer" means a condition in which the vehicle's yaw rate is greater than the yaw rate that would occur at the vehicle's speed as result of the Ackerman Steer Angle.

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1/ An axle group shall be treated as a single axle and dual wheels shall be treated as a single wheel.

3.5. "Sideslip or side slip angle" means the arctangent of the ratio of the lateral velocity to the longitudinal velocity of the centre of gravity of the vehicle.

3.6. "Understeer" means a condition in which the vehicle's yaw rate is less than the yaw rate that would occur at the vehicle's speed as result of the Ackerman Steer Angle.

3.7. "Yaw rate" means the rate of change of the vehicle's heading angle measured in degrees/second of rotation about a vertical axis through the vehicle's centre of gravity.

3.8. "Peak braking coefficient (PBC)": means the measure of tyre to road surface friction based on the max deceleration of a rolling tyre.

3.9. "Common space" means an area on which more than one tell-tale, indicator,

identification symbol, or other message may be displayed but not simultaneously.

3.10. "Static Stability Factor" means one-half the track width of a vehicle divided by the height of its center of gravity, also expressed as SSF = T/2H, where: T = track width (for vehicles with more than one track width the average is used; for axles with dual wheels, the outer wheels are used when calculating "T") and H = height of the center of gravity of the vehicle.

4. General Requirements. Each vehicle equipped with an ESC system shall meet the general requirements specified in paragraph 4., the performance requirements of paragraph 5., the test procedures specified in paragraph 6. and the test conditions specified in paragraph 7. of this regulation.

4.1 Functional requirements. An electronic stability control system shall be one that:

(a) Is capable of applying braking torques individually to all four wheels 2/ and has a control algorithm that utilizes this capability;

(b) Is operational over the full speed range of the vehicle, during all phases of driving including acceleration, coasting, and deceleration (including braking), except:

(i) When the driver has disabled ESC,

(ii) When the vehicle speed is below 20 km/h,

(iii) While the initial start-up self test and plausibility checks are completed, not to exceed 2 minutes when driven under the conditions of paragraph 7.10.2.,

(iv) When the vehicle is being driven in reverse;

(c) Remains capable of activation even if the antilock brake system or traction control system is also activated.

5. Performance Requirements. During each test performed under the test conditions of paragraph 6. and the test procedure of paragraph 7.9., the vehicle with the ESC

2/ An axle group shall be treated as a single axle and dual wheels shall be treated as a single wheel.

system engaged shall satisfy the directional stability criteria of paragraphs 5.1. and 5.2., and it shall satisfy the responsiveness criterion of paragraph 5.3. during each of those tests conducted with a commanded steering wheel angle of 5A or greater (but limited as per paragraph 7.9.4.), where A is the steering wheel angle computed in paragraph 7.6.1.

5.1. The yaw rate measured one second after completion of the Sine with Dwell steering input (time $T_0 + 1$ in Figure 1) shall not exceed 35 per cent of the first peak value of yaw rate recorded after the steering wheel angle changes sign (between first and second peaks) ($\dot{\psi}_{Peak}$ in Figure 1) during the same test run; and

5.2. The yaw rate measured 1.75 seconds after completion of the Sine with Dwell steering input shall not exceed 20 per cent of the first peak value of yaw rate recorded after the steering wheel angle changes sign (between first and second peaks) during the same test run.

5.3. The lateral displacement of the vehicle centre of gravity with respect to its initial straight path shall be at least 1.83 m for vehicles with a GVM of 3,500 kg or less, and 1.52 m for vehicles with a GVM greater than 3,500 kg when computed 1.07 seconds after the Beginning of Steer (BOS). BOS is defined in paragraph 7.11.6.

5.3.1. The computation of lateral displacement is performed using double integration with respect to time of the measurement of lateral acceleration $a_y$ at the vehicle centre of gravity, as expressed by the formula:

$$\text{Lateral Displacement} = \iint a_{y\,C.G.}\,dt$$

As an alternative, a method based on GPS data can be used.

5.3.2 Time t = 0 for the integration operation is the instant of steering initiation, known as the Beginning of Steer (BOS). BOS is defined in paragraph 7.11.6.

5.4. ESC Malfunction Detection. The vehicle shall be equipped with a tell-tale that provides a warning to the driver of the occurrence of any malfunction that affects the generation or transmission of control or response signals in the vehicle's electronic stability control system. The ESC malfunction tell-tale:

(a) Shall be displayed in direct and clear view of the driver while in the driver's designated seating position with the driver's seat belt fastened;

(b) Shall appear perceptually upright to the driver while driving;

(c) Shall be identified by the symbol shown for "ESC Malfunction Tell-tale" below or the text "ESC":

(d) Shall be yellow or amber in colour;
(e) When illuminated, shall be sufficiently bright to be visible to the driver under both daylight and night time driving conditions, when the driver has adapted to the ambient roadway light conditions;
(f) Except as provided in paragraph 5.4.(g), the ESC malfunction tell-tale shall illuminate when a malfunction exists and shall remain continuously illuminated under the conditions specified in paragraph 5.4. for as long as the malfunction exists, whenever the ignition locking system is in the "On" ("Run") position;
(g) Except as provided in paragraph 5.4.1., each ESC malfunction tell-tale shall be activated as a check of lamp function either when the ignition locking system is turned to the "On" ("Run") position when the engine is not running, or when the ignition locking system is in a position between "On" ("Run") and "Start" that is designated by the manufacturer as a check position;
(h) Shall extinguish at the next ignition cycle after the malfunction has been corrected in accordance with paragraph 7.10.4.;
(i) May also be used to indicate the malfunction of related systems/functions, including traction control, trailer stability assist, corner brake control, and other similar functions that use throttle and/or individual torque control to operate and share common components with ESC.

5.4.1. The ESC malfunction tell-tale need not be activated when a starter interlock is in operation.

5.4.2. The requirement of paragraph 5.4.(g) does not apply to tell-tales shown in a common space.

5.4.3. The manufacturer may use the ESC malfunction tell-tale in a flashing mode to indicate ESC operation.

5.5. <u>ESC Off and Other System Controls</u>. The manufacturer may include an "ESC Off" control which shall be illuminated when the vehicle's headlamps are activated and which has a purpose to place the ESC system in a mode in which it may no longer satisfy the performance requirements of paragraphs 5., 5.1., 5.2., and 5.3. Manufacturers may also provide controls for other systems that have an ancillary effect upon ESC operation. Controls of either kind that place the ESC system in a mode in which it may no longer satisfy the performance requirements of paragraphs 5., 5.1., 5.2., and 5.3. are permitted, provided that the system also meets the requirements of paragraphs 5.5.1. to 5.5.3.

5.5.1. The vehicle's ESC system shall always return to the manufacturer's original default mode that satisfies the requirements of paragraphs 4. and 5. at the initiation of each new ignition cycle, regardless of what mode the driver had previously selected. However, the vehicle's ESC system need not return to a mode that satisfies the requirements of paragraphs 5. through 5.3. at the initiation of each new ignition cycle if:

(a) The vehicle is in a four-wheel drive configuration which has the effect of locking the drive gears at the front and rear axles together and providing an additional gear reduction between the engine speed and vehicle speed of at least 1.6 or 2.0 3/, selected by the driver for low-speed, off-road driving; or

(b) The vehicle is in a four-wheel drive configuration selected by the driver that is designed for operation at higher speeds on snow-, sand-, or dirt-packed roads and that has the effect of locking the drive gears at the front and rear axles together, provided that in this mode the vehicle meets the stability performance requirements of paragraphs 5.1. and 5.2. under the test conditions specified in paragraph 6. However, if the system has more than one ESC mode that satisfies the requirements of paragraphs 5.1. and 5.2. within the drive configuration selected for the previous ignition cycle, the ESC shall return to the manufacturer's original default ESC mode for that drive configuration at the initiation of each new ignition cycle.

5.5.2. A control whose only purpose is to place the ESC system in a mode in which it will no longer satisfy the performance requirements of paragraphs 5., 5.1., 5.2., and 5.3. shall be identified by the symbol shown for "ESC Off" below or the text, "ESC OFF".


5.5.3. A control for an ESC system whose purpose is to place the ESC system in different modes, at least one of which may no longer satisfy the performance requirements of paragraphs 5., 5.1., 5.2., and 5.3., shall be identified by the symbol shown below with the text "OFF" adjacent to the control position for this mode.

Alternatively, in the case where the ESC system mode is controlled by a multi-functional control, the driver display shall identify clearly to the driver the control position for this mode using either the symbol in paragraph 5.5.2. or the text "ESC OFF".

3/ The value of either 1.6 or 2.0 to be selected at the discretion of the Contracting Party.

5.5.4. A control for another system that has the ancillary effect of placing the ESC system in a mode in which it no longer satisfies the performance requirements of paragraphs 5., 5.1., 5.2., and 5.3. need not be identified by the "ESC Off" identifiers in paragraph 5.5.2.

5.6. "ESC Off" Tell-tale. If the manufacturer elects to install a control to turn off or reduce the performance of the ESC system under paragraph 5.5., the tell-tale requirements of paragraphs 5.6.1. to 5.6.4. shall be met in order to alert the driver to the lessened state of ESC system functionality. This requirement does not apply for the driver-selected mode referred to in paragraph 5.5.1.(b).

5.6.1. The vehicle manufacturer shall provide a tell-tale indicating that the vehicle has been put into a mode that renders it unable to satisfy the requirements of paragraphs 5, 5.1., 5.2., and 5.3., if such a mode is provided.

5.6.2. The "ESC off" tell-tale:

(a) Shall be displayed in direct and clear view of the driver while in the driver's designated seating position with the driver's seat belt fastened;

(b) Shall appear perceptually upright to the driver while driving;

(c) Shall be identified by the symbol shown for "ESC Off" in paragraph 5.5.2. or the text "ESC OFF"; or
Shall be identified with the English word "OFF" on or adjacent to either the control referred to in paragraph 5.5.2. or 5.5.3. or the illuminated malfunction tell-tale;

(d) Shall be yellow or amber in colour;

(e) When illuminated, shall be sufficiently bright to be visible to the driver under both daylight and night time driving conditions, when the driver has adapted to the ambient roadway light conditions;

(f) Shall remain continuously illuminated for as long as the ESC is in a mode that renders it unable to satisfy the requirements of paragraphs 5., 5.1., 5.2., and 5.3.;

(g) Except as provided in paragraphs 5.6.3. and 5.6.4., each "ESC Off" tell-tale shall be activated as a check of lamp function either when the ignition locking system is turned to the "On" ("Run") position when the engine is not running, or when the ignition locking system is in a position between "On" ("Run") and "Start" that is designated by the manufacturer as a check position;

(h) Shall extinguish after the ESC system has been returned to its manufacturer's original default mode.

5.6.3. The "ESC Off" tell-tale need not be activated when a starter interlock is in operation.

5.6.4. The requirement of paragraph 5.6.2.(g) does not apply to tell-tales shown in a common space.

5.6.5. The vehicle manufacturer may use the "ESC Off" tell-tale to indicate an ESC level of function other than the fully functional default mode even if the vehicle would meet paragraphs 5., 5.1., 5.2., and 5.3. at that level of ESC function.

5.7. ESC System Technical Documentation. To ensure a vehicle is equipped with an ESC system that meets the definition of "ESC System" in paragraph 3., the vehicle manufacturer shall make available to the regulatory entity designated by the Contracting Party, upon request, the documentation specified in paragraphs 5.7.1. to 5.7.4.

5.7.1. System diagram identifying all ESC system hardware. The diagram shall identify what components are used to generate brake torques at each wheel, determine vehicle yaw rate, estimated side slip or the side slip derivative and driver steering inputs.

5.7.2. A brief written explanation sufficient to describe the ESC system basic operational characteristics. This explanation shall include the outline description of the system's capability to apply brake torques at each wheel and how the system modifies propulsion torque during ESC system activation and show that the vehicle yaw rate is directly determined. The explanation shall also identify the vehicle speed range and the driving phases (acceleration, deceleration, coasting, during activation of the ABS or traction control) under which the ESC system can activate.

5.7.3. Logic diagram. This diagram supports the explanation provided under paragraph 5.7.2.

5.7.4. Understeer information. An outline description of the pertinent inputs to the computer that control ESC system hardware and how they are used to limit vehicle understeer.

6. Test Conditions.

6.1. Ambient conditions.

6.1.1. The ambient temperature is between 0° C and 45° C.

6.1.2. The maximum wind speed is no greater than 10 m/s for vehicles with SSF > 1.25 and 5 m/s for vehicles with SSF ≤ 1.25.

6.2. Road test surface.

6.2.1. The tests are conducted on a dry, uniform, solid-paved surface. Surfaces with irregularities and undulations, such as dips and large cracks, are unsuitable.

6.2.2. The road test surface has a nominal peak braking coefficient (PBC) of 0.9, unless otherwise specified, when measured using either:

(a) The American Society for Testing and Materials (ASTM) E1136 standard reference test tyre, in accordance with ASTM Method E1337-90 without water delivery, at a speed of 40 mph; or

(b) The method specified in the Annex 6, Appendix 2 of UNECE Regulation No. 13-H.

6.2.3. The test surface has a consistent slope between level and 1 per cent.

6.3. Vehicle conditions.

6.3.1. The ESC system is enabled for all testing.

6.3.2. Vehicle Mass. The vehicle is loaded with the fuel tank filled to at least 90 per cent of capacity, and total interior load of 168 kg comprised of the test driver, approximately 59 kg of test equipment (automated steering machine, data acquisition system and the power supply for the steering machine), and ballast as required by differences in the mass of test drivers and test equipment. Where required, ballast shall be placed on the floor behind the passenger front seat or if necessary in the front passenger foot well area. All ballast shall be secured in a way that prevents it from becoming dislodged during test conduct.

6.3.3. Tyres. The tyres are inflated to the vehicle manufacturer's recommended cold tyre inflation pressure(s) e.g. as specified on the vehicle's placard or the tyre inflation pressure label. Tubes may be installed to prevent tyre de-beading.

6.3.4. Outriggers. Outriggers may be used for testing if deemed necessary for test drivers' safety. In this case, the following applies:
For vehicles with a Static Stability Factor (SSF) ≤ 1.25;

(a) Vehicles with a mass in running order under 1,588 kg shall be equipped with "lightweight" outriggers. Lightweight outriggers shall be designed with a maximum mass of 27 kg and a maximum roll moment of inertia of 27 $kg{\cdot}m^2$.

(b) Vehicles with a mass in running order between 1,588 kg and 2,722 kg shall be equipped with "standard" outriggers. Standard outriggers shall be designed with a maximum mass of 32 kg and a maximum roll moment of inertia of 35.9 $kg{\cdot}m^2$.

(c) Vehicles with a mass in running order equal to or greater than 2,722 kg shall be equipped with "heavy" outriggers. Heavy outriggers shall be designed with a maximum mass of 39 kg and a maximum roll moment of inertia of 40.7 $kg{\cdot}m^2$.

6.3.5. Automated steering machine. A steering machine programmed to execute the required steering pattern shall be used in paragraphs 7.5.2., 7.5.3., 7.6. and 7.9. The steering machine shall be capable of supplying steering torques between 40 to 60 Nm. The steering machine shall be able to apply these torques when operating with steering wheel velocities up to 1,200 degrees per second.

7. Test Procedure.

7.1. Inflate the vehicles' tyres to the manufacturer's recommended cold tyre inflation pressure(s) e.g. provided on the vehicle's placard or the tyre inflation pressure label.

7.2. Tell-tale bulb check. With the vehicle stationary and the ignition locking system in the "Lock" or "Off" position, activate the ignition locking system to the "On" ("Run") position or, where applicable, the appropriate position for the lamp check. The ESC malfunction tell-tale shall be activated as a check of lamp function, as specified in paragraph 5.4.(d), and if equipped, the "ESC Off" tell-tale shall also be activated as a check of lamp function, as specified in paragraph 5.6.6. The tell-tale bulb check is not required for a tell-tale shown in a common space as specified in paragraphs 5.4.2. and 5.6.4.

7.3. "ESC Off" control check. For vehicles equipped with an "ESC Off" control, with the vehicle stationary and the ignition locking system in the "Lock" or "Off" position, activate the ignition locking system to the "On" ("Run") position. Activate the "ESC Off" control and verify that the "ESC Off" tell-tale is illuminated, as specified in paragraph 5.6.4. Turn the ignition locking system to the "Lock" or "Off" position. Again, activate the ignition locking system to the "On" ("Run") position and verify that the "ESC Off" tell-tale has extinguished indicating that the ESC system has been reactivated as specified in paragraph 5.5.1.

7.4. Brake Conditioning. Condition the vehicle brakes in the manner described in paragraphs 7.4.1. through 7.4.4.

7.4.1. Ten stops are performed from a speed of 56 km/h, with an average deceleration of approximately 0.5g.

7.4.2. Immediately following the series of 56 km/h stops, three additional stops are performed from 72 km/h.

7.4.3. When executing the stops in paragraph 7.4.2., sufficient force is applied to the brake pedal to activate the vehicle's antilock brake system (ABS) for a majority of each braking event.

7.4.4. Following completion of the final stop in 7.4.2., the vehicle is driven at a speed of 72 km/h for five minutes to cool the brakes.

7.5. Tyre Conditioning. Condition the tyres using the following procedure of paragraphs 7.5.1. through 7.5.3. to wear away mold sheen and achieve operating temperature immediately before beginning the test runs of paragraphs 7.6.and 7.9.

7.5.1. The test vehicle is driven around a circle 30 meters in diameter at a speed that produces a lateral acceleration of approximately 0.5g to 0.6g for three clockwise laps followed by three counterclockwise laps.

7.5.2. Using a sinusoidal steering pattern at a frequency of 1 Hz, a peak steering wheel angle amplitude corresponding to a peak lateral acceleration of 0.5g to 0.6g, and a vehicle speed of 56 km/h, the vehicle is driven through four passes performing 10 cycles of sinusoidal steering during each pass.

7.5.3. The steering wheel angle amplitude of the final cycle of the final pass is twice that of the other cycles. The maximum time permitted between all laps and passes is five minutes.

7.6. Slowly Increasing Steer Procedure. The vehicle is subjected to two series of runs of the Slowly Increasing Steer Test using a constant vehicle speed of 80 ± 2 km/h and a steering pattern that increases by 13.5 degrees per second until a lateral acceleration of approximately 0.5g is obtained. Three repetitions are performed for each test series. One series uses counterclockwise steering, and the other series uses clockwise steering. The maximum time permitted between each test run is five minutes.

7.6.1. From the Slowly Increasing Steer tests, the quantity "A" is determined. "A" is the steering wheel angle in degrees that produces a steady state lateral acceleration (corrected using the methods specified in paragraph 7.11.3.) of 0.3g for the test vehicle. Utilizing linear regression, "A" is calculated, to the nearest 0.1 degrees, from each of the six Slowly Increasing Steer tests. The absolute value of the six A's calculated is averaged and rounded to the nearest 0.1 degrees to produce the final quantity, A, used below.

7.7. After the quantity "A" has been determined, without replacing the tyres, the tyre conditioning procedure described in paragraph 7.5. is performed immediately prior to conducting the Sine with Dwell Test of paragraph 7.9. Initiation of the first Sine with Dwell test series shall begin within two hours after completion of the Slowly Increasing Steer tests of paragraph 7.6.

7.8. Check that the ESC system is enabled by ensuring that the ESC malfunction and "ESC Off" (if provided) tell-tales are not illuminated.

7.9. Sine with Dwell Test of Oversteer Intervention and Responsiveness. The vehicle is subjected to two series of test runs using a steering pattern of a sine wave at 0.7 Hz frequency with a 500 ms delay beginning at the second peak amplitude as shown in Figure 2 (the Sine with Dwell tests). One series uses counterclockwise steering for the first half cycle, and the other series uses clockwise steering for the first half cycle. The vehicle is allowed to cool-down between each test run of 90 seconds to five minutes, with the vehicle stationary.

7.9.1. The steering motion is initiated with the vehicle coasting in high gear at 80 ± 2 km/h.

7.9.2. The steering amplitude for the initial run of each series is 1.5A, where "A" is the steering wheel angle determined in paragraph 7.6.1.

7.9.3. In each series of test runs, the steering amplitude is increased from run to run, by 0.5A, provided that no such run will result in a steering amplitude greater than that of the final run specified in paragraph 7.9.4.

7.9.4. The steering amplitude of the final run in each series is the greater of 6.5A or 270 degrees, provided the calculated magnitude of 6.5A is less than or equal to 300 degrees. If any 0.5A increment, up to 6.5A, is greater than 300 degrees, the steering amplitude of the final run shall be 300 degrees.

7.9.5. Upon completion of the two series of test runs, post processing of yaw rate and lateral acceleration data is done as specified in paragraph 7.11.

7.10. ESC Malfunction Detection.

7.10.1. Simulate one or more ESC malfunction(s) by disconnecting the power source to any ESC component, or disconnecting any electrical connection between ESC components (with the vehicle power off). When simulating an ESC malfunction, the electrical connections for the tell-tale lamp(s) and/or optional ESC system control(s) are not to be disconnected.

7.10.2. With the vehicle initially stationary and the ignition locking system in the "Lock" or "Off" position, activate the ignition locking system to the "Start" position and start the engine. Drive the vehicle forward to obtain a vehicle speed of 48 ± 8 km/h at the latest 30 seconds after the engine has been started and within the next two minutes at this speed, conduct at least one left and one right smooth turning manoeuvre without losing directional stability and one brake application. Verify that the ESC malfunction indicator illuminates in accordance with paragraph 5.4. by the end of these manoeuvres.

7.10.3. Stop the vehicle, deactivate the ignition locking system to the "Off" or "Lock" position. After a five-minute period, activate the vehicle's ignition locking system to the "Start" position and start the engine. Verify that the ESC malfunction indicator again illuminates to signal a malfunction and remains illuminated as long as the engine is running or until the fault is corrected.

7.10.4. Deactivate the ignition locking system to the "Off" or "Lock" position. Restore the ESC system to normal operation, activate the ignition system to the "Start" position and start the engine. Re-perform the manoeuvre described in paragraph 7.10.2., and verify that the tell-tale has extinguished within the time it takes or immediately afterward.

7.11. Post Data Processing – Calculations for Performance Metrics. Yaw rate and lateral displacement measurements and calculations shall be processed utilizing the techniques specified in paragraphs 7.11.1. to 7.11.8.

7.11.1. Raw steering wheel angle data is filtered with a 12-pole phaseless Butterworth filter and a cut-off frequency of 10 Hz. The filtered data is then zeroed to remove sensor offset utilizing static pre-test data.

7.11.2. Raw yaw rate data is filtered with a 12-pole phaseless Butterworth filter and a cut-off frequency of 6 Hz. The filtered data is then zeroed to remove sensor offset utilizing static pre-test data.

7.11.3. Raw lateral acceleration data is filtered with a 12-pole phaseless Butterworth filter and a cut-off frequency of 6 Hz. The filtered data is then zeroed to remove sensor offset utilizing static pre-test data. The lateral acceleration data at the vehicle centre of gravity is determined by removing the effects caused by vehicle body roll and by correcting for sensor placement via use of coordinate transformation. For data collection, the lateral accelerometer shall be located as close as possible to the position of the vehicle's longitudinal and lateral centres of gravity.

7.11.4. Steering wheel velocity is determined by differentiating the filtered steering wheel angle data. The steering wheel velocity data is then filtered with a moving 0.1 second running average filter.

7.11.5. Lateral acceleration, yaw rate and steering wheel angle data channels are zeroed utilizing a defined "zeroing range". The methods used to establish the zeroing range are defined in paragraphs 7.11.5.1. and 7.11.5.2.

7.11.5.1. Using the steering wheel rate data calculated using the methods described in paragraph 7.11.4., the first instant steering wheel rate exceeding 75 deg/sec is identified. From this point, steering wheel rate shall remain greater than 75 deg/sec for at least 200 ms. If the second condition is not met, the next instant steering wheel rate exceeding 75 deg/sec is identified and the 200 ms validity check applied. This iterative process continues until both conditions are ultimately satisfied.

7.11.5.2. The "zeroing range" is defined as the 1.0 second time period prior to the instant the steering wheel rate exceeds 75 deg/sec (i.e. the instant the steering wheel velocity exceeds 75 deg/sec defines the end of the "zeroing range").

7.11.6. The Beginning of Steer (BOS) is defined as the first instance filtered and zeroed steering wheel angle data reaches - 5 degrees (when the initial steering input is counterclockwise) or +5 degrees (when the initial steering input is clockwise) after time defining the end of the "zeroing range". The value for time at the BOS is interpolated.

7.11.7. The Completion of Steer (COS) is defined as the time the steering wheel angle returns to zero at the completion of the Sine with Dwell steering manoeuvre. The value for time at the zero degree steering wheel angle is interpolated.

7.11.8. The second peak yaw rate is defined as the first local yaw rate peak produced by the reversal of the steering wheel. The yaw rates at 1.000 and 1.750 seconds after COS are determined by interpolation.

7.11.9. Determine lateral velocity by integrating corrected, filtered and zeroed lateral acceleration data. Zero lateral velocity at BOS event. Determine lateral displacement by integrating zeroed lateral velocity. Zero lateral displacement at BOS event. Lateral displacement at 1.07 seconds from BOS event is determined by interpolation.

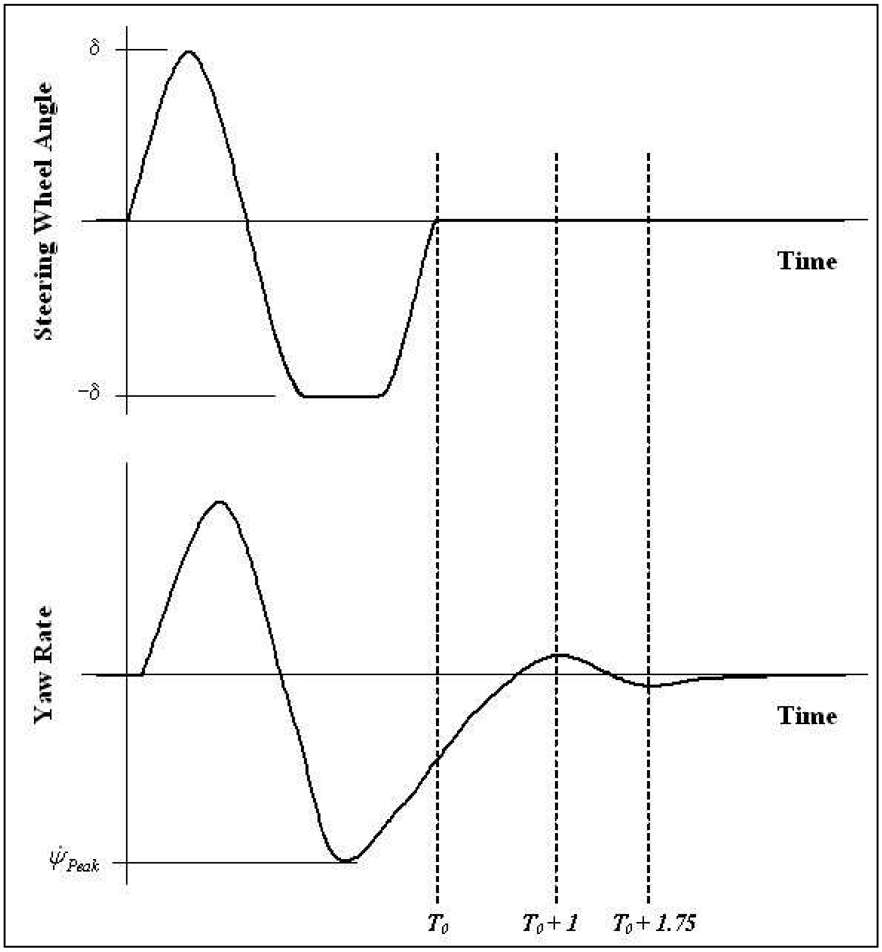


Figure 1. Steering wheel position and yaw velocity information used to assess lateral stability.

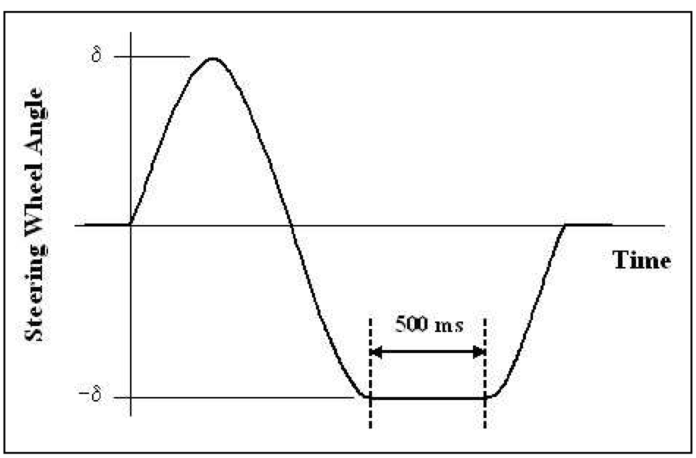


Figure 2. Sine with Dwell steering profile.

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