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AGREEMENT CONCERNING THE ESTABLISHING OF GLOBAL TECHNICAL REGULATIONS FOR WHEELED VEHICLES, EQUIPMENT AND PARTS WHICH CAN BE FITTED AND/OR USED ON WHEELED VEHICLES
(ECE/TRANS/132 and Corr. 1)
Done at Geneva on 25 June 1998

Addendum

Global Technical Regulation No. 6 (?)

ELECTRONIC STABILITY CONTROL (ESC) SYSTEMS

(Established in the Global Registry on XX MONTH 200X)

UNITED NATIONS

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A. Statement of Technical Rationale and Justification

1. Introduction

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. **[CITE?]** 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. **[CITE?]** Therefore, regulators and others with an interest in vehicle safety and public health must 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).

Crash data studies conducted in the United States, Europe, and Japan indicate that ESC is very effective in reducing single-vehicle crashes. **[CITES?]** U.S. studies of the behavior 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 percent and single-vehicle crashes of sport utility vehicles (SUVs) by 59 percent. **[CITE?]** The same recent U.S. study showed that ESC prevents an estimated 71 percent of passenger car rollovers and 84 percent of SUV rollovers in single-vehicle crashes. **[CITE?]** 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

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 which could potentially be impacted by a global technical regulation for ESC.

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.

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 the available crash data programs. According to 2004 U.S. data from FARS, 10,555 people were killed as occupants in light vehicle rollover crashes, which represents 33 percent 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 percent of the people who died in single-vehicle rollover crashes were not using a seat belt, and 61 percent were partially or completely ejected from the vehicle (including 50 percent who were completely ejected). The data also show that 55 percent of light vehicle occupant fatalities in single-vehicle crashes involved a rollover event.

Using U.S. data from the 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 percent of those people who suffered a serious injury in a single-vehicle tow-away rollover crash were not using a seat belt, and 52 percent were partially or completely ejected (including 41 percent who were completely ejected). Estimates from the data indicate that 82 percent of tow-away rollovers were single-vehicle crashes, and that 88 percent (202,000) of the single-vehicle rollover crashes occurred after the vehicle left the roadway. An audit of 1992-1996 data showed that about 95 percent 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 tire/road interface friction as in the case of untripped rollover events.

3. Operation of ESC Systems

Although ESC systems are 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 maneuvers by keeping the vehicle headed in the direction the driver is steering even when the vehicle nears or reaches the limits of road traction.

When a driver attempts an "extreme maneuver" (*e.g.*, one initiated to avoid a crash or due to misjudgment 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 maneuvers using countersteering (*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 countersteer to regain control.

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 maneuver 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 effectively intervene 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

The following explanation of ESC operation illustrates the basic principle of yaw stability control. An ESC system maintains as "yaw" (or heading) control by determining the driver's intended heading, measuring 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 measurements are used to determine the driver's intended heading. The vehicle response is measured 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.

The concept of "yaw rate" can be illustrated by imagining the view from above of 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 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.

While driving in a circle, the driver notices that he must hold the steering wheel tightly to avoid sliding toward the passenger seat. The bracing 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.

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. Of course, 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.

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.

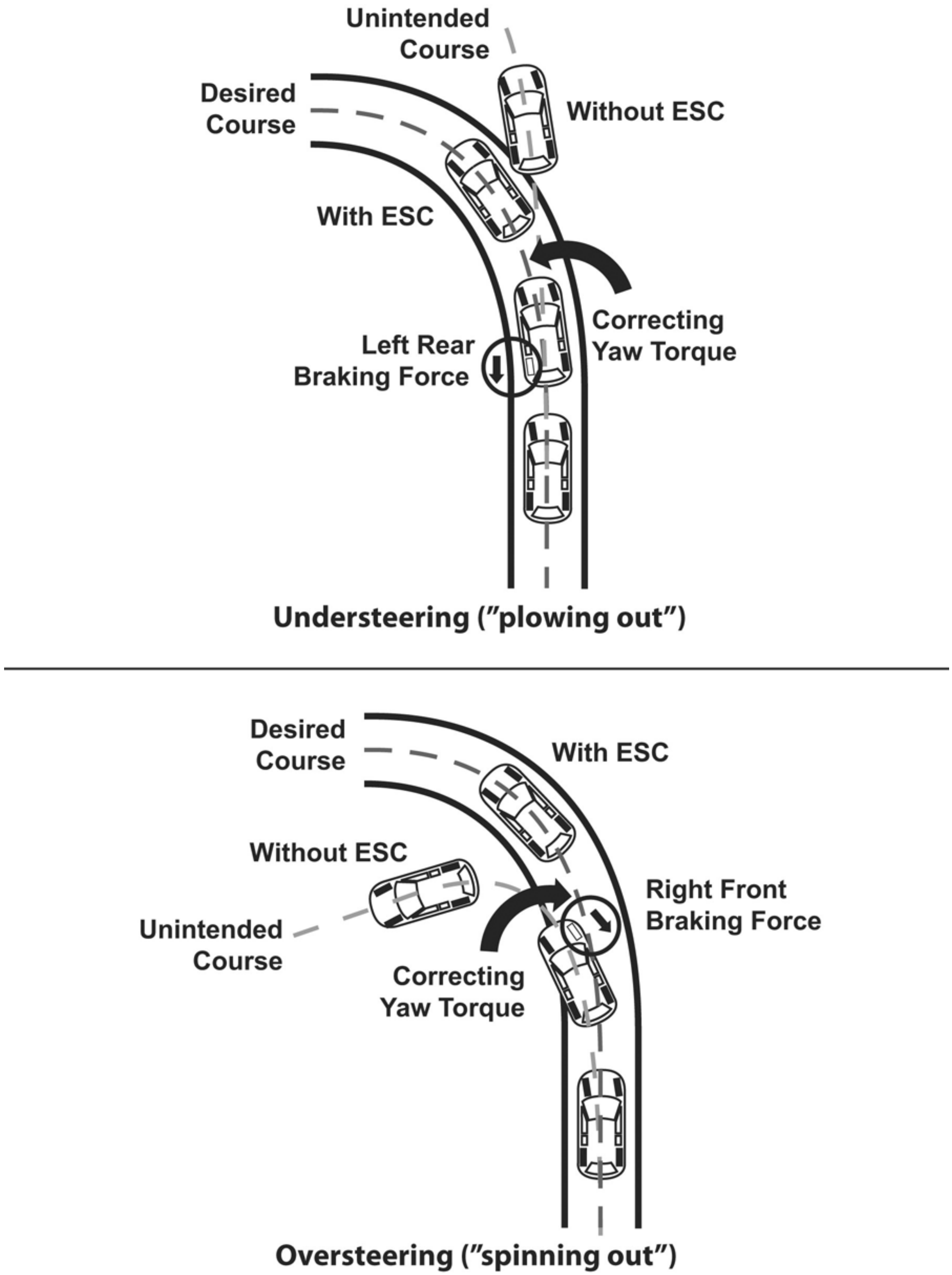

Figure 1. ESC Interventions for Understeering and Oversteering

- Oversteering. In Figure 1 (bottom panel), the vehicle has entered a left curve that is extreme for the speed it is traveling. 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.

- 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.

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 maneuver such as a double lane change.

Although ESC cannot change the tire/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.

In vehicles without ESC, the response of the vehicle to steering inputs changes as the vehicle nears the limits of road traction. All of 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 loose control and crash because the familiar actions learned by driving in the linear range would not be the correct steering actions.

However, ordinary linear range driving skills are much more likely to be adequate for a driver of an ESC-equipped vehicle equipped with ESC 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.

Besides allowing drivers to cope with emergency maneuvers 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 tires 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 tire traction because both the braking force of the individual tire 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 maneuver ultimately is limited by the tire/pavement friction, ESC maximizes an ordinary driver's ability to use the available friction.

b. Additional Features of Some ESC Systems

In addition to the basic operation of "yaw stability control," many ESC systems include additional features. For example, most systems 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.

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.

ESC systems used on vehicles with a high center 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

[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

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.

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

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 must 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.

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.

However, there is insufficient data to currently 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

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.

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.

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 reduces 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 center of gravity vehicles (*e.g.*, passenger cars, minivans and two-wheel-drive pickup trucks), as well as of the higher center 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

A 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 kph) followed by another curve that appeared to be similar but that had a decreasing radius that was not evident upon entry.

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[2] 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.

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

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

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.

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 percent 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.

c. Crash Data Studies of ESC Effectiveness

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. However, the sample sizes of crashes of vehicles new enough to have ESC tended to be small in these studies. As an example, a preliminary study published in September 2004[5] of crash data from 1997-2003 in the U.S. 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 percent and in SUVs by 67 percent.

A later peer-reviewed study[6] of ESC effectiveness found that that ESC reduced single-vehicle crashes in passenger cars by 34 percent and in SUVs by 59 percent, and that its effectiveness was greatest in reducing single-vehicle crashes resulting in rollover (71 percent reduction for passenger cars and an 84 percent 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 percent and in SUVs by 67 percent and reduced fatal single-vehicle crashes involving rollover by 69 percent in passenger cars and 88 percent in SUVs.

5. Input on the Substance of the ESC GTR

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, other governmental representatives, seven automobile manufacturers and their trade associations, nine suppliers of automobile equipment and their trade association, and four safety advocacy organizations. In addition, international automobile manufacturers

[4] See Footnote 3.
[5] Dang, J. (2004) Preliminary Results Analyzing Effectiveness of Electronic Stability Control (ESC) Systems, Report No. DOT HS 809 790. U.S. Department of Transportation, Washington, D.C.
[6] Dang, J. (2006), Statistical Analysis of The Effectiveness of Electronic Stability Control (ESC) Systems, U.S. Department of Transportation, Washington, D.C. (publication pending peer review).

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.

The overwhelming majority of these participants supported establishing a technical regulation for ESC systems installed on new light vehicles. Instead, the difference of opinion among the participants involved the stringency of the standard (including a requirement for advanced features) and the test procedures (including need for understeer performance requirements). Other topics included making the "ESC System" definition more performance-based, lateral responsiveness criteria, ESC performance requirements, ESC malfunction detection requirements, ESC telltale requirements, system disablement and the "ESC Off" switch, test procedures, impacts on the aftermarket, and other topics. 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.

6. Discussion of Key Issues

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 must meet in order to comply with the requirements of the GTR. This GTR applies to all Category 1-1 and 1-2 vehicles with a gross vehicle weight rating (GVWR) of 4,536 kg or less.

During the development of the GTR, all issues were thoroughly discussed. The following discussions reflect the evaluation of the issues that lead to the final recommendations.

a. Applicability

As noted above, this GTR applies to all Category 1-1 and 1-2 with a GVWR of 4,536 kg or less.

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.

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.

Vehicles with Dual Wheels on the Rear Axle

According to the automobile industry, there are a small number (unspecified) of incomplete vehicles with a GVWR of 4,536 kg or less that are equipped with dual wheels on the rear axle ("dualies")(typically completed as commercial vehicles), 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.

Although "dualies" may require manufacturers to make certain technical adjustments in their ESC systems, we note that such vehicles were included as part of the final regulation adopted in the United States. Thus, to the extent that such vehicles fall within scope of applicable vehicles, they are subject to the requirements of this GTR.

b. Definitions

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 we are adopting is necessary to ensure that the ESC system

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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 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.

is robust and meets a level of performance at least comparable to that of current production ESC systems.

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

(1) Augments vehicle directional stability by applying and adjusting the vehicle brake torques individually to induce a correcting yaw moment to a vehicle;

(2) Is computer-controlled, with the computer using a closed-loop algorithm[9] to limit vehicle oversteer and to limit vehicle understeer;

(3) Has a means to determine vehicle yaw rate[10] and to estimate its sideslip[11] or the time derivative of sideslip;[12]

(4) Has a means to monitor driver steering input;

(5) Has an algorithm to determine the need, and a means to modify engine torque, as necessary, to assist the driver in maintaining control of the vehicle, and

(6) Is operational over the full speed range of the vehicle (except at vehicle speeds less than 15 km/h[13] or when being driven in reverse).

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] A "closed-loop algorithm" is a cycle of operations followed by a computer that includes automatic adjustments based on the result of previous operations or other changing conditions.

[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 side slip and the time derivative of side slip angle are intimately mathematically related, when one of these values is known, it is then possible to determine the other. This regulation permits this key value for ESC operation to be determined by alternate means.

[13] To determine an appropriate low-speed threshold, three relevant factors were considered:

(1) ESC should not be active when the vehicle's Antilock Brake System (ABS) is not active. If the vehicle's ESC was active but the ABS was inactive, then ESC brake applications could result in one or more of the vehicle's wheels locking up. While one wheel locking up may not cause safety problems, if two or more wheels lock up, the vehicle may experience lateral instability. Even at low speeds, this situation may result in a safety problem.

(2) All ABSs must have a low-speed threshold below which the ABS becomes inactive. Otherwise, it would be impossible to use the vehicle's brakes to bring a vehicle to a complete stop, because the ABS would keep activating and releasing the brakes when the driver tried to stop. Wheel lock-ups below a low-

The GTR also specifies a number of other definitions intended to clarify the operation of ESC systems or related performance testing under this GTR. 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"; and (6) "Yaw rate."

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 15 km/h" means that ESC would typically not have to be active when the vehicle is in reverse.

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 are integrated into a single system, all of which are 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 together addressing vehicle instabilities.

When defining the ESC hardware and software requirements for the GTR, focus was on specific technologies known to be effective in reducing real world crashes, rather than systems of features that only theoretically might have a safety impact. For example, one participant recommended inclusion of a provision related to sideslip of the tire contact patch. However, although contemporary ESC systems meet the definitional requirements of regulation, they do not necessarily estimate the sideslip of the tire contact patch, and an effective technology for measuring the sideslip of the tire contact patch has not been

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speed threshold are not a safety concern. However, lock-ups at vehicle speeds above 15 km/h can cause safety problems (see Snyder et al., "NHTSA Light Vehicle ABS Performance Test Development" (NHTSA Technical Report), DOT HS 809 747 (June 2005), at 47. Available at http://www-nrd.nhtsa.dot.gov/vrtc/ca/capubs/ABSperformancefinalreport.pdf.). Similarly, ECE Regulation 13-H, which contains performance requirements for ABSs, sets a low-speed threshold of 15 km/h (9.3 mph) (see United Nations Economic Commission for Europe, Regulation No. 13-H, "Approval of Passenger Cars with Regard to Braking, Rev. 2, World Forum for Harmonization of Vehicle Regulations (WP.29 ECE R13-H), May 11th 1998. Available at http://www.unece.org/trans/main/wp29/wp29regs1-20.html.).

(3) ESC systems obtain much of their information about the state of the vehicle from the ABS's wheel-speed sensors. At low vehicle speeds, the ABS wheel-speed sensors rotate more slowly, which could create unacceptable amounts of noise in the data sent to ESC. The European standard (ECE Regulation No. 13-H) shows that sensor data of acceptable quality can be obtained at speeds down to 15 km/h, although certain changes may be required for some current ESC systems.

Based on the preceding analysis and in order to promote consistency with other relevant international regulations, 15 km/h has been selected as the appropriate low-speed threshold above which ESC must be active.

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 tire 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

In addition to the definitional requirements discussed above, ESC systems must also meet the following additional requirements of the GTR.

(1) Basic System Operation

The ESC system, as defined above, is required to be capable of applying brake 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 (6) 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.

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-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, roll stability control).

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

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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 invention or four-wheel automatic braking during an intervention, even though these systems also produced substantial (but lesser) benefits.

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 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.

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.

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.

Without the definition of "ESC System," it would not be feasible to comprehensively assess the operating range of resulting devices, particularly for understeer intervention, that might be installed in compliance with the safety standards. If manufacturers were to only 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]

Under this topic, we also note that the automobile industry expressed concern about variability (in the responsiveness portion of the oversteer intervention test). Even under test conditions chosen for high repeatability, the industry maintains that the performance requirements must be decreased to allow a larger margin of compliance. However, the requested margins of compliance would make a very weak regulation.

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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 October 22, 1998, the Department of Justice and EPA announced a settlement with seven major diesel engine manufacturers. Accordingly, we do not believe 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."

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 must 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.

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]

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 favor of concepts that have not yet demonstrated any safety benefits, much less the enormous benefits associated with current brake torque-based ESC systems.

Furthermore, all of these other ESC-related components (including "roll stability control"[18]) lack supporting data to assess their effectiveness and to determine whether

[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

[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 percent for cars and 84 percent for SUVs. None of the vehicles in the NHTSA crash data study had roll stability control. The crash data study was a study of the benefits of yaw stability control. The first 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 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 her 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.

Based upon the above consideration, it was concluded that there is 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.

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.

Participants also raised certain specific issues related to when the ESC system will be operable, including the following.

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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 percent 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 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.

ESC Initialization Period

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 traveled, 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 15 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 15 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 15 km/h should be adequate to initialize ESC.

Industry participants pointed out that some types of diagnostic checks cannot be performed unless the vehicle is making turns or traveling at relatively high speeds. Accordingly, the regulation's test procedure accommodates these types of diagnostic checks. ESC manufacturer 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.

ESC Calibration

Determining when ESC intervention must 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. We believe the Sine with Dwell maneuver, 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.

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

Because the benefits of the ESC system can only be realized if the system is functioning properly, the system must be able to detect and alert the driver of ESC system malfunctions (through illumination of a telltale described below). This regulation requires that the vehicle must be equipped with a telltale 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.

Specifically, the ESC malfunction telltale must 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 Telltale” as described in this regulation. The ESC malfunction telltale must 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 telltale must 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 telltale need not be activated when a starter interlock is in operation. The ESC malfunction telltale must extinguish after the malfunction has been corrected. Manufacturers may use the ESC malfunction telltale in a flashing mode to indicate ESC operation.

Several participants raised a variety of concerns regarding operation of the ESC malfunction indicator and telltale (with malfunction telltale-related issues discussed subsequently).

Types of Malfunctions to be Detected

Regarding the issue of which vehicle components are subject to ESC malfunction testing, a rule of reason applies. Simply stated, if a vehicle malfunction were to “affect the generation or transmission of control or response signals in the vehicle’s electronic stability control system,” it must be detectable by the ESC system. In other words, if the malfunction impacts the functionality of the ESC system, the ESC system must 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.

As a specific example for the sake of clarity, the disconnection of the “ESC Off” switch would be a malfunction suitable for simulation under the regulation, because it directly impacts ESC operability (even though a manufacturer voluntarily provides such a switch). However, disconnection of an ancillary function, such as a hill-holding aid that may be controlled by a shared ESC computer, would not be considered to be a fault in the ESC system itself.

Practicability Issues with ESC Malfunction Detection

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.

Suggestions that ESC malfunction testing should be limited to only those malfunctions amenable to detection based upon static activation and deactivation were not adopted. In contrast, in developing the ESC malfunction detection section of the regulation, it was our intention 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.

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

Minimum Performance Level

At least one participant suggested that the regulation should set a defined minimum performance level for a vehicle when the ESC system is deactivated (*i.e.*, “off”) or when there is an ESC malfunction (which again may result in a failure mode of ESC “off”). This concern was that unless this is done, negative safety consequences may arise under conditions where a driver is not aware of the vehicle’s baseline stability behavior. We decline to follow this recommendation for the reasons that follow. ESC is a safety feature added to vehicles whose basic chassis properties have been designed to match their intended purposes. As discussed under the section on lateral responsiveness criteria, it is expected that ESC will not cause changes in the basic chassis properties of vehicles. It is further expected that ESC activations will be rare events in panic situations and that drivers will not depend upon the ESC system in the ordinary operation of the vehicle. In the case of an ESC malfunction or failure, the ESC telltale warns the driver that the ESC system is non-operational and may require repair. However, pending the repair, the driver would be no more at risk than a person driving an older car without ESC. Unless future developments prove these assumptions to be false, there is no need for additional “minimum performance” requirements on base vehicles equipped with ESC.

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

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 telltales, it has been decided that a single malfunction telltale 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.

(3) Telltale Specifications

ESC Malfunction Telltale

Because the benefits of the ESC system can only be realized if the system is functioning properly, a telltale is required to be mounted inside the occupant compartment in front of and in clear view of the driver. The ESC malfunction telltale must be identified by the following ISO symbol or text:

SYMBOL	WORD OR ABBREVIATION	CONTROL	COLOR
	**ESC**	TELLTALE	YELLOW

The ESC malfunction telltale 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. Such telltale must 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 telltale must extinguish at the next ignition cycle after the malfunction has been corrected.

Except as provided in the regulation, each ESC malfunction telltale must 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 telltales shown in a common space.) In addition, the ESC malfunction telltale need not be activated when a starter interlock is in operation.

Vehicle manufacturers are permitted to use the ESC malfunction telltale in a flashing mode to indicate ESC operation.

Telltale Labeling

In terms of how to label the ESC malfunction telltale, it is our intention to provide flexibility to vehicle manufacturers via alternative text terms for telltales, 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 telltale. Therefore, the regulation permits use of the term "ESC" at the manufacturer's discretion instead of the ISO symbol.

In light of the importance of promoting drivers' understanding of ESC and whether or not their vehicle is equipped with ESC, some participants recommended combining the ISO symbol with the acronym "ESC." However, it was decided that augmenting the ESC malfunction telltale by adding that term is unlikely to address that concern, because available research indicates that most drivers do not yet understand what "ESC" means. Insofar as drivers will have to learn the precise meaning of any telltale offered by manufacturers to convey the idea of ESC, it necessary at this time to specifically require a telltale 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 telltales over time, and that the ESC malfunction telltale 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 telltales, it is noted that it is permissible to augment the ISO symbol with the text "ESC" is permissible.

Use of Message Centers

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

Color Requirement

The use of message/information centers for presentation of ESC malfunction information is permissible to the extent that the relevant requirements of the regulation are met, including the yellow color requirement. The intent of the color requirement is that the color 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 (ISO) 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 color 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 must be maintained in order to properly communicate the level of urgency with which the driver must seek to remedy the malfunction of this important safety system.

Illumination Strategy

In terms of illumination strategy, it is noted that some current ESC systems utilize a telltale control logic that illuminates the "ESC Off" telltale whenever the ESC malfunction telltale is illuminated. We confirm that when an ESC malfunction situation exists, manufacturers may choose to illuminate the "ESC Off" telltale or display "ESC Off" text in a message/information center in addition to illuminating the separate ESC malfunction telltale to emphasize to the driver that ESC functionality has been reduced due to the failure of one or more ESC components. However, the reverse situation (*i.e.*, illuminating the ESC malfunction telltale in addition to the "ESC Off" telltale when ESC has been manually switched off by the driver) is prohibited, unless an actual ESC malfunction condition exists. In such situations, an ESC system actively disengaged by the driver through an appropriate control is not malfunctioning, but is instead functioning properly. Furthermore, such an illumination strategy could cause driver confusion, which may in turn decrease confidence in the ESC system.

Telltale Extinguishment

In terms of telltale 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 returned to service.

Telltale Location

Although some participants suggested that the regulation should require an appropriate telltale in that vehicle's "instrument cluster" where its message would be more prominent, rather than in the vehicle's center console (*i.e.*, where the radio and climate control mechanisms are normally located), we do not believe that such a narrow locational requirement is necessary. Instead, the regulation's requirement that the ESC malfunction telltale "[m]ust be mounted inside the occupant compartment in front of and in clear view of the driver" should be sufficiently stringent to ensure that vehicle manufacturers will locate the ESC malfunction telltale in a reasonable location.

(4) <u>Optional ESC Off Switch and Telltale</u>

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.*, "sport" mode or full-off mode). However, if the vehicle manufacturer chooses this option, it must ensure that the ESC system always returns to the fully-functional default mode (*i.e.*, the mode that satisfies the performance requirements by the greatest margin) at the initiation of each new ignition cycle, regardless of the mode the driver had previously selected (with certain exceptions for low speed off-road axle/transfer case selections that turn off ESC, but cannot be reset electronically).

If the vehicle manufacturer chooses this option, it must also provide an "ESC Off" control and a telltale that is mounted inside the occupant compartment in front of and in clear view of the driver. The purpose of this telltale is to indicate to the driver that the vehicle has been put into a mode that renders it unable to satisfy the requirements the standard. The ESC Off telltale must be identified by the following symbol (the ISO symbol J.14 with the English word "Off") or text:

SYMBOL	WORD OR ABBREVIATION	CONTROL	COLOR
	**ESC OFF**	Telltale Control (Illuminated)	Yellow --

Such telltale must remain continuously illuminated for as long as the ESC is in a mode that renders it unable to meet the performance requirements of the standard, whenever the ignition locking system is in the "On" ("Run") position. Except as provided in this regulation, each "ESC Off" telltale must 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" telltale need not be activated when a starter interlock is in operation. The "ESC Off" telltale must extinguish after the ESC system has been returned to its fully functional default mode.

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

System Disablement and the "ESC Off" Control

Most participants expressed support for the decision to permit vehicle manufacturers to install ESC off switches, 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 tire, tires of mismatched sizes, or tires with chains are installed on the vehicle.

In contrast, some safety advocacy organizations expressed concern that ESC on-off switches may place motorists at unnecessary risk, particularly where disengagement occurs for "driving enjoyment" or racing purposes; one organization argued that this small minority of drivers can 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. One organization suggested that it may be unnecessary to permit ESC disablement, if ESC systems can operate in conjunction with vehicle traction control systems or that if the agency continues to believe that ESC disablement switches should be permitted, disablement should require either: (1) a long switch engagement period, or (2) sequential switch engagement actions.

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

First, we acknowledge that 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 traveling via the wheel speeds, rather than using an accelerometer or other sensor. While the GTR only requires ESC to operate at travel speeds of 15 kph 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.

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.

In response to the suggestion that it may be unnecessary to permit ESC disablement, if ESC systems can operate in conjunction with traction control, we do not believe 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.

Switch for Complete ESC Deactivation

Some participants suggested that for certain sporty models, the regulations should provide for a separate mode (perhaps activated with a switch) which would give the driver discretion to completely disable the ESC for race track use. As described, such 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).

Because the GTR permits, rather than requires an ESC Off switch and is not specifying the extent to which ESC function must be reduced via the switch, manufacturers have the freedom to provide drivers with a switch that has the ability to completely disable ESC.

ESC Operation After Malfunction and “ESC Off” Control Override

At least one automobile manufacturer expressed concern 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.

We agree that just because the manufacturer permits the ESC system to be disabled under some circumstances, that does not mean that the manufacturer must 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” switch 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 must 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.

Default to “ESC On” Status

Some participants acknowledged that there may be certain situations in which ESC disablement may be appropriate (*e.g.*, vehicles stuck in snow or mud), but objected to permitting the ESC system to remain disabled until the next ignition cycle (*i.e.*, default mode upon vehicle start-up be ESC “on”). 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 regulation require that, once disabled, the ESC system must 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).

In response, we note that although ESC systems must always return to a 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. However, as discussed above, there are at least two situations in which drivers may desire to turn off ESC, specifically when a vehicle is stuck in the snow and when a driver chooses to engage in sporty driving or racing. The latter of these two situations is the only one that warrants a potentially more prolonged delay of ESC re-enablement until the next ignition cycle. However, if the GTR were to require automatic reengagement of a fully-functional ESC mode after a certain time delay or upon the vehicle reaching a certain speed threshold, many vehicle operators might face a considerable obstacle if they wished to continue engaging in sports driving. As mentioned above, we believe that there could be safety disbenefits associated with sports drivers who try to permanently disable the ESC system themselves.

Operation of Vehicle in 4WD Low Modes

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 when drivers select ESC modes 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 driving. It was added that in those cases, the ESC "Off" telltale should be illuminated, in order to remind the driver of the ESC system's status as being unavailable.

We agree 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 enabled status just because the ignition has been cycled. In these situations, keeping the ESC disabled and illuminating the ESC "Off" telltale, in order to remind the driver of the ESC system's status as being unavailable, makes more sense. We agree that this approach should have no substantial effect on safety because the operating conditions for these vehicle modes tend to involve low-speed driving.

Labeling of the "ESC Off" Control

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 telltale that would illuminate whenever the system is in a mode other than "full on," they should be permitted discretion to optimize control labeling in ways that would facilitate driver understanding of variable ESC modes (*i.e.*, permitting a message other than "ESC Off").

We share the concern for ensuring driver understanding of ESC status and also agree that it would be beneficial to encourage drivers to select ESC modes other than "full on" <u>only</u> when driving conditions warrant. However, we nevertheless believe that standardized control labeling of an "ESC Off" control must be maintained, and, therefore, manufacturers must 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, we are distinguishing between an actual "ESC Off" control (*i.e.*, one whose 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 must bear the required "ESC Off" labeling) and two other possible types of controls (which would not be required to bear the "ESC Off" labeling).

The first 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 must turn off the ESC system as a consequence of an operational conflict with the function that it controls. In this case, such control would be made confusing by adding "ESC Off" to its functional label. Nevertheless, in such situations, the "ESC Off" telltale must illuminate to inform the driver of ESC system status.

The second 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's is permitted, but not required, to use the "ESC Off" telltale beyond the default mode to signify lesser modes that still satisfy the test criteria.

Location of the "ESC Off" Control

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

For the reasons that follow, we have decided that the "ESC Off" switch location must be visible to and operable by the driver while properly restrained by the seat belt. We believe that 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 switch when drivers encounter a new vehicle.

ESC Deactivation on Wheelchair-Accessible Vehicles

One participant representing manufacturers and dealers of mobility equipment (*e.g.*, for use by the disabled) stated that ESC system sensors are normally located under one of the front row seats. However, it was argued that because ESC systems are position-sensitive, their relocation is likely to affect the accuracy, performance, and effectiveness of those systems. (It was pointed out that yaw rate and sideslip are functions of the vehicle center of gravity, and also, the ESC's horizontal plane of reference will likely be altered when an ESC system is relocated, further altering its performance.) The organization expressed concern that whenever the system sensors must be moved in the process of modifying vehicles to make them accessible to the disabled, the ESC system could generate potentially dangerous and unpredictable vehicle responses under certain driving conditions.

Therefore, that participant recommended that the regulation should require an original equipment manufacturer to provide a means to permanently deactivate an ESC system for vehicles manufactured, altered, or modified after first sale to accommodate persons with disabilities. According to that organization, it would be possible to ensure that the ESC system is not accidentally activated by equipping the vehicle with a permanent, key-operated "off" mechanism and an associated warning lamp (similar to one provided on an air bag deactivation system). Alternatively, it stated that there could be a provision stating that third parties are permitted to permanently deactivate the ESC system on vehicles that are manufactured, altered, or modified after first sale to be accessible to persons with disabilities.

In response, we do not believe that any specific action is necessary to address concerns about vehicles modified to make them accessible to disabled individuals. Parties who must certify that their vehicles are in compliance with the regulation prior to first retail sale should have the capability to ensure the functionality of the ESC system installed in their vehicles. However, aftermarket modifiers who adapt vehicles for persons with disabilities would not likely be able to move ESC components without some level of assistance from vehicle manufacturers or ESC system suppliers.

We strongly urge original equipment manufacturers to work with vehicle modifiers to identify alternative locations or other modification methods so that the benefits of ESC may be retained for drivers of adapted vehicles. The number of vehicles that are popular for adaptations for persons with disabilities is quite limited, and we believe it is practical for manufacturers to provide assistance to modifiers who must remove original equipment seats, supply alternative seats, or modify floors, so that the modifiers may relocate ESC components is a way that preserves the proper functioning of the system.

ESC Off Controls for Vehicles with Towed Trailers

According to one participant, vehicles capable of towing a trailer should be required to have an ESC on/off control, because current ESC systems do not communicate with the trailer when intervening to maintain stability. It was argued that because the ESC-equipped towing vehicle's brake lights do not activate, the aftermarket trailer's brake controllers cannot participate. It was stated further that towing vehicles' dive and trailer hitches rise during heavy braking, so unless care is taken, a two-to-four ton trailer could lift and overpower the towing vehicle. Thus, careful evaluation was urged of such effects using special trailer test rigs that have motor-controlled swinging masses and numerous hitch combinations, as well as additional tests simulating air disturbance from oncoming trucks on two-lane roads. Ultimately, a recommendation was made to adopt specific pass/fail towing criteria that vehicle manufacturers must meet, as part of the ESC regulation.

We have no evidence supporting the supposition that ESC intervention will adversely affect the safety of a vehicle hauling a trailer, nor has any vehicle or ESC manufacturer stated that lack of communication between a tow vehicle and trailer will negatively affect ESC functionality. ESC systems operate in extreme driving situations where a loss of control is anticipated (*i.e.*, excessive oversteer or understeer situations). On some vehicles with high centers of gravity, ESC may also intervene during impending on-road, untripped rollover situations. In each of these loss-of-control situations, we do not believe ESC stabilization of the tow vehicle would result in a subsequent loss of trailer stability.

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.

Telltale Labeling

Similar to the above reasoning of how to label the ESC malfunction telltale, it is our intention to provide flexibility to vehicle manufacturers via alternative text terms for telltales, 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.

Color Requirement

Similar to the above reasoning for the yellow color requirement for the ESC malfunction telltale, the use of message/information centers for presentation of required ESC information is permissible to the extent that the requirements of the regulation (including the yellow color requirement) are met. 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 color 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." We believe that operating ESC in a mode other than "full on" qualifies as a condition of "compromised performance." Therefore, the yellow color requirement must be maintained in order to properly communicate the condition of potentially decreased safety to the driver.

"ESC Off" Telltale Clarification

In response to industry request, it should be clarified that it is permissible under this GTR to illuminate the "ESC Off" telltale 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.

"ESC Off" Telltale Strategy

In developing the provisions for the ESC Off telltale, one vehicle manufacturer sought clarification whether the following ESC telltale 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 center, and illuminate a yellow light-emitting diode (LED) in the "ESC Off" button which is in clear view of the driver. Such a strategy is not permissible under this GTR for the reasons that follow.

The regulation provides that the ESC malfunction telltale shall be illuminated "…after the occurrence of one or more malfunctions." 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 telltale can only be used when a malfunction exists. Specifically, if the ESC malfunction telltale were permitted to be presented simultaneously with the "ESC Off" telltale, 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 telltale in addition to an "ESC

Off" indication when ESC has been disabled via the driver-selectable control and no system malfunction exists is prohibited.

Use of Two-Part Telltales

Some industry stakeholders stated that vehicle manufacturers should be permitted the flexibility to use two adjacent telltales, one containing the ISO symbol for the proposed yellow ESC malfunction indicator and another yellow telltale 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.

While acknowledging these concerns regarding limited instrument panel area available for locating telltales, we are not adopting this recommendation, because allowing a two-part telltale in such manner would create conflicting regulatory requirements. Indication of a malfunction condition must always be the predominant visual indication provided to the driver by a telltale. As a result, if a two-part ESC telltale were used and an ESC malfunction occurred, only the malfunction portion of the telltale could be illuminated. However, other provision in the regulation state that a telltale consisting of the symbol for "ESC Off" or substitute text must 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 ESC mode. If a two-part telltale were used, and an ESC malfunction condition occurred after the ESC had been turned off by the driver, the malfunction indication would take precedence over the "off" indication, thereby requiring that the "off" portion of the two-part telltale be extinguished. This situation would result in a conflict amongst the regulation's provision. In light of this conflict, the request to permit use of a two-part ESC telltale has been denied.

Conditions for Illumination of the "ESC Off" Telltale: Speed

The automobile industry sought clarification that the "ESC Off" telltale (if provided) need not illuminate when the vehicle is traveling below the low-speed threshold at which the ESC system becomes operational. That understanding is correct. The regulation requires that the ESC system must 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 traveling at low speeds. Furthermore, the regulation requires the vehicle manufacturer to illuminate the "ESC Off" telltale 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" telltale must be illuminated when the vehicle is traveling at low speeds, and it is sufficiently clear in defining the conditions under which the "ESC Off" telltale must be illuminated.

Conditions for Illumination of the "ESC Off" Telltale: Direction

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

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 15km/h or when being driven in reverse). In such instances, the ESC systems 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" telltale 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 must be illuminated when the ESC system is manually disabled (*i.e.*, placed in a non-compliant mode) by the driver via the "ESC Off" switch, a very different situation from a vehicle being placed in reverse.

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

Participants offered a variety of viewpoints regarding provision of an indication of ESC activation to the driver. Some supported a visual telltale; 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 it interpreted as suggesting that flashing illumination increases driver distraction, or even suggesting that a flashing telltale could elicit a panic reaction in which the driver fails to even attempt to steer the vehicle), whereas other argued that such indicator should be permitted to flash. Still others stated that an activation telltale is unnecessary and potentially distracting to the driver or lead to annoyance, which may cause drivers to deactivate the ESC system.

After careful consideration of the substantial input on this issue, the GTR provides that manufacturers may use the ESC malfunction telltale 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.

In a 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 telltale. Owner's manuals examined typically indicated that the purpose of the flashing telltale was to inform the driver that the ESC was "active" or "working."

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.

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 telltale 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 telltale or no telltale. Insofar as a flashing telltale draws a driver's attention away from the road, where we believe it should be during an emergency loss-of-control situation, we cannot logically require it. We agree that 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 disagree that it would 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.

While research to date shows that drivers looked at a flashing telltale twice as often, this did not result in significantly different rates for loss of control, road departures, and collisions than with steady-burning telltales or no telltales. Thus, despite the logical risk of looking away from the road during an ESC-worthy maneuver, there is no apparent detriment from the increased glances at a flashing telltale. 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.

Once additional data from relevant research become available and are analyzed, it may be possible to further clarify 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, we will not require or prohibit such an indication.

Consistent with available research, we believe that 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, we do not consider these results from a single, simulator study to provide sufficient justification to prohibit use of an auditory ESC indicator. Therefore, while we would discourage use of an auditory ESC activation warning, even when combined with a visual indication, current data do not justify a prohibition of such approach.

Flashing Telltale as Indication of Intervention by Related Systems/Functions

The automobile industry requested that it be permitted to flash the ESC malfunction telltale 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 telltales used for related functions.

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 in their discretion. We expect 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.

Bulb Check -- Waiver of Bulb Check for Message/Information Centers

Except when a starter interlock is in operation, the GTR requires that each ESC malfunction telltale and each "ESC Off" telltale must 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.

Industry participants stated that while such requirements are appropriate for traditional telltales, those requirements are not appropriate for vehicle message/information centers 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 center would be blank. Therefore, it was requested that ESC system status indications provided through a message/information center be excluded from the regulation's bulb check requirements.

In response, we agree that a bulb check is not relevant or necessary for the type of display technology utilized for information/message centers.

Presumably, if an information/message center experiences a problem analogous to one which would be found by a telltale's bulb check, the entire message center would be non-operational, a situation likely to be rapidly discovered by the driver. Therefore, we have decided to waive the bulb check requirement for ESC system status indications provided via a message/information center.

Clarification Regarding Bulb Check

One participant sought clarification that the bulb check for the ESC malfunction telltale and ESC Off telltale (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 telltales. Because we are not concerned with the precise mechanism of how the bulb check for an ESC-related telltale is accomplished (provided that this performance requirement is met), we have decided to accommodate this request in this regulation.

(5) Technical Documentation

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 must 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 describing the ESC system's basic operational characteristics, a logic diagram supporting the explanation of system operations, and a discussion 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

ESC-equipped vehicles covered under this GTR are also required to meet performance tests. Specifically, such vehicle must satisfy the GTR's stability criteria and responsiveness criterion when subjected to the Sine with Dwell steering maneuver test. This test involves a vehicle coasting at an initial speed of 80 kph while a steering machine steers the vehicle with a steering wheel pattern as shown in Figure 2 of the regulatory text. The test maneuver is then repeated over a series of increasing maximum steering angles. This test maneuver 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.

The maneuver 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.

(1) Lateral Stability Criterion

The quantitative stability criteria are expressed in terms of the percent 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 percent of the peak value after one second and that it continues to drop to no more than 20 percent after 1.75 seconds.

(2) Lateral Responsiveness Criterion

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 GVWR of 3,500 kg or less must 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.) It also requires that a heavier vehicle with a GVWR greater than 3,500 kg must move at least 1.52 m laterally in the same maneuver for specified steering angles (*i.e.,* conducted with a commanded steering wheel angle of 5A or greater). These computation are for the lateral displacement of the vehicle center of gravity with respect to its initial straight path.

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. The performance test includes the procedure for normalizing the steering wheel angle and calls for performing the Sine with Dwell maneuver 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 trucks and vans in the weight class with a GVWR 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 trucks in the test procedure.

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 Maneuver 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.

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 maneuver must be capable of applying steering torques between 40 and 60 Nm at steering wheel velocities up to 1200 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.

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.

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.

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 maneuver. 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.

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 must avoid causing vehicles to be designed with chasses that are unstable at GVWR and rely on ESC in normal operation. In addition, some very large vans with a high center 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.

While we agree with the industry's suggestion that a lower responsiveness criterion for vehicles with higher GVWRs is appropriate, we disagree with the recommended 5,500-pound GVWR break point. Some large passenger cars, such as the Mercedes-Benz S-class, have GVWRs near this level. With this break point, minivans like the Honda Odyssey and midsize SUVs like the Toyota 4Runner and Jeep Cherokee would be considered to have the same limitations as 15-passenger vans and trucks with a GVWR of 4,536 kg. Thus, the GTR establishes a more representative break point at a GVWR of 3,500 kg.

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

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

Participants stated that, given the short interval of time in the initial phase of the lane change maneuver, 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 maneuver's steering inputs), the integration errors are expected to be so small as to be negligible.

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 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 percent, 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 percent), 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.

(3) The Issue of Understeer Performance

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.

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, tire inflation pressure,

[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 (elsewhere called "limit-handling"), 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.

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 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.

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.

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 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.

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.

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 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, as evidenced by the lack of large enough basalt test pads anywhere in the United States for this kind of testing. 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 very low criteria.

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 maneuver 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 maneuver, 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 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.

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 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.

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 a discussion 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. (In appropriate cases, the Contracting Party might ask for additional data, including the results of a manufacturer's understeer testing.) It is understood that much of the above information may be proprietary and would be submitted under a request for confidential treatment.

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 considering taking further action, as appropriate.

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).

(4) Other Test Requirement Issues

(Post Data Processing Calculations)

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.

Determining the Beginning of Steering

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.

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 must remain greater than 75 deg/sec for at least 200 ms. If the condition is not met, the next time steering wheel velocity that exceeds 75 deg/sec is identified and the 200 ms validity check is applied. 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 counterclockwise) 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.

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 maneuver. 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 participants’ suggestion for a 5 degree steering measurement. The value for time at the start of steering, used for calculating the lateral responsiveness metrics, is interpolated.

Determining the End of Steering

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 industry 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.

Removing Offsets

Participants stated that, given the potential for the accelerometers used in the measurement of lateral displacement to drift over time, 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 maneuver, the driver must 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 maneuver, 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 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.

Use of Interpolation

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.

Method for Determining Peak Steering Wheel Angle

The automobile industry 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 must meet the responsiveness criteria.

Need for a Common Data Processing Kernel

Because data processing methods can have a significant impact on the results generated, necessary data processing details have been added to the regulatory text.

e. <u>Test Conditions</u>

(1) <u>Ambient Conditions</u>

Ambient Temperature Range

The regulation states that testing will be conducted when the ambient temperature is between 7º C and 40º C. Although consideration had been given to specifying a lower temperature range for testing of 0º C, it was decided, based upon participant input, that the temperature value should be raised. The reason is that research demonstrates that responsiveness is reduced at higher temperatures, which is typical of vehicles with all-season tires. The temperature values reflect the general desirability of reducing sources of variability in vehicle testing, in order to preventing testing at temperatures that favor a vehicle’s chance of passing the test. Higher minimum temperature values were considered (*e.g.*, 10º C), 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.

Industry participants stated that their analysis has demonstrated ESC test variability due to temperature. It was suggested that, at near-freezing temperatures, certain high performance tires 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 degrees 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.

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 tires varies with fluctuating ambient temperatures. According to the industry, the data indicate that lateral displacement for test vehicles equipped with all-season tires increases as the ambient temperature decreased, suggesting that the displacement requirement could be met more easily at lower ambient temperatures. However, this same relationship was not manifest for test vehicles equipped with high performance tires. (Some high-performance tires are not designed for operation under freezing conditions, and the performance variability of these tires under cold ambient temperatures is unknown, because in our repeatability studies, we only test tires in the 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, we have set the lower bound of the temperature range for ESC testing to 7 degrees C. We believe 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 at least one brand of high performance tires of which the agency is aware.

Wind Speed

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.

We agree that wind speed could have some impact on the lateral displacement for certain vehicle configurations, including large sport utility vehicles and vans. However, we also

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[21] We note that this is the industry's term. We believe 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 tires. The industry seems to assert that because of their composition, for certain high performance tires, 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.

believe that a maximum wind speed to 5m/s can impose additional burdens by restricting the environmental conditions under which testing can be conducted. With these considerations in mind, we have decided to set the wind speed requirement at 5m/s for multipurpose passenger vehicles (including SUVs, vans), trucks, and buses, but we set the wind speed for passenger cars at 10 m/s. This approach will reduce test variability for those vehicles expected to be most effected by wind speed and minimize any additional burdens on test laboratories.

We note that if we set the wind speed requirement at 5 m/s for all light vehicles, that would unduly limit the number of days on which testing could be performed, and we further believe that wind speed up to 10 m/s would not have an appreciable impact on the testing of passenger cars due to their smaller side dimensions.

(2) Road Test Surface

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 percent. Although consideration was given to requiring a test surface with a slope up to 2 percent (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 percent or less, which is so slight that a directional specification is unnecessary.

The GTR also provides that the road test surface must produce a peak friction coefficient (PFC) of 0.9 when measured using an American Society for Testing and Materials (ASTM) E1136-93 (1993) standard reference test tire, in accordance with ASTM Method E 1337-90 (reapproved 1996), at a speed of 64.4 km/h, without water delivery. (These standards are incorporated by reference as explained in paragraph 2.2 above.)

As an alternative, Contracting Parties may use an alternative method for determining PFC. **[Working Group to provide details.]**

The surface coefficient specification of a peak friction coefficient (PFC) of 0.9 is based upon (brake) testing in the United States. While it is unlikely that any facility has exactly that PFC, testing in the United States is performed on a surface with a PFC somewhat higher than the specification which creates a margin for clear enforcement; manufacturers who are assuring themselves of compliance may test on a surface slightly below the specification to create a compliance margin for themselves.

(3) Vehicle Conditions

Vehicle Test Weight

In the test procedures, the GTR specifies that the vehicle is loaded with the fuel tank filled to at least 75 percent 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 weight 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.

One participant stated that the test conditions for vehicle weight leave only 109 kg as the maximum driver test weight. It was suggested that the total interior load should be increased to 181 kg (thereby permitting a maximum driver test weight of 122 kg), which would provide greater flexibility in testing by accommodating a broader weight variance between drivers without making a substantive change to the intent of the regulation or test results. However, given that the weight of a 95th percentile male is 102 kg,[22] we believe that the maximum allowable weight allocated for the test driver (109 kg) is conservative and should not impose an unreasonable testing burden on parties performing ESC testing.

The industry recommended clarifying the location where ballast (if required) is to be placed in the vehicle to account for varying weights of test drivers and test equipment. We agree and have incorporated such specification 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 maneuver to dislodge and/or relocate unsecured ballast during testing. Contracting Parties may provide further direction in the any accompanying laboratory test procedure, as appropriate.

Outriggers

Industry participants conceded that the use of outriggers may be appropriate during testing, but recommended that the regulation should explicitly clarify the vehicle classes 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. In response to these suggestions, we agree that the use of outriggers has the potential to influence vehicle dynamics during ESC testing. Therefore, in order to reduce test variability and increase the repeatability of test results, the GTR specifies that outriggers are to be used on all vehicles other than passenger cars and also includes maximum weight and roll moment of inertia specifications for outriggers.

[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 20.

f. Test Procedure

Accuracy Requirements

One automobile manufacturer requested specification of accuracy requirements for the following measurement instruments used in the ESC test procedures: (1) yaw rate sensor; (2) steering machine, and (3) lateral acceleration sensor. However, we have 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:

Yaw rate: Range ±100 degrees/s; Nonlinearity ≤0.05% of full scale.

Steering machine encoder: Range ±720 degrees; Resolution ±0.10 degrees (combined resolution of the encoder and D/A converter).

Accelerometers: Range ±2 g,; Nonlinearity <50μg/g^2

Tolerances

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 tires.

One industry participant recommended that the GTR should outline specific tolerances for vehicle speed and deceleration to condition the tires and brakes prior to compliance testing, thereby helping to ensure consistent test conditions.

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

Location of Lateral Accelerometer

One industry participant 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 center of gravity; in those cases, it reasoned, a correction factor will be necessary to accommodate this different sensor positioning.

We agree that it may not always be possible to install a lateral acceleration sensor at the location of the vehicle's actual center of gravity. For this reason, it is important to provide a coordinate transformation to resolve the measured lateral acceleration values to the vehicle's center 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 incorporated into a laboratory test procedure prepared by Contracting Parties to this GTR.

Calculation of Lateral Displacement

One participant expressed concern with an ESC test procedures that would compute lateral displacement by using double integration with respect to time of the measurement of lateral acceleration at the vehicle center 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.

Technically speaking, the lateral displacement evaluated under the regulation is not the "lateral displacement of the vehicle's center of gravity," but an approximation of this displacement. In the present context, the location of the vehicle's center of gravity

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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.

corresponds to the longitudinal center 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 center of gravity using coordinate transformation equations. The use of accelerometers is commonplace in the vehicle testing community, and installation is simple and well understood. Although the use of GPS-based measurements for vehicle dynamics testing is increasing, achieving high dynamic accuracy requires differential post-processing (a process the agency has found to be time-consuming), a real-time differential service, or real-time kinematics base station correction of the data. Each of these options introduces significant cost and complexity to the testing effort. However, the system described by the participant is approximately forty times more expensive than the calculation method prescribed by this GTR.

Therefore, for the purposes of the ESC performance criteria, we believe 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 maneuver'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 vehicle's (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 $\leq 10\ \mu g$, and (4) output noise ≤ 7.0mV. An overview of suitable instrumentation for use during Sine with Dwell tests is provided in the table below.

Data Measured	Type	Range	Manufacturer	Accuracy	Model Number
Steering Wheel Angle	Angle Encoder	±720 degrees	Automotive Testing, Inc.	±0.10 degrees (1)	Integral with ATI Steering Machine
Longitudinal, Lateral, and Vertical Acceleration; Roll, Yaw, and	Multi-Axis Inertial Sensing System	Accelerometers: ±2 g Angular Rate Sensors: ±100°/s	BEI Technologies, Inc. Systron Donner Inertial Division	Accelerometers: <50μg/g² (2) Angular Rate Sensors: ≤0.05% of full scale (2)	MotionPak Multi-Axis Inertial Sensing System MP-1
Left and Right Side Vehicle Ride Height	Ultrasonic Distance Measuring System	10-102 cm	Massa Products Corp.	0.25% of maximum distance	M-5000 / 220 kHz
Vehicle Speed	Radar Speed Sensor	0.16-201 kph	B+S Software und Messtechnik	0.16 kph	DRS-6

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

Maximum Steering Angle

One automobile manufacturer participant expressed concern that steering angles under the test procedure not be too large for vehicles that have a large steering gear ratio. It argued that the upper limit of an average driver's steering velocity is approximately 1000º/sec; thus, the steering angle is 227º 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.

We disagree with this recommendation. 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] We concede 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 was a 2005 Ford F250. This vehicle 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 maneuver 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.

[24] As background, the frequency of the sinusoidal curve used to command the Sine with Swell maneuver 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 maneuvers 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.

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.

Data Filtering

Industry participants 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 industry recommended the following filtering protocol 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.

We agree that data filtering methods can have a significant impact on final test results used for determining vehicle compliance with this regulation, and we further agree that the same filtering and processing protocols must 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.

Brake Temperatures

Industry participants provided their assessment of the affect 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 artifact 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.

Because we agree that 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. We believe that 90 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 tires remain at operating temperatures, a feature we believe is important since test procedures endeavor 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.

Rounding of Steering Wheel Angle at 0.3 g

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 0.3 g 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 degree to produce the final quantity, A.

Industry participants recommended against rounding the steering wheel angle measurement at 0.3 g 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 0.3 g to the nearest 0.1 degrees, so as to eliminate this source of test variability.

We agree with the recommendation to round the steering wheel angle at 0.3 g to the nearest 0.1 degree 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.

Alternative Test Procedures

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

We believe 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. We are confident these criteria provide an extremely effective way of objectively assessing whether the lateral stability of ESC-equipped vehicle is adequate.

We believe the responsiveness criteria proposed for use in this GTR, that a vehicle must achieve at least 1.83 m (1.52 feet for vehicles with a GVWR of greater than 3,500 kilograms) of lateral displacement when the Sine with Dwell maneuver is performed with normalized steering angles (normalized steering wheel angles account for differences in steering ratios between vehicles) 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.

Intervention intrusiveness can refer to how the vehicle manufacturer and its ESC vendor "tune" an ESC system for a particular make/model, specifically how apparent the intervention is to the driver. We do not believe 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 our lateral stability and responsiveness performance criteria, we believe intervention intrusiveness should be a tuning characteristic best specified by the vehicle/ESC manufacturers.

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

The first stage began with identification of three important attributes: (1) high maneuver severity ("maneuver 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 maneuver possessed these attributes, adjectival ratings ranging from "Excellent" to "Fair" were assigned to each of the twelve maneuvers, for each of the three maneuver evaluation criteria. Of the twelve test maneuvers, only four received "Excellent" ratings[25] for each of the maneuver 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).

Stage two of the maneuver 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 maneuver severity, face validity, and performability of the four maneuvers

[25] The adjectival ratings used to rate the test maneuvers were "Excellent," "Good," and "Fair," with "Excellent" being the best and "Fair" being the worst. We considered an "Excellent" maneuver as 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 maneuver 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.

selected in the first stage. The ability of the four maneuvers to satisfy these three evaluation criteria were compared and rank ordered.

Of the four candidate maneuvers, we concluded 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 maneuver 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), we assigned the Sine with Dwell maneuver a higher maneuver severity ranking than that assigned to the YASR with Pause maneuver.

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

Each of the four candidate maneuvers 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 maneuver. However, of the four maneuvers, we believed the Increasing Amplitude Sine maneuver possessed the best face validity. Conceptually, the steering profile of this maneuver 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 maneuver's maximum effective steering rate was a very reasonable 650 deg/sec. For these reasons, the Increasing Amplitude Sine maneuver received the top face validity rating.

The two YASR maneuvers 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 maneuver can require steering rates very near what we believe is the maximum capability of a human driver.

The performability of the Sine with Dwell and the Increasing Amplitude Sine maneuvers were deemed to be excellent. These maneuvers are very easy to program into the steering

[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.

machine, and their lack of rate or acceleration feedback loops simplifies the instrumentation required to perform the tests. Conversely, the YASR maneuvers require the use of specialized equipment (an angular accelerometer), and these maneuvers 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 maneuver severity and test outcome.

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

Regarding the implication of measurement errors, we note 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.

We 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, we concede 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 that effect of instrumentation and/or calculation errors is likewise believed to be very small. Since the performance of most contemporary vehicles resides far enough away from the regulation's performance thresholds, we believe it is extremely unlikely that measurement complications will be solely responsible for having the performance of a non-compliant vehicle being deemed acceptable.

Representativeness of Real World Conditions

A few participants questioned how many tests are necessary to ensure that the ESC system is robust, and how many different configurations of tires, 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.

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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 http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv19/05-0221-O.pdf.

We have reviewed many crash data studies quantifying real world ESC effectiveness.[29] Regardless of the origin of the data used for these studies (*i.e.*, whether from the United States, Germany, Japan, France, Sweden, 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 maneuvers (*e.g.*, lane changes or off-road recovery maneuvers).

We note that the Sine with Dwell maneuver is specifically designed to excite an oversteer response from the vehicle being evaluated. While this maneuver 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 maneuver are within the capabilities of actual drivers, not just highly trained professional test drivers.

We are not aware 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 must 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.

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. We believe this configuration is highly representative of how the majority of vehicles are loaded. Our 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).

We believe 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.

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[29] See 71 FR 54712, 54718 (Sept. 18, 2006) footnote 11,

[30] Data were analyzed for the development of the rollover NCAP star ratings criteria. It is data for six 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).

Although we do believe it is important to understand how vehicle loading can influence ESC effectiveness and presently have research programs designed to objectively quantify those effects, we believe requiring ESC on all light vehicles will save thousands of lives per year. Accordingly, we do not believe it is 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, we believe that the available data strongly support our decision to adopt this GTR for ESC at this time.

7. Benefits and Costs

a. Summary

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.

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 percent of the light vehicle fleet with ESC by 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 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 percent discount and $0.26 to $0.45 million at a 7 percent discount.

b. Benefits

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.

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.

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).

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

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).

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 percent installation of ABS and ESC. The estimated MY 2011 installation rates are presented in Table 1.

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

Table 1. MY 2011 Predicted Installations
(% of the light vehicle fleet)

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

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

Table 2. Percent of the Light Vehicle Fleet Requiring Technology to Achieve 100% ESC Installation

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

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 have ABS currently, $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 mill.
Light Trucks	$29.2	$262.7 mill.
Total	$58.0	$985.2 mill.

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, totaling $985 million annually across the new U.S. light vehicle fleet.

In addition, this regulation is expected to add weight to vehicles and consequently to increase their lifetime use of fuel. Most of the added weight is for ABS components and very little is for the ESC components. Since 99 percent of light trucks in the U.S. are predicted to have ABS in MY 2011, the weight increase for light trucks is less than one pound and is considered negligible. The average weight gain for passenger cars is estimated to be 0.97 kg, resulting in 9.8 liters more gallons 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 percent discount rate and \$3.35 at a 3 percent discount rate.

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 Regulation

1. Scope and 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 and Incorporation by Reference.

2.1. Application. This regulation applies to all Category 1-1 and 1-2 with a gross vehicle weight rating (GVWR) of 4,536 kilograms or less.

2.2. Incorporation by reference. ASTM E1337–90 (reapproved 1996), Standard Test Method for Determining Longitudinal Peak Braking Coefficient of Paved Surfaces Using a STD Reference Test Tire, and ASTM E1136-93 (1993), Standard Specification for a Radial Standard Reference Test Tire, are incorporated by reference in paragraph 6.2.2. Copies of ASTM E1337-90 (rev. 1996) and ASTM E1136-93 (1993) may be obtained from the ASTM Web site at *http://www.astm.org*, or by contacting ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428–2959.

3. Definitions. For the purpose of this GTR, vehicle categories, listed in paragraph 2.1, are defined in Special Resolution No. 1, Concerning the Common Definitions of Vehicle Categories, Masses and Dimensions (S.R. 1) (http://www.unece.org/trans/doc/2005/wp29/TRANS-WP29-1045e.doc). 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 augments vehicle directional stability by applying and adjusting the vehicle brake torques individually to induce a correcting yaw moment to a vehicle;
(b) That is computer controlled with the computer using a closed-loop algorithm to limit vehicle oversteer and to limit vehicle understeer;
(c) That has a means to determine the 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;
(e) That has an algorithm to determine the need, and a means to modify engine torque, as necessary, to assist the driver in maintaining control of the vehicle, and

(f) That is operational over the full speed range of the vehicle (except at vehicle speeds less than 15 km/h or when being driven in reverse).

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.

3.5. "Sideslip or side slip angle" 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.

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 center of gravity.

4. General Requirements. Each vehicle must be equipped with an ESC system that meets the general requirements specified in section (4) and the performance requirements in section (5) under the test procedures specified in section (6) and under the test conditions specified in section (7) of this regulation.

4.1 Required Equipment. Vehicles to which this regulation applies must be equipped with an electronic stability control system that:

(a) Is capable of applying brake torques individually to all four wheels and has a control algorithm that utilizes this capability;
(b) Is operational during all phases of driving including acceleration, coasting, and deceleration (including braking), except when the driver has disabled ESC, the vehicle speed is below 15 km/h, or the vehicle is being driven in reverse; and
(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 system engaged must satisfy the stability criteria of paragraphs 5.1 and 5.2, and it must satisfy the responsiveness criterion of paragraph 5.3 during each of those tests conducted with a commanded steering wheel angle of 5A or greater, 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) must not exceed 35 percent 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 must not exceed 20 percent 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 center of gravity with respect to its initial straight path must be at least 1.83 m for vehicles with a GVWR of 3,500 kg or less, and 1.52 m for vehicles with a GVWR 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 at the vehicle center of gravity, as expressed by the formula:

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

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. <u>ESC Malfunction Detection</u>. The vehicle must be equipped with a telltale that provides a warning to the driver of the occurrence of one or more malfunctions that affect the generation or transmission of control or response signals in the vehicle's electronic stability control system. The ESC malfunction telltale:

(a) Must be mounted inside the occupant compartment in front of and in clear view of the driver;

(b) Must be identified by the symbol shown for "ESC Malfunction Telltale" below or the text "ESC";

(c) Except as provided in paragraph 5.4(d), the ESC malfunction telltale must illuminate only when a malfunction(s) exists and must remain continuously illuminated under the conditions specified in paragraph 5.4

for as long as the malfunction(s) exists, whenever the ignition locking system is in the "On" ("Run") position; and

(d) Except as provided in paragraph 5.4.1, each ESC malfunction telltale must 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;

(e) Must extinguish at the next ignition cycle after the malfunction has been corrected.

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

5.4.2. The requirement of paragraph 5.4(d) does not apply to telltales shown in a common space.

5.4.3. The manufacturer may use the ESC malfunction telltale 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 (illuminated when the vehicle’s headlamps are activated) whose only purpose is to place the ESC system in a mode in which it will no longer satisfy the performance requirements of paragraphs 5.1, 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 will no longer satisfy the performance requirements of paragraphs 5.1, 5.2, and 5.3 are permitted, provided that the system also meets the requirements of 5.5.1 through 5.5.3.

5.5.1. The vehicle’s ESC system must always return to a 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 except if that mode is specifically for enhanced traction during low-speed, off-road driving and is entered by the driver using a mechanical control that cannot be automatically reset electrically. If the system has more than one mode that satisfies these requirements, the default mode must be the mode that satisfies the performance requirements of paragraph 5 by the greatest margin.

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 5.1, 5.2, and 5.3 must be identified by the symbol shown for “ESC Off” below or the text, “ESC Off.”

5.5.3. 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 of paragraphs 5.1, 5.2, and 5.3 need not be identified by the "ESC Off" identifiers in paragraph 5.5.2, but the ESC status must be identified by the "ESC Off" telltale in accordance with paragraph 5.6.

5.6. ESC Off Telltale. If the manufacturer elects to install a control to turn off or reduce the performance of the ESC system under paragraph 5.5, the telltale requirements of paragraphs 5.6.1 through 5.6.9 must be met in order to alert the driver to the lessened state of ESC system functionality.

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

5.6.2. The "ESC Off" telltale must be identified by the symbol shown for "ESC Off" in paragraph 5.5.2 or the text "ESC Off."

5.6.3. The "ESC Off" telltale must be mounted inside the occupant compartment in front of and in clear view of the driver.

5.6.4. The "ESC Off" telltale must remain continuously illuminated for as long as the ESC is in a mode that renders it unable to satisfy the requirements of paragraphs 5.1, 5.2, and 5.3, and

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

5.6.6. Except as provided in paragraphs 5.6.7 and 5.6.8, each "ESC Off" telltale must 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.

5.6.7. The "ESC Off" telltale need not be activated when a starter interlock is in operation.

5.6.8. The requirement of paragraph 5.6.6 does not apply to telltales shown in a common space.

5.6.9. The“ESC Off” telltale must extinguish after the ESC system has been returned to its fully functional default mode.

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 must make available to the regulatory entity designated by the Contracting Party, upon request, the documentation specified in paragraphs 5.7.1 through 5.7.4.

5.7.1. System diagram identifying all ESC system hardware. The diagram must 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. Written explanation describing the ESC system basic operational characteristics. This explanation must include a discussion on the system’s capability to apply brake torques at each wheel and how the system modifies engine torque during ESC system activation. The explanation must 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. Specifically for mitigating vehicle understeer, the manufacturer must provide a discussion of the pertinent inputs to the computer or calculations within the computer and how its algorithm uses that information and controls ESC system hardware to limit vehicle understeer.

6. Test Conditions.

6.1. Ambient conditions.

6.1.1. The ambient temperature is between 7° C and 40° C.

6.1.2. The maximum wind speed is no greater than 10m/s for passenger cars and 5 m/s for multipurpose passenger vehicles, trucks and buses.

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 must produce a peak friction coefficient (PFC) of 0.9 when measured using an American Society for Testing and Materials (ASTM) E1136-93 (1993) standard reference test tire, in accordance with ASTM Method E 1337-90 (reapproved 1996), at a speed of 64.4 km/h, without water delivery. (These standards are incorporated by reference as explained in paragraph 2.2 above.)

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

6.3. Vehicle conditions.

6.3.1. The ESC system is enabled for all testing.

6.3.2. Test Weight. The vehicle is loaded with the fuel tank filled to at least 75 percent 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 weight 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. Tires. The vehicle is tested with the tires installed on the vehicle at time of initial vehicle sale. The tires are inflated to the vehicle manufacturer's recommended cold tire inflation pressure(s) specified on the vehicle's placard or the tire inflation pressure label. Tubes may be installed to prevent tire de-beading.

6.3.4. Outriggers. Outriggers must be used for testing trucks, multipurpose passenger vehicles, and buses. Vehicles with a baseline weight under 2,722 kg must be equipped with "standard" outriggers and vehicles with a baseline weight equal to or greater than 2,722 kg must be equipped with "heavy" outriggers. A vehicle's baseline weight is the weight of the vehicle delivered from the dealer, fully fueled, with a 73 kg driver. Standard outriggers shall be designed with a maximum weight of 32 kg and a maximum roll moment of inertia of 35.9 kg-m^2. Heavy outriggers shall be designed with a maximum weight of 39 kg and a maximum roll moment of inertia of 40.7 kg-m^2.

6.3.5. Automated steering machine. A steering machine programmed to execute the required steering pattern must 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 must be able to apply these torques when operating with steering wheel velocities up to 1200 degrees per second.

7. Test Procedure.

7.1. Inflate the vehicles' tires to the cold tire inflation pressure(s) provided on the vehicle's placard or the tire inflation pressure label.

7.2. Telltale 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 telltale must be activated as a check of lamp function, as specified in paragraph 5.4(d), and if equipped, the "ESC Off" telltale must also be activated as a check of lamp function, as specified in paragraph 5.6.6. The telltale bulb check is not required for a telltale shown in a common space as specified in paragraphs 5.4.2 and 5.6.8.

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" telltale 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" telltale 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 0.5 g.

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. Tire Conditioning. Condition the tires 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 0.5 to 0.6 g 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 0.5-0.6 g, 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 Test. 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 0.5 g 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 0.3 g 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 tires, the tire 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) telltales 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 provided a cool-down period 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. 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.

7.9.3. 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.

7.9.4. 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 telltale lamp(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. Place the vehicle in a forward gear and obtain a vehicle speed of 48 $\pm$ 8 km/h. Drive the vehicle for at least two minutes including at least one left and one right turning maneuver. Verify that within two minutes of obtaining this vehicle speed, the ESC malfunction indicator illuminates in accordance with paragraph 5.4.

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. Verify that the telltale has extinguished.

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

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

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

7.11.3. Raw lateral acceleration data is filtered with a 12-pole phaseless Butterworth filter and a cutoff frequency of 6Hz. The filtered data is then zeroed to remove sensor offset utilizing static pretest data. The lateral acceleration data at the vehicle center 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 centers 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 S7.11.4, the first instant steering wheel rate exceeds 75 deg/sec is identified. From this point, steering wheel rate must remain greater than 75 deg/sec for at least 200 ms. If the second condition is not met, the next instant steering wheel rate exceeds 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 maneuver. 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.

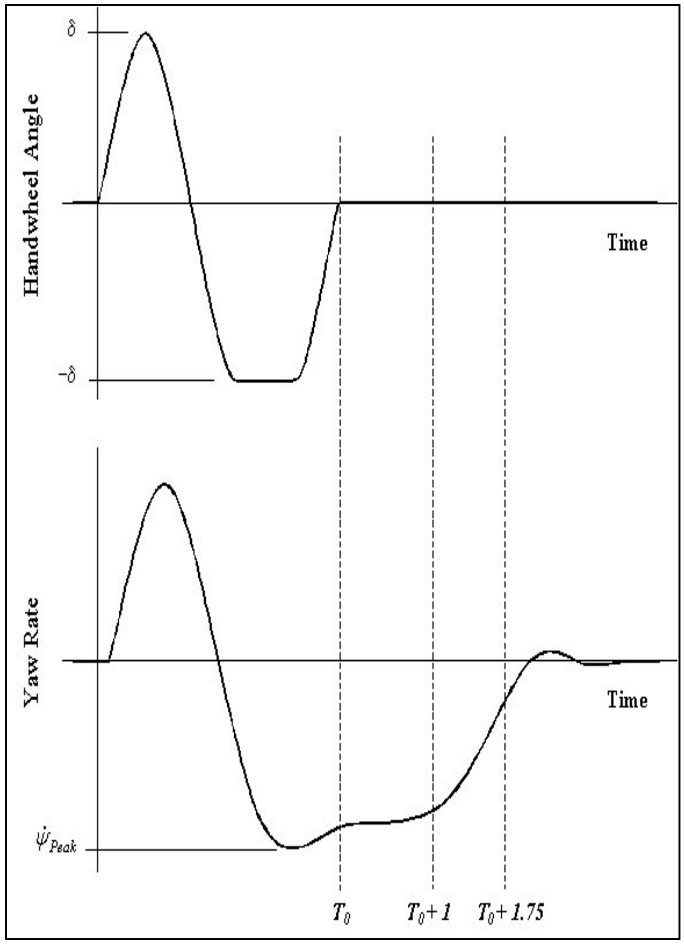

Figure 1. Steering wheel position and yaw velocity information used to assess lateral stability.

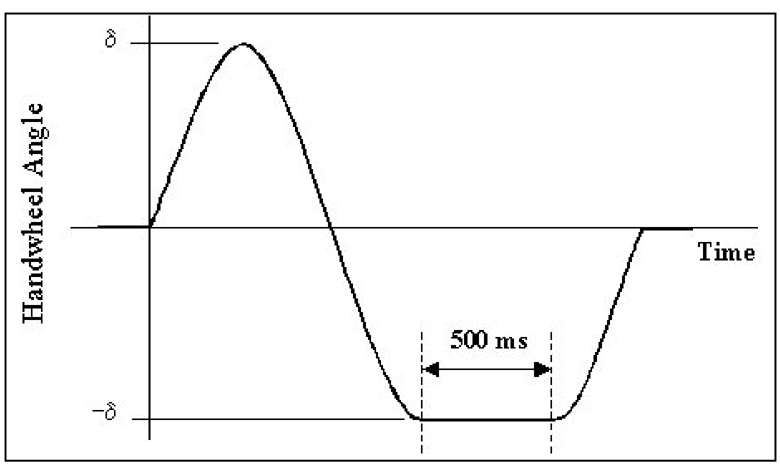

Figure 2. Sine with Dwell steering profile.