Active Safety Control for Automobiles
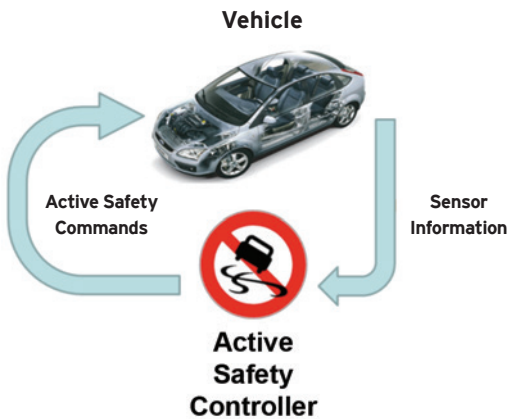
Vehicle

Active Safety Commands

Sensor Information

Active Safety Controller

The rapid evolution of technology over the last 20 years has made automobiles much safer than ever before. Active safety is a relatively young branch of the automobile industry whose primary goal is avoiding accidents and at the same time facilitating better vehicle controllability and stability, especially in emergency situations.

The driver + vehicle + environment form a closed-loop system, with the driver providing control actions by manipulating three primary actuators: the steering wheel and the brake and accelerator pedals. In certain cases, as a result of environmental or vehicle conditions, or the driver's actions, the car may end up in an unsafe state, with the driver's ability to control the vehicle curtailed. Active systems correct such situations by automatically applying differential braking and cutting engine torque (and in the near future, correction of wheel turn).
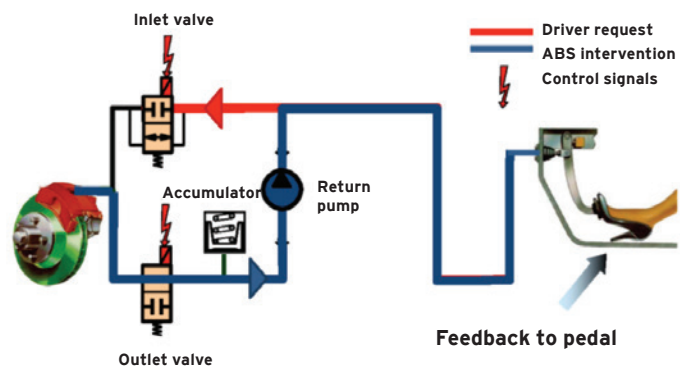
Some Active Safety Control Mechanisms

- Antilock braking systems (ABSs; available today)

- Traction control (TC; available today)

- Electronic stability control (ESC; available today)

- Automatic steering correction (future)

Antilock Braking

The first active electronic safety system was the anti-skid Sure-Brake system proposed by Chrysler and Bendix in 1971; a previous all-mechanical system was introduced by Dunlop in 1950 for aircraft. The first production use was in 1978 when Bosch mounted an ABS on trucks and the Mercedes-Benz S-Class.

The main objectives of ABS are to minimize stopping distance under braking and to avoid wheel locking to maintain the drivability of the vehicle. Since wheel locking occurs when the slip ratio between road and tire (that is, the normalized difference between the peripheral velocity of the tire and the longitudinal velocity of its hub) exceeds a maximum value, the ABS tries to avoid this situation.

As depicted in the figure below, the driver, through the brake pedal, imposes a certain pressure in the hydraulic system. The inlet and outlet valves initially work for normal braking, that is, open and closed, respectively (the opposite of the situation in the figure); in this case, the brake fluid (in the red branch) pushes the caliper into the braking disk. If this braking action determines a slip ratio on the wheel close to the maximal slip ratio, the control strategy changes the state of valves by closing the red branch and opening the blue one so that the pressure on the caliper decreases (and hence the slip ratio). The inversion of fluid flow causes a "feedback" vibration at the pedal. Notice that the opening/closing actions of the hydraulic system are cyclical (a form of high-frequency switching control) such that the slip ratio is kept close to its maximal value. The principal manufacturers are Bosch, Delphi, Continental Teves, and Kelsey-Hayes, which formed a group in 2000 called the ABS Education Alliance and estimated that almost 28% of the accidents on wet roads are caused by uncontrolled braking.

Inlet valve

Driver request
ABS intervention
Control signals

Accumulator

Return pump

Outlet valve

Feedback to pedal

ABS in operation: the automatic release phase when the inlet/outlet valves are in closed and open status, respectively

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Cost-benefit analyses of these systems for EU-25 show that in the decade 2010-2020, the use of ESC can return benefits (in terms of accident avoidance) of €2.8-4.4 for each euro spent. This has convinced governments to make the installation of ESC systems on all cars in the European Union and the U.S. mandatory from 2012. Mandates for ABS are also in effect or in progress, including for motorcycles.

Traction Control

Traction control (TC) systems (or anti-slip regulators) have the opposite goal of ABS in that they try to keep the wheels from spinning in acceleration. This is done by maintaining the slip ratio (opposite in sign with respect to the braking situation) within a certain threshold, modulating the traction torque on the wheels. TC is available in two different versions: one, produced by Saab in collaboration with Teves and Hella, uses the braking system and engine torque variation; the other one, produced by Honda and Bosch, uses only the engine torque variation.

Electronic Stability Control (ESC)

ABS only works well during longitudinal panic braking and TC in start-up maneuvers; neither is effective when vehicle stabilization involves lateral dynamics (sideslips). ESC systems fulfill this need. They act on individual brakes and possibly engine torque, based on measurements or estimated errors of two vehicle variables and their respective (computed online) reference signals: the yaw velocity (the angular velocity around the vertical axis) and the sideslip angle (the angle between the longitudinal axis of the vehicle and the direction of the velocity vector). In particular, the yaw velocity must track a reference trajectory computed on the basis of the steering wheel angle and the vehicle velocity, and the sideslip angle must not exceed a certain threshold. The whole control action (estimation + actuator command generation) is performed in a strict sampling time (10-20 ms). Human drivers would not be able to simultaneously coordinate braking of four individual wheels and cutting of engine torque (if longitudinal velocity is too high) so as to correct the vehicle direction.
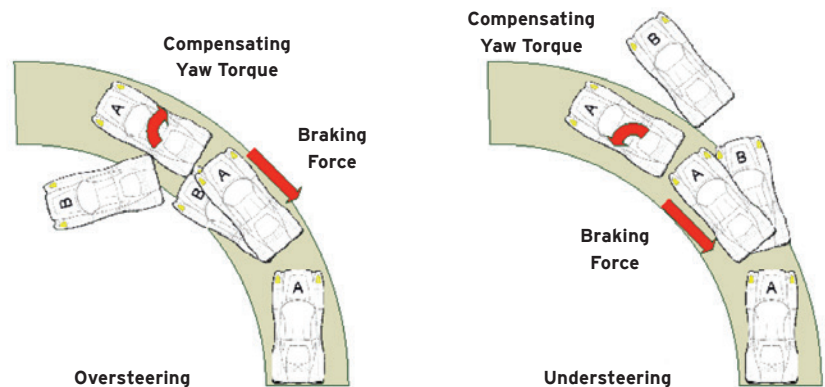
Correcting oversteer and understeer with ESC

The first commercial ESC was developed between 1987 and 1992 by Mercedes-Benz and Robert Bosch GmbH. Today ESCs are available under trade names such as AdvanceTrac, Dynamic Stability Control (DSC), Dynamic Stability and Traction Control (DSTC), Electronic Stability Program (ESP), Vehicle Dynamic Control (VDC), Vehicle Stability Assist (VSA), Vehicle Stability Control (VSC), Vehicle Skid Control (VSC), Vehicle Stability Enhancement (VSE), StabiliTrak, and Porsche Stability Management (PSM). These products differ in the combination of actuators used and the conditions for activating the control strategy.

The Future: Advanced Model-Based Control

Active safety control systems are typically designed using gain-scheduled single-input, single-output controllers whose calibration is obtained after extensive real-time simulations and tests on the track. Furthermore, the coordination among multiple subsystems is done through heuristic rules that determine activation conditions and manage shared resources. Limitations of this approach are that new actuators or sensors are difficult to integrate and it cannot take into account from the beginning the multivariable and constrained nonlinear nature of the global problem. Hence, research is under way to introduce more complex model-based and robust control design methods, exploiting the increased computational power available on board.