CHAPTER 3

VEHICLE SAFETY

Learning how to drive defensively makes sense, but accidents can and will happen. Luckily, modern cars are equipped with a number of devices that are designed to prevent accidents, and to keep the driver and occupants safe if an accident does occur. These devices generally fall under two categories: active safety and passive safety.

The first, mainly used in the US, refers to safety systems that help avoid accidents, such as good steering and brakes. In this context, passive safety refers to features that help reduce the effects of an accident, such as seat belts, airbags and strong body structures. This use is essentially interchangeable with the terms primary and secondary safety that tend to be used in the UK.

In the automotive sector the term Active Safety (or Primary Safety) refers to safety systems that are active prior to an accident. This has traditionally referred to non-complex systems such as good visibility from the vehicle and low interior noise level.

3.1 ACTIVE SAFETY

Active safety refers to devices and systems that help keep a car under control and prevent an accident. These devices are usually automated to help compensate for human error, the single biggest cause of car accidents.
Active Safety is increasingly being used to describe systems that use an understanding of the state of the vehicle to both avoid and minimize the effects of a crash.

For example:

3.1.1 Anti-Lock Brakes

ABS prevent the wheels from locking up when the driver brakes, enabling the driver to steer while braking.

**Safe braking without wheel lockup:** The introduction of the world’s first Antilock Braking System for passenger cars by Bosch in 1978 is a milestone in the area of active driving safety. Since then Bosch have developed ABS further to offer smaller, lighter and more powerful systems.

**Working principle:** In an emergency braking situation the braking force applied by the driver may be greater than the tire can handle: the wheel locks. The tire can now no longer transfer any lateral traction forces. The vehicle becomes unstable and uncontrollable, since the vehicle no longer reacts to the steering input of the driver. In a vehicle equipped with an Antilock Braking System, wheel-speed sensors measure the speed of rotation of the wheels and pass this information to the ABS control unit. If the ABS control unit detects that one or more wheels tend to lock, it intervenes within milliseconds by modulating the braking pressure at each individual wheel. In doing so, ABS prevents the wheels from locking and ensures safe braking: the vehicle remains steerable and stable. Generally, the stopping distance is also reduced.

In a vehicle equipped with an Antilock Braking System, the ABS control unit constantly evaluates the speed of all wheels. If the ABS wheel-
speed sensors placed at each wheel detect a lock-up, ABS intervenes within milliseconds by modulating the braking pressure at each individual wheel. In this way ABS prevents the wheels from locking during braking, thus ensuring steerability and stability combined with the shortest possible braking distance.

**Wheel-speed sensors** : The ECU uses the signals from the wheel-speed sensors to compute the speeds of the wheels. Two different operating principles are used: passive (inductive) and active (Hall) speed sensors. Active sensors are becoming more and more widespread. They use a magnetic field for the contactless detection of the wheel speed and are capable of recognizing the direction of rotation as well as a standstill.

**Hydraulic unit with attached control unit** : The hydraulic unit puts the ECU’s commands into effect and regulates the pressure in the individual wheel brake cylinders by means of solenoid valves. It is located in
the engine compartment between the brake master cylinder and the wheel brake cylinders, so that the hydraulic lines to the brake master cylinder and the wheel brake cylinders can be kept short.

The hydraulic unit has input and output solenoid valves for controlling the pressure in the individual wheel brakes. The ECU takes over all electrical and electronic tasks as well as the control functions of the system.

3.1.2 Traction Control Systems

TCS prevent the wheels from slipping while the car is accelerating. You may occasionally experience a wheel spin when starting off or accelerating, particularly on a slippery or wet road surface. The Traction Control System prevents wheel spin. While the Antilock Braking System prevents the wheels from locking during braking by reducing the braking pressures, TCS ensures that the wheels do not spin when driving off or accelerating. To do this, the drive torque at each driven wheel is reduced correspondingly. TCS improves the traction of the vehicle and increases vehicle safety by avoiding unstable driving situations within the limits of physics.

TCS supplements the ABS function. If one of the driven wheels tend to spin, TCS is activated. The traction control system reduces the drive torque supplied by the engine and, if necessary, brakes individual wheels in order to regulate the slip of the driven wheels as quickly as possible to the optimum level.

Acceleration without wheel spinning: The Traction Control System (TCS) is a further development of the ABS technology and was first launched onto the market by Bosch in 1986 – at first for commercial vehicles and in 1987 for passenger cars.
1. Driver wants to drive off, wheels start spinning  
2. The slipping wheels cannot transfer the motive force onto the road  
3. The vehicle goes into an uncontrollable skid

**Figure 3.2 Driving off uphill on a slippery road – With TCS**

With TCS  
1. Driver wants to drive off, wheels threaten to spin  
2. TCS individually reduces the wheels drive torque  
3. Stability is maintained while the vehicle drives off

**Figure 3.3 Driving off uphill on a slippery road - With TCS**
The Traction Control System from Bosch prevents wheel spin when starting off or accelerating, particularly on a slippery or wet road surface. While the Antilock Braking System prevents the wheels from locking during braking by reducing the braking pressures, TCS ensures that the wheels do not spin when driving off or accelerating. To do this, the drive torque at each driven wheel is reduced correspondingly. TCS improves the traction of the vehicle and increases vehicle safety by avoiding unstable driving situations within the limits of physics.

**Working principle:** If one of the driven wheels tends to spin, TCS is activated. The Traction Control System reduces the drive torque supplied by the engine and, if necessary, brakes individual wheels in order to regulate the slip of the driven wheels as quickly as possible to the optimum level.

### 3.1.3 Electronic Stability Control

ESC keeps the car under control and on the road. Every year in Europe almost 30,500 people are killed in traffic crashes and that 1.5 million are injured. Sometimes even just a single bend is enough to put your life right off track.

Worldwide crash studies prove that skidding and the often resulting lateral impact is one of the main causes of severe and fatal road crashes. The Electronic Stability Program ESP counteracts skidding: it stabilizes your vehicle and reduces the risk of skidding. ESP makes a significant contribution towards road safety.

If your vehicle has ESP on board, it also provides you with two further active safety systems: the Antilock Braking System ABS and the Traction Control System TCS. ABS prevents the wheels from locking during braking; TCS prevents the wheels from spinning when starting off and
accelerating. While ABS and TCS intervene on a vehicle’s longitudinal dynamics, ESP additionally improves the lateral dynamics, thus ensuring stable driving in all directions.

ESP substantially reduces the complexity of the steering process and lessens the demands placed on the driver. ABS, TCS, and ESP were all introduced to the market by Bosch.

ESP is always enabled. A microcomputer monitors the signals from the ESP sensors and checks 25 times a second, whether the driver's steering input corresponds to the actual direction in which the vehicle is moving. If the vehicle moves in a different direction ESP detects the critical situation and reacts immediately – independent of the driver. It uses the vehicle's braking system to stabilize the vehicle. With these selective braking interventions ESP generates the desired counteracting force, so that the car reacts as the driver intends. ESP not only initiates braking intervention, but can also reduce engine torque to slow the vehicle. So, within the limits of physics, the car is kept safely on the desired path.

![Figure 3.4 Hydraulic unit with attached control unit](image)

Figure 3.4 Hydraulic unit with attached control unit
The hydraulic unit executes the commands from the control unit and regulates, via solenoid valves, the pressures in the wheel brakes. The hydraulic unit is the hydraulic connection between the master cylinder and the wheel cylinders. It is located in the engine compartment. The control unit takes over the electrical and electronic tasks as well as all control functions of the system.

**Wheel-speed sensor**: The control unit uses the signals from the wheel-speed sensors to compute the speed of the wheels. Two different operating principles are used: passive and active wheel-speed sensors. Both measure the wheel speed in a contract-free way via magnetic fields. Today active sensors are more commonly used and can identify both the direction of rotation and the standstill of a wheel.

**Steering-angle sensor**: The task of the steering-angle sensor is to measure the position of the steering wheel by determining the steering angle. From the steering angle, the vehicle speed and the desired braking pressure or the position of the accelerator pedal, the driving intention of the driver is calculated (desired state).

A yaw-rate sensor registers all the movements of the vehicle around its vertical axis. In combination with the integrated lateral-acceleration sensor, the status of the vehicle (actual state) can be determined and compared with the driver’s intention.

**Communication with engine management**: ESP control unit is able to communicate with the engine control unit via the data bus. In this way, the engine torque can be reduced if the driver accelerates too much in certain driving situations. Similarly, it can compensate for excessive slip of the driven wheels provoked by the engine drag torque.
3.2 PASSIVE SAFETY

Passive safety refers to systems in the car that protect the driver and passengers from injury if an accident does occur. Passive Safety (or Secondary Safety), which are active during an accident.

Pedestrian protection electronics which precisely trigger passive safety systems such as airbags and seat-belt tensioners in the event of a crash or collision. Thus vehicle manufacturers are helped to provide better protection for both vehicle occupants and other road users.

The central airbag control unit evaluates sensor signals to identify the force and direction of an impact and triggers the vehicle’s restraint devices for optimal occupant protection and systems for active pedestrians protection respectively.
3.2.1 Air Bags

Air bags provide a cushion to protect the driver and passengers during a crash. The typical sequence of a collision can be divided into three phases:

**Pre-crash phase:** Even the few milliseconds preceding a crash can be utilized to prepare the occupant protection systems in the best possible way. Sensors and evaluation systems register the situation in and around the vehicle: driving status, proximity to an object, position of vehicle occupants etc. With this information, the thresholds to trigger the restraint devices can be adapted even before impact. Reversible restraint devices such as belt pretensioners can be activated at this stage.

**Crash phase:** The sensors precisely and rapidly register the direction and severity of the impact. The airbag control unit processes this information and controls the activation of the restraint devices.

**Post-crash phase:** After the crash, the airbag control unit switches off the fuel supply, unlatches the doors and interrupts the electrical power supply. A modern system can automatically send an emergency call with the precise location of the vehicle.

Intelligent occupant protection electronics recognize the type and severity of the crash and adapt the protective devices to the body features and seating positions of the occupants. In case of a crash, optimal protection is given to occupants.
A crucial element for optimal occupant protection is the matching of the airbag deployment with the occupant's forward position. An optimal seat-belt protection requires that the seat-belt tensioners are triggered as early as possible in co-ordination with the airbag.

The following protective devices can be triggered:

- Single- and multi-stage front airbags
- Belt pretensioner
- Knee airbags
- Footwell airbags

**Side Impact**: After frontal impact, side impact is the second most frequent type of impact. To allow sufficient time for the deployment of the lateral protection systems after a collision, the airbag control unit has to determine in less than 5 milliseconds, dependent on the type and severity of the impact, whether triggering is required or not.
The following protective devices can be triggered:

- Belt pretensioner
- Side and head airbags
- Rollover bar

**Rear Impact:** Rear collisions even at low speeds frequently lead to injuries to the cervical vertebrae. Although injuries of this kind are rarely life-threatening, they are being increasingly taken into account in consumer tests and by legislators.

Airbag control units offer the possibility of deploying active headrest systems. These systems reduce the risk of injury in the event of a rear collision. Adapted to the crash situation, the headrests of the vehicle are moved forward towards the heads of the vehicle occupants.

The following protective devices can be triggered:

- Belt pre-tensioner
- Active headrest

**Rollover:** Many crashes with fatal outcome for vehicle occupants are associated with the vehicle overturning. In the USA, the figure is around 20%. As early as 1988, the first company worldwide to offer a series-produced electronic system to sense vehicle rollovers. Networking with ESP® can further improve performance.

The following protective devices can be triggered:

- Belt pretensioner
- Side and head airbags
- Rollover bar
3.2.2 Seat Belts

Seat belts hold passengers in place so that they aren't thrown forward or ejected from the car. A seat belt, also known as a safety belt, is a vehicle safety device designed to secure the occupant of a vehicle against harmful movement that may result during a collision or a sudden stop. A seat belt functions to reduce the likelihood of death or serious injury in a traffic collision by reducing the force of secondary impacts with interior strike hazards, by keeping occupants positioned correctly for maximum effectiveness of the airbag (if equipped) and by preventing occupants being ejected from the vehicle in a crash or if the vehicle rolls over.

When driving the driver and passengers are travelling at the same speed as the car. If the car suddenly stops or crashes then the driver and passengers will carry on going at the same speed the car was going before it stopped. A seatbelt applies an opposite force to the driver and passengers to prevent them from falling out or making contact with the interior of the car.
3.2.3 Rollover Bars

Rollover bars protect the car's occupants from injury if the vehicle rolls over during an accident. The New Beetle Cabriolet has an active rollover bar system behind the rear head restraints, providing additional occupant safety in the event of the vehicle rolling over.

The roll-over bar system consists of two separate housings fitted behind the rear seats, each fixed by six coupling points between the twin rear panels. Thanks to their efficient sectional design and full bolt fixing, the roll-over bars are able to absorb much higher forces than previous systems.

In the same way that the crash sensors detect a possible roll-over or collision (at the front, rear or side), the safety system is activated by the airbag control unit.

Figure 3.8 Rollover Bars

A release system is triggered, causing the supporting sections to shoot up by a maximum of 265 millimetres within 0.25 seconds. The sections are locked in place in their end positions and, together with the extremely rigid front windscreen frame, provide protection for all four seats. If the convertible top is up, the roll-over bar makes spring-loaded contact with the
headlining. If the car does not roll over, the bars can be pushed back into their housings by hand. This helps to avoid repair costs which might otherwise be incurred.

3.2.4 Head Restraints

Head restraints prevent the driver and passengers from getting whiplash during a rear-end collision. Head restraints are an automotive safety feature, attached or integrated into the top of each seat to limit the rearward movement of the adult occupant's head, relative to the torso, in a collision — to prevent or mitigate whiplash or injury to the cervical vertebrae. Since their mandatory introduction in the late 1960s, head restraints have prevented or mitigated thousands of serious injuries.

A patent for an automobile "headrest" was granted to Benjamin Katz, a resident of Oakland, California, in 1921. Additional patents for such devices were issued in 1930 and in 1950 and subsequently. The major U. K. supplier of head restraints, Karobes, filed patents in the late 1950s and was still competitive in 1973 when British tests evaluated the quality of these devices.

Optional head restraints began appearing on North American cars in the late 1960s,[citation needed] and were mandated by the U.S. National Highway Traffic Safety Administration (NHTSA) in all new cars sold in the U.S. after 1 January 1969. The U.S. regulation, called Federal Motor Vehicle Safety Standard 202, requires that head restraints meet one of the following two standards of performance, design, and construction.

- During a forward acceleration of at least 8g on the seat supporting structure, the rearward angular displacement of
the head reference line shall be limited to 45° from the torso reference line, or

- Head restraints must be at least 700 mm (27.6 in) above the seating reference point in their highest position and not deflect more than 100 mm (3.9 in) under a 372 N·m (3,292 in·lbf) moment. The lateral width of the head restraint, measured at a point either 65 mm (2.56 in) below the top of the head restraint or 635 mm (25.0 in) above the seating reference point must be not less than 254 mm (10.0 in) for use with bench seats and 171 mm (6.73 in) for use with individual seats. The head restraint must withstand an increasing rearward load until there is a failure of the seat or seat back, or until a load of 890 N (200 lbf) is applied.

An evaluation performed by NHTSA in 1982 on passenger cars found that "integral" head restraints, a seat back extending high enough to meet the 27.5 in (698.5 mm) height requirement reduces injury by 17 percent, while adjustable head restraints, attached to the seat back by one or more sliding metal shafts, reduce injury by 10 percent. NHTSA has said this difference may be due to adjustable restraints being improperly positioned.