

INTELLIGENT ELECTRONIC SYSTEMS IN COMMERCIAL VEHICLES

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Abstract

Looking at the future trends of the road traffic, one will recognize that the commercial vehicle participation will not decrease, although it is required from the environmental and social viewpoints. The reason is that the other means of freight transport (water, railway, air) do not provide the same flexibility as the road transport, and direct business interest of those companies, who are using this transport form is larger than the eventual loss caused by the penalties to be paid (taxes, compensation of higher axle load). This conflict is hard to solve, but the effect can be minimized. The commercial vehicle industry attempts to introduce systems to the vehicles, which are targeting on reduction of the environmental impacts caused by heavy vehicles. These systems, which are named generally as “intelligent chassis systems”, electronically control the operation of the chassis subsystems (engine, transmission, brake, suspension) and co-ordinate their operation on a higher level (vehicle controller, intelligent control systems, such as adaptive cruise control, video camera based lane change recognition system, etc.). This paper reviews the state-of-the-art of the commercial vehicle chassis systems, and tries to project their future development.

Keywords

Traffic safety, electronically controlled chassis systems, active safety, ITS, commercial vehicles

1. INTRODUCTION

The automotive industry is one of the leading industrial branches all around the world. The main reason of this fact is that this is the primary field of „civil” application of the newest scientific results reached in the space, aviation and military research, as well as a good trial opportunity for the new innovations in other scientific areas. No doubt, the passenger car development, application of new ideas and technology is leading comparing to the other (road) vehicle systems. The explanation for it is obvious: the price of passenger cars, usually bought for pleasure rather than making profit, can incorporate the extra costs of the advanced systems. This is the ground for the wide application controlled vehicle systems in passenger cars: ABS, TCS, electronic engine control, semi-active and/or adaptive suspension controls are all standard (options) in even medium size passenger cars.

The application of advanced, electronically controlled systems in commercial vehicles somehow has not been as fast as in the passenger cars in the past. The explanation of this situation shows the constrains for the development and marketing of these systems:

1. The primary reason why the commercial vehicle is purchased is business like: making profit, which means low price of the vehicle, and low maintenance cost, reliability throughout the life cycle of the vehicle. This fact is contradictory to the application of any advanced system, since normally they make the vehicle more expensive, although their impact on the vehicle safety, on the costs of operation is obvious.
2. The commercial vehicle market is more conservative, does not like to accept new systems unless it is convinced about the definite advantages. Typical example is the reluctance of the market concerning the electro-pneumatic brake systems for heavy commercial vehicles, whereas the advantages are obvious, but people "would not see the brake actuation (i.e. there are no pneumatic lines, tubes, valves to control the wheel brake) since it is done electronically. This was the reason (besides the legislation) that redundant pneumatic circuits had to be installed in parallel to the otherwise very safe electronic brake system.

However, with growing number of the vehicles all around the world the demand of the society on the traffic safety is also increasing. Since the transportation infrastructure cannot keep up with the rising number of vehicles there is severe task for the transportation as well as control and mechanical engineers to control the traffic flow in the way of enhancing traffic safety and, at the same time, increasing the efficiency of the transportation, i.e. increasing the traffic density. As seen, there is an obvious contradiction between the mentioned two facts, since increasing the traffic density will result in growing probability of traffic accidents. This contradiction cannot be relieved, but it can be optimized by a certain way, giving intelligence both to the vehicle itself, and also to the infrastructure, making the information flow between the road and the car possible. The traffic flow control, however, cannot be solved only by giving directions to the vehicle operator (by traffic signals, signs, etc.), since he/she is a human being with all deficiencies of his/her nature: mood/age/sex dependent reactions, incorrect, slow and delayed actions. As it will be seen later in this paper, beside the electronic control of vehicle subsystems, such as engine, brake, the overall control of a single, or eventually more vehicles is also possible.

These and similar requirements explain the need of the society for safer, less polluting, less dangerous heavy vehicles, which have no significantly different performance as the passenger cars. These facts make the development of commercial vehicle advanced systems more interesting and more challenging for developing engineers and scientist, since to fulfill all the

technical conditions, at (relatively) lower price, resulting in a less complex system is not an easy task.

2. SPECIAL PROBLEMS OF COMMERCIAL VEHICLES

As it was already mentioned, the design of commercial vehicle systems requires special attention because of the different customer and social requirements. In this chapter some of these differences will be considered.

2.1 Different Design Criteria of Commercial Vehicle Chassis Systems

As it was already mentioned earlier, the commercial vehicle industry operates on a different platform as the passenger car industry. The design requirements are different, as shown in Figure 1.

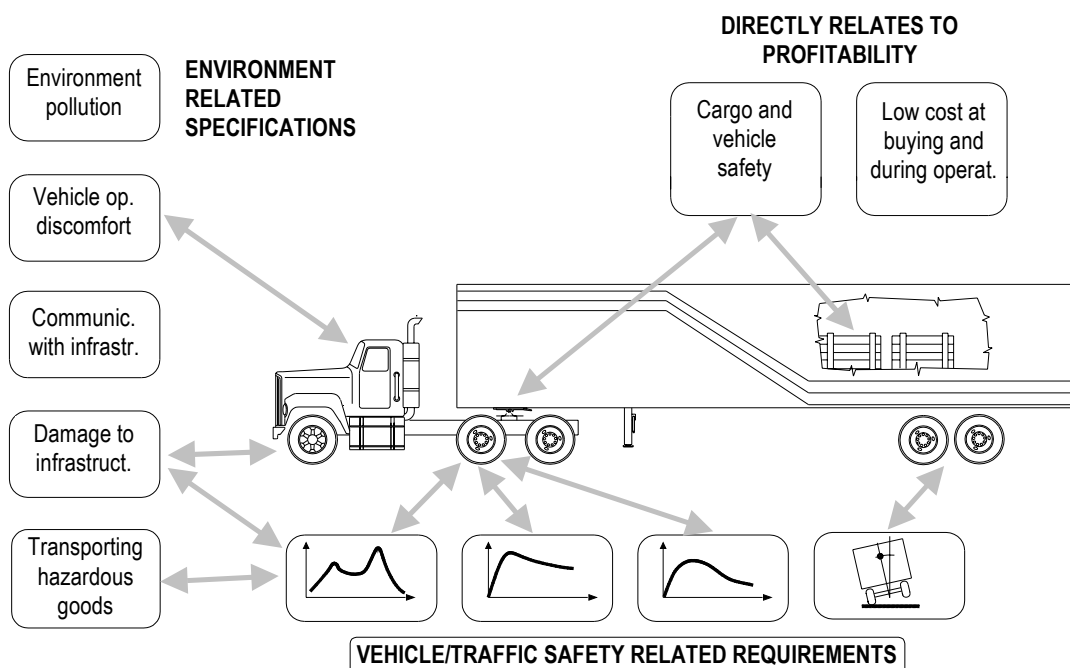


Figure 1 Design criteria of chassis systems for commercial vehicles

As seen in Figure 1, the general requirements for commercial vehicle chassis systems can be divided into three main groups, which from design viewpoint have different weights:

1. The first group directly relates to the profitability (for which purpose the vehicle has been purchased), which means:
 - transporting the cargo safely, without damage to the desired location,
 - reducing the duration of the transport,
 - purchasing the given vehicle at low price,
 - the system should be highly reliable, resulting in high lifetime and low cycle cost,
 - the system should be simple enough to make the necessary maintenance anywhere.

This group is the most important incentive in the development process: the competitiveness of the manufacturers requires the optimisation of the overall vehicle

costs, i.e. reduce the component and their installation costs, utilise the possible synergy in case of actuators, sensors, available data, provide value-added features to the end customer. This very high cost sensitivity might result in compromises in some of the cases, but this pressure brings also very innovative solutions, which are technically also very interesting (for example the recognition of the roll-over danger of the semi-trailer in a combination vehicle, as will be mentioned later).

2. The second group, which covers the vehicle/traffic safety related criteria, in some sense in contradiction with the first group (e.g. high speed = higher efficiency, and at the same time, high speed = lower traffic safety). From point of view of chassis systems, the design criteria relate to the primary and secondary brake systems, the suspension and steering systems. There are again contradictory conditions in this group: optimising the primary suspension for cargo “comfort” (reduced vibration), the road holding, and thus the safety of the vehicle is reduced and vice versa. The wear compensation in electronic braking system (EBS) is in conflict with the proper brake distribution among the axles of the vehicle. However, there are some primary demands which has to be fulfilled without any trade-off: the brake system has to be able to decelerate the vehicle by a proper reduction of the kinetic energy, and the suspension has to provide the necessary force transmission from the wheels to the chassis, improving vehicle stability in different manners (roll stability, yaw stability, etc.)
3. The third group of requirements is formulated by the demands of the environment, including the society as well. Generally, the systems cannot load the environment by any means more than necessary or technically possible. The reduction of the pollution caused by for example the brake pad materials, or the energy transmitting substance, or the reduced noise and vibration caused by the wheel brakes, reduced damage to the road surface are all desired by the human society. The driver’s fatigue has to be reduced as well, which is a real problem in case of commercial vehicles (see in Amirouche (2)) the long termed prolonged vibration to which the driver's spine is exposed is causing severe illness after being in service for decades. The reason can be found in the above mentioned contradictions: making heavy vehicle front suspension “softer” (i.e. reducing the body acceleration), results in reduced roll stiffness, which means reduced roll stability. Very important issue is the transport of dangerous goods. The accident of such vehicles might results in severe loss in human life, and long term environmental damage.

There is one more aspect, which belongs here: the legislation. In contradiction with the passenger car industry, the commercial vehicle market and thus the industry is more conservative, which is mirrored in the legislation. As an example, the first trucks with EBS have been in the market for sale in September, 1996, but the 9th modification of the UN ECE 13 Regulations, dealing with brake systems have been effective since the beginning of 1997 only.

This short description is intended to give a little insight into the complexity of the problem.

2.2 Stability Problems of Heavy Combination Vehicles

The stability problems, and the resulting accidents of commercial, more specified, combination vehicles, although their proportion in traffic is rather small in comparison with passenger cars, always attract high publicity because of their severity (similar to aircraft accidents). When a bus carrying 40-50 persons is involved in an accident, or when a 40 tons vehicle rolls over, they can be found in the highlight of the media. To understand the special problems here, this chapter is assigned to commercial vehicle accidents and the role of the driver in accidents.

2.2.1 Classification of commercial Vehicle Accidents

The most dangerous motions of tractor/semi-trailer vehicle combination can be classified after Verma et al (100) into three groups. The first type is called *jack-knifing*, which is mainly caused by the uncontrolled large relative angular motion of the tractor and the trailer, which results in the lateral slip of the rear axles of the tractor. The jack-knifing phenomenon is one of the most common causes of serious traffic accidents in which tractor/semi-trailers are involved. The main problem with this type of stability loss is that if the articulation angle exceeds a certain critical limit, the driver becomes unable to control the motion of the vehicle by steering the tractor. Even before reaching this critical angle, the problem may become worse if the driver steers the tractor in an inappropriate direction. The aim of a control design is to prevent this critical situation from developing. By using a suitable control strategy, the probability of jack-knifing can be decreased and the possibility of inappropriate driver reaction exacerbating the situation can be avoided.

The second typical class of dangerous motions of articulated vehicles is the *lateral oscillation of the trailer*, which may be caused by some disturbances (e.g., side wind gust, abrupt steering effort by the driver) acting on the vehicle. When the design and/or operating parameters of the system are close to the critical values, the vehicle becomes self-excited. This means that after some disturbance, the vehicle loses its stability and the system's trajectory will tend to some other limit set. In studies conducted by Troger et al (94) and Kacani et al (36) the non-linear stability problems of tractor/semi-trailer combinations are discussed in detail and the vehicle systems were investigated for their loss of stability. El-Gindy (17) and Woodroffe (112) have proposed a set of safety-related performance measures, which can be used for heavy vehicle design and regulation purposes. These performance measures also can be used for selecting a suitable control strategy for a heavy vehicle.

The last typical reason for heavy commercial vehicle accidents is the *roll-over*. An interesting statistics was found by Sarks et al (86), which is visualised in Figure 2.

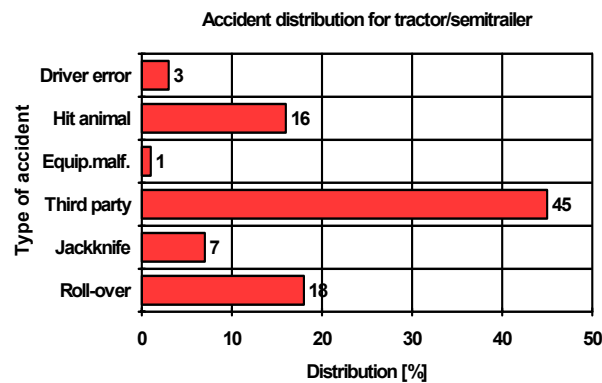


Figure 2 Tractor/semi-trailer accident distribution (Source: Sparks et al (86)).

Based on the mentioned investigation, the roll-over accidents were categorised as follows:

- *preventable*, which means that the driver would have been able to avoid the accident if a warning device had been installed on the vehicle. Only 3.3% of a total accidents were judged to be preventable;
- *potentially preventable*, which means rollover might have been prevented depending on the skill of the driver and performance of the warning device (38.4%);
- *non-preventable*, into which class the 49.7% of the total accidents were categorised; and
- *preventable unknown*, which involves only 8.6% of the total number of accidents.

These statistics prove two facts:

- some of the accidents might have been avoided if the vehicle had been installed with a warning system that would signal the driver to correct the vehicle's motion in some appropriate way before roll-over occurs; and
- the majority (almost 50%) of the roll-over accidents would not have been avoided with just a warning system as even a skilled driver would not have been able to control the vehicle motion behind a certain point.

2.2.2 Driver's Role in Accidents

The behaviour of a commercial vehicle driver is different as of the passenger car. The commercial vehicle driver's are aware of the weight and performance of their vehicles and these are important factors in their decisions. While a fairly inexperienced – at least in comparison with a professional heavy truck driver – reacts to a traffic situation very spontaneous, a truck driver would evaluate the consequences. As an example, in some critical situation a truck driver would not apply full brake because of being afraid of jack-knifing and its consequences (totally uncontrollable vehicle), but rather having a rear-end collision with the preceding vehicle. Their decision is made on the vehicle outputs that can be sensed directly. The vehicle outputs can be categorised as either those sensible directly by the driver or those not sensible by the driver. The signals belonging to the first class are primarily lateral acceleration, acceleration/deceleration, roll angle (all of the tractor). The following signals cannot be sensed by a driver: the articulation rate, roll dynamics of the trailer (especially if it is a full trailer), tire forces and several others. The goal of the controller application is to measure or estimate these signals and react according to both sensible and non-sensible signals to improve the performance of the vehicle. As an example, Figure 3 shows a situation, which would definitely result in a rollover of the vehicle, but the driver has very little information at the stage shown in the picture.

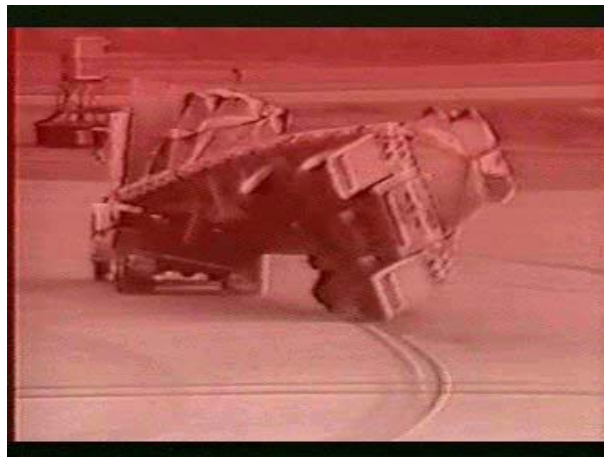


Figure 3 Typical stage before roll-over of a tractor/semi-trailer vehicle

By analysing the behaviour of articulated vehicles, one can observe that the driver's steering input is governed mainly by his/her reaction to the behaviour of the lead vehicle unit (tractor or truck). Therefore, the behaviour of the towed unit(s) (semi-trailer or full trailer) in a real closed-loop driver-vehicle system is not controlled directly by the driver. The other problem is that the vehicle driver has only a limited number of actuators (steering wheel, accelerator and brake pedal), that are not enough in all situations.

The other problems are the deficiencies of the driver as human being: delayed reaction, wrong decisions, or disability to control the vehicle behaviour on the stability limits. The aim of a controller design is to influence the motion of the combination according to the estimated states of the articulated vehicle units.

2.2.3 How These Problems Are Handled?

As can be seen from the above analysis, the driver's natural deficiency is one of the primary cause of the traffic accidents.

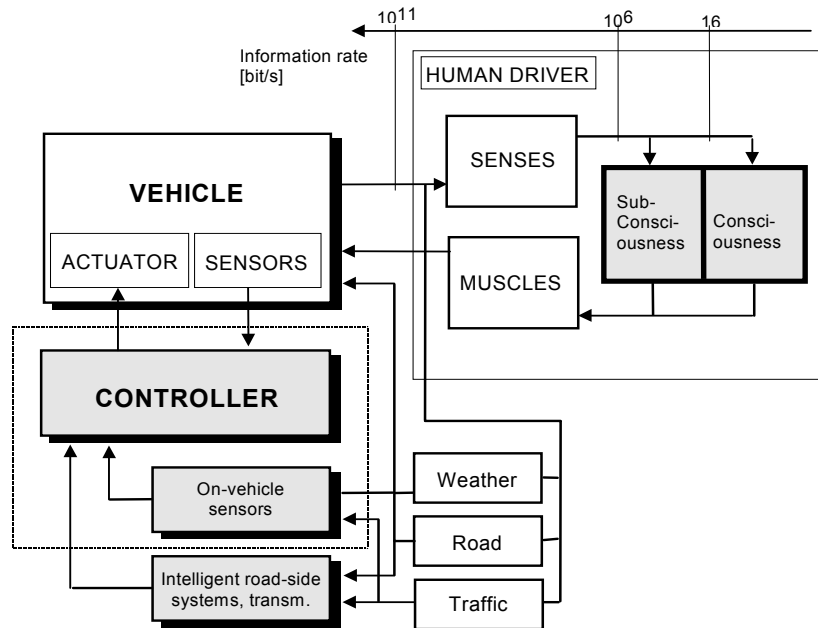


Figure 4 Proposal for overcoming the driver's deficiencies

As depicted in Figure 4, the driver's action mechanism is rather slow. Although the driver receives the information on a rather high rate (see in Glasner (26)), the muscle reaction will become rather slow. The basic idea of the electronically controlled systems is to shortcut the driver, and based on the same (or most) information, which go to the driver, take some action. The variety of these actions is very wide: it starts with a simple warning until the full autonomous control of the vehicle. In the main part of the paper these systems are classified and their actual status will be given.

3. CLASSIFICATION OF CHASSIS ELECTRONIC SYSTEMS

Intelligent systems enhancing the traffic safety can either be only on-vehicle systems or systems installed both on the vehicle and the infrastructure communicating with each other. The former group includes already applied systems, such as ABS, ASR, anti-jackknifing systems, and a series of newly invented systems making some of the vehicle subsystems autonomous, producing a stabilizing effect on the vehicle without any activity of the driver, or giving an early warning to the driver. These kind of systems are the drive stability systems producing coordinated brake force, roll-over detection and preventing systems, or active 4WS, having no feedback from the environment, but only from the vehicle. The IHVS (Intelligent Highway-Vehicle Systems) also cover those solutions when the vehicle's on-board computer receives information about the environment, road conditions and geometry, or about the other members of the traffic flow and the on-vehicle systems, after processing these information, activates some of the vehicle system to react to the external information. There is a wide variety of such systems under development: platooning of the vehicles on the highway, to improve the traffic density, intelligent following distance systems, navigation systems transferring information to the vehicle about the traffic conditions and road data, etc.

The classification of the systems is shown in Table 1 as described below:

- The first set of the systems are installed on the vehicle, obtaining information only from the vehicle installed sensors, measuring the vehicle absolute variables (such as wheel speeds, yaw rate, acceleration, vibration, etc.), but no information on the road or the traffic. These systems can either be a driver's assisting ones, acting when the driver conducts a certain maneuver, but the driver remains fully in the loop. The other set of such systems is operating autonomously, based on measured data, but without the driver's intention, and he/she can even be overruled.
- The second main group differs from the former one in only one respect: they utilize signals from vehicle mounted sensors obtaining information on the environment, i.e. road, traffic, weather conditions. These systems can also act autonomously or giving only assistance to the driver.
- The third set of the systems uses information transmitted by transducers installed at roadside. In this case the receptors are mounted on the vehicle, the information is processed in the vehicle's ECU. The other way communication is also possible, the vehicle can also transmit information to the public domain.

As seen in the table, besides the above classification, a further division of the systems is possible. From the system autonomy viewpoint, the systems can be categorised as follows:

- Driver triggered: the system requires direct actuation from the driver, and when the measured state variables (wheel speed/slip, yaw rate) approaches the critical range, the system will interact and modify these variable in order to increase the vehicle safety. Such system is typically the passive 4WS, or the ABS.
- They send a warning to the driver that some of the system variables are changed, and indicate what the driver should do. Such systems are for example the vehicle surround observing systems, which indicate audibly or visually an obstacle in the vicinity of the vehicle when manoeuvring. There are systems, which belong to this group, but they produce a slight counter-effect on the pedal or steering wheel, indicating the direction of the proposed action, which might be taken by the driver. However, this action (steering wheel rotation, or gas pedal push-back) is very small and the driver can overcome easily their effect and consequently remains fully in the control loop.
- Some systems react autonomously, when they detect that the vehicle behaviour is significantly different than a reference model calculated behaviour, and try to help the driver to improve the vehicle stability. Such system is the VDC (Vehicle Dynamic Control), which helps to realize the driver's demand. It is very important to note here that these systems do not oppose the driver's intention, if the required steering input is to the right, the system helps to go in that direction. This means that the driver remains in the control loop even if the system intervenes autonomously.
- The last group of the systems is when the driver is fully or temporarily excluded from the vehicle control loop, the intelligent system makes decision and takes action instead of the driver. Such systems are the lane departure avoidance systems, which will intervene based on video input, or the control system when the vehicles are platooning.

Table 1 Electronic commercial vehicle systems and their classification

SYSTEM DESCRIPTION	DRIVER'S ROLE	SOME EXAMPLES	STATUS
System's operation only based on signals measured on the vehicle, no measured information on the environment, no information received outside of the vehicle	Driver's intention is necessary to activate the system, the driver is kept in the control loop	ABS/ASR Passive or speed dependent 4WS 4WD Suspension control Power-train management	Already available Already available Already available Already available Already available
	Driver's intention is not necessary, system is activated autonomously, but the driver remains in the control loop	Vehicle condition recognition Roll-over detection system, warning to the driver Active braking for stability enhancement (DSC, ESP, FDR) Active 4WS, additional steering Roll-over protection	Under investigation, some types exist Some types are available Already available for commercial vehicles Investigated, some available Commercially available
Information about the environment and traffic is used, sensors are installed on the vehicle, no information from vehicle-extern sources are received	The on-board system gives assistance or warning to the driver, who remains in the control loop	Adaptive Cruise Control Heading Control Road friction estimation for system adaptation	Already available Being investigated Being investigated
	Based on sensor signals the safety system is activated autonomously, the driver will be excluded from the control loop temporarily (Remark: these systems can also be used as warning, than belong to above)	Radar Braking System Intelligent Cruise Control Lane departure avoidance system using image processing	Being investigated Being investigated Being investigated
Information received from external sources, such as road infrastructure based sensors, satellite, etc.	Information, warning is given to the driver	Car navigation system Electronic cornering speed control via GPS Road side transmitters with curvature, elevation data Magnetic markers transmitting warning to vehicle about danger Commercial vehicle traffic control system using GPS/GSM	Already available Being investigated Being investigate or partially available Already installed Some variants available
	Safety system is activated autonomously	Lane departure avoidance systems using reflecting markers Fully automated system with roadside communication (magnetic markers)	Being investigated Being investigated

4. SYSTEM OVERVIEW

In this paragraph the detailed review of the systems listed in Table 1 will be given. One more dimension for the classification will be introduced: the forces and moments between the tire and the road determine the vehicle behavior and thus the stability, so the systems are grouped further according to the wheel force direction. Thus the systems influencing the mentioned forces in longitudinal, lateral and vertical direction are further divided. Of course, there are sub-systems in the vehicle, which can have influence on more directions (such as the brake system), these are considered separately.

4.1 On-Vehicle Systems - No Information on the Environment

4.1.1 Longitudinal Motion Control Systems

The longitudinal vehicle motion control systems are targeting on the improvement of the vehicle ability of braking and accelerating. The brake, the power-train (engine, transmission, retarder, clutch, differential) and the suspension systems influence the vehicle longitudinal dynamics. Considering the vehicle safety, the brake system is the key element, so the achievements in this field are introduced here in more detail, while the necessary sub-systems of the power-train will be also mentioned until the necessary details.

4.1.1.1 *Brake System*

The braking performance and the behaviour during braking of the passenger cars and heavy commercial vehicles significantly differ from each other. This difference in many cases has been the cause for severe accidents because of different reasons: the longer stopping distance, the higher response time of air-braked vehicles, much larger kinetic energy, intention for jack-knifing are all dangerous in a traffic situations when both passenger car and commercial vehicle are involved.

The commercial vehicles of the past used the compressed air as energy source and control substance as well. The vehicle driver expresses the brake demand by pushing the brake pedal, and his/her demand is transmitted to the brake chambers via several modifying valve assemblies to achieve the desired brake force on the axles. Due to this fact, the dynamics of the air flow is being modified and the system has different time constants, and exposed to large time delays, the optimal control of the traditional pneumatic brake system is difficult to achieve. In addition, the system is rather complex, contains many elements, complicated lining. The realisation of the load dependent brake force distribution in pneumatic systems is a difficult task to solve. The traditional load sensing valves operate based on the static deflection of the rear suspension, but they are not able to compensate for the dynamic load transfer between the front and rear axles, which might result in locking wheels or early ABS intervention on the rear axle. A further problem is the condition of the trailer's brakes. With bad condition of the brake system on the trailer the motor vehicle has to compensate for the trailer brake deficiency, resulting in higher brake lining wear, and overheating of the tractor brake system. This is caused by the incompatibility of the towing vehicle and trailer brake systems. Although the application of the auxiliary (not wear) brake systems, such as drive-line retarder, engine brake (see in Pressel and Reiner (76)) will reduce the probability of occurrence of brake fading, and results in less lining wear, their optimal operation requires certain experience from the driver. Another problem with the conventional brake system is that there is no opportunity for system diagnosis, besides the ABS self-test and the driver visual checks.

4.1.1.1.1 ABS/TCS System in Commercial Vehicles

The introduction of the ABS system improved the situation, but until the vehicle does not reach the higher slip region where wheel lock might occur, the ABS has no influence on the brake performance. The commercial vehicle ABS systems became state-of-the-art, and also

mandatory almost all over the world. After the first generation, mostly feed forward like control algorithm, the new generation has more advanced mostly closed-loop control algorithms. Due to the low cost of a state-of-the-art ABS system, it became a popular platform for new functions, so the assumptions of Emig et al (19) are fulfilled. A good overview of the ABS system development is given by Leonard and Buckman (48).

The *electronic load sensing (ELS)* is one of these functions. In Europe and Asia the brake force distribution between the front and rear axle, and also on the trailer is maintained by a load dependent proportioning valve. This valve is a complex, expensive and maintenance intensive valve, and also the provided brake force proportioning is not optimal. The new technology made possible to use the ABS pressure control modulators for limiting the brake pressure on the rear axle of the vehicle, thus providing the optimal brake force distribution. The basic idea of the system is the so-called *slip control*, which means that the brake force distribution is optimal, if the slip difference between the front and rear axle is minimal, that is:

$$\Delta s = (v_2 - v_1) / v_{\text{absolute}} \sim (v_2 - v_1) / v_1 = 0 \quad (1)$$

where v_2 is the rear wheel, v_1 is the front wheel speed. The principal operation of the ELS is shown in Figure 5. This function is already available in passenger cars, however its realization in commercial vehicles is not straightforward, since the loading conditions of the commercial vehicles can

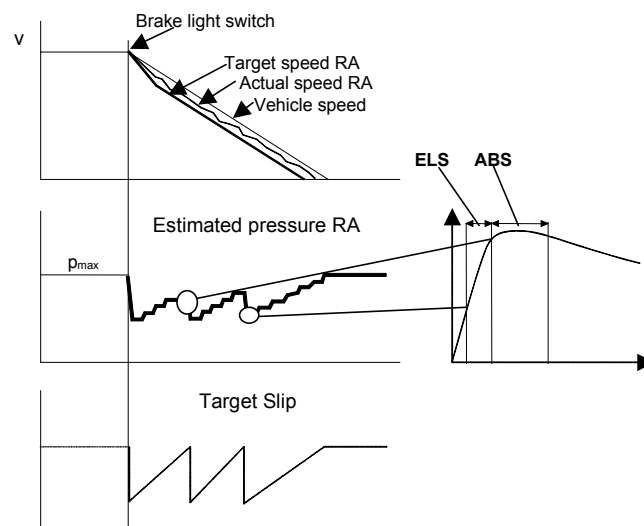


Figure 5 Proposal for overcoming the driver's deficiencies

A similar new function of the ABS is the optimal brake force distribution when braking in a curve, or the so call Drag Torque Control, which prevents the high slips on the drive-axle when the throttle reduced abruptly by increasing the engine torque in order to maintain a wheel-slip in a stable region.

There are markets, where the ABS is, and in fact, will be the wheel-slip control system, the propagation of the EBS system will take more time. On these markets the ABS ECU is used as a platform for other functions, such as fleet management, diagnostics, and similar function.

4.1.1.1.2 Electronic Braking System

The electronic brake system (EBS) targets on the elimination of the problems of pneumatic brake systems mentioned before. The basic targets are as follows:

- to keep the compressed air, as energy source, but for the brake control electronic transmission is used, i.e. the driver's electronically measured brake demand is transmitted to the valve blocks, which connect the reservoirs with the brake cylinders. The time delay and the response time of the system is significantly reduced, thus the stopping distance is lower.
- A more compact system will be achieved, with less components, with higher level of system integration, resulting in lower installation costs,
- the signals, necessary for the optimal control of the brake force distribution are measured electronically (rear axle load, wheel speeds, lining wear, etc.), thus more accurate axle or wheel pressure control can be achieved,
- the tractor/trailer compatibility problem is automatically handled, adapts the control algorithm to the trailer, and controls the brake pressures accordingly,
- resulting from the above features, the EBS is a safer, better performing brake system with reduced stopping distance and enhanced braking stability,
- to provide a platform for future systems, such as adaptive cruise control (ACC), radar brake system, drive stability control system.

At the moment, there is no unique EBS philosophy (unlike for ABS), there is no industry standard. The EBS systems were already in development from mid of the eighties as seen in the literature, but introduced in bigger volumes only after 1996. The brake by wire concept has been introduced in the paper from Wrede, Decker (114), Straub (90) deals with the legislation concerning EBS, and truck manufacturers reports their status in Wiehen, Neuhaus (104, 105), Incardona, Moore (32), Stephan et al. (89), Winterhagen (110), Bassi (3), Beyer et al. (4). The special aspect, the compatibility between the trailer and truck is investigated in papers from Glasner et al. (27), Lindemann (50).

The available systems are differ from each other in the component arrangement, but the system layout, control philosophy, data transmission, back-up principles, functionality are quite similar. Figure 6 shows the simplified layout of the Knorr Bremse EBS 2 generation system, which is a so-called distributed architecture system, since besides the central ECU, the axle/wheel modules have also a small electronics, which provides an enormous flexibility of the system.

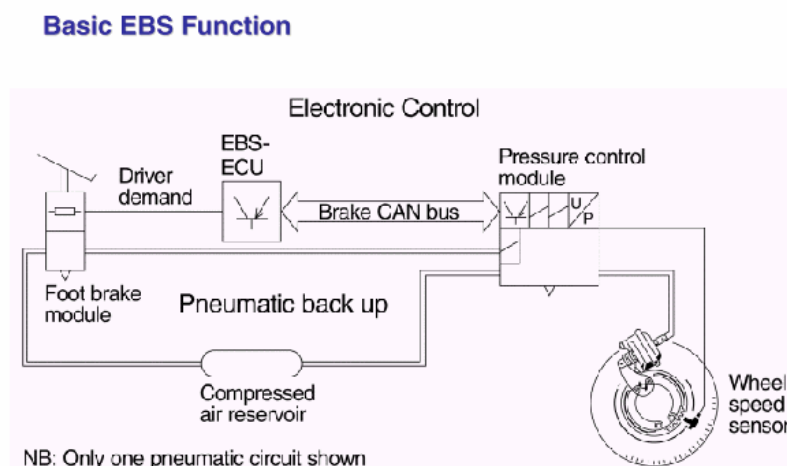


Figure 6 Basic EBS function

The brake signal transmitter, or the foot brake module has the same function as the previously used pedal valve, namely to transfer the brake demand of the driver to the wheel brakes. In fact, due to the back-up principle, the current EBS systems contain the same two independent pneumatic circuits, which are controlled by the pedal valve in case of electronic failure. The

brake signal transmitter is assembled with double potentiometers in order to measure the driver's demand.

The ECU converts the measured deceleration demand into pressure demands, which are transmitted to the axle/wheel modulators via the brake CAN (Controller Area Network). This module is an electro-pneumatic actuator, in which the requested pressure is generated and also the slip value of the actual wheel is maintained. The wheel speed sensor signal and also the wear sensor signal is fed into the module ECU.

The electronic braking system provides the platform for many new functions, which are shown in Figure 7. The block diagram illustrates the principal operation of the system as well.

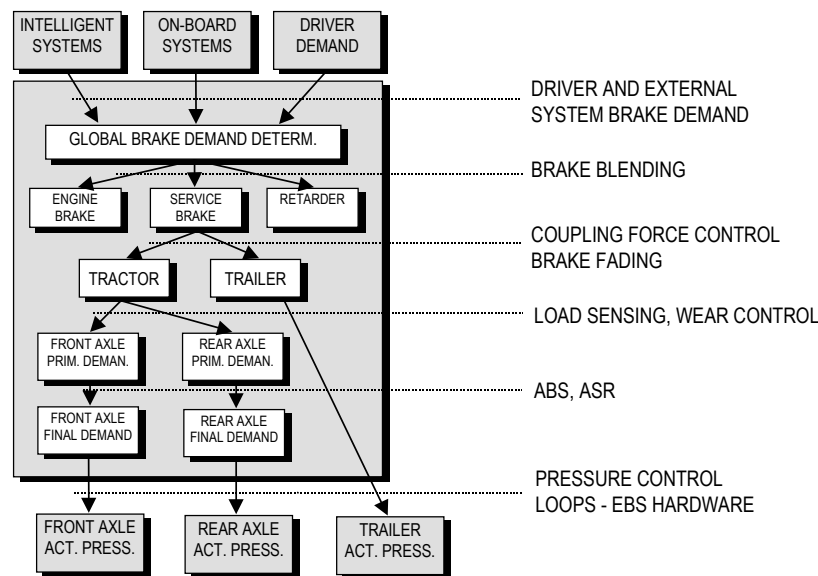


Figure 7 Block diagram of the EBS pressure modification logic

The EBS system functions, among others, are the *coupling force control*, which provides the compatibility between the towing vehicle and trailer, *brake blending*, which means the integrated control of all brakes (besides the wear brake), such as the engine, exhaust brake and the drive-line retarder, *wear control*, which means the balancing of the wears between the front and rear axle brakes. As it will be seen later, the feature of the EBS, that it is able to produce brake force without the driver's intention, is utilized in VDC and other systems.

Although the today's EBS system has double redundancy (in addition to the electronic control, there is a double circuit pneumatic brake system, the so-called 1E+2P system), the target is to eliminate this because of cost and complexity reasons. The first target is to realize a pure brake-by-wire system for control, but still keeping the pneumatics for actuation of the wheel brake and, in a later stage, an electro-mechanic system, which actuates the wheel brake by using electro-motors. In both cases the 2E system (in this case the pneumatic back-up is totally eliminated, the system has 2 separated electronic control circuit) requires multiple and totally redundant energy supply for control, and in the latter case also for actuation purposes. Although the future system layout will look differently, Figure 8 shows a fully redundant brake system, where every component is doubled. Of course, in the commercial systems the wheel/axle modulators will not be doubled, since the regulations do not require that, but if the brake control will be realized purely electronically, the double electronic circuit has to be realized. This means two batteries, which are galvanically separated, and also separated electronic circuits. While for the actuation of the wheel brakes the compressed air will be used, the today solution with two pneumatic reservoirs is suitable. When the brakes will be actuated

electronically, the same double-circuit electronic system will provide the energy, which fulfills the regulation (in fact, this system layout does not differ from the pure 2P system, same redundancy is provided but electronically).

The electromechanical brake system is in the center of the passenger car manufacturers, since the hydraulics is difficult to handle. Looking at the development in the field of the steering systems it is clear: the hydraulics will disappear from passenger cars, and it will bring significant benefits for the vehicle manufacturers from design, complexity, functional and cost viewpoints. However in commercial vehicles this trend is not so clear, since the compressed air is more friendly to produce and handle (there are no environmental issues) and as long as the suspension of commercial vehicles (both primary and secondary) requires this working substance, it will be used. Of course there are developments in the commercial vehicle brake industry as well, but the tendency is more to move the components from the frame to the wheel-end (axle, brake caliper, etc.) because of installation simplicity. The question rather is how to fulfill this requirement, definitely one of the solutions is the electro-mechanical brake.

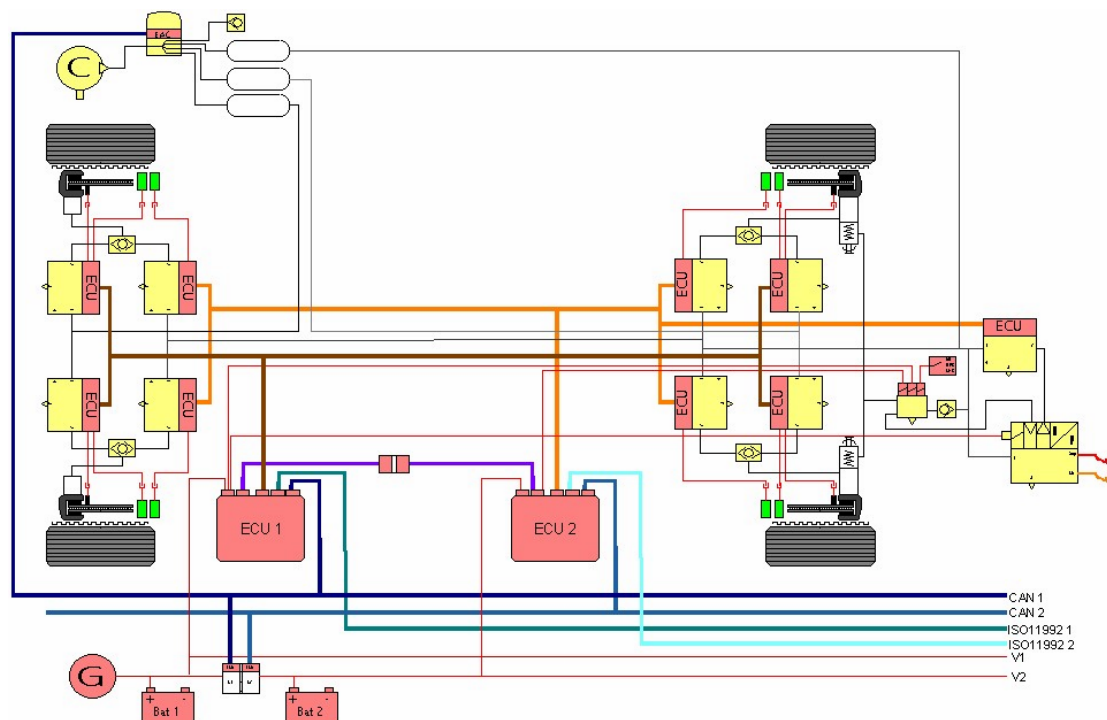


Figure 8 Fully redundant electronic brake system – theoretical solution

An additional important aspect, which determines the line of the development, is the fact that the cabin should not have any pneumatic connection, because it makes the installation more difficult since pneumatic tubes have to be brought up. This results in the fact that the today pneumatic systems, having the actuators in the cabin (such as the parking brake, the trailer brake in some countries) will go down to the frame and only the electric switch/potentiometer will be in the cabin. It means electronically actuated parking brake or trailer brake. However, this system requires a more advanced safety system.

4.1.2 Lateral Motion Control Systems

4.1.2.1 *Steering System*

For influencing the vehicle lateral motion the obviously used system is the steering. The development of the servo-steering systems in commercial vehicles did not differ from the passenger cars systems significantly in the past, until the hydraulics have been used for

powering the system. However the latest developments in passenger cars have shown clearly that the hydraulics (as it was mentioned earlier) will disappear, since these systems will be powered electronically and the development goes in the direction of the steer-by-wire system. This trend in commercial vehicles looks differently, since the electric motor provided torque might not reach the power need of the commercial vehicle steering with significantly heavier wheel load. That is why the direction of development is mostly the electro-hydraulic steering support, which can be applied for both front and rear axle steering system, and provides the opportunity for driver-independent steering action, first at least in some limited range, but later for full autonomy (see in Hughes, Elser (31)).

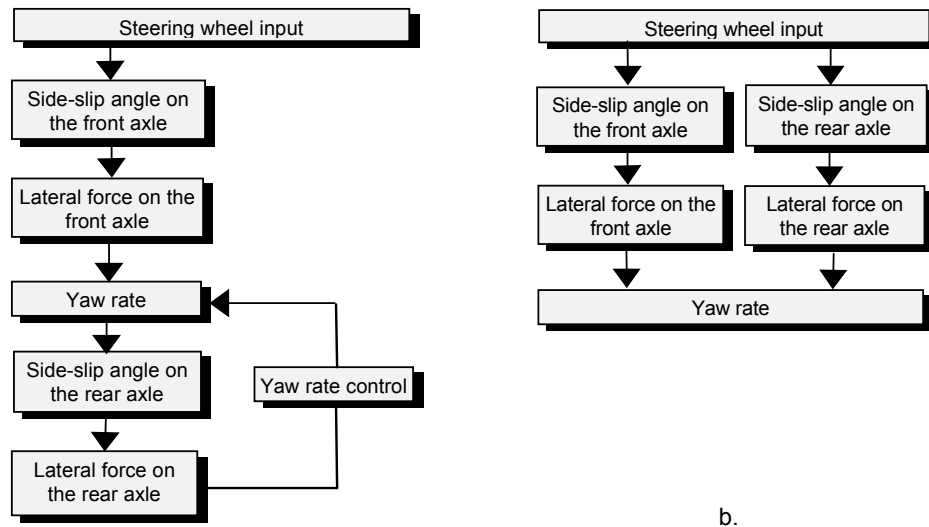


Figure 9 Flow chart of the (a) front-wheel-steering (b) four-wheel steering systems

Rear Axle Steering

The front wheel steering does not give the optimal control, because of the time delay between the steering (the lateral force appears first on the front axle) and the generation of the control force on the rear axle, as the flow chart shown in Figure 9/a. Especially in case of longer vehicles and in combination vehicles this effect is significant.

The high yaw rate of the vehicle results in enhanced danger of total loss of stability (the vehicle spins out) on slippery road or at too high speed. With four-wheel-steering the lateral control force on the rear axle is generated at the same time (see Figure 9/b) as on the front axle, thus the vehicle yaw rate and lateral acceleration can be kept at lower values. In the 4WS systems existing in the passenger car market the rear axle steering angle depends mostly on the speed: at low speed the rear wheels are steered opposite to the front ones, improving the low speed maneuverability, while at high speed the rear wheels are steered in the same direction, which decreases the vehicle yaw rate. The active 4WS systems are able to react autonomously to external disturbances, such as side wind gust. This means, when the vehicle is subjected to a sudden side wind disturbance, the ECU measures the driver's intention (by a steering wheel sensor) and the actual yaw rate, which differs from the calculated one, and compensates for the disturbance with small rear axle steering. In this case the driver's action is not really necessary, the system is acting autonomously, eliminating the driver from the control loop. The four wheel steering has been examined as one of the possible vehicle dynamic control system, since manipulation of the wheel slips on the rear axle has great effect on behavior of the towed vehicle (trailer, semitrailer), as seen in many publications: Suzuki et al. (92), Watanabe et al. (102, 103), Vaugh and Miller (99), Momiyama, Morikawa (54), Keller, Kogel (38) and Pflug

et al. (74). Stability analysis for articulated vehicles has been carried out by Chikamori, Kawasaki (11) and combined with differential braking by O'Brien, Piper (60).

The 4WS in commercial vehicles has also an opportunity as shown in some publications of already realized system. The control strategy of this system does not differ significantly from the passenger car systems and provides definite advantages in high speed stability and low speed maneuverability.

However, the serial applicability of the rear axle steering in commercial vehicles is problematic from cost and design problems. To realize the steering of the rear axle with the necessary control is simply more than doubling the cost of the front wheel steering. From the design viewpoint the steering of the double-tired wheels, with that heavy axle load on the driven axle (in case of tractors, for example) is a very difficult task. With the application of super-wide tires this complexity will be reduced, the others remain.

In case of combination vehicles the trailer's axle(s) can also be steered to minimize the turning radius, decrease the tire wear and improve high-speed stability. The so-called forced steering is already state-of-the-art in some type of trailers (especially the long ones). The active steering of the trailer wheels is also an option (TWS) and can bring quite a good improvement especially in trailer handling, however the energy supply problems on the trailer and also the complexity does not justify for that.

Front axle steering

The front axle steering will be modified also in the future. The electronic control for some of the steering aid functions is also available today (for example the speed dependent assist torque as in passenger cars), but there is a need for a certain autonomy in the steering system as well. On a long term, the full *steer-by-wire* is the target, since:

- this is necessary for advanced vehicle control systems, such as autonomous driving, or vehicle stability control,
- from design viewpoint it provides an enormous freedom for the constructors since the mechanical link between the steering gear, which is on the frame and the driver's cabin does not limit this.

However the full (without mechanical link) steer-by-wire system has a severe acceptance problem today, smaller from the legislation, definitely bigger from the end user side. The scenario is more and less the same, as in case of the brake system, a double redundant electronic system should provide the safety. However, while the brake system has 2 physically separated actuator circuits (front and rear axle circuit) the steering has only one actuator, which is not redundant (only its control and energy supply, but physically the actuator not). This acceptance problem will enforce some interim solutions, where the mechanical link is kept, but a certain freedom of the steering is given to the system, for example for lane keeping.

An interesting direction is the integration of the brake and steering based VDC system, which operates based on the existing sensor signals (see below) and uses the steering system in the silent (tolerance) range of the brake based system and contributes to the reduction of the driver's efforts during μ -split braking by additional steering.

4.1.2.2 Braking System Based Drive Stability Control

It was mentioned above, that the addition of a new steering system to the rear axle is expensive, the full steer-by-wire has acceptance problems. Besides these, however, there are technical problems as well: alone by the steering the whole longitudinal and lateral slip range cannot be influenced, because of the nature of the system. This observation resulted in the fact

that other systems were taken into account for the vehicle stabilization purposes, which overcome the mentioned problems. The brake system is the only logical consequence, since:

- it has the most powerful actuators in the chassis (for example, 4 disk brakes in a heavy vehicle are able to dissipate over 10,000 HP power), not only for decelerating the vehicle, but also for controlling its lateral movement by individual braking of wheels,
- it is able to control the whole wheel slip range, as seen in Figure 10. The brake system modifies not only the longitudinal, but also the lateral tire characteristics as well, and thus provides the opportunity for the wheel slip manipulation in all directions,

This fact was recognized by many researchers, and quite a lot of early publications can be found: from Kimbrough et al. (40, 41), Palkovics et al. (61-68), El-Gindy et al. (18).

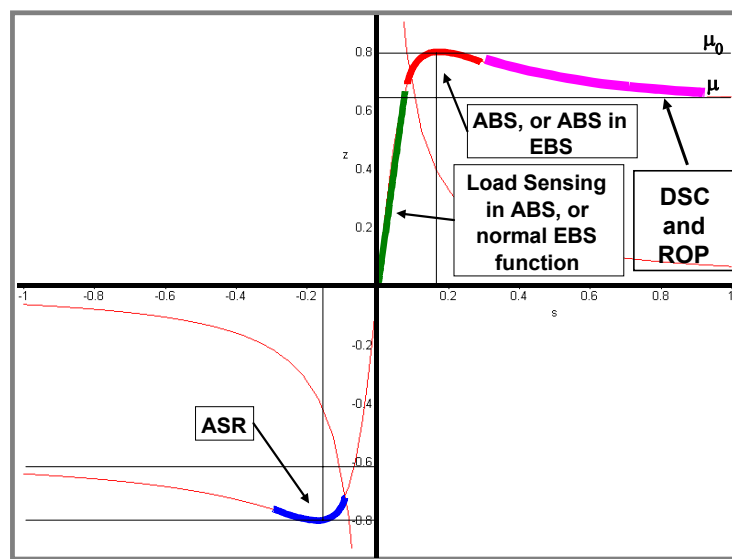


Figure 10 Slip control ranges of the brake system

- it is already installed on the vehicle, there is no need for new actuators and partially sensors, the wheel individual braking can be realized by the EBS, only very few additional sensors (steering angle, yaw rate, and acceleration) are necessary.

The control logic of the DSC system in commercial vehicles is very similar to those in passenger cars as shown in Figure 11, the only principal difference is that the commercial vehicle VDC system controls also the brakes of the trailer in case of jack-knife dangerous situations (Figure 13/a). The major difference to passenger cars is that in trucks there is no need for extra instrumentation to generate the driver-less braking, since the EBS provides that.

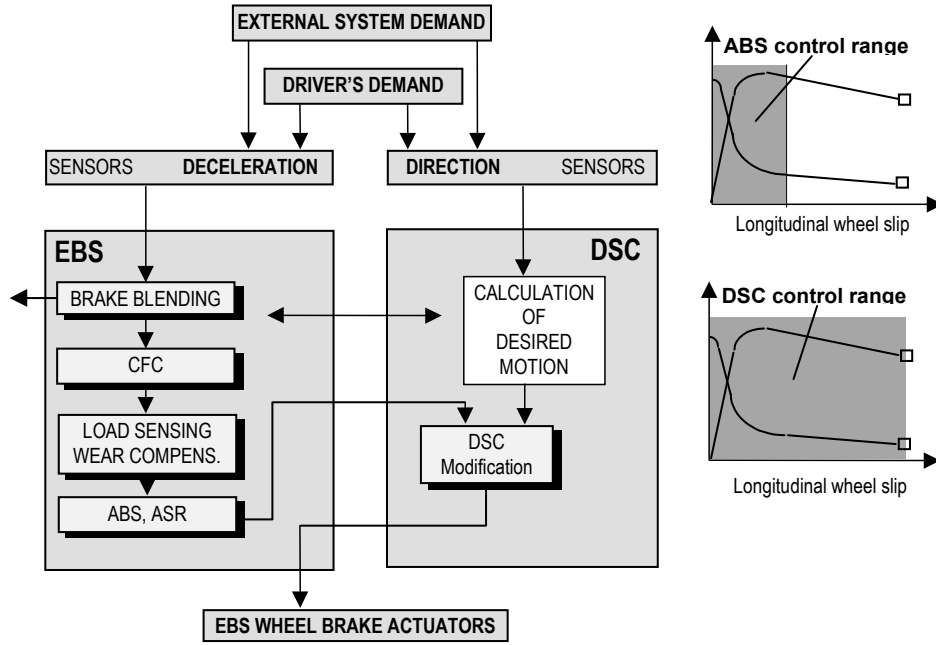


Figure 11 Integration of the DSC into the EBS system

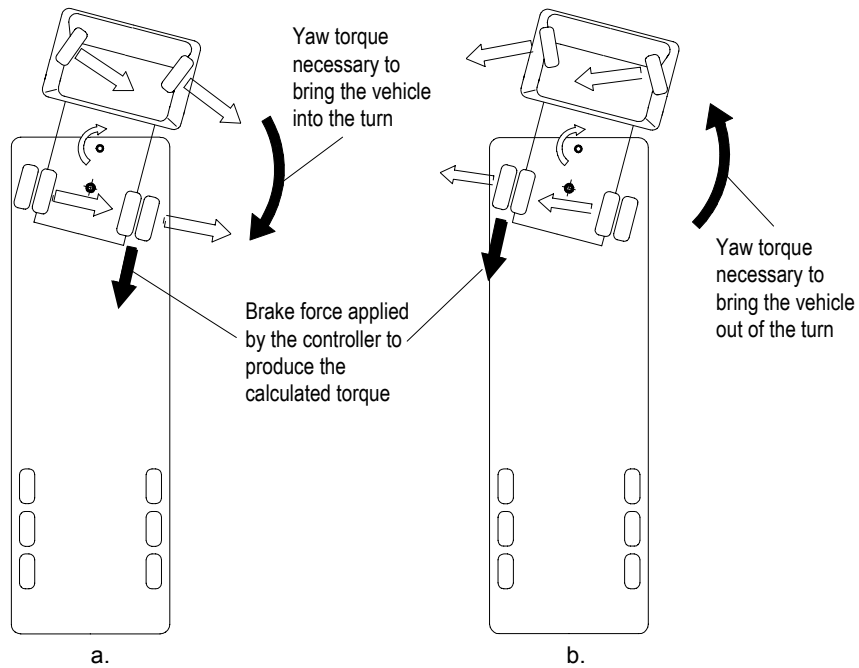


Figure 11 DSC intervention when (a) going into (b) getting out of a turn (wheel lateral forces are only for explaining the phenomena, not for exactly reflecting the reality)

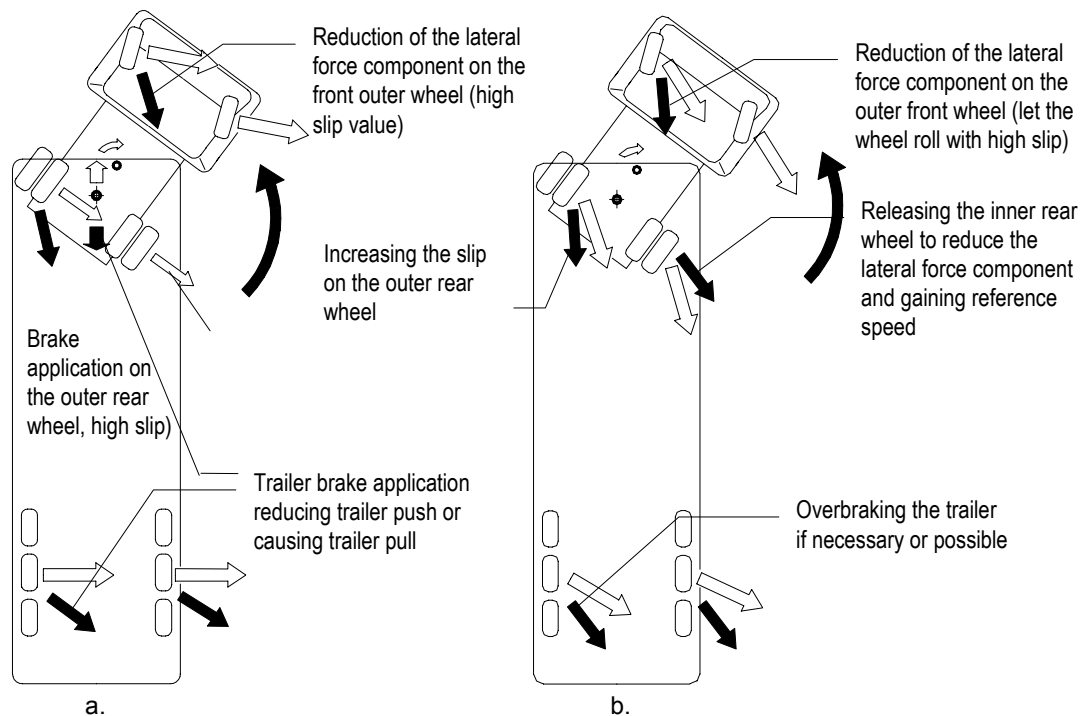


Figure 12 DSC intervention in jack-knifing situation (a) without (b) with driver brake application

Palkovics et al. (69, 70), Petersen, E., Neuhaus, D., Glabe, K. (73) reports more advanced status of the DSC systems in commercial vehicles. The original DSC concept concentrates on the towing vehicle only, however the EBS on trailer provides also a platform for vehicle dynamic control. In case of full trailers the yaw control of the dolly can be realized, and for longer combinations (A and B doubles) the trailer EBS based system offers an alternative solution as shown Fancher et al. (21, 22), or Lugner et al. (51). Chen, Tomizuka (9), investigate a coordinated steering and braking controller in their works.

4.1.2.3 Other Lateral Control Systems

Besides the braking and steering systems, other systems have been investigated for controlling the vehicle lateral motions. These solutions are mostly concentrating on the interface between the truck and trailer, they intend to control the connecting force and torque. The hitch torque control system uses a semi-active controllable damper to reduce the oscillation of the trailer and functions as an anti-jackknifing device. The controlled lateral movement of the hitch point is also an alternative solution, and can influence the trailer behavior. However these systems are complex to install (design problems) and also their cost has to be considered. No doubt, they can be used in some special cases (for example the jack-knifing device in articulated buses of pusher type), their wide spread use is not quite possible. Kageyama, Saito (37), Palkovics, El-Gindy (69) propose such solutions.

4.1.3 Vertical- and Roll-Dynamics Control

Unlike in passenger cars (although some recent cases has modified this believe) the vertical and roll behavior of commercial vehicles is a very important aspect. The center of gravity of commercial vehicles varies over a wide range depending on the type of the vehicle and the cargo. The rollover of commercial vehicles is one of the most severe accidents, as it was introduced earlier in this paper. In addition to the safety criteria, two groups of requirements have to be considered: the economy and the environmental issues. The driver's comfort and the cargo's security requirements contradict the environmental and safety aspects, and their fulfillment is not quite simple.

The evaluation of the systems used for influencing the vehicle roll and vertical dynamics is given in Table 2.

4.1.3.1 *Electronic Leveling Control (ELC) System*

The ELC systems have been available for heavy commercial vehicles for a few years. The new generation ELC system is targeting on providing the traditional leveling functions, such as:

1. leveling function when loading or unloading the vehicle, with storable ramp data,
2. fixed vehicle body position during traveling, which is optimal from point of view of stability, comfort, etc. and depends on vehicle parameters such as loading, vehicle speed, etc.
3. a certain delay, which means that the system does not operate continuously, only in discrete time intervals it checks the suspension travel sensor values, and corrects it, thus reducing the air consumption,
4. kneeling or discharging function, which is important in buses and tankers, where the vehicle body is set askew (lateral and longitudinal direction, respectively),
5. automatic as well as manual lift axle control, which hinders the driven axle from overloading above the limits prescribed in the legislation,
6. start support operated by the driver, which means that the lift axle load, or in case of tractor/semi-trailer the some trailer axle load can be temporarily reduced to enhance traction,

and new functions, can be realized on this platform:

7. automatic traction enhancing function, which means the automatic lift axle load release while the TCS is active. The ELC ECU receives this information from the EBS via CAN interface,
8. lateral stability support, which is intended to increase the roll-stiffness of the suspension while cornering.

As seen from the above functions, the ELC system is mostly practical but does not provide to much of extra safety features. The new functions 7 and 8 are targeting on stability increase, but due to the nature of the pneumatic system (large air quantities, time lag, etc.) they are not effective in severe situations. Function 8 is able to compensate the body roll angle in a large radius turn, but during a much faster lane change maneuver remains ineffective. However, the ELC system with its sensors and actuators provides the platform for other suspension systems. There are several solutions on the market and in research as shown in Schonfeld et al. (83), Vogel, Claar (101), Glasner et al. (25), Goehring et al. (28), Kutsche et al. (44), Muijderman et al. (56), Holdmann, Holle (30), Stein (1998), Bode et al. (5).

4.1.3.2 *Adaptive Damper Control*

The adaptive damper control system is not other but a semi-active suspension control system using continuously variable shock absorbers. The control strategy for a semi-active damper is not discussed here, since it is a state-of-the-art and can be found in many references (see in Cole et al. (12), Muijderman et al. (57), Bode et al. (6), Isobe et al. (33), Roh, Park (77), Novak, Valasek (59), Kitching et al. (42).

The application of the classical control strategies is not quite appropriate in commercial vehicles because of cost constraints. This means that instead of the traditionally used vertical accelerations at the body and wheel ends the already available signals are used for input to the system, as seen in Figure 13. The damper control strategy has three preference levels:

- the third level preference is the cargo/driver comfort, this is considered as a „default” setup. In most of the time (more than 95%) this setup is valid, in this case the ELC system works as described above, the semi-active shock absorbers are controlled by using a sky-hook principle.
- the second preference is the so-called attitude control, which means the vehicle body pitch and roll control during braking/accelerating and cornering. In this cases the shock absorbers are controlled in order to reduce the dynamic body roll and pitch angle,
- the first preference is the vehicle stability, which means the support of the brake system based DSC functions. If, for example, the DSC operates the brake on a given wheel, the shock absorber on that wheel is switched to the maximum position to provide the highest available tire force by means of reducing the dynamic tire load.

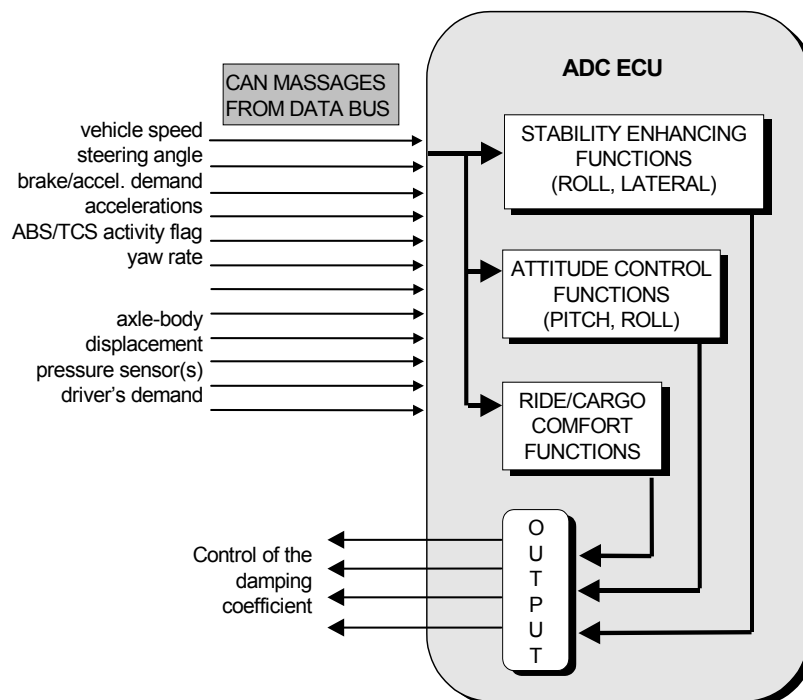


Figure 13 Adaptive semi-active damper control

As seen from Figure 13, the ADC system receives all input information from the vehicle CAN bus, and requires no additional sensor signals. The ECU controls only the damper solenoids, and as such, functions as a standalone system.

The above system exist also in pneumatic version, in this case the control of the by-pass valve in the shock absorber is based on a pneumatic pressure (this is also a proportional valve). This system is a rather low-bandwidth solution, since the pneumatic pressure is normally equal to the air cushion pressure, which does not vary very dynamically. Normally the PDC (pneumatic damper control) can be used in cases where it is enough to modify the damping characteristic according to the actual load, for example for tanker trailers. Special design aspect, the road friendliness is considered in the works of Vaculin et al. (96), Valasek, Kortüm (97), Valasek et al. (98).

4.1.3.3 Cabin/Seat Suspension System

Due to the design problems of the primary wheel suspension system in commercial vehicles (if the wheel suspension is comfort optimized, there is a problem with the load and road holding), the driver's comfort can be realized by the optimization of the secondary suspension systems,

such as the cabin and the seat suspension control. The reduction of the driver's fatigue in commercial vehicles is a severe issue since:

- Low-back pain is one of the most common disabling health problem for commercial vehicle drivers,
- Low-back pain is the leading cause of industrial disability payments and second most common medical cause of work loss,
- Epidemiological studies indicate significant association of the low-back pain complaint with seated vibration exposure and vehicular vibration,
- Long term exposure to vibration can cause spinal disorders, fatigue, disk raptures, vibration syndrome
- Drivers, who had surgical treatment may be even more susceptible to adverse effects of vibration and shocks.

These facts directed the interest of the truck manufacturers to the problem and started to put more emphasize on the cabin and seat suspensions. The cabin suspension has a similar structure as the primary wheel suspension (air-spring and shock absorber) and lately started to use integrated solutions for leveling and also semi-active dampers. Further references to this topic can be found in Savkoor, Mandez (81), Amirouche et al. (2), Wiesmeier, Uffelmann (106), Lee et al. (47), Williams et al. (107).

However, there are some indicators, which show that the cabin leveling system will have no long future. The opinion of some of the truck manufacturers is that the tilt cabin is not necessary, since the vehicle driver or the road maintenance service is not in the position anymore to make any kind of fixing along the road side because of the high complexity of the vehicle electronic systems. Instead of repairing the vehicle along the road, they will be towed to a certified workshop, where the cabin can be lifted off with the suitable equipment. This means however, that for providing the proper working conditions to the driver, the seat suspension has to be intensively developed.

The possible solutions for the seat suspension control are as follows:

- Fully active suspension control – hydraulic cylinder or similar,
- Control of the spring element – steel or air
- Damper control – adaptive or controllable shock absorber
- Continuously adjusted level – leveling control
- “Intelligent” cushion – using special material in the cushion, which acts as asymmetric damper, as produces variable resistance for the airflow through the cushion material.

As an example the modification in the vertical acceleration transfer function is shown in Figure 14, where pneumatic damper control is added to the actual seat suspension system with leveling control.

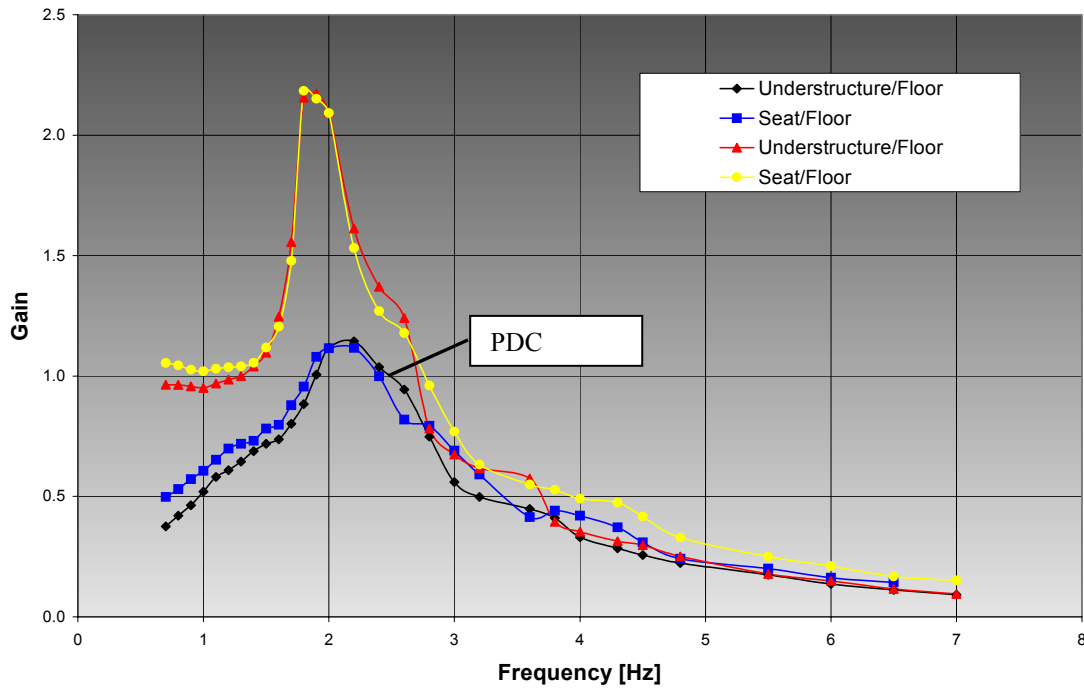


Figure 14 Modification in the transfer function when PDC is used in a seat suspension

4.1.3.4 Brake System Based Rollover Protection/Warning System

As it was mentioned at the description of the ELC system, by means of compensating the level variation in curve the danger of the rollover is not significantly minimized. The explanation to that is given in Figure 15.

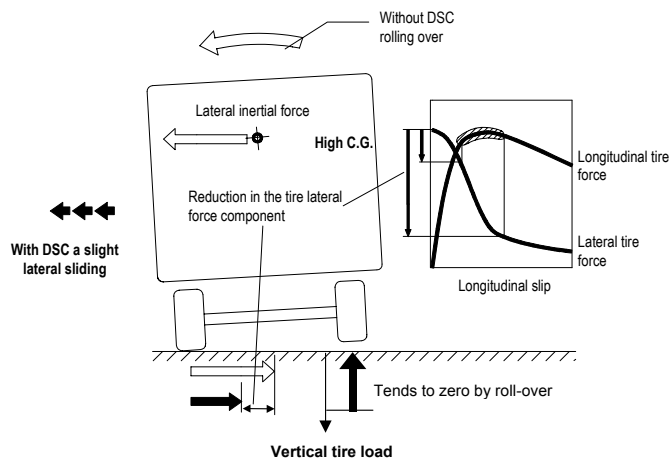


Figure 15 Physics of the rollover and its recognition principle

The roll-over of a vehicle can start when the tire-road contact force on one of the curve-inner side wheels becomes zero. This situation has to be detected or measured. However, a force transducer for measuring the vertical wheel load is available or not feasible (there exist tire-tread built sensors for measuring the tension in the tire tread for slip calculation, but they are expensive and not really applicable). The roll-over responsible pair-of-force is arising from the high lateral inertial force and its counterpart on the road, which is generated by the tire, the

lateral force component. If the CG point position is high, the resulted moment is also large and can result in roll-over. From this it can be seen that only by means of the controlled suspension the prevention of roll-over is not possible, since it cannot reduce the lateral tire force component, the only (mostly theoretical, since it cannot be achieved by air suspension) effect is to keep the vehicle body perpendicular to the road, thus eliminating at least the rolling torque of the gravitational force.

Many different approaches can be found how to handle this problem, as seen in Cole (13), Eisele and Peng (16), Dunwoody and Froese (15), Sampson and Cebon (80), Lin, Cebon (49) and Winkler, Fancher, Ervin (108). A complete review of the available systems is given by Winkler et al (109).

The basic idea of the roll-over protection and warning systems is if one cannot sense the vertical wheel load directly, one has to find another quantity, which is in strong relationship with the previous one and they vary together. This finding resulted in a system (see in Palkovics et al. (72)) which stimulates the wheels via the brake or throttle system by applying a test pulse in the brake systems or slightly reducing the throttle if the calculated lateral acceleration exceeds a certain limit value (e.g. 0.4g). If this small effect produces high slip difference between the left and right wheels, that means that one wheel is about to loose the contact with the road. The described procedure gives the only direct indication of the wheel lift-off. This information can be used either for warning the driver, or for intervention.

For the prevention also the brake system is used. As seen in Figure 15, the roll-over responsible pair of force has to be reduced, which means the reduction of the lateral inertial force by means of speed reduction with the combined reduction of the lateral force component by means of manipulating the tire slip according to the figure. These two effects together are enough to prevent rollover on both a combination and also on a solo vehicle.

The major advantage of this system is that it does not require any additional sensors to the EBS, since it uses for detection only the existing wheel speed sensors and for actuation the wheel brakes. The product itself is “nothing more” than software, however, the safety aspects of the system are very complex, the original EBS safety management has to be modified significantly. Of coarse, this system cannot provide 100% safety, but reduces the probability of the occurrence of the rollover.

If the vehicle is equipped with DSC system, that system can also provide a rollover protection function. The DSC estimates the loading situation of the trailer and makes an estimation of the maximum permissible lateral acceleration. If the actual one exceeds this level, the system will reduce the vehicle speed by limiting the throttle or also by braking. The integration of the ROP into the DSC will result in a smoother function, but of coarse at the cost of all the sensors, which are necessary for the DSC.

4.1.3.5 *Tire Pressure-Monitoring Systems*

As part of the suspension, the tire is also considered as one of the chief components of the commercial vehicle safety. The appropriate tire pressure is a key of the vehicle stability and thus the safety. In addition to the safety related aspects, the economical aspects are also important: running with not a properly inflated tire the fuel consumption is also increased.

This topic has gained high importance lately, and the tire pressure monitoring system will be mandatory in the USA. Basically two different solutions exist: either based on directly measured pressure information, or indirectly, from the wheel speeds they calculate the modified wheel diameter. Both solutions can be found in the literature, see for more details in Rohr, Mendez (78), Mortensen et al. (55), Iwazaki et al. (34), Sakiyama et al. (79), Freigang (23).

The direct measurement of the tire pressure gives more precise indication, but results in a more complex system, since the data transfer from the rotating wheel to the ECU is problematic. The other solution is more straightforward, since uses the already available wheel speed sensors, and does not require any new component besides the software (which can be implemented in the ABS or EBS ECU), but less accurate, especially in case of tires with larger profile.

Table 2 Possible primary and secondary suspension control strategies

Main Group	VERTICAL AND ROLL CONTROL SYSTEM	SENSORS	ACTUATORS	ENERGY DEMAND	SOFTWARE	PRICE	EFFECT ON RIDE & CARGO COMFORT	EFFECT ON VEHICLE STABILITY/ROAD	FEASIBILITY
PRIMARY (WHEEL) SUSPENSION CONTROL	Electronic leveling control	Pressure sensor, level and angular sens.	Valve block, servo valve	Medium	Relative simple, communic. with brake management	Low	Steady state effect, no reaction to dynamical disturbances	Limited, mostly influences the steady-state roll motion	There is a need for it on the market
	Adaptive air-spring control	As for leveling control, some more is possible	As for leveling control	High	Complex, communic. with brake management	Low	Improves ride/cargo comfort	Reduces dynamic tire load, road damage	Feasible, has to be investigated
	Active or semi-active air-spring control	Accelerometer on the axle and body	Modified faster valve designed for higher pressure	Very high	Complex	High	Improves sufficiently	Could improve sufficiently	Not feasible
	Fast (semi-active) damper control (electronic)	As for the adaptive air spring control	Third party electronically controlled damper	Low	Simple, electr. control to be solved, can be integrated	Medium	Improves, response to dynamic effects as well	Improves road holding and dynamic roll stability	Feasible, cooperation with damper manufacturer is necessary
	Slow (adaptive or limited bandwidth semi-active) damper control (pneumatic)	As for semi-active damper control	Pneumatically controlled damper	Low	Simple	Lower than electronic control	Improves roll/pitch comfort, slow effect	Improves roll stability	Feasible, cooperation with damper manufacturer is necessary
	Pneumatically operated anti-roll control	As above	Pneumatic cylinder and servo valve	Depending on the actual solution, low or medium	Complex	High	Improves roll and pitch comfort	Improves roll stability and road holding	OEM dependent, feasible if low cost
	Adaptive tire pressure control	As above	Provided by a supplier	Low	Integration is simple	?	Improves ride comfort in average	Might improve road holding (?)	Can be integrated into ELC, cooperation is necessary
SECONDARY SUSPENSION CONTROL	Cabin suspension control (semi-active) or driver seat control	Acceleration sensor and angular sensor on the cabin	Variable damper, valve block and servo valve	Low	Complex, information from brake management should be used	Medium	Improves driver comfort only	Influences traffic safety via reducing the driver's fatigue	Feasible, question how much the vehicle buyer is interested in the comfort of the driver

4.1.4 Integrated Chassis Management System

In order to achieve the optimal performance and cost level, the chassis systems in commercial vehicles should utilize the synergic effect, which can be found in the communication among each other. This system called integrated chassis management, has the following characteristics:

- has optimized number of sensors and actuators, since the information exchange via the vehicle data bus is possible, thus lower cost and complexity of the overall system can be reached,
- the optimal performance of the system is possible to achieve, since the operation of different controlled systems can be synchronized,
- flexible system, since the integration of new systems can be achieved easily.

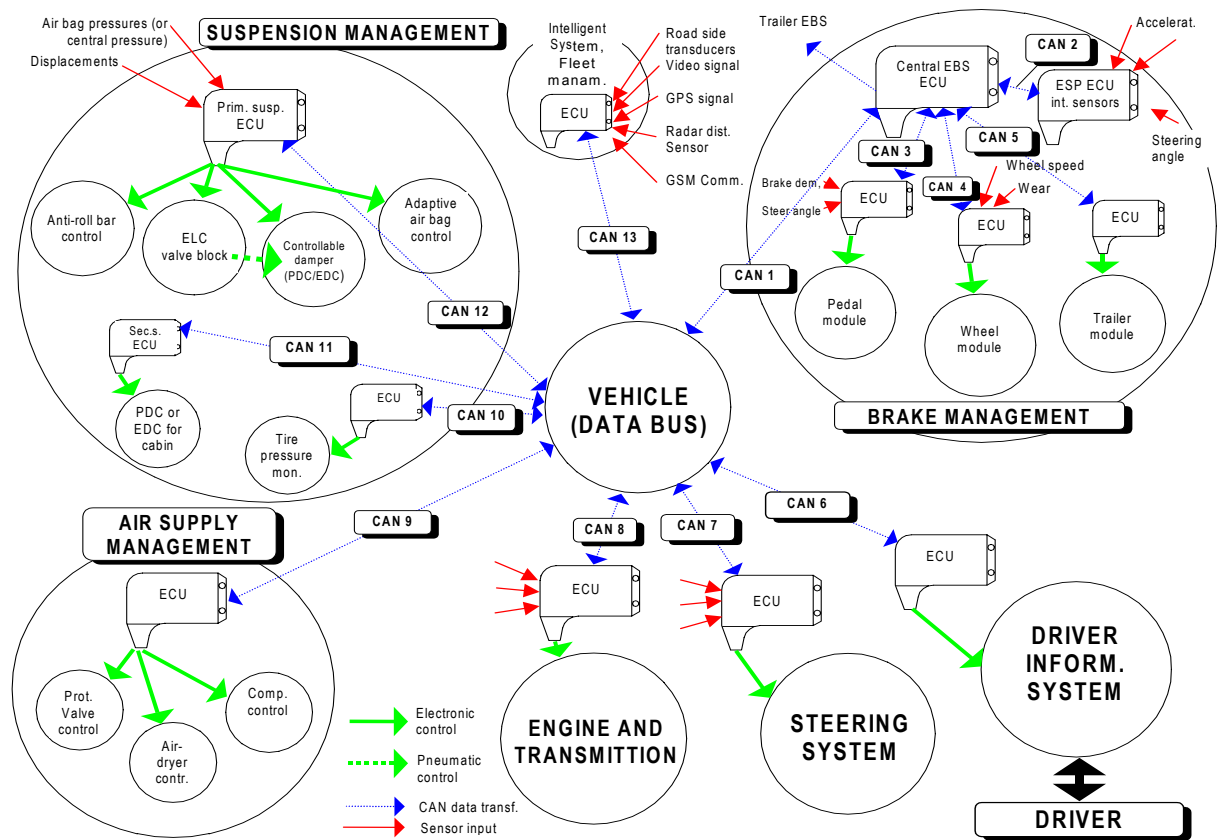


Figure 16 Structure diagram of the chassis management system

Figure 16 shows the structure diagram of the chassis management system for a typical heavy vehicle: 3 main systems are operated by compressed air: the air-supply, suspension and brake systems. The air-supply system in traditional vehicles is controlled by pneumatic valves, which do not provide optimal performance, and cause unnecessary air and energy consumption. In the new generation of air-supply systems the control functions (such as the 4-circuit protection valve, compressor, and air dryer) are achieved electronically, and due to the communication with the brake and suspension system, the supplied air correspond to the actual consumption of the systems (as an example, when the ABS is active the system consumes more air, than during normal braking, which information is available now), and also the brake system diagnosis becomes possible.

The suspension control in traditional systems means only leveling, achieved by applying pneumatic leveling valves. However, the performance of these valves is not perfect, and causes high air consumption, since its reaction to dynamic suspension deflection cannot be eliminated. The electronic leveling control systems do not have this problem, but besides the electronically controlled leveling functions other, mostly stability and control related functions couldn't be realized. The information exchange with brake system, engine management makes possible to adjust the suspension parameters according to the vehicle behavior in advance, providing faster and more accurate control (sending the brake and accelerator demand and steering wheel angle signals to the suspension ECU, which can react). An example for the sensor number optimization: the EBS uses the rear axle pressure sensors, which is also necessary for ELC - there is no need for redundant sensors, the signal can be transmitted via a digital data bus.

The information exchange between the EBS and the engine, transmission management is already used, however, it is currently being standardized using CAN interface. The communication with engine management is two directional: the engine data (rpm, torque) are sent to EBS, while EBS sends the desired torque value to the engine. Similar data exchange is conducted between the EBS and retarder via CAN: the retarder control signal is transmitted from EBS, while the brake torque and retarder temperature data arrive.

4.2 Intelligent Powertrain Concept

Although this paragraph disturbs the previously introduced structure of this paper, it is important to mention this topic here, between the chassis and the systems, using information from the vehicle environment. References to the intelligent powertrain topic are as follows: Glasner (26), Powel (75), Winterhagen (111) or Borodani, P. (7).

The so called intelligent powertrain concept described by Spiegelberg (87) is based on the separation of the decision making and actuation levels in commercial vehicles. This separation is valid both for the hardware and also for the control hierarchy as well. The explanation of this separation is given in Figure 17.

Control Level

Execution Level

Figure 17 Intelligent Powertrain Concept (Spiegelberg (87))

The *physical separation* means the chassis of the vehicle contains all systems, which are necessary to “move” the vehicle, that is to execute the commands from the control level, which is physically the vehicle cabin with all the systems, which are necessary to determine the demand for the “movement”.

The levels of the *control architecture* are assigned to this separation as well. On the control level the inputs are collected and evaluated, if necessary corrected based on some future information (predictive input correction), and a general speed vector is formulated, which determines the necessary motion direction and magnitude for the vehicle. This speed vector is transferred to the execution level, to the intelligent power train, which will realize this requirement, and if necessary, corrects this based on past information (this is the so-called reactive input correction). This speed vector is the connection between the paragraph 4.1 and the next 4.3 and 4.4 parts of this paper.

4.3 On-vehicle Systems - Environment Information in the Control Loop

In a normal case the systems described in part 4.1 are actuated based on a rather simple speed vector, the driver wants to follow the road and determines the direction (by steering) and vehicle speed (acceleration or braking). The problem starts when the driver is not in the position to determine the correct input, because his/her abilities are not enough for doing that. In this case, if there are no additional information for modifying the driver wished speed vector, the situation might result in a traffic accident.

If the driver does not pay enough attention, for example, to the vehicle or obstacle in front of him the systems in the intelligent powertrain are not able to react or warn the driver. As an example, the accident distribution related to the driver's falling asleep in different ranges of a day is depicted in Figure 18. Due to the special working regime of commercial vehicles, this type of accident is rather typical, and has been in the center of investigations for years.

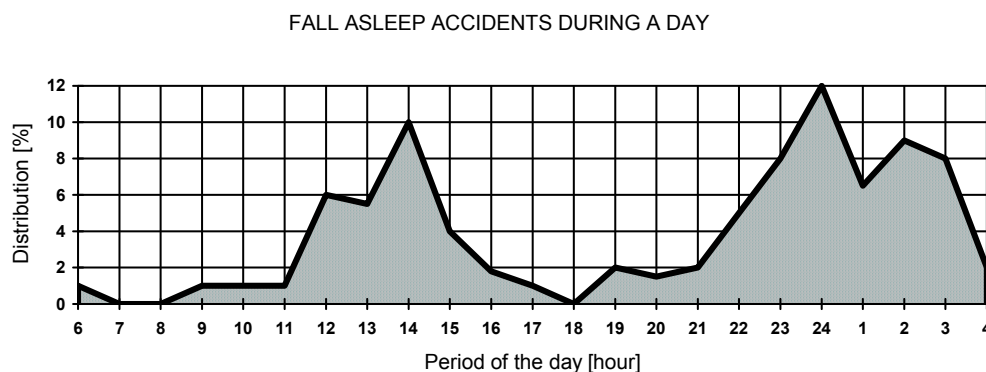


Figure 18 Distribution of the fall-asleep accidents during the day

As a result of falling asleep, the vehicle might collide with the moving or standing object in front of it, or it can leave the lane, and might go to the opposite traffic lane or to the ditch. To avoid such accidents, the modification of the speed vector is necessary based on additional information. These systems will be introduced in this chapter. One has to note that the truck and passenger car systems do not differ from each other very much from functional viewpoint. However, there are some typical situations where commercial vehicle drivers are more frequently involved than passenger car drivers (night driving, platooning for longer time, etc.) so it is worth to point out the importance of these systems in case of commercial vehicles.

4.3.1 Longitudinal Motion Control

The longitudinal motion control systems aim either on the collision avoidance of the standing or moving objects in front of the vehicle or on the optimization of the traffic flow. The former group includes the automatic brake systems, which scan the area in front of the vehicle and calculates the vehicle's future motion, and either warns the driver or automatically actuates the brakes, when it is judged to be too late for driver's action. The control logic of the radar brake system is shown in Figure 19 adapted from Fujita et al. (24).

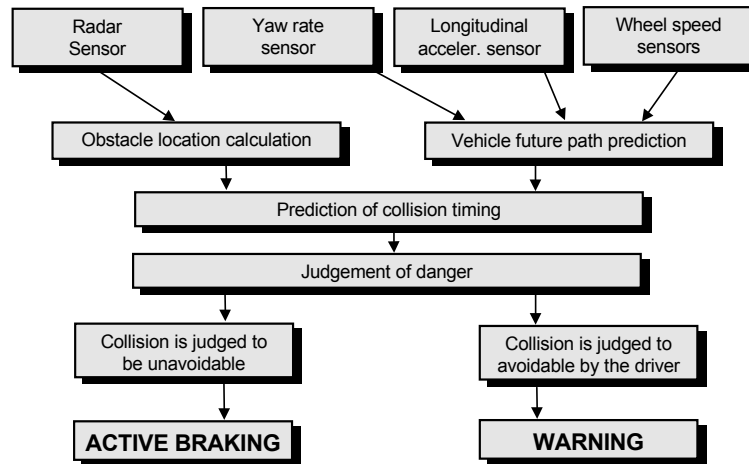


Figure 19 Schematic block-diagram of the radar brake system

The on-board system processes the radar information (relative distance and relative velocity to the object), and from the yaw rate, wheel speed and the acceleration sensor calculates the vehicle future motion. If the algorithm forecasts that the obstacle and the vehicle's path will intersect each other it calculates the time until the collision. If the calculated time is in between 1.6-2.2 seconds, the algorithm will send a warning to the driver, because in this case the time is enough for the driver to react. When the calculated time until the impact is less than 1.5 seconds, the algorithm will apply full brake pressure.

Although the idea is clear, the automatic (driver independent) application of brake system is always a critical issue, since in this case the driver is eliminated from the control loop, since he/she cannot reduce the braking effort. If in this case another type of accident happens, the question will be asked: who is responsible. This is the reason that the manufacturers and also the legislation are somewhat hesitating concerning this topic, although the technical opportunity as we saw in the brake system paragraph is available.

To overcome this problem, for passenger car application a system is proposed by Naab, Reichart (58)). In this case the control system gives only assistance to the driver, how to react, but it does not act autonomously, which means the driver remains fully in the control loop and responsible for the vehicle motion. In this case the vehicle is assembled with active accelerator pedal, which is forcing the driver's foot into the correct direction, but the driver can easily overrule the pedal. Further opportunity is the dynamic variation of the gas pedal characteristics, which means that in speed critical situations detected by the controller the pedal characteristic is shifted so that the driver has to apply it more to reach the same throttle.

The radar braking system is the basis for the intelligent or adaptive cruise control (ICC or ACC) system (see for example in Fancher, Berekeit (20)). The aim is the minimization of the distance between the following and the preceding vehicle. The potential of such systems is the increase of the highway's traffic capacity at no increased danger of accidents. It also has a positive effect on the decreasing environment pollution because it eliminates the low speed "stop and go" traveling. It also increases the driver's comfort, thus reduces his/her stress, and thereby decreasing the probability of traffic accidents. Figure 20 visualizes the difference

between the driver controlled and ICC controlled platoon. The ACC system has high potential in commercial vehicles. The heavy-duty vehicles are not dynamic participants of the traffic flow as the much smaller passenger cars, consequently making overtaking maneuvers is not very frequent. This means, however, that they drive normally in a platoon, which is very stressful for the driver, and a potential source of accident.

This is the reason that the intelligent or adaptive cruise controlled systems are more and less state-of-the-art, all vehicle and system manufacturers have their own system, as seen in the following references: Chakraborty et al (8), Grace and Benjamin (29), Woll (113), Schiehlen et al (82), Yanakiev, Kanakopoulos (115), Powel (75).

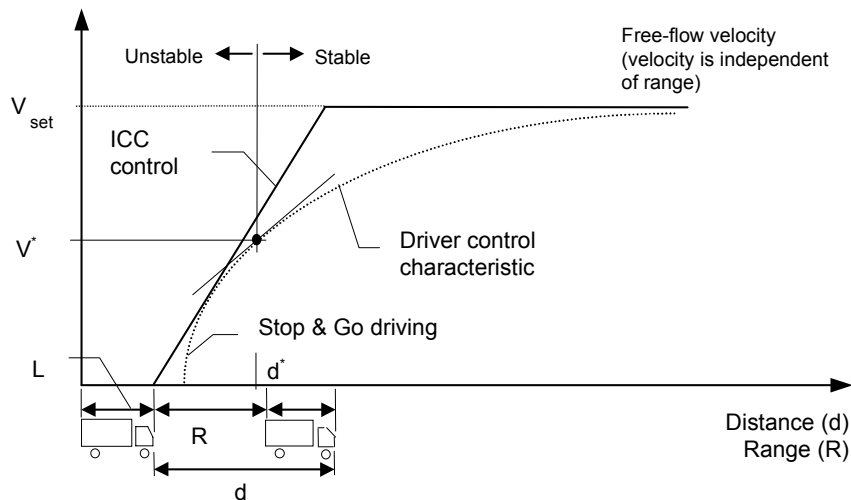


Figure 20 Comparison of ICC and driver control of the platoon (see in Fancher, Berekeit (20)).

4.3.2 Lateral Motion Control

As it was mentioned before, the VDC systems offer enhanced steerability and stability for the vehicle, but are not able to handle a situation when the driver's intention to steer is missing (e.g. the driver is sleeping or late with his intervention). In such situations the vehicle has to have information if there is an objects on the road in front it, to calculate its own future motion. There are many systems under investigation, developed for driver assistance heading control, whose operation mostly is based on lane recognition using video image processing (see in LeBlanc et al. (46), Naab, Reichart (58) and many others). In the following part, a system developed by the research team TU Budapest, Institute of Automation and Computer Sciences of the Hungarian Academy of Sciences, and Knorr Bremse is introduced in more detail (see further references in Soumelidis et al. (91), Kovacs et al. (43), Palkovics et al. (71)).

In order to detect the lane-departure, it is necessary to produce a robust estimation of the road geometry in front of the vehicle. Three parameters have to be determined: the road curvature, the width of the lane, and the vehicle's lateral offset from the lane centre. The detection algorithm is based on the optimization of two functionals.

Step 1: Estimation of the road curvature. The radius of the road curvature is relatively large on public roads and highways. Thus the road section in front of the vehicle can be approximated with a straight line. The detection system determines the angle $\bar{\alpha}$ between this straight line and the front face of the vehicle. The perspective view of the roadway can be transformed to a top view picture with parallel lane boundaries using equations of the perspective transformation. Then a $2N+1$ -dimensional array of the examined discretised angle range is

defined: $[-\alpha_N, K, 0, K, \alpha_N]$. An intensity profile vector $p(\alpha_k)$ is assigned to each angle α_k . This vector contains the sums of the grey-scales intensities in direction under angle α_k starting from the pixels of the bottom line of the top view road image. Next the vector corresponding to $\hat{\alpha}$ should be selected. An optimisation problem is formulated for this task. Another set of vectors $\delta p(\alpha_k)$ containing absolute values of the differences between elements of each intensity profile vector $p(\alpha_k)$ is formed.

Then the angle $\hat{\alpha}$ is estimated as:

$$\hat{\alpha}_{\text{est}} = \arg \max_{\alpha_k} \|\delta p(\alpha_k)\|_1 \quad (2)$$

This method for estimation of the road curvature is independent of the type of lane boundaries. They can be formed with solid or broken line lane marks, the lane boundary can be paved or it can be a simple transition from asphalt to grass (or gravel). The curve on the left side in the processed image of Figure 21 shows the estimated angle as a function of the time. The highest bar in the lower of the two bar graphs above the trapezoid of the top view image shows the estimated direction $\hat{\alpha}_{\text{est}}$, meanwhile the upper graph shows the corresponding difference vector $\delta p(\hat{\alpha}_{\text{est}})$.

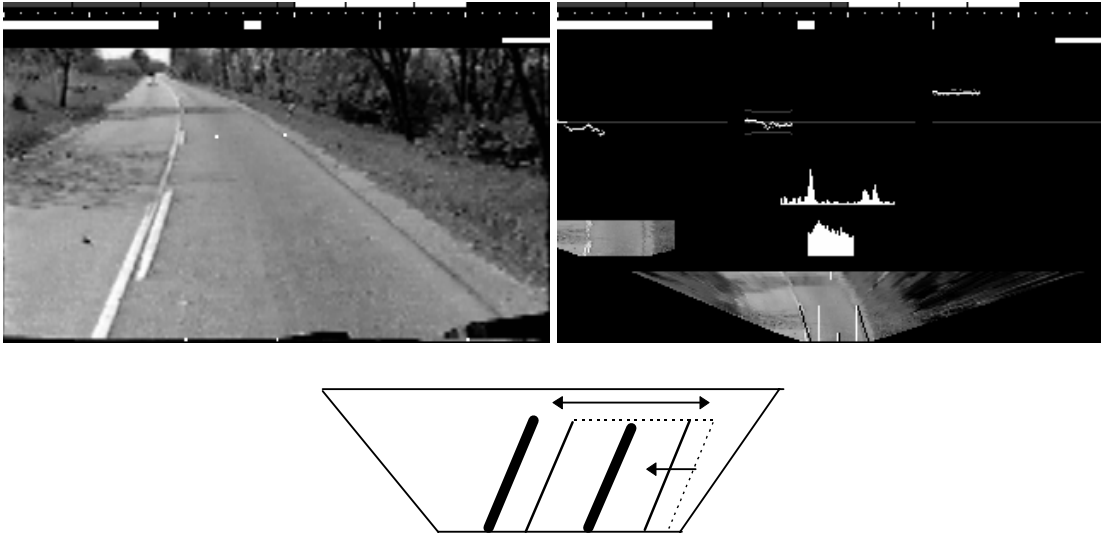


Figure 21 Input image and recognition of the lane geometry

Step 2: Estimation of the lane width and the vehicle's lateral offset from the lane centre.

To solve these problems also an optimisation method is formulated which uses the result of the Deriche's edge detection operator applied to the input image. This powerful edge detection operator was derived with the optimisation of three functionals characterising the noise reduction, the localisation, and the uniqueness properties (4). The method for determining the width of the lane and the vehicle's relative offset from the lane centre is as follows. A pair of parallel lines with angle determined in Step 1 are moved in the top view trapezoidal image (see bottom chart on the Figure 21). The distance of the parallel lines is varying. The best fit to the significant edges determines the needed parameters. This method can be formalised as follows.

Let $\hat{w} \in [w_{\min}, w_{\max}]$ denote the width of the lane and $\hat{o} \in [-\hat{w}/2, \hat{w}/2]$ the vehicle's lateral offset from the centre of the lane. Let $v(\hat{\alpha}_{\text{est}}, d, i)$ be a vector of the length d under the estimated angle $\hat{\alpha}_{\text{est}}$ starting from a bottom line pixel of the top view image (formed from the result of the Deriche's edge detection operator applied to the original image) shifted from the

centre pixel by i points to the right. $v_j(\cdot)$ denotes its j th element. The parameters \bar{w} and \bar{d} can be estimated using the following formulae

$$\hat{o}_{\text{est}} = i_{\text{opt}} - \frac{\hat{w}_{\text{est}}}{2} \quad (3)$$

where

$$[\hat{w}_{\text{est}}, i_{\text{opt}}] = \arg \max_{\substack{w \in [w_{\min}, w_{\max}] \\ i \in [0, w]}} \sum_{j=1}^d v_j(\hat{\alpha}_{\text{est}}, d, i - w) v_j(\hat{\alpha}_{\text{est}}, d, i) \quad (4)$$

All the estimated parameters have been filtered with a 2nd order Butterworth filter to achieve better performance. The second and the third line from the left on the Figure 21 show the vehicle's lateral offset from the lane centre and the estimated lane width. The presented optimisation procedure can be easily generalised to higher order curves approximating the lane geometry in front of the vehicle.

The above described algorithm has been tested under several environmental conditions (wet road, dirt on the surface, road signs, during night, partially covered by snow, etc.) and the robustness of the system has been surprising. In this form the system is appropriate to detect the road edges, but it is not suitable for identifying other objects on the road. The investigation is expanded in the direction of the stereovision.

The video signal can also be used for other purposes: the so-called drowsy driver detection system (see in Grace and Benjamin (29)) is installed in the vehicle and observes the driver's eye-lid motion. When the driver is close to sleep, the frequency of the eye-lid movement will be reduced, and it can give indication to the controller to take some action. The question is what that action can be. The opportunities are the same as above: either to warn the driver by acoustic or video signals, or to provide an indication, what he/she has to do, or to intervene into the vehicle control and take steering or braking action. The problem is the same or even more severe, as in case of the cruise control systems: who has the responsibility. The indication of the proposed direction by means of applying a slight steering torque on the steering wheel is an opportunity, especially when the vehicle has a steer-by-wire system or electric power assisted system. In this case the driver will recognize that there is a dangerous situation and will intervene.

The other definitive opportunity is the autonomous control by means of steering, or also by unilateral braking. A proposal for the VDC integrated system has been made by Palkovics et al. (71). The control loop of the proposed intervention is shown in Figure 22.

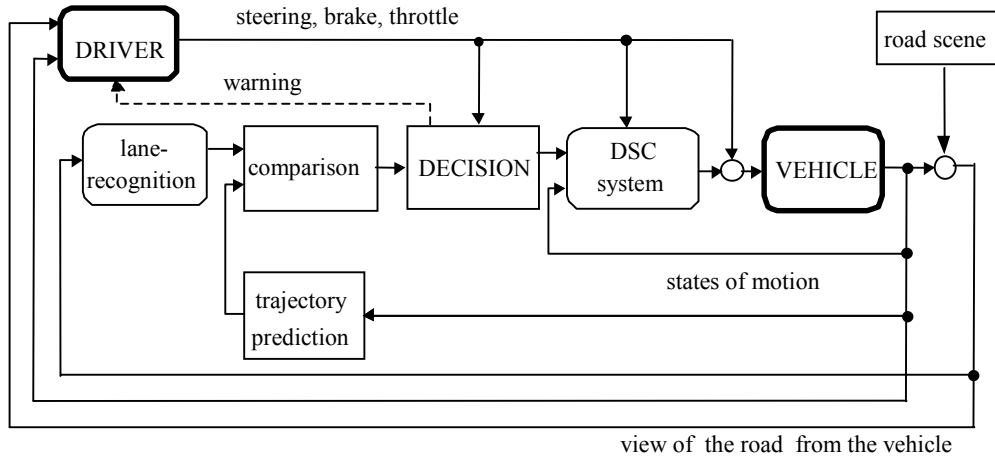


Figure 22 VDC integrated lane departure avoidance system

The brake system has enough power to control the vehicle’s lateral motion and, at the same time to reduce the vehicle speed. Since the situation in this case is considered as understeering, the controller will apply the rear wheel brake, which means that the driver will not be disturbed. Video images of a typical situation can be seen in Figure 23/a, while Figure 23/b shows the related state variables of the vehicle and the controller.



Figure 23/a Vehicle behaviour during intervention and the resulted behaviour

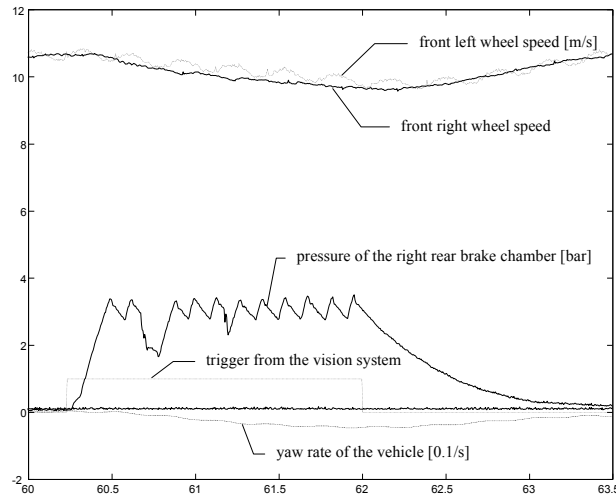


Figure 23/b Vehicle's and the controller's state variables during the manoeuvre

4.4 Systems Using Off-Vehicle Information

The systems have been described in the previous parts of this paper had all the installation on the vehicle, they were not receiving any external information. In some of the cases, however, those information are still not able to guarantee the safety of the traffic flow and the individual vehicle. There are certain attempts around the world to increase the number of available information about the road segments, weather, etc. There are many projects, which deal with the research of intelligent highway vehicle systems. Such a project was the European PROMETHEUS, or the North-American PATH. As outputs of these projects, several systems were proposed or partly realized; these are not discussed here.

Just a typical example, the majority of roll-over and spinning out accidents happens during a turning maneuver, when the speed of the vehicle is not correctly determined. The ramp leaving the highway usually has a decreasing turning radius, so when it is negotiated with constant speed a sliding out or roll-over can occur. There are several proposals that the vehicle driver or the on-board computer should be aware of the radius of the turn. If this information would be available, the VDC unit is able to calculate the maximum speed, with which the turn can be taken without any kind of stability loss.

The major question here is how to transmit these kind of information to the vehicle, do we really need to modify the road infrastructure, or is there another solution. The road and related infrastructure are normally built for longer time intervals (decades) without having any major restructuring during this period. This means a very rigid structure, since parallel, the technology is developing with much higher speed. This conflicting fact causes that the early attempts to make the road infrastructure intelligent are shifted now to the non-road related systems. With the current level of telecommunication, telemetry offers an ultimate solution to overcome this problem, and provide a much more flexible opportunity for the intelligent traffic control systems.

4.4.1 Commercial Vehicle Fleet Management System

The fleet management system for a freight cargo company is not an option, but a must. To provide the optimal utilization of resources, finding the optimal routes from point A to point B, to provide the safety and security of the vehicle and the cargo these are all tasks for the fleet management system. There are many systems and methods available already for solving both the technical and also the logistical problems. Some of them are listed also in the references under the title of fleet management: Taniguchi et al. (93), Mato (53), Jung and Haghani (35)

offer solutions to the vehicle routing problem, Luettrignhaus (52) introduces a telematic system for fleet operators, or An and Jung (1) proposes a radio communication based system for providing the fleets with freight and traffic information. These are only few examples one cannot really review all the publications published in this field because of the enormously high quantity.

What is very important to recognize here is the following: the reserves of further optimizing the costs of the freight transport, reducing the safety of the traffic, producing less load on the environment based only on the vehicle development, are more and more declining. Both active and passive safety of the vehicle are reaching their limits, the VDC systems, the electronic braking, the vision system all provide the maximum available safety today. The road friendly suspension, the super low emission engines are generating the least today possible load on the environment. Of course, there is a lot to do, but a significant jump cannot be achieved only from the vehicle side.

The potential of the qualitative change is in the communication, between the vehicles, with the infrastructure, and also with the information system controlling the traffic flow. The principal block diagram of the fleet management system is shown in Figure 24.

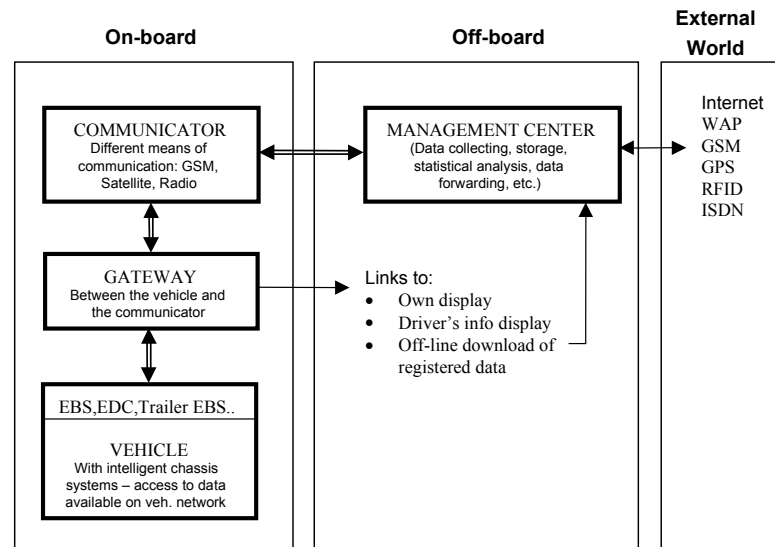


Figure 24 Structure of the fleet management system

As seen in Figure 24, the fleet management system has 3 major parts:

- The *on-board system*, which is in the vehicle,
- The *off-boards system*, which is the fleet management center,
- The 3rd part is the information, which can be obtained from public domain or any third party system.

In the next paragraphs some details of these systems will be given.

4.4.1.1 The On-Board System

The vehicle on-board system can be further divided:

- The electronically controlled vehicle systems, which were analyzed in the previous parts of this paper, such as chassis control system, intelligent systems, etc.

- The so called *communicator* unit, which serves for the positioning and also for the data transfer between the vehicle and the management center, or other 3rd party systems (for example for the inter-vehicle communication),
- And the gateway, which solves the data interchange between the vehicle and the communicator.

The *communicator* includes both the vehicle positioning, as well as the data transfer from the vehicle in motion. Analyzing the developments in this field, the potentials are tremendous.

For the positioning system the following alternatives exist:

- GPS - satellite based position information, in standard form, which can be transferred into any other format. Precision is in the 10 m range or below, since the civil purpose satellite information are not disturbed anymore
- DGSP - differential GPS, which improves the precision of the normal GPS information by means of using a fixed-point information broadcasted by a radio station. Very high precision can be obtained, if necessary for special applications (for example guided bus system door positioning and the stopping stations, or automatic backwarding system for multi-unit vehicles)
- MPS (Mobile Positioning System) - a localization system using GSM network developed by Ericsson. The precision of the location information is in the range of 100-130 m, which might be suitable for some applications,
- Satellite photo can also be used for positioning, however for on-line applications the feasibility is questionable,

For the communication system the today available solutions can be listed, but this field is developing so rapidly, that this list might be modified until the appearance of this paper:

- Radio networks - in short ranges the radio network can be used for data transfer, however, the effective range is small (40 km), data receiving frequency is high, but no roaming is possible.
- Analogue radio phone (450 MHz) - data receiving frequency is smaller, locally viable, no roaming is possible, but provides a cheap solution. For domestic or local fleets (such as bus companies) offers a cost efficient and reliable solution.
- Generation 2 GSM - the today's system - both direct data transfer, as well as SMS is available, roaming is possible. The direct data transfer is expensive, the SMS is cheaper and the system has relatively low bandwidth (15 kbit/sec), which does not make some on-line control options possible.
- G2.5 GSM system, which is a intermediate solution, with some new functions, which are interesting from the fleet management viewpoint:
 - GPRS (General Packet Radio Service) based on packed information transfer - the user pays after the transmitted information amount (not the time), high bandwidth is available (up to 115 kbit/sec), TCP/IP communication (always in connection), parallel voice call is possible, already available in 2000.
 - EDGE (Enhanced Data rates for Global Evolution) - using the above network infrastructure, the EDGE is a combination of a high speed modulation and GPRS technology. Depending on the application, 384 kbit/sec bandwidth will be available in 2001.
- G3 - 3rd generation GSM phone system with high bandwidth (2 Mbit/sec), and voice, picture, data package parallel transfer will be available. Appropriate for on-line control. Start of the availability in test systems in 2001/2002.

- Closed networks, today available only for closed applications (police, military, etc.); civil application is under development. Such a system is the TETRA, which can send SMS like messages without disturbing the normal voice communication.
- Data transfer via satellite - existing opportunity, data is being transferred from a mobile unit via satellite to a ground unit, which uses normal ISDN to send the data to the host computer. The Inmarsat D provides this service.
- Data download when vehicle is back to the home base, or reaches points with such terminals: high bandwidth infra red data transmission (IRDA) and similar

As it can be seen, both for communication and positioning there is a wide variety of systems, with different performances available. It is very difficult to see, what will bring the future. For the today's application for communication the GPS positioning + GSM SMS for data transfer is used. The reason is the simplicity and the relatively low price.

Important part of the system is the *gateway*. Its importance is not in the technology, since it is relatively simple. The problem is the accessibility to the vehicle data. Until the system has to solve only the positioning and some general data transfer of the position and speed information, the system does not require any communication with the vehicle. However, the vehicle and cargo security, the traffic safety, the vehicle economy require very intensive communication with the vehicle data bus, which is already problematic. These data on the vehicle has a specific owner (vehicle or system manufacturer), who wants to utilize these in order to "sell" them to the end user, who can optimize its transport process, consequently make money with it. There are attempts to standardize the accessibility to these data, today without success.

4.4.1.2 Off-Board System and Service

The advanced fleet management system should offer functions to the fleet owner, which has certain \$-value. That means that the fleet applies some of the function packages, that should bring benefit to the owner. For that purpose, several function groups can be defined as seen in Figure 25, like traffic management, safety, diagnostics or cargo security package. Of course, the availability of the functions of these packages depends on the technical level of the system (complexity). Just a few examples: route optimization is possible based on the actual geographic information, however, if there is no actual traffic jam information, the previously defined route might not be the best one, or if there is a warning of misuse of the vehicle to the management center (continuous overspeeding, high lateral accelerations) the vehicle speed can be remotely limited via the communication to the engine management.

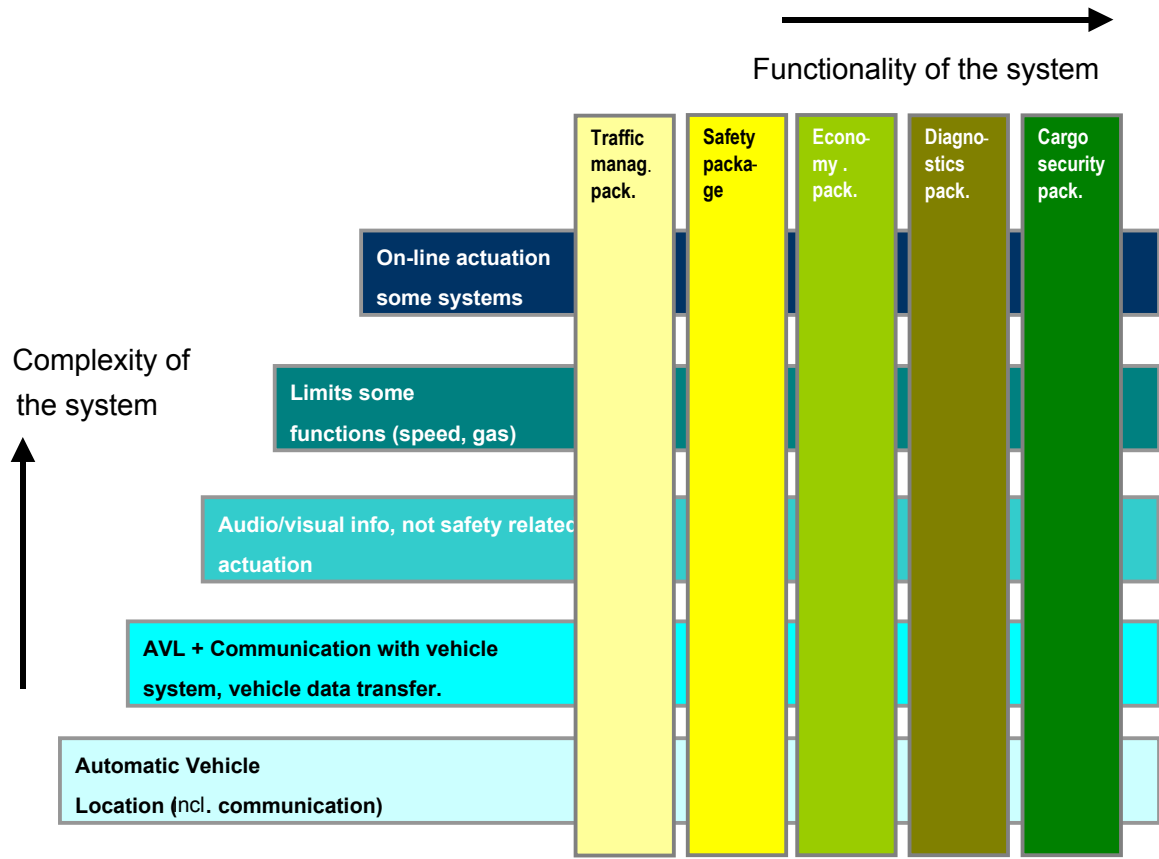


Figure 25 Functionality of a fleet management system with different complexity levels

These are just a few examples what can be achieved with such systems, definitely it will rapidly develop in the future. What is going to give a big push to this field is the fact that also the vehicle manufacturers recognized the value of the information from their own systems, and besides selling only the vehicle, they started to sell also service, one of them is the fleet management, at different levels. With the development of the communication systems outlined above, the commercial vehicle behavior will be monitored and exact on-line information will be available for the owners (of the vehicle and of the cargo as well) about the actual status of their property.

5. CONCLUDING REMARKS

The target of this paper was to summarize the actual status of the commercial vehicle chassis electronic systems affecting the vehicle and traffic safety. The basic conflict, that on the one hand the vehicle is produced for making return on the investment and thus has to fulfill very severe economic requirements and on the other hand, because of the society/environmental constrains, it has to fulfill high technical requirement, resulting in a very rapid development during the last decade. While 15 years ago, the studies have shown that the basic design of an average truck did not differ significantly from the design at the beginning of the Second World War, a top class heavy vehicle of today is technically at least as advanced as the best passenger car. In the fields of safety, stability, environmental compatibility and comfort the commercial vehicles are competitive with passenger cars.

The intelligent systems outlined in this paper are mostly taken over from passenger cars and adapted to the special truck environment, but there are also systems, where commercial

vehicles were more advanced, for example the electro-pneumatic braking system is available in trucks since 1994, and today all heavy vehicles are assembled with EBS. The electro-hydraulic braking (analogue to EBS) is under development in passenger cars. Definitely, the developments in technology, electronics, navigation and the related fields make this rapid development possible, and it projects a very exciting future. It is possible to realize a fully autonomous commercial vehicle even today, which has only electronically controlled systems, starting with steering, braking, engine management, transmission. Those, who visited the 2000 IAA (commercial vehicle exhibition) in Frankfurt, Germany can remember the presentation of the DaimlerChrysler PTU: the visitors could drive a truck in Hannover from a driver's seat in Frankfurt. That means the technology is already available, perhaps yet not as developed as it would be required, but the tendency is clear: it develops towards to the fully electronically controlled systems in commercial vehicles.

As a conclusion, the image of heavy vehicles as the "road-eater ugly monsters" is being changed.

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