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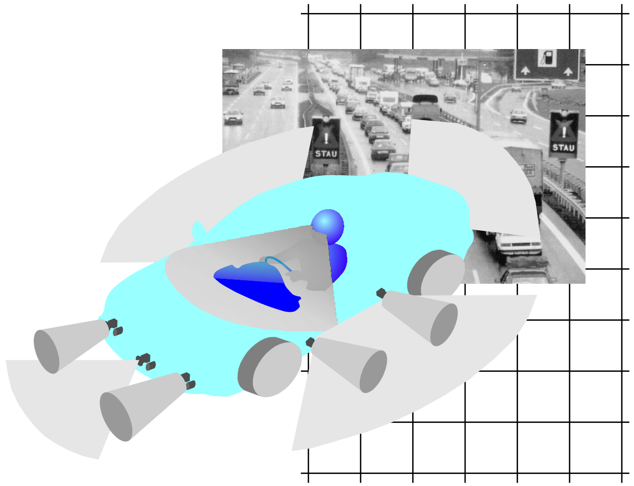
Automotive Engineering III

Safety-Related Vehicle Systems:

Accident Research, Pre-/ Post-Crash ●
Lightimg Systems, Vehicle Air Conditioning ●
Driver Assistance Systems ●
Longitudinal- and Transverse-Dynamics Control ●
Biomechanics, Restraint-Systems ●



Lecture script Automotive Engineering III

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Content

1 Demands on the Automobile Engineer

Considering the demands of the past, there were essentially three areas in which automobile engineers could be effective, Fig 1-1. Apart from the fields of competence where technical depth and special component knowledge were to be seen as the principal requirements there was also the area wherein the automobile engineer had to have distinct constructional and computational skills.

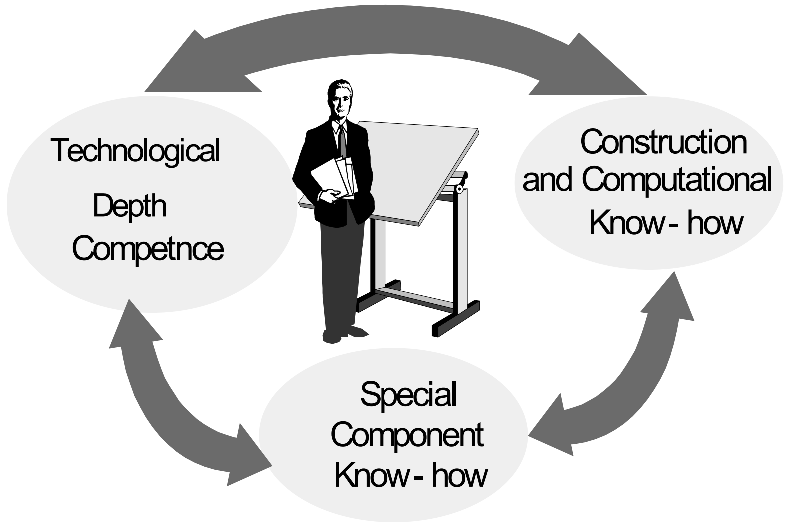


Fig 1-1: Required profile of an automobile engineer in the past

The classical automobile engineer is a component specialist with special abilities in the areas of the construction, computation, packaging (design of complete vehicle) and testing of specific components in his field of activity. He has a strong foundation of theoretical and practical technical knowledge.

A combination of the existing and the projected demands of an engineer in the automotive industry can be summarised as in Fig 1-2. Today, apart from technical depth, the component know-how as well as the constructional or computational know-how is of a greater significance, when compared to the past.

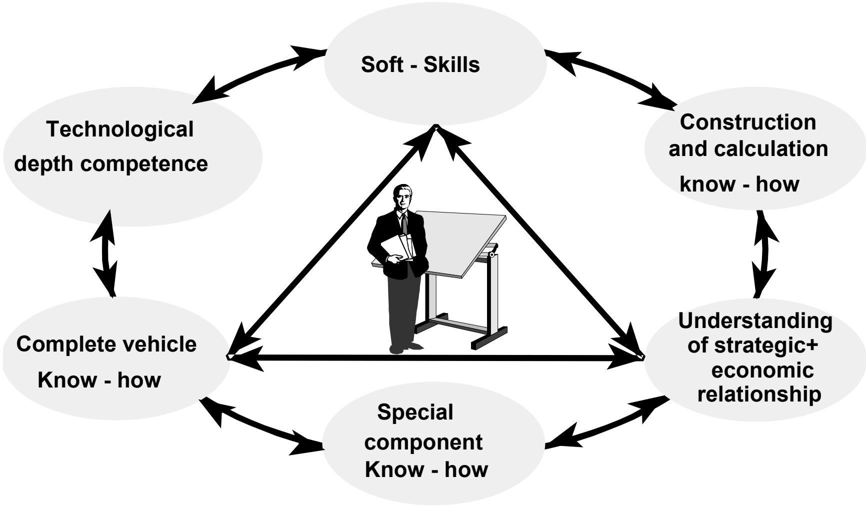


Fig 1-2: Required profile of an automobile engineer today / future

Today, the demands that are based on a strong technical background are not the only essential requirements of an automobile engineer. Additionally, he has to possess the so-called "soft skills" like adjusting actively to the dynamic conditions or changes within the industry. The necessary attributes, which he has to fulfil, are:

- Multi-lingual skills
- Openness towards new working conditions at world-wide locations
- Accomplishment of new and unexpected functions as well as
- Constant readiness to analyse and question the known and look for new options.

The automobile engineer should also possess interdisciplinary skills, such as a strong team working ability so that he can participate in projects requiring teamwork. The necessary attributes of a team player are:

- Ability to communicate
- Sensitivity to problems of colleagues
- Persuasive power
- Personnel Management skill

Meanwhile engineers are required to possess the total vehicle know-how as extensively as possible. The car manufacturers also expect, an increasing know-how

concerning total vehicle concepts, from their suppliers. The automobile engineer must, on the basis of his "field of activity", understand, which interactions and resulting interface conditions exist between a particular component, module or system and hence the entire vehicle. Hence, he is expected to have a basic knowledge, which concerns the following aspects, among other things:

- Longitudinal, lateral and vertical dynamics
- Material properties
- Constructional and manufacturing methods
- Electronics and Mechatronics

To an Automobile Engineer the understanding of strategic and economical relationships is also of increasing importance. Fig 1-3 illustrates the influence of different aspects on the technology out of which products evolve.

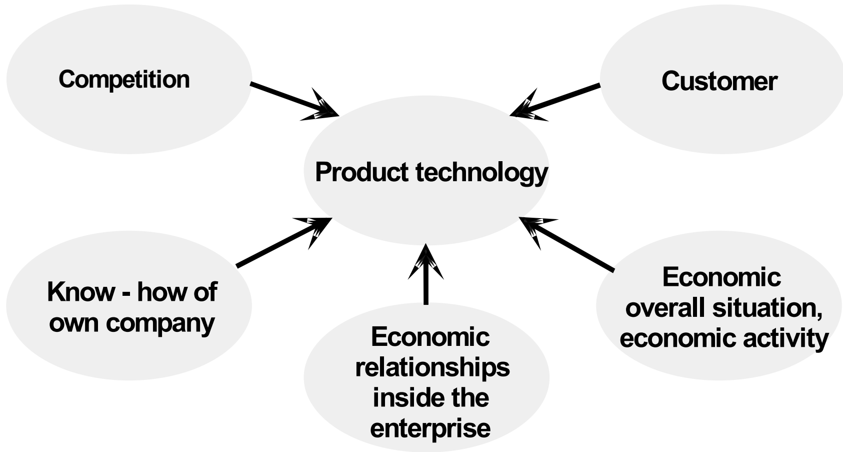


Fig 1-3: Factors influencing the product technology of automobiles

The strategic placement of a product that is to be introduced into a market must be oriented around the total economic situation of the industry. It is important to know whether the product that is to be introduced into the market is competitive. This is especially useful when evaluated at the point of introduction of the product into the market. Since the development period for products of the automotive industry requires several years, it is of special interest to study the needs of the market and henceforth, of customers, together with the legal limitations as early as possible.

Sufficient information should be gathered prior to product development, so that the automobile engineer knows promptly, under which aspects he has to develop the product.

A product, developed without keeping in mind the competition, has never made a successful entry into the market. The knowledge required by the automobile engineer, in order to satisfy these products, can be summarised as follows:

- Knowledge of the most important products and capabilities of the competitor.
- Knowledge of the advantages and disadvantages of the products available on the market

To obtain this knowledge, an engineer uses important tools like benchmarking of products, processes and strategies of competitors. Patent references and extensive literature surveys are also very important.

In the past the car manufacturers introduced products that were successful in the market and that were accepted by the customer. Today, the opinion of the customer as well as the interest in custom-made vehicles has gained more significance than ever. Hence it is of paramount importance for the automobile engineers, particularly for the development engineers, to understand the needs and demands of the customer and to design products based on those demands. The important questions concerning the fulfilment of customer demands are:

- Who are the target customers?
- What expectations does the customer have as to the product regarding costs, aesthetics, function, image, etc.?
- Compared to the competitor, how can one provide more to the customer utilising his own resources (solutions)?
- What additional services can the automobile engineer offer to his customers directly or indirectly?

The knowledge of the automobile engineer concerning competition, customer and market conditions are not the only factors that possess a high value in the context of product development. Apart from the above, he should know his own organisation well enough to have the ability to organise the technical implementation of the product according to the specific capabilities of his own enterprise. The following questions should henceforth be interesting for him:

- Where does the distinguishing (from competitors) know-how lie?

- Which customer requirements can be completely fulfilled today?
- Where do drawbacks (concerning the product) exist within the enterprise?
- Who are the key contacts within the enterprise?

Especially the last aspect is quite important since a good communication among employees is essential for a successful product design. The activities of an automobile engineer contribute crucially to the financial success or failure of the organisation, and for this reason the knowledge of economical influences has to be of substantial interest to him, Fig 1-4.

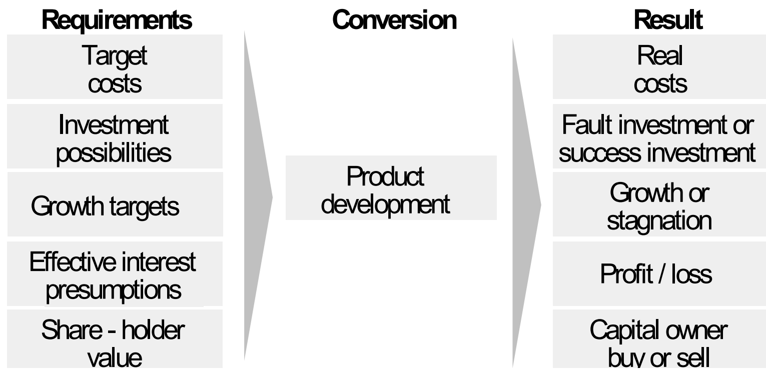


Fig 1-4: Economical relationships.

The automobile engineer tries to realise the product development and implementations based on the internal guidelines which act as a control by different branches of the enterprise, like management, marketing or the executive committee. One of the substantial targets is the achievement of costs actually estimated prior to development and production. The right investment in personnel, material and processes has to be made to succeed on the product with a long-term view.

In addition, the target of an enterprise should be to achieve an increase in sales with profitable products. As a result a possibility for growth exists for the enterprise and a further capital ownership can also be achieved. Hence, the position of the enterprise can be strengthened so as to assume an important role within the automotive industry in future.

2 The Environment of the Automobile Industry

In the following section, the structure of the automobile industry is described in detail. Primarily, the changes within the car industry are considered. Then the restructuring of the automobile industry is discussed. In addition to construction, the integration of suppliers under the three aspects those being innovation of products, orientation of products as well as the increasing globalisation of the automobile market, is also illustrated.

2.1 Modifications in the Automobile Industry

The structure of the today's automobile industry is represented in Fig 2-1. Apart from the car manufacturers, also called OEMs (Original Equipment Manufacturer), the automotive sector comprises of System and Module suppliers (1st-tier Supplier) as well as Component suppliers (2nd-tier Supplier) and Element suppliers (3rd-tier Supplier).

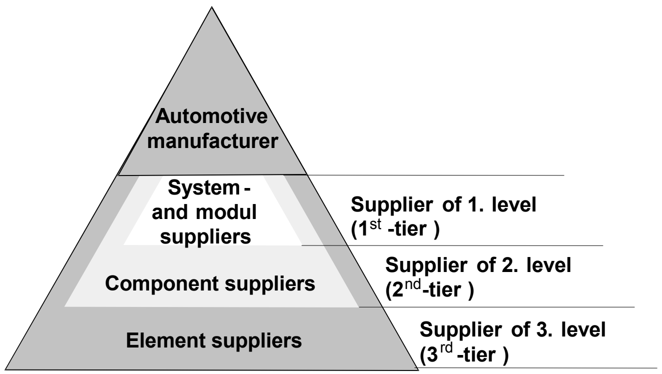


Fig 2-1: Hierarchy of the manufacturers and the suppliers in the automotive industry

The system and module supplier who, for example, produces brake systems or front-end modules, are in direct contact with the vehicle manufacturer. The component suppliers (e.g. fuel pump manufacturers) and element suppliers (producer of screws) co-operate closely with the system and module suppliers and are not always in direct contact with the car manufacturers.

Among other things, the increased number of model and version variety as well as the demands for large and high performance or small and economical vehicles are ranked based on customer specific trends,

Fig 2-2. Additionally, the vehicles have to be customised to meet individual requirements. The so-called niche vehicles belong to this segment (e.g. Roadsters and SUVs - Sport Utility Vehicles).

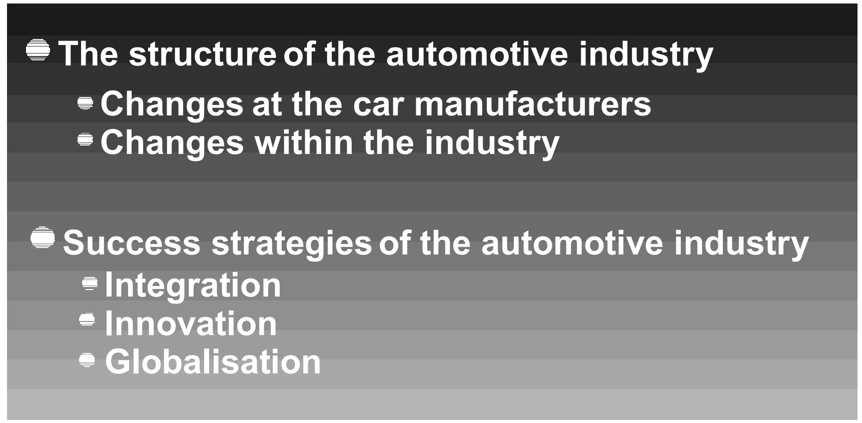


Fig 2-2: Modifications within the automotive industry

The automobile industry had been consolidated in the past due of the aspects mentioned above. Formerly important car manufacturers were either displaced from the market or were taken over by stronger manufacturers. For example the formerly independent automobile companies VW, Audi, Seat, Skoda and Bentley developed into a joint Volkswagen company. Similar developments took place in companies like Ford, General Motors or Daimler Chrysler, whose product portfolios increased with mergers or take-overs of other enterprises. Further, a substantial aspect of these mergers is the synergy potential that they offer. The usage of resources (material and personnel) in development and production can be decreased in order to reduce costs. This implies that the profit gained for the products supplied can be increased. The possibility of successfully fulfilling the ever-growing demands of the automobile industry can be achieved by merging.

2.2 Modifications in Automobile Suppliers

Just as car manufacturers have to change according to the demands of the market and customers, so must the supporting industry, i.e. the suppliers. Far-reaching changes within the supplier industry are brought in by the new demands of the automobile manufacturer, end user, capital markets, new market entries and exits as well as by new technologies and changed legislations.

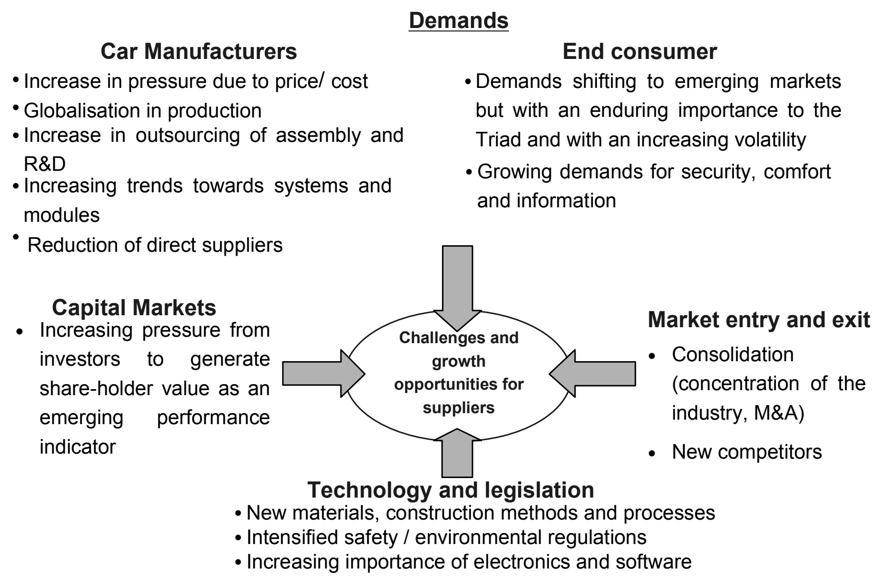


Fig 2-3: Main trends in the automobile supplier industry [MKI99]

The objective of having a profitable growth increases the pressure on the supplier to be more efficient. The supplier sees himself subjected to increasing fastidious cost targets than the vehicle manufacturer. The demands on delivery also rise in global markets. [MKI99]

The intensified outsourcing strategy of the car manufacturer, i.e. the additional purchasing power, offers the supplier a possibility to adopt new assembly lines and development strategies. Hence the demands on the supplier increase simultaneously, and this also implies more responsibility towards the product and with an increasing added value.

Currently outside the triad (i.e. Europe, North America and Japan) a rapid growth in demand, which is subject to strong short-term fluctuations, is noticed. The knowledge of the end user plays an important role in the success of a large number of supplier industries in the triad markets. [MKI99]

The structure of the automobile industry is changing. On the one hand supplier enterprises attached to a company appeared as monopolies in the market while on the other hand many medium-size suppliers perceived themselves to be under

pressure to consolidate. This resulted in a multiplicity of mergers and take-overs. Many enterprises are interested in developing aggressive strategies to strengthen their position in the market [MKI99].

On the technological front, a further usage of systems and modules is expected so that modifications can also be evident in development and supply. A modification in technology is a direct consequence of innovation and constantly increasing legislative restrictions. For example, the rising proportion of electronics and software components in vehicles will affect traditional areas of competition. So suppliers must develop new abilities in order to survive. This results in new market opportunities for competitors, who did not have a representation in the automobile industry so far. For example, software developers and manufacturers of electronic components for automobiles, see promising areas of application with which they could extend their options for growth [MKI99].

Further aspects, which cause technological modifications, refer to the serious demands on safety and environmental protection. Regulations that concern emissions (exhaust and noise) and recycling imply risks on one side and opportunities on the other, for suppliers.

The objective of the supplier should be to advance towards the required demand. Hence they must achieve capabilities in all areas including the ones in which they were not active so far, so as to be able to participate in the globalisation strategies of their customers besides the expectation on the suppliers to undertake new scopes of supply in order to fulfil the ever increasing demands for integration.

Additionally, they must move towards the end user, so that they can re-structure themselves to user's needs better. The pressure of competition will be increasingly intense due to the multiplicity of demands finally resulting in a reduction of the number of suppliers.

Observing the development of the worldwide automobile market, one can state that there is a steady shift of demand towards the new so-called threshold markets (China, Eastern Europe and South America) from the triad markets, Fig 2-4.

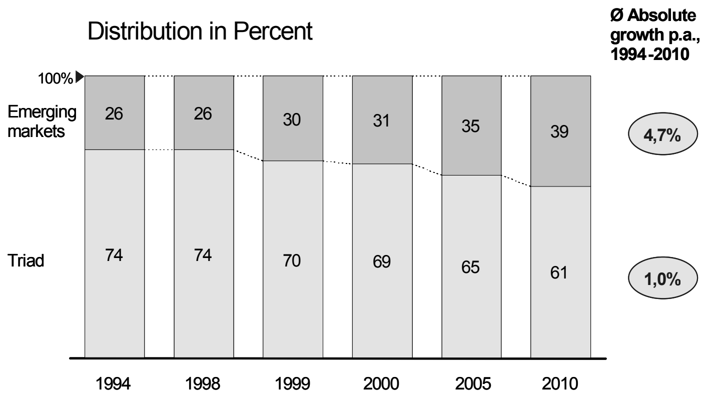


Fig 2-4: Development of the worldwide automobile market [MKI99]

Hence the market share of new markets will presumably increase from the present 31 % during the year 2000 to 39 % during the year 2010, as against that of the triad markets (69 % to 61 %). Further, an absolute annual growth of 4,7 % is projected here, for the emerging markets and 1 % for the triad markets in the year 2010.

Fig 2-5 describes the increase in automobile production during 1997-2003. It is evident that the major growth of automobile production will take place in the new markets.

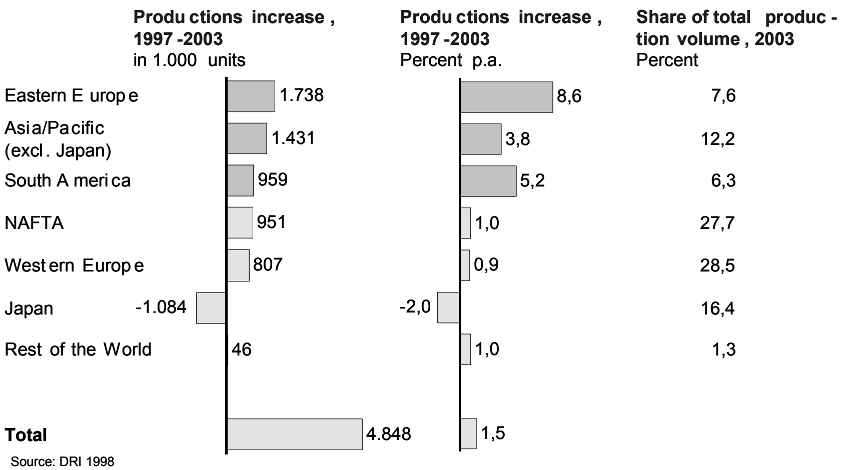


Fig 2-5: Development of vehicle production [MKI99]

If one examines the non-triad markets, an increase of the production capacities is noticed in case of passenger vehicles and light commercial vehicles for different car manufacturers, Fig 2-6.

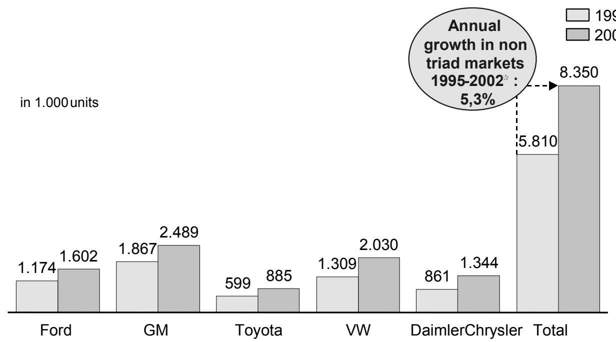


Fig 2-6: Increase of production capacities in the non-triad markets (passenger car, light commercial vehicles) [MKI99]

It is expected that large car manufacturers from the triad will strengthen their production capacities in the new markets. Presumably, an annual growth of 5.3 % in the non-triad markets is projected during the period up to 2002.

If one considers a vehicle in detail, systems and modules are expected to be of increasing importance in the future, Fig 2-7. Some modules and systems available in the market today as well as those that were already established in the market in past are e.g. seats, sunroofs, ABS systems as well as air conditioning systems.

	Modules	Systems
Existing modules/ systems	• Seats • Sun roofs	• ABS-brakes • Air conditioning
Emerging modules/ systems	• Front modules • Door modules • Axle modules • Cockpit modules	• Dynamic vehicle control systems (ESP) • Adaptive cruise control • Navigation systems
Future modules/ systems	• Corner modules • Overall body design modules	• Collision avoidance systems • "Brake by wire"

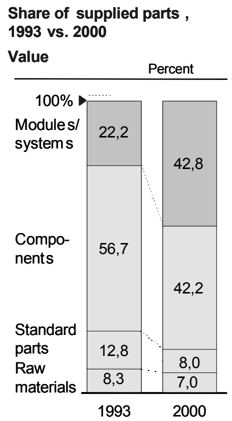


Fig 2-7: Development of the market for systems and modules [MKI99]

In addition to the existing ones, new modules and systems such as front-end modules, door modules, axle modules and dashboard modules as well as driving dynamics (ESP), speed controllers and navigation systems have found their way into current vehicle concepts. In future this category will possibly give way to "Corner modules", meaning modules comprising of wheel carriers, suspension with spring and damper, total body modules as well as collision avoidance and " Brake by wire" systems. It is noticed that not only new modules and systems will find their way into vehicles, but also that their importance in the supplier industry will be increased. If one regards the period between 1993-2000, the proportion of delivered parts for the OEM has almost doubled from 22.2 % to 42.8 %. But the proportion of components, standard parts and raw materials has decreased by the same quantity. From the car manufacturers´ point of view a tendency towards a reduction of the number of direct suppliers is noticed, Fig 2-8. For suppliers, it is not only important to be accepted by over coming strong competition but also they must be able to withstand and sustain the price reductions by the OEM.

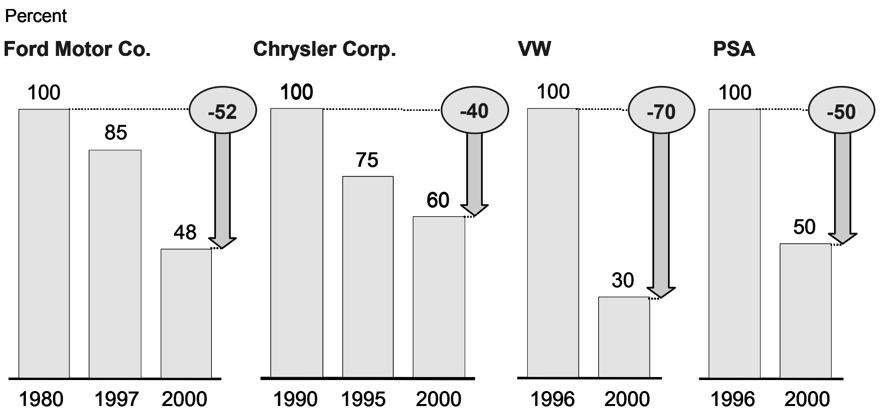


Fig 2-8: Number of direct suppliers of different OEM [MKI99]

A further aspect for consideration in the future is that the suppliers must take over a substantially larger proportion of component development, Fig 2-9.

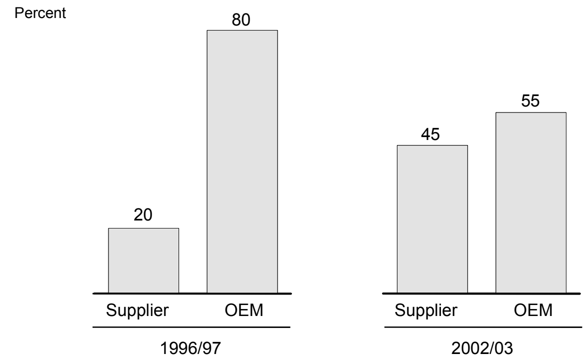


Fig 2-9: Proportion of the scopes for development for total Vehicles 1996/97 and 2002/03 [MKI99]

The increase in responsibility of the suppliers towards development is justified by the fact that the vehicle manufacturers would like to concentrate on their core competences, for example body development, in the future and then transfer the development of components, systems and modules to the supplier.

Certain supplied products, which are expected to show enormous growth rates in the future, are represented in Fig 2-10. It can be stated generally that the market for comfort, safety and information technologies will exhibit a clear growth, so the suppliers will be able to cater to their typical fields of operation.

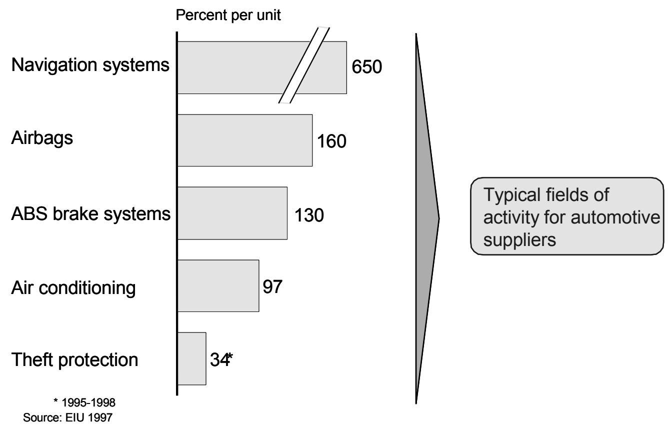


Fig 2-10: Growth rates of selected supplied products for comfort, security and information, 1996-2005 [MKI99]

When one considers the market tendency of passenger car components in detail, a clear market growth in electronic components can be noticed during the period 1996-2001. There is an annual growth rate forecast of 6.1 % here. Thus the growing importance of electronics and software products will cause clear modifications within the structure of the industry, Fig 2-11. Hence a shift from the " Mechanical " industry towards a " Mechatronic " and " Electronic " industry is to be expected.

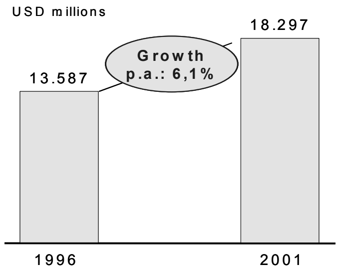


Fig 2-11: Worldwide market development in passenger car electronic components [MKI99]

An intensive effort is put into design of vehicles optimised for weight as this conforms to the given boundary conditions concerning the weight reduction and also emission reduction of motor vehicles. This leads to the use of light alloys e.g. aluminium, magnesium, plastics, Fig 2-12.

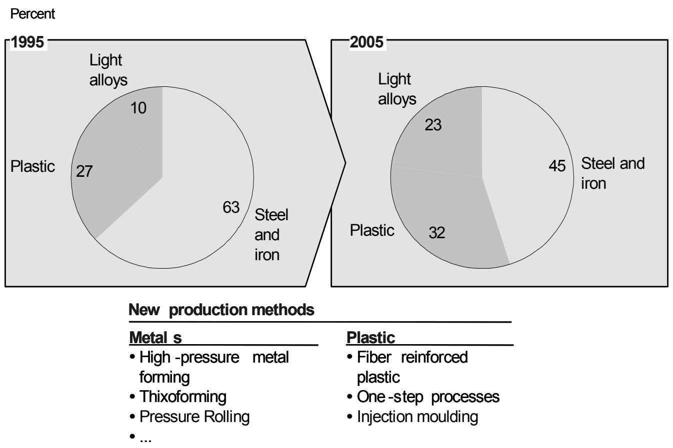


Fig 2-12: Modifications in the material composition of passenger cars, 1995-2005 [MKI99]

Certain new manufacturing processes, such as internal high pressure transformation, thixoforming and pressure rolling for metals, the use of fibre reinforced plastic components, one step processes and backing techniques open new potentials for lightweight construction, which can be used for the manufacture of vehicles optimised for weight.

Apart from new materials and particularly those that are lightweight materials there are new constructional processes and technologies that are increasingly applied in all branches of vehicle technology. In body engineering, lightweight constructions suggest the use of high-stiffness steel and space frame structures, Fig 2-13. In the chassis area, the applications include pneumatic suspension and shock absorption systems as well as integrated lightweight construction and active vehicle dynamics control. With further development of drive units, the gasoline directs injection, hybrid concepts and the fuel-cell technique are of interest.

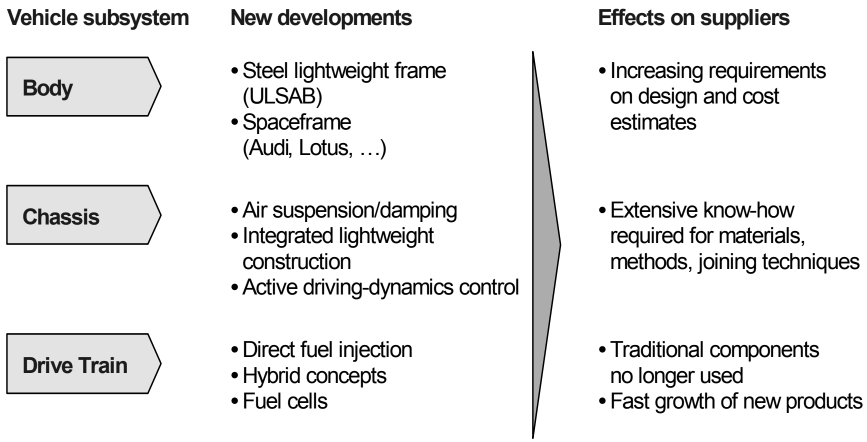


Fig 2-13: Effects of new building method / technologies on suppliers [MKI99]

The effect of these new technologies and building methods at the construction and calculation stages is an increase in demand for greater knowledge in the areas of materials especially forming procedures and joining techniques. In the past when new products had replaced common components, they experienced a particularly strong growth.

2.3 Success Strategies for the Automobile Industry

Until this section, the modifications brought about by car manufacturers and suppliers consequent to changes in the market, were dealt with. In the following section, the methods used by suppliers to meet these demands successfully are illustrated. The success of any organisation depends on the evaluation of growth and the subsequent profitability. Fig 2-14 shows the wide range of the attainable net profit (profit on turnover = profit from sales) and annual growth of a successful enterprise in comparison to the lesser successful ones. The substantial differences point out the large "action clearance" for profitable growth within the industry.

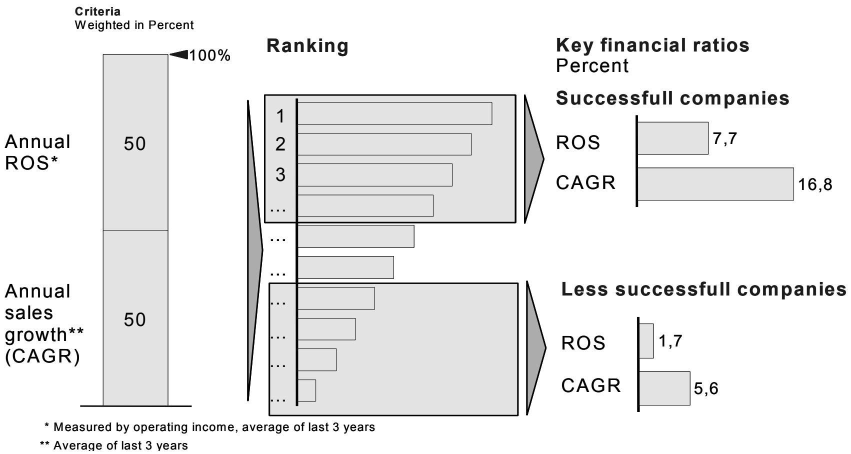


Fig 2-14: Indicator for the success of enterprises and characteristic numbers [MKI99]

The modifications in the automobile industry connected with operational excellence (i.e. high quality and high productivity) that were previously described can be regarded as a prerequisite for profitable growth and these cause three substantial growth levers for the suppliers, Fig 2-15. The creation of value proportion in the total product can be increased by the suppliers by transferring additional performance strategies in the form of intensive integration, transfer of research and development functions as well as assembly to the project strategies.

Apart from innovation in products, processes and services, there are other possibilities for competitors in the market that contribute to their growth.

The demand for an increasing degree of globalisation in the automobile industry, which refers to production and marketing of products in particular, offers not only the possibility for potential market competitors to start off, but also presents an enormous challenge to the suppliers to be able to offer products and services world-wide with consistent quality and stable costs.

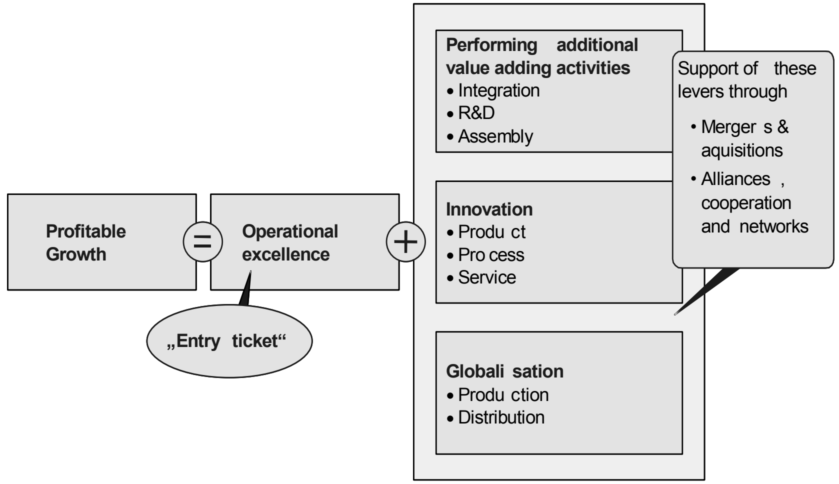


Fig 2-15: Growth levers in connection with operational excellence [MKI99]

The growth levers mentioned above are influenced by mergers and take-overs as well as by the structure of alliances, co-operation and networking with other companies.

2.3.1 Transfer of Additional Performance Strategies by Integration

There are two existing strategies, shown in Fig 2-16, which are useful to the suppliers. They are based on the use of systems and modules to increase the degree of integration.

Functional integration is said to be achieved when new functions are added to existing products or linked together with existing functions, an example of which would be locking systems with integrated security alarms and immobilisers.

In cost-driven integration, one tries to reduce the number of assembly interfaces by way of integration of sections and components into modules. Moreover, one would like to use the potential for interface reduction and optimisation, which arise as a result of the better connection or even the omission of sections and components. As a result, optimisation in terms of body construction as well as weight reduction can be achieved.

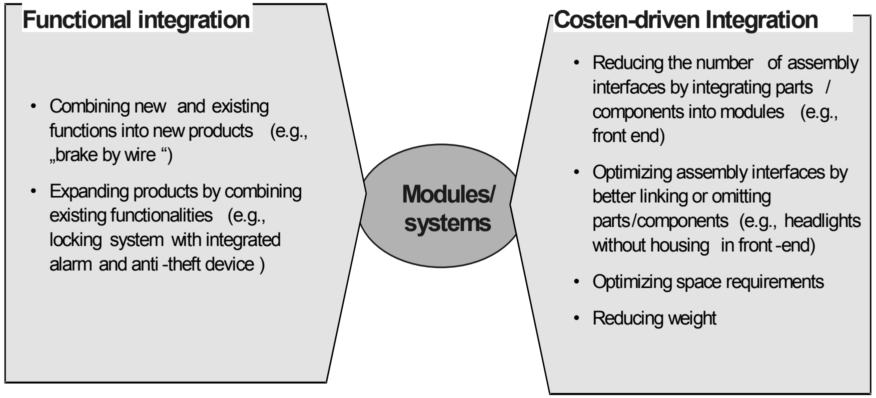


Fig 2-16: Possibilities of integration [MKI99]

The methodology used in the implementation of Functional Integration is depicted in Fig 2-17. One achieves these by combining already available as well as new product functions. In the past, brake components and Anti-lock Brake System (ABS) electronics were developed and manufactured separately. However, today, the development and manufacture of brakes and ABS takes place together as a complete ABS-Brake System. A similar trend is also noticed in the development of drive train components and the appropriate control electronics, which are meanwhile conceived for the entire drive train management. Electronic Stability Program (ESP), which is the regulation of driving dynamics, has evolved into an advanced stage of these two developments. In connection with Adaptive Cruise Control (ACC), which has resulted from a combination of drive management system and sensor technology, the regulation of driving dynamics could be developed further with the aid of navigation systems as well as elements of driver assistance in order to realise the autonomous vehicle guidance concept.

In a cost-driven integration, one tries to cut costs by connecting spatially matching components. If one regards seat development, seats, seat adjustment mechanisms and seat belts were developed individually in the past and then assembled by the car manufacturer and finally installed onto the vehicle. Today in upper class vehicles integral seats are used, which consist of the seat, adjustment mechanism and belt system. These integral seats are pre-assembled by the seat manufacturer and then directly supplied to the assembly section of the OEM.

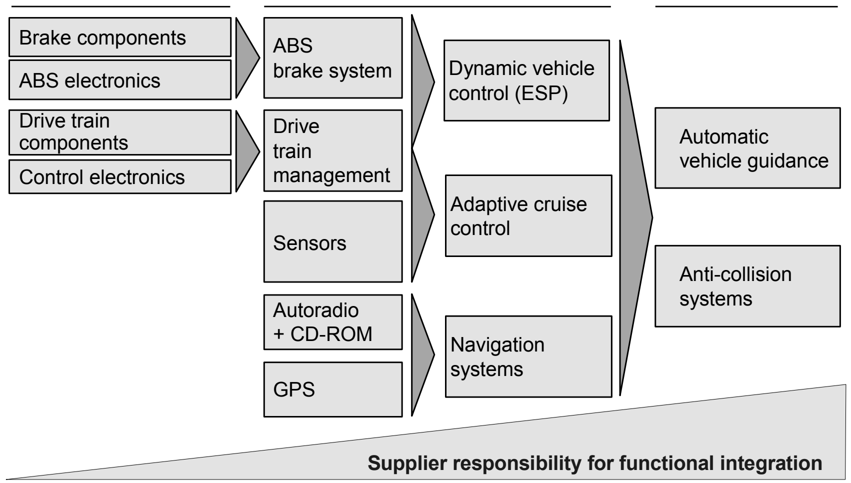


Fig 2-17: Examples for the development of functional integration [MKI99]

With respect to vehicle instrumentation, a development towards cockpit modules is noticed. A combination of integral seats and elements of interior trim as well as the upholstery of the vehicle complete with carpets, maybe seen in the future as complete vehicle interior modules.

On one hand, the consequence of Functional Integration for suppliers of these modules and systems is the increased proportion of value addition in the supplied products which enables the supplier to increase his turnover and hence his profits. While, on the other hand, the product responsibility for the suppliers rises due to an increased integration of the suppliers into these areas of vehicle development, the proportion of the effort required for production on the side of the car manufacturer thus decreases. The supplier thus achieves higher volumes of supply.

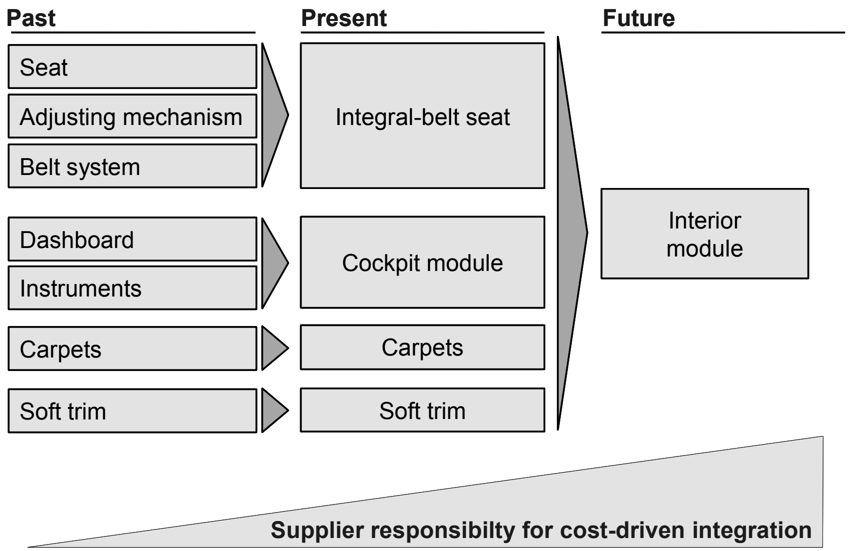


Fig 2-18: Development of Cost-Driven Integration [MKI99]

2.3.2 Innovation

Apart from integration, innovation also offers the automobile supplier a strategy for success. As a result of the innovative orientation of products, the potential to obtain a competitive advantage in the market improves. Innovative companies maybe singled out by the fact that they set for themselves fastidious growth targets and also concentrate on new product development.

During the period 1994-1997, if one regards innovative companies in detail, it becomes evident that they have registered a higher growth in turnover compared to the lesser innovative ones, Fig 2-19. There is a substantial difference regarding the achievable growth options, for the innovative and less innovative suppliers, in the orientation of the product range. The innovative suppliers work towards the targeted growth by developing products, which can be newly introduced. This proportion of new products will clearly increase in innovative companies compared to the lesser innovative ones.

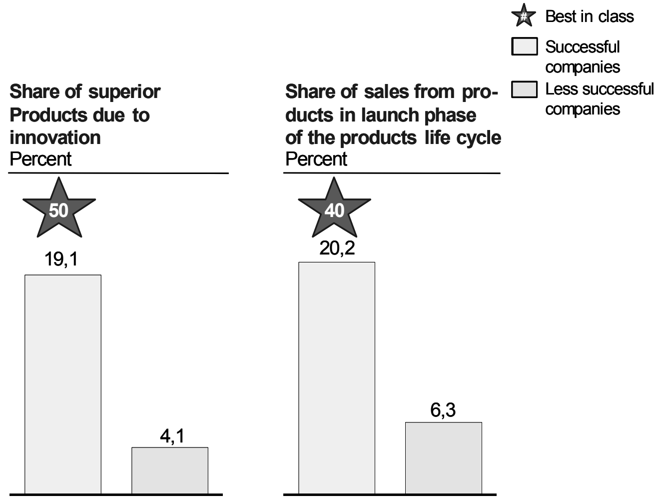


Fig 2-19: Objectives of innovative and less innovative enterprises (1997-2000) [MKI99]

Fig 2-20 shows the development of profit and growth in turnover during the period 1994-1997 for innovative and less innovative companies. The innovative suppliers achieved twice the net profit and up to four times the growth in turnover compared to the lesser innovative ones.

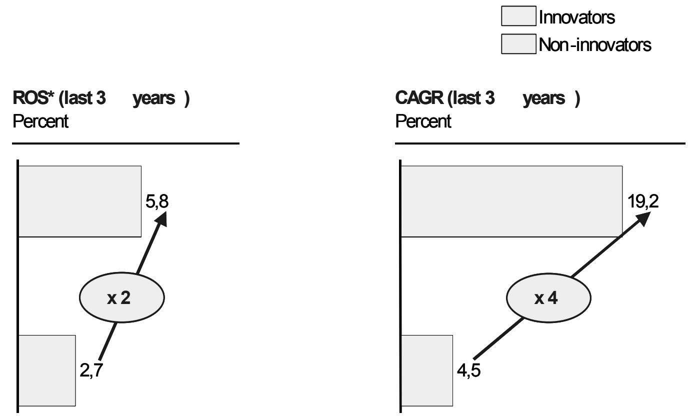


Fig 2-20: Financial success of innovative and less innovative enterprises [MKI99]

In order to be able to offer innovative products, it is of paramount importance that the manufacturer possesses an understanding of customers and global markets. This offers the possibility of selecting the best among ideas, which are independently compiled and which later could also turn out to be successful in the market. Fig 2-21 gives an overview of the proportion of employees who are active in the fields of research and development, involvement techniques, which reinforce the understanding, by the company, of the customer and that of the market.

Apart from analysing the competitor, quality function deployment and the final customer opinion poll along with non-customer opinion polls are executed, in order to orient one's own products directly in line with the demands of the market. Here it is not enough to know only current market demands but also knowledge of projected demands and boundary conditions for products occurring in the future market are important. To predict these requirements and to design the products to meet these demands is of crucial importance for the success of innovative products.

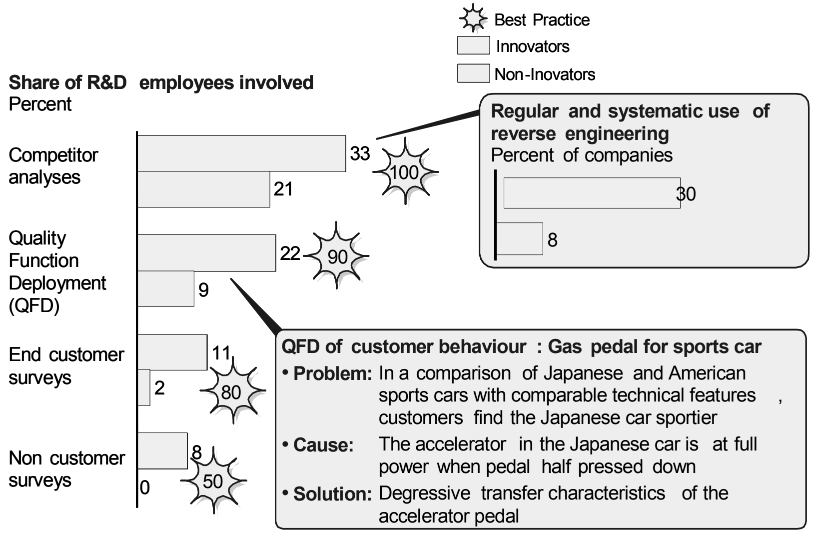


Fig 2-21: Techniques for market analysis [MKI99]

The analysis of the competitors and customer opinion polls are not the only techniques of market analysis available for the successful orientation of products. A further possibility to achieve this goal exists in the execution of common projects with customers and suppliers, as shown in Fig 2-22. Here the constitution of teams depends on the degree of integration of the company with the customer.

Innovative companies strive to undertake projects in an intensive manner with customers and suppliers. With such projects, the proportion of product development, which is executed in advance to and in parallel with the commencement of production, increases. In addition, projects that begin after the commencement of production aid in product optimisation also hold a substantial value. During the formation of the teams consisting of employees of the company and those that of the customers or suppliers, it should be kept in mind that in strong integrated partnerships a large proportion of development teams comprises of employees of the customer and the supplier, in comparison to the employees of the company. Only the teams that are formed in combination with standard part suppliers consist of the employees of the customer. In a co-operation involving component specialists and system designers, the teams comprising the company's employees and those that of the customer and supplier outnumber the specialists.

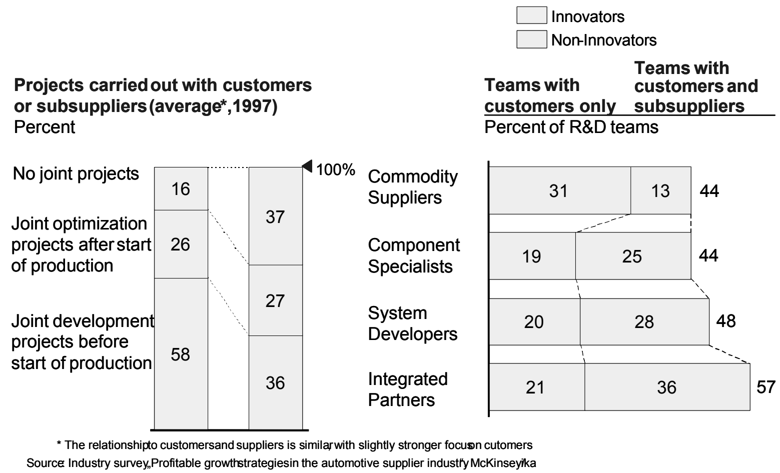


Fig 2-22: Co-operation with the customers and suppliers [MK199]

2.3.3 Globalisation

Globalisation represents a further yardstick in the improvement of profitable growth of a company along with the assumption that there is an increase in the market by innovative products leading to additional volumes for supply by way of integration in the form of research and development, as well as for assembly. A successful analysis of one's own company in terms of accomplishment of the demand for globalisation is needed and this requires a constant enterprise strategy along with a consistent functional implementation.

With the strategy of globalisation, the supplier starts depending heavily on his primary customers. Targets, which are pursued with the globalisation strategy, are to be defined more precisely. Based on these targets decisions are made whether to react to the market demand pro-actively or reactively. Besides, in the course of globalisation, one tries to enter into partnerships with and takeovers of other companies. By integrating development, production and marketing departments into the process of globalisation, one would like to achieve a functional implementation of these areas, which are advantageous particularly in terms of cost reduction.

If one considers prominent companies that pursue a consistent globalisation strategy, it is noticed that these companies, on an average, show a net profit that is almost double compared to the companies, which are less active in global markets, Fig 2-23. Regarding the growth in turnover, it turns out that prominent global companies indicate a growth almost twice in comparison to competitors in the market. They are seen to achieve an average growth in turnover of about 16.5 % annually.

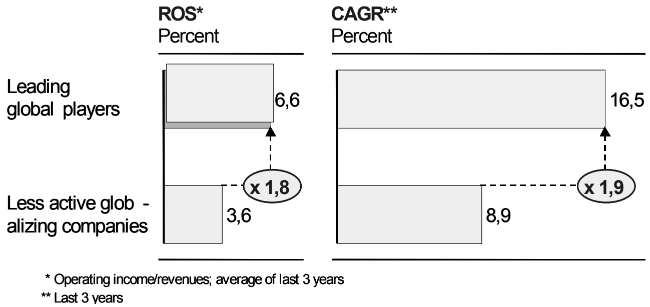


Fig 2-23: Success of an enterprise through globalisation [MKI99]

It can be inferred from Fig 2-24 that prominent global enterprises predominantly follow their existing customers abroad. Global enterprises that are less active select a rather pro-active path. On one hand the optimum version for the execution of a consistent globalisation strategy lies in the establishment of an operational presence overseas. Here there can be an existing possibility of supplying the customer directly with specially manufactured products for the company. While on the other hand that operational presence can be used for the acquisition of new customers. In this way, new and also additional fields of application could open up for the supplier. The result could then be a growth in turnover.

Prominent global companies have partnerships with a lot of other companies. Even then, they strive to increase the number of partnerships. The substantial types of partnerships are takeovers, joint ventures and co-operations with other companies.

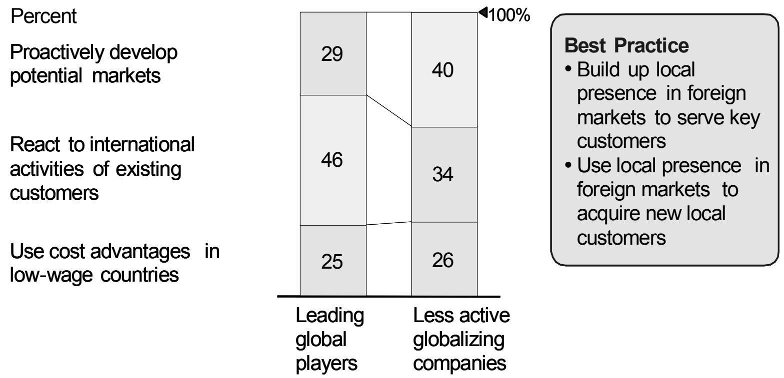


Fig 2-24: Basic approach to globalisation [MKI99]

Further, leading global enterprises possess an intensified policy of sending basic and application engineers abroad. The global experience of these high-level personnel is of crucial importance for the successful implementation of the globalisation strategy. For example, the employees of the "Top management" of global enterprises gain valuable experience particularly, in Western Europe and in the NAFTA region (Canada, the USA, Mexico), which is important for the growth and development of the company in these regions.

2.3.4 Summary

The attributes that serve for the basic orientation of the supplier also contribute to an achievement of a profitable growth, maybe summarized as follows:

- The capabilities of the supplier are indicated only by **operational excellence** (high quality and productivity) and not entirely by the ability of the supplier to achieve maximum performances in gain and turnover growth because this is not sufficient anymore but it must always be available within the enterprise.
- The **integration** of the supplier does not necessarily guarantee higher net profits, but a growth in turnover since the value of the enterprise increases.
- By implementing disciplined **innovative strategies**, a high profitability might be achieved.
- A **globalisation strategy**, which is oriented to the needs of the customer and characterised by clear regional accents, pays off and increases the value of the enterprise. [MKI99]

The suppliers may achieve an increased profitability by the above-mentioned aspects, as long as they succeed in implementing them.

3 Introduction into vehicle safety

An essential aspect in the development of a vehicle is the vehicle- and traffic safety. As a measure for the traffic safety, usually the number of traffic accidents is taken including the number of persons killed or injured during those accidents. In 2003 there were about 2,25 Million traffic accidents in Germany with 460000 people injured and about 6600 casualties. The aim of traffic safety and vehicle development is to decrease the number of traffic accidents to a minimum and soothing the aftermath. The long-term aim is „Vision Zero“, traffic with no accidents at all.

In order to reach those aims there are two different methods:

- active safety
- passive safety

Active safety describes all actions taken to prevent traffic accidents. Passive safety on the other hand identifies measurements, which do not prevent an accident, but sooth the aftermath and reduces the heaviness of the injuries from the passengers or the accident partners Active safety actions can be classified for example in a better infrastructure, an advanced vehicle concept, an adapted driving behaviour, laws, technical systems which intervene in dangerous situations etc. Passive safety systems include the structure of the vehicle, restraint systems, rescue services etc..

Many active as well as passive safety precautions were invented in the past. The positive effect can be shown in the tendency of the number of accidents, which is illustrated in Fig. 3-1. From the 1950s on the number of accidents increased continuously due to the growing traffic value. Today the number of accidents is five times higher. The number of accidents correlates up to 1990 with the kilometrage performance (the sum of annual kilometres driven by each person in the individual traffic). Since the 1990s a discrepancy between the kilometrage performance and the number of accidents is visible. This can be recognised as a result of active safety. It means that even though the traffic value increased, the number of accidents stagnated or did not increase in the same way. The active safety precautions, invented in the years before, were not sufficient enough for such an effect. Systems like ESP, improved chassis, suspension and vision concepts, a better product quality of safety-relevant systems, increased police controls and actions in the infrastructure (reducing of crucial traffic points, more traffic light junctions etc.) take part in these effect.

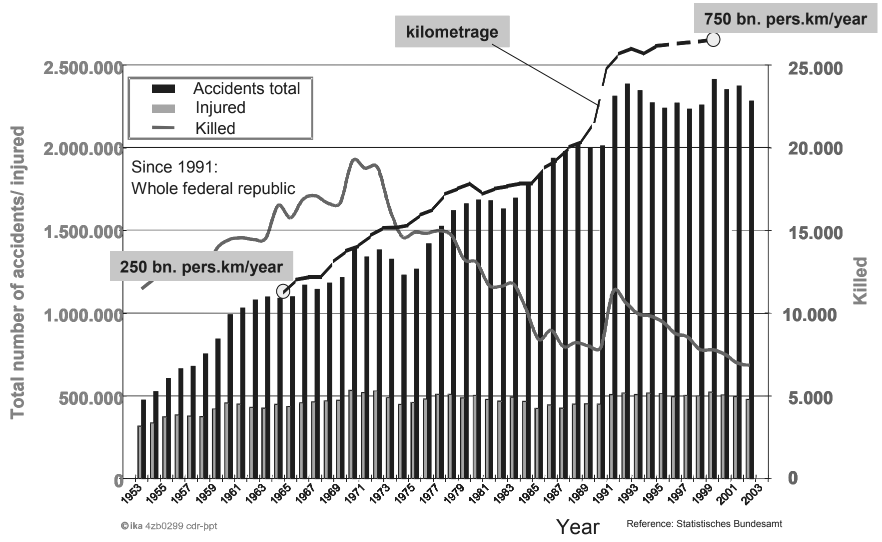


Fig. 3-1: Development of the number of accidents in Germany

Regarding the number of accidents including people injured or killed, it is evident, that those numbers stagnate (injured) or even decrease (killed). This can be correlated to the advances of passive safety systems. Improved vehicle body structures, which provide the conservation of the passenger cab and by the same time allow a maximum absorption of energy and the use of restraint systems like seat-belts or airbags obtained the greatest effect. Fig. 3-1 illustrates how laws and fines, like the mandatory seat belt usage, had effects on the number of killed persons.

Today the number of killed persons in traffic accidents still counts about 6600 per year in Germany. The European commission has set up a demand to reduce the number of casualties in Europe to a half up to the year 2010. In order to reach this aim it is necessary to use the whole potential of possibilities to increase the traffic safety. Therefore new active safety measures have to be considered. In the following chapter the methods are introduced which can be used. The safety relevant elements of the traffic are described.

3.1 Methodology for improvement of traffic safety

It is important to identify the causes of accidents and the precise human injury mechanism, before precautions for improvements in traffic safety can be developed and prefaced. Therefore accident research, –analysis and biomechanics are considered.

The aim of the accident analysis is to collect all accident-relevant factors and consider these while deducing precautions. The analysis of an accident reconstructs the accident details into technical solutions for passive and active safety. The analysis normally is based upon the accident databanks, which contain the protocols of all accidents listed by the police. The databank provides information about the type of the accident (in Germany accidents are divided into 445 different types by the Karlsruhe accident type catalogue, see Fig. 3-2), the situation of the accident, time of day, season, number of involved persons, road classification, accident severity, cause of accident etc. for every listed accident. With the help of those data the most frequent causes of accidents or crucial accident points can be identified, in order to take specific actions.

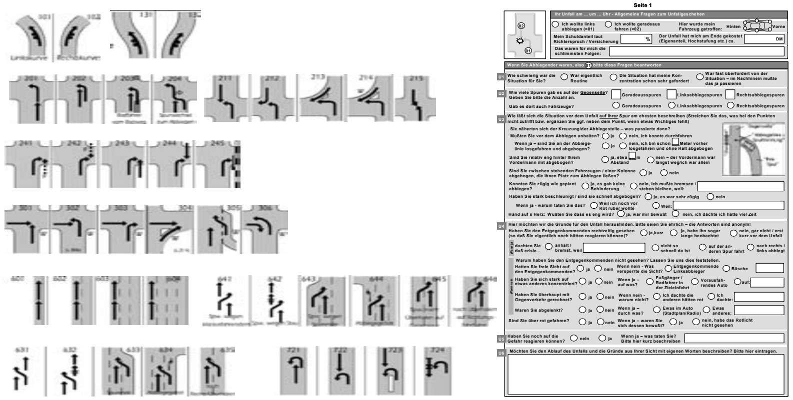


Fig. 3-2: Resources for an accident analysis, left: extract out of the Karlsruhe accident type catalogue, right: questionnaire for the analysis of cross road accidents

In order to gather information, which cannot be included into the accident databanks (subjective assessments), involved persons are interviewed. The aspect of vision and the assessment of the pre-crash-situation have a high relevance. The situation of the accident might not have been registered correctly by the person who caused the accident due to a dynamic obscuration. For solutions (especially technical applications) it is important to know these effects. The most popular listed reason, „speeding“, is not sufficient. In case the accident occurred in the dark in a curve, a system to illuminate the curve would make sense (accident databank). In case the driver was sleepy, a system to recognise the tiredness of the driver would be more

sufficient instead (interview). In case it was foggy at the accidents site at the specific time, the accident might be avoided by a foresight warning system (interview). In chapter 4 the analysis of an accident will be described in details.

Biomechanics describes the characteristics of the human body. It has a high relevance to deduce precautions in decreasing the heaviness of an accident (passive safety). In the beginning it is necessary to know the strain limits of the human body and consider them during the development of a vehicle, in order to stay under those limits in the case of an accident. In chapter 10 biomechanics will be discussed.

3.2 Traffic safety from the sight of the course of traffic

To be able to deduce precautions and to increase the traffic safety on the basis of researching accidents, the different elements, which affect the vehicle safety, must be known. Those elements can be explained with the help of the course of traffic (Fig. 3-3):

- safe course of traffic regarding the macroscopical level
- minimising the risk of an accident on a microscopical level
- avoiding the accident in a conflict situation
- protection of occupants and passengers in case of an accident
- initiation of a quick rescue and nursing of injured people after the accident

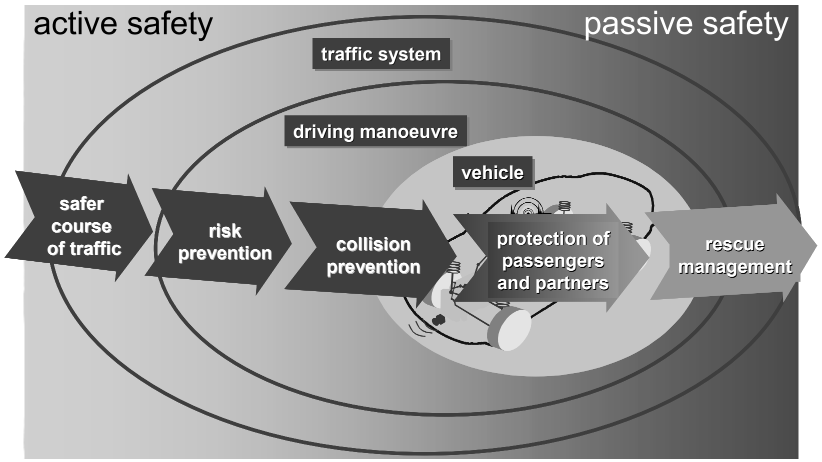


Fig. 3-3: Elements for improvement of traffic safety

Looking at the traffic system, the macroscopical sight of the course of traffic must be focused. The description of the traffic and the actual situation results from the traffic flow (number of vehicles per minute, which pass a specific cross section), the average velocity and the traffic density (number of vehicles in a specific track section). The Behaviour of a single vehicle or a single driver is on this level not relevant. The aim is to establish an efficient and safe course of traffic, with an a priori smaller account of potential accident situations.

The microscopical sight focuses on the closer look at single vehicles. Driving manoeuvres and driving situations are the keywords in that context. Minimising the risks of an accident can improve the traffic safety from this point of view.

The next level of the elements of traffic safety deals with the explicit conflict situation (potential collision). The main task at this level is the avoidance of the collision.

In case a collision is unavoidable, minimising the aftermath of the collision is the aim. Technical systems to protect the passengers and the opposing party are used.

Rescue and nursing of injured people after an accident is of paramount importance. Securing the accident site to avoid further accidents has also to be considered by the rescue management.

3.2.1 Safe course of traffic

Three factors mainly have influence in the safety of the course of traffic:

- The traffic behaviour of the driver
- The infrastructure and the environment (traffic condition, road network and the traffic control)
- The legislation

In order to evaluate the effect of one of these factors concerning the safety of the course of traffic, a dimension for traffic safety is required. Therefore the „Time-To-Collision" (TTC) has been established in traffic research. TTC describes the time, which remains at a stationary driving condition (constant velocity) until the accident occurs. It is calculated with the quotient of distance and relative velocity between two vehicles. Positive TTC-values result in an approach manoeuvre, negative ones mean a departure manoeuvre. The rate of low and positive TTC-values in a certain period of time and in a defined section is relevant for the evaluation of the traffic safety. TTC-values, which are lower than five seconds have to be considered as dangerous. An accident is usually not avoidable with TTC-values smaller than one second. The

reaction time of a driver amounts to about a second in average. In case the driver began to react previously, such values may even occur in reality without an accident happening. In literature there may be cases in which the TTC is not calculated with a constant velocity but with the actual acceleration.

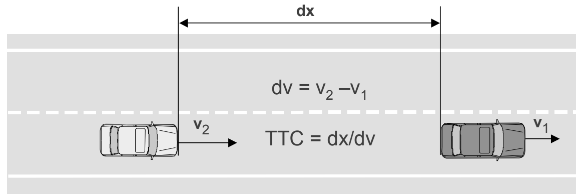


Fig. 3-4: Definition of TTC

The driver represents a factor concerning the safety of the course of traffic on the macroscopic level as well. On this level his traffic behaviour is important. This is regarded as the general driver behaviour, i.e. whether the driver is more defensive or aggressive (the type of driver and the distribution of different driver types). This must not be confounded with the driver behaviour, which is related to the situation being allocated to the microscopic level (risk prevention). Fig. 3-5 shows an example of the influence of the driver's behaviour on traffic safety.

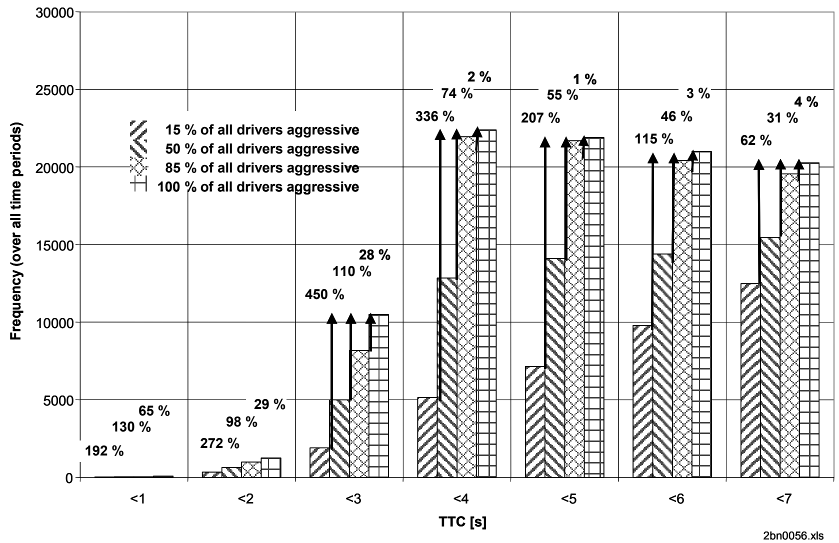


Fig. 3-5: Effects of the traffic behaviour regarding traffic safety

Traffic simulations were executed with different driver populations of aggressive drivers. The diagram shows the rate of low TTC for the respective population. For a driver population of 100 % aggressive drivers the relevant TTC smaller than five seconds is up to 4,5 times higher than a driver contingent with only 15 % of aggressive drivers.

The infrastructure and the traffic environment take main effect on the traffic safety on this level of course of traffic. Depending on the traffic conditions and on the stress they are exposed, the drivers make mistakes, which depend on the complexity of the driving task. The traffic condition depends on the amount of vehicles moving in traffic, the available road network (e.g. a highway with four or six lanes) and on the traffic control (e.g. general speed limit, no right-passing etc.).

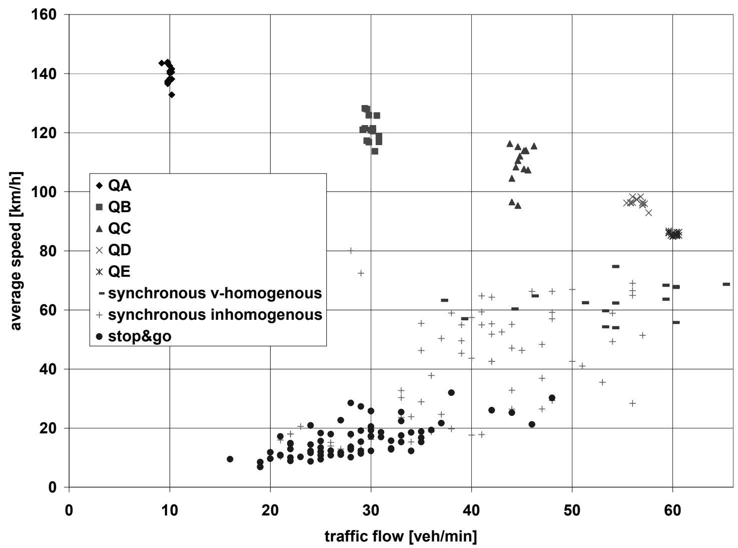


Fig. 3-6: Distinguishable traffic conditions[1]

The traffic flow can be categorized into five different traffic conditions (so-called quality steps A – E), as regarded in the manual for the dimensioning of road traffic constructions [HBS01]. These conditions vary in the average velocity and in the traffic

[1] The discrimination and simulation of these traffic conditions were done within the scope of the Virtual Institute „Human-centered Automation“

flow. The quality step A is characterized by the highest average vehicle velocity, while the quality step QE shows the lowest velocities of the free traffic flow (not congested). In case the traffic flow increases farther in condition QE (quality step E) the traffic begins to collapse. The result is congested traffic. Congested traffic can be divided into the traffic conditions „synchronous homogeneous“ (vehicles move with similar velocity, nearly no lane changes), „synchronous v-homogeneous“ (vehicles move with similar velocity but the traffic intensity varies), „synchronous inhomogeneous” (so called “traffic jam waves”, although velocity as well as traffic flow vary) and “stop & go” (complete collapse of the traffic flow). In Fig. 3-6 those traffic conditions are plotted in a so-called fundamental diagram (average velocity and traffic intensity are shown on a defined cross section).

Depending on the current traffic condition driving mistakes lead to different consequences. In this context the term of “fault tolerance“ of a specific traffic condition is used. For example driving mistakes at lane changing on the highway (lane change without setting turning indicators, lane change without consideration of the vehicles on the neighbour lane) are at the traffic condition QC most dangerous. At this traffic condition the probability to constrain another vehicle on the neighbour lane is highest. At same time the differences in the velocity of the different vehicles are also very high. At other traffic conditions the probability to restrain somebody else is lower or the differences in the velocity of the vehicles on different lanes are not so high.

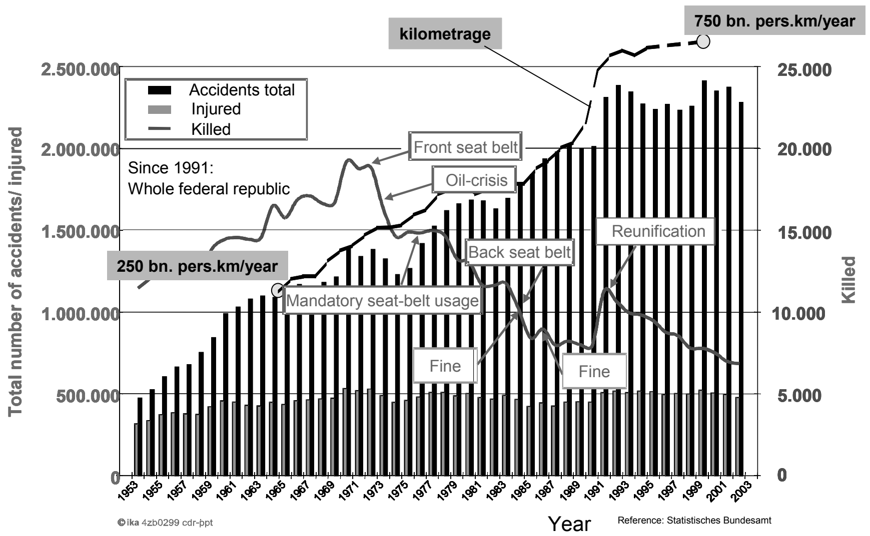


Fig. 3-7: Influence of the legislation on the number of deaths

The traffic control influences the traffic safety in a direct way, besides the indirect connection according to the traffic condition. In the past the road traffic regulations affected explicitly the number of accidents, as it is shown in Fig. 3-. The introduction of the mandatory seat-belt usage for the driver and the passengers led to a drastic reduction of the casualties (about 5000 casualties less in one year). However this effect has been superposed by the oil crisis. The main effect though is due to the mandatory seat-belt usage, because the accident rate did not increase again after the oil crisis. Fines also show a similar effect, as shown in Fig. 3-7.

3.2.2 Risk avoidance

Risk avoidance summarizes every setting element, which does not contribute to the accident avoidance directly, but minimizes the accident risk. Therefore four factors have to be considered:

- Driver
- Vehicle
- Infrastructure and environment
- Legislation

The situational driving behaviour and the driving condition is most important concerning the driver. The choice of velocity during driving through a curve or the choice of distance while following another vehicle can be assigned to the situational driver's behaviour. The driver's behaviour describes also characteristics such as fatigue, stress, attention etc. Those factors do not lead necessarily to a traffic accident but they influence the accident risk significantly. The driver can be supported during his activity through technical systems (so-called driver assistance systems, which are explained in chapter 8)

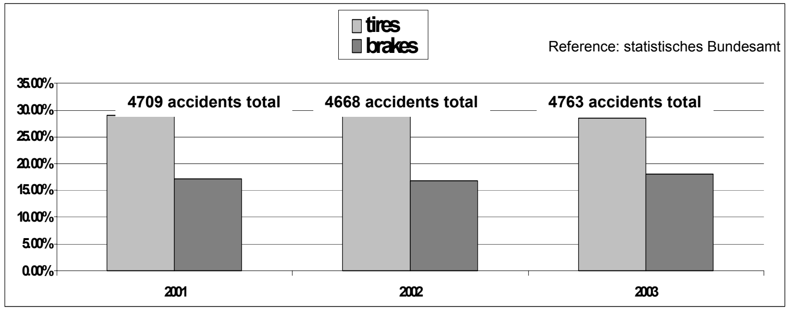


Fig. 3-8: Amount of accidents being caused by technical defects (tires and breaks)

The vehicle body and vehicle conception influence also the accident risk. Important aspects regarding the accident risk are the chassis concept, the quality of safety relevant parts, the concept of control elements the sight conception, climate conditioning, illumination and lighting etc. It is important for the driver to be able to evaluate the kind of lateral force the vehicle may carry, e.g. during cornering. Therefore the feedback of the vehicle is important (e.g. tire squeal). About 45 % of all accidents are caused through technical defects, which can be traced back to the tires and the brakes (see Fig. 3-8). This fact hardly changed in the last three years and can be traced back to the overall lifetime of modern vehicles as well. It has to be regarded in the development process of new vehicles. The aim is to design a vehicle, which gives consideration to the abilities and the limits of the human driver.

Regarding the relation of the kilometrage at day and night and the amount of accidents occurring at day and night the importance of illumination and lighting is becoming obvious. During the day the amount of kilometrage is three times higher than at night, but the accident rates do not differ very much (see Fig. 3-9). Besides the poor visibility this effect certainly is superposed by fatigue and other night-specific phenomenon. However the figure shows the potential of an optimised lighting unit (road lighting as well as vehicle lighting). Chapter 5 deals with the different lighting units in a more detailed way. Further aspects of the vehicle design, such as control conception, sight conception and conditioning will be explained in chapter 6 respectively chapter 7.

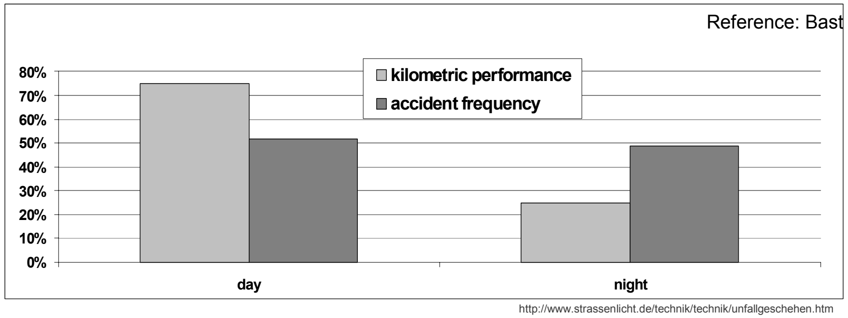


Fig. 3-9: Influence of the lighting on the accident

The third most important factor, the infrastructure and the environment, is a key object in order to minimize the risk of an accident. In this connection however, not every element in the reduction of the accident risk can be influenced, such as weather conditions. With infrastructure measures, for example variable message signs, the driver can be informed to the changed conditions in order to adapt his driving style. Infrastructure measures are also the safe configuration of potentially dangerous track sections and junctions, such as crossroads or curves (traffic lights, traffic light control, turning lanes, street lighting, road condition, speed limit etc.). Many accidents happen at so-called crucial sites, which can be avoided by a redesign of that specific site. Fig. 3-10 shows a negative example for the design of an intersection. This construction of several intertwined roundabouts is complex and confusing particularly for foreigners or older people. The driver almost needs every resource in order to orientate. Therefore he may react too late to unexpected events.

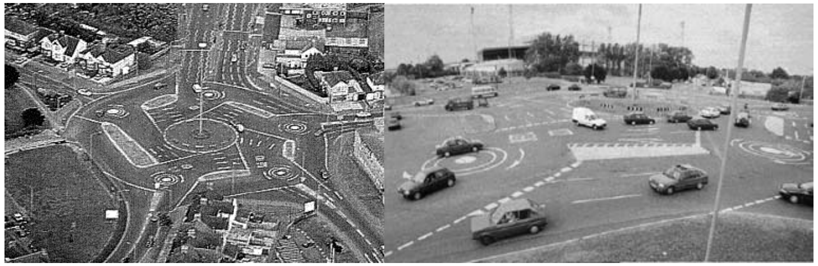


Fig. 3-10: „Magic roundabout“ (Swindon, England)

The legislation takes influence on the accident risk through the traffic regulation (speed limits, prescribed safety distances, right of way rule etc.) and the control of the compliance.

3.2.3 Collision avoidance

In a potential collision situation the degrees of freedom to avoid a collision decline. Swinging out or braking are the only possibilities in these situations, see Fig. 3-11.

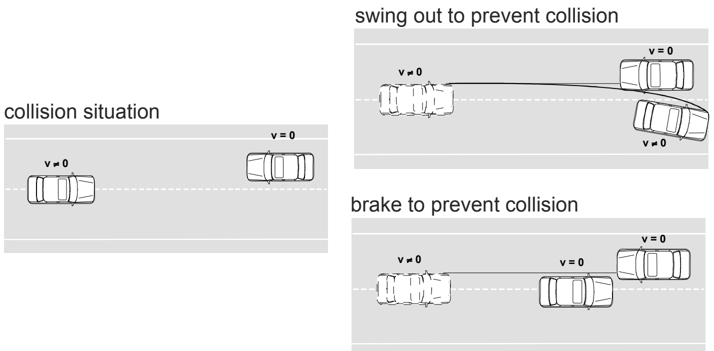


Fig. 3-11: Possibilities to avoid a collision in a conflict situation

The driver and the vehicle are main factors for the collision avoidance. The infrastructure only plays a minor role (friction coefficient). The recognition and the assessment of the situation are significant for the driver. If he recognises the situation correctly, he can take actions to avoid the collision. In order to determine if his action is successful, the driver’s skills are important (reaction time, foot- and handstrength etc.). The vehicle itself has to transfer the reaction of the driver. The vehicle has to provide enough braking force to reach the required braking distance or enough lateral force to swing out. Technical systems can assist or take over parts of the tasks from the driver in the overall process of the collision avoidance. This can be realized from detection of the critical situation, to the assessment of the situation up to the realisation of the reaction (see also chapter 8 and chapter 9).

3.2.4 Protection of passengers and opposing party

Precautions to reduce the accident aftermath have to be initiated, if an accident cannot be avoided. Therefore three main topics have to be considered:

- Vehicle structure
- Restraint systems
- Pre-crash-systems

The task of the vehicle structure for the protection of the passengers is to obtain the passenger cell, absorbing as much kinetic energy as possible and limiting the deceleration. For the protection of accidents partners a crash-compatibility is needed which adapts to the opposing party (pedestrian, motorcyclist, vehicle). Further details referring to the structure are given in the lecture „Structural design of motor vehicles“.

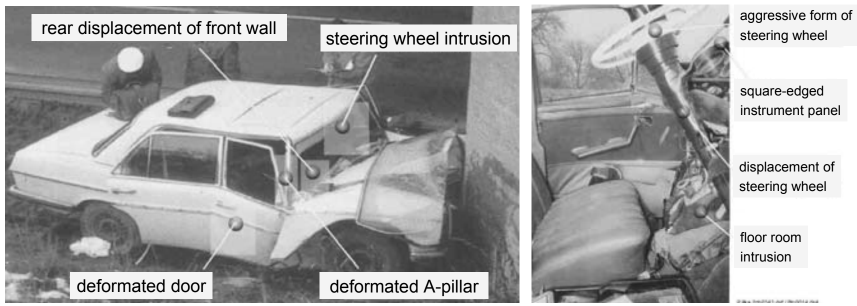


Fig. 3-12: Vehicle body in the past: unfavourable structure, no restraint systems

Restraint systems provide protection up to the biomechanical limits of the human body. They should obtain a constant deceleration of the passenger by using the available shifting space. Fig. 3-12 and Fig. 3-13 give a first impression of the development of vehicle structures and restraint systems in the past decades. Restraint systems and their realisation are described in chapter 12.

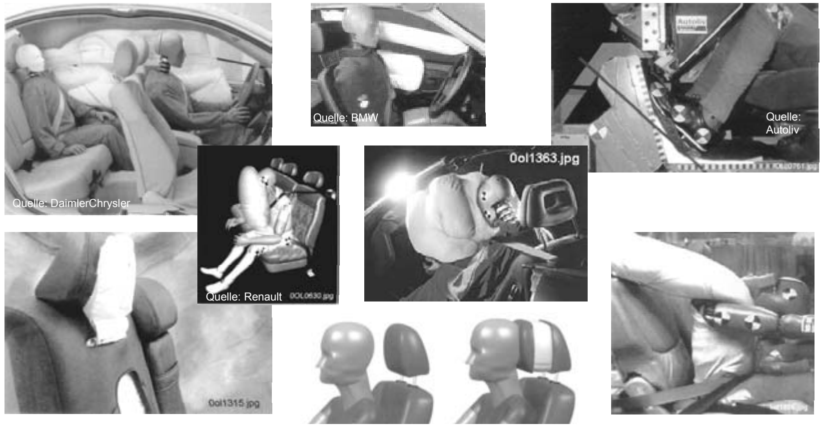


Fig. 3-13: Restraint systems in a modern vehicle

Modern restraint systems react before the crash. Thanks to different sensors an accident can be stated before the contact of the vehicles. These information can be used in different applications e.g. reducing kinetic energy through an emergency braking. The system reaction time can be compensated through an early release of the restraint system. Adaptive crash-structures for a better energy absorption can be activated before the crash. An ideal positioning of the passengers is conceivable (seat adjustment). Detailed description of pre-crash-systems follows in chapter 13.

The aftermaths of a crash can be minimised, by initiating a suitable rescue management. This can be divided into different steps. First of all it is important to inform the rescue forces. Relevant information are:

- Time and place of the accident
- Type of accident
- Number of injured passengers and other involved people
- Possible intensity of injuries

The next step of the rescue management is to secure the accident site. Technical systems can warn other vehicles, which approach the accident site. Additionally the security forces should be advised, to initiate further precautions in order to secure the accident site. In chapter 13.3 post-crash-systems are explained.

4 Accident Research

The following chapters deal with the measures for the improvement of the passive safety and its scopes that are represented in Fig. 4-1. Action priorities result primarily from the outcome of the accident research, which can be divided in the areas accident investigation, accident statistics, accident reconstruction and accident analysis. The results of these investigations regarding the injury mechanisms can be used for the creation of continuative safety measures. The task of the biomechanics consists in the determination of the load ability of single body parts. The use of numerical and experimental simulations under consideration of these limits allows to give statements concerning the efficiency of the corresponding measures already before the series introduction.

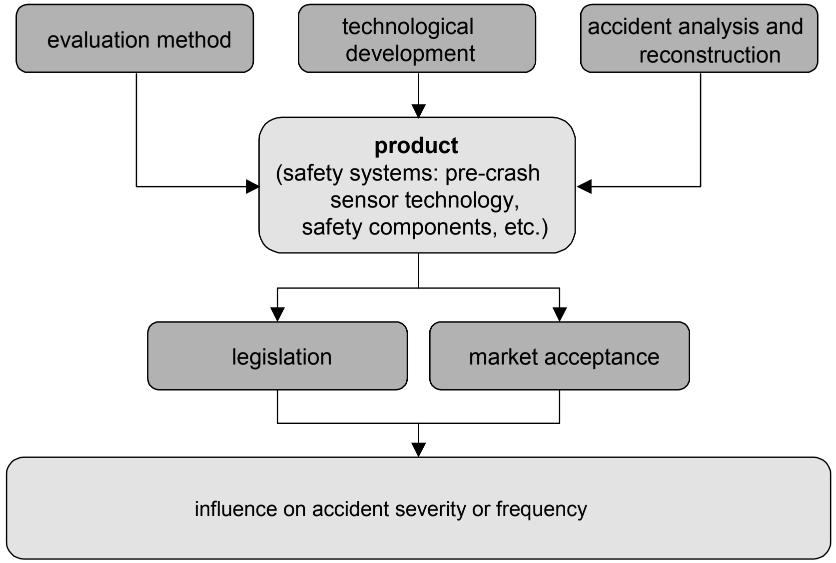


Fig. 4-1: Development and mode of function of safety relevant systems

The task of accident research is to clear up accident causes and thus to show the call for action at the real traffic. Especially injury relevant and often happening accident configurations can be investigated with regard to its biomechanical injury mechanisms. Constructive improvement measures at the vehicle can then be developed and tested on this basis (compare with Fig. 4-2).

Accident analyses allow efficiency controls of the safety measures by comparing investigations and previous/afterwards-analysis. Thus they provide the possibility, to orientate the necessary mass of passive safety at the actual accident situation.

A classification of the accidents according to speed ranges, collision types and mass proportions of the accident partners, as well as the type and amount of injuries allows the determination of standard accidents. The safety research can concentrate itself on these standard accidents, which cover the predominant part of the accident situations. Thus the safety research can control corresponding safety measures on its efficiency with regard to conditions close to reality.

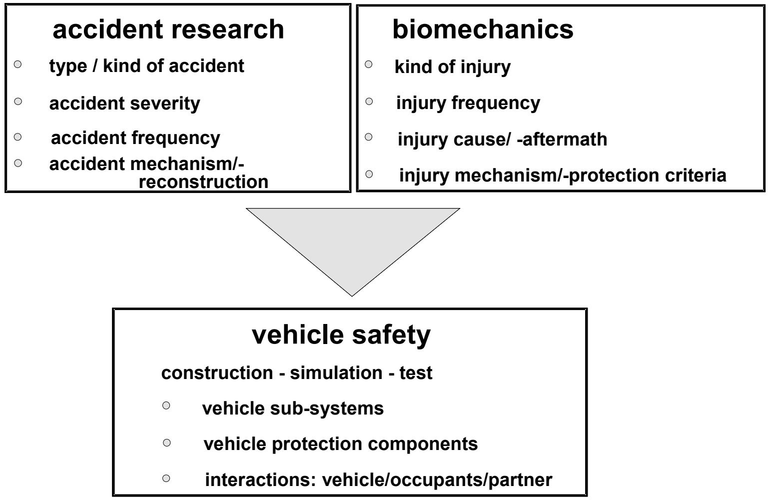


Fig. 4-2: Effects of Accident Research and Biomechanics on the Vehicle Safety

The tasks of the accident research can be subdivided into a technical, medical and a psychological area.

The technical area should determine characteristic factors, which describe the mechanic behaviour of human beings, vehicles and environment during an accident. The results of experiments with volunteers, dead bodies, animals and dummies as well as from numerical simulations with calculative models serve as input parameters.

The evaluation of medical reports (e.g. from hospitals), medical diagnosis and pathological statements in order to get statements about the type and the causes of injuries, can be assigned to the medical range.

The psychology should finally analyse the causes that lead to an accident by means of interviews with accident participants and accident witnesses.

4.1 Accident Statistics

The basis for the accident analysis is the data collection and the statistics in order to achieve an understanding of the accident- and the injury mechanics. Two sources are available at the moment for the provision of the necessary accident data. On the one hand, information from notification sheets by the police are used, which are available for a large number of accidents. They are primarily generated for the clarification of the question of guilt after collision and thus are often not significant for the scientific accident analysis. The second possibility is the use of results from so-called „in-depth"-investigations, which are generated by professional accident research teams. Into these surveys, single accidents are concretely analysed on location and interviews with participants are performed.

The gained information is evaluated with statistical means so that e.g. temporal developments or frequency distributions are established.

Fig. 4-3 shows exemplarily a worldwide comparison of deadly accidents in the year 1997.

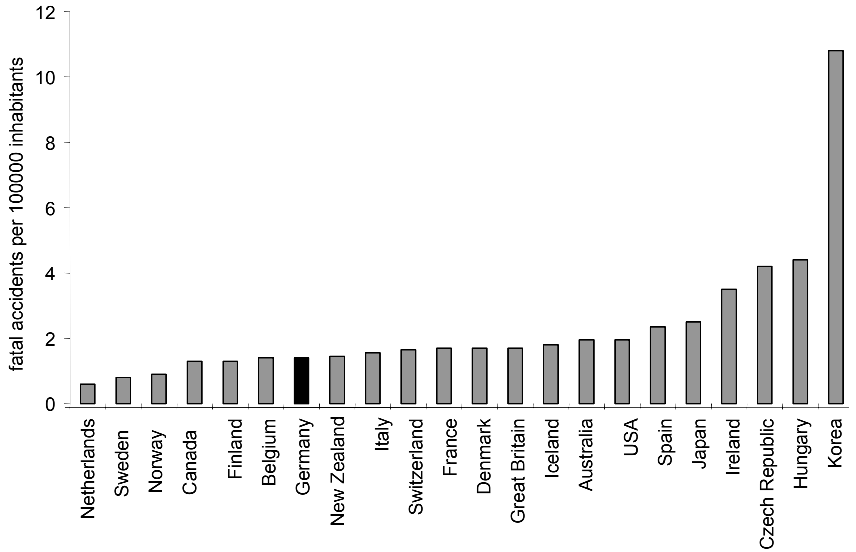


Fig. 4-3: Deadly accident 1997 [SZA04]

The outstanding ranking of the Scandinavian countries as of Belgium and the Netherlands is eye-catching, while Germany performs comparably well with less then two deadly accidents per 100.000 inhabitants. The good positioning of the Scandinavian countries can be ascribed to the low density of population and the high development of the infrastructure and the traffic organisation. Korea in contrast has a high population density, which means a high density of pedestrians and traffic combined with a significantly bigger participation of cyclists, which are less protected than car drivers. Furthermore, the European countries normally provide a faster medical attendance compared to Korea [GIE02].

An itemisation of the killed and injured persons in Germany due to the type of their traffic participation (2003) can be taken from Fig. 4-4. Nearly two thirds of the victims belong to the group of the passengers. The exterior traffic members are involved in about 25 % at the accident event, but it has to be considered that their proportion is rising in urban areas and reaches a value above 50 % [STA03].

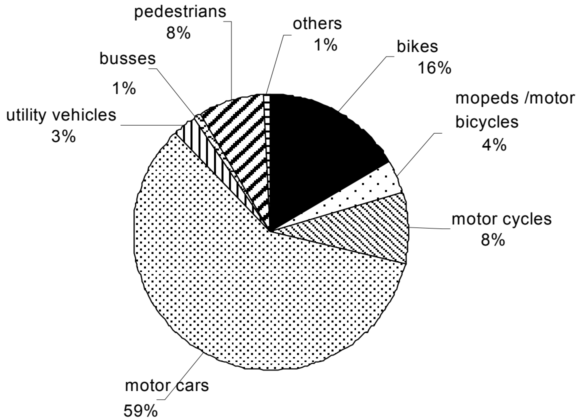


Fig. 4-4: Proportions of casualties at accidents in [STA03]

The causes of the accidents with bodily injuries can be divided into general causes, like for example roadway slickness, line-of-sight obstruction or crossing game, as technical defects and malpractice of the driver

Fig. 4-5). The general causes decreased from 35.782 to 34.230 between 2001 and 2003, technical defects, which occur predominantly on brakes and tires, were at 4.709 (2001) respectively 4.763 (2003) [STA04]. But the far biggest part of the accidents is caused by the malpractice of the drivers.

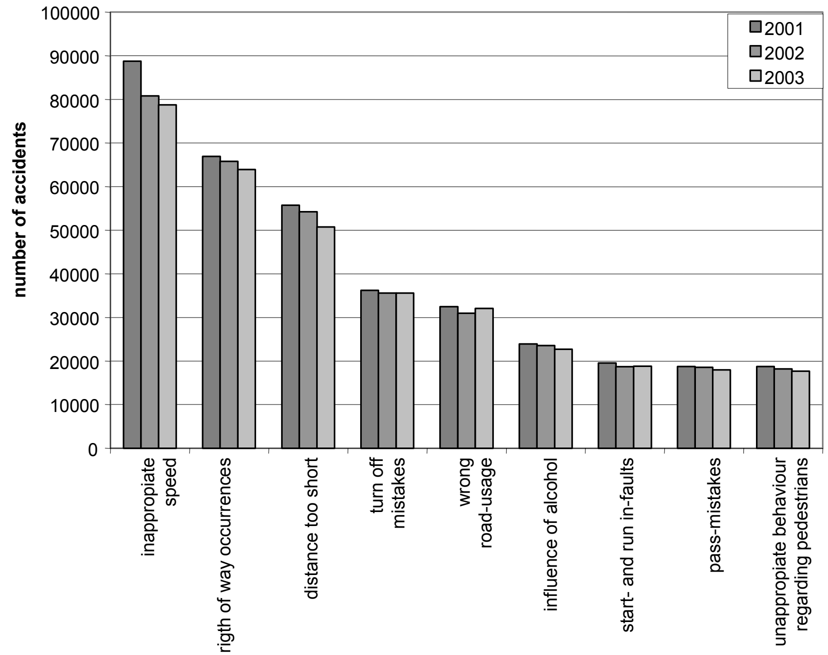


Fig. 4-5: Accident causes by malpractice of the driver [STA04]

The absolute figures decreased from 466.863 (2001) to 443.293 [STA04] in 2003, whereby you can see in Fig. 4-5, that this reduction is distributed regularly in the single causes. This results of several reasons. First of all of the technical improvement in the vehicle construction and better security equipment and second as of a more and more dense rescue system. [ADA03]

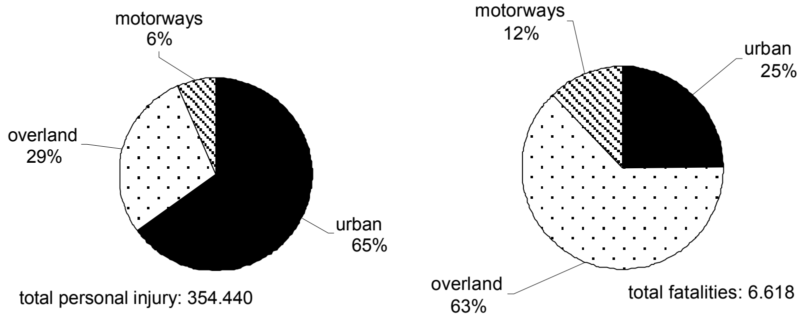


Fig. 4-6: Accidents with bodily injury an killed people by location in 2003 [STA03]

Fig. 4-6 shows the rate of accidents with bodily injuries and killed people according to the locations urban, overland (without motorways) and motorways. In spite of an overly part of bodily injuries urban (65 %), the ratio of the killed people is just 25 % because of the slower velocities. The respective ratio of accidents on motorways is the lowest. The reason is the more concise flow of traffic. This relatively high part of killed people in accidents on motorways has to be pointed out which shows that these accidents have a high relevance on injuries.

4.2 Classification of Accidents

A classification of the accident to a definite structure is necessary in order to be able to assign an accident to a specific category and thus to create the basis for statistic evaluations, see Fig. 4-7.

At first a definition of different **kinds of accidents** is necessary due to the diverse collision properties of the single traffic members. The most frequent kinds of accidents are:

- passenger car accident
- bicycle accident
- commercial vehicle accident
- pedestrian accident

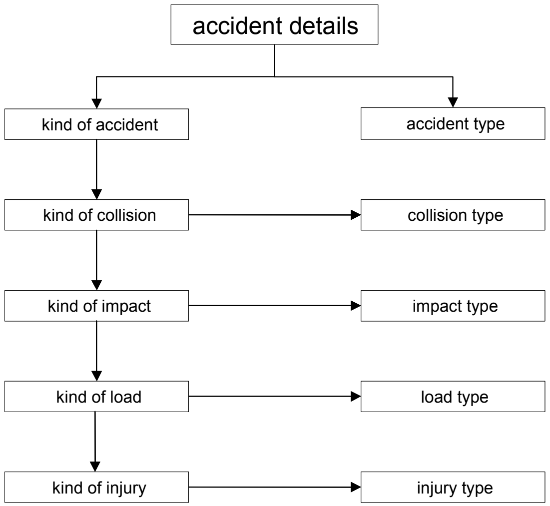


Fig. 4-7: structure of accident details [KRA98]

A further important aspect in the frame of the accident research is the minimisation of the consequential costs of accidents. They are represented for different collision types in Fig. 4-8. Passenger car accidents, which cause about 84 % of the injury costs, form the greatest proportion also in this case. At accidents with participation of cyclists or pedestrians, the complete costs occur on the side of the exterior traffic members. A reduction can therefore exclusively be reached by an improvement of the exterior safety.

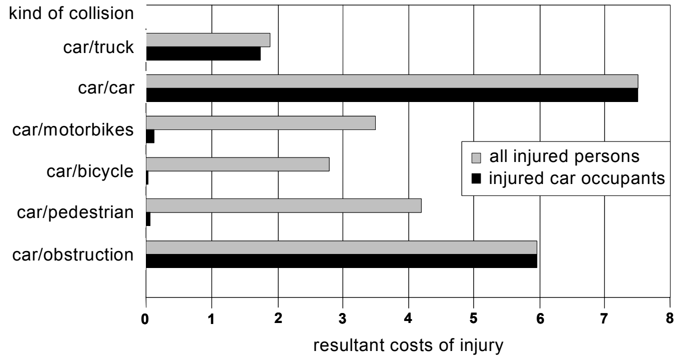


Fig. 4-8: Consequential Costs of Passenger Car Accidents [KRA98]

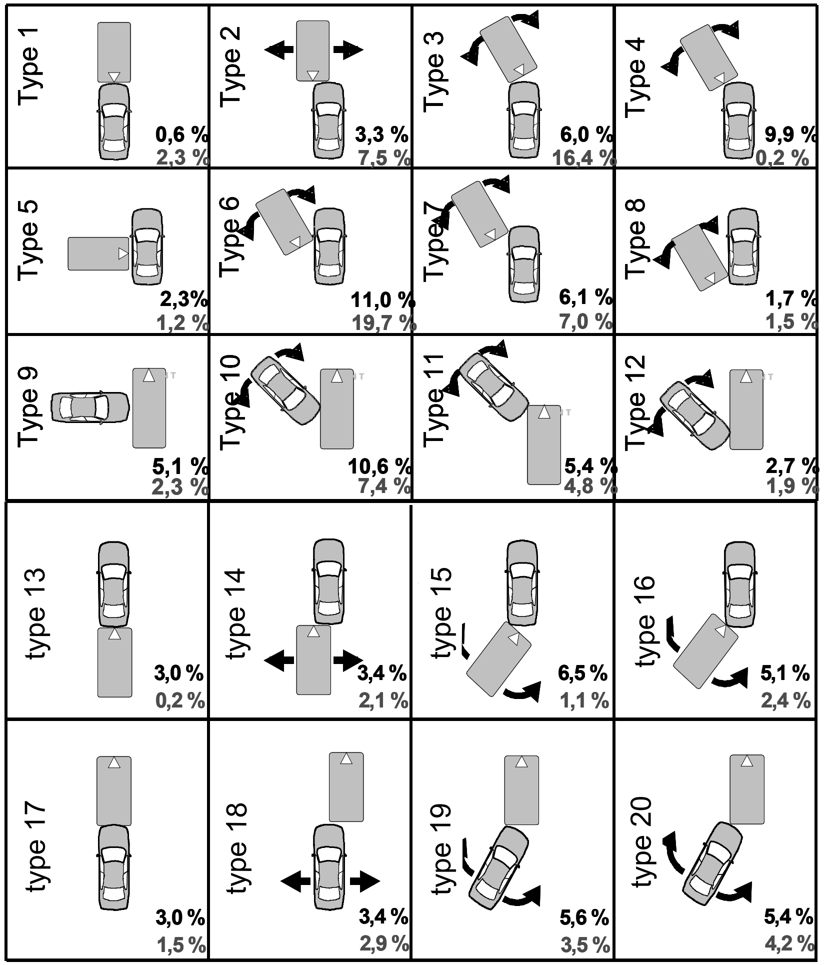
The classification of the **accident type** takes place according to the accident development. The accident type can be distinguished as follows:

- driving accident
- turn off accident
- crossroad accident
- pedestrian crossing accident
- accident by resting traffic (e.g. parked vehicles)
- accident in the transversal traffic
- other accidents

It has to be stated that a big part (ca. 85 %) of the traffic fatalities is killed by the driving- and pedestrian crossing accident so that this accident types deserve a special consideration in the frame of passive safety improvements.

The possible multiple counting at the classification of different kinds of accidents will be prevented by the definition of different **kinds of collisions** , because a classification due to all accident participants takes place in this case (e.g. car/car-accident, car/pedestrian-accident).

A matrix of different **collision types**, which considers the geometrical realities of the accident, is generated for each kind of collision. A matrix like this is represented here for the collision types car/car (comp. Fig. 4-9) and car/obstruction (comp. Fig. 4-10).

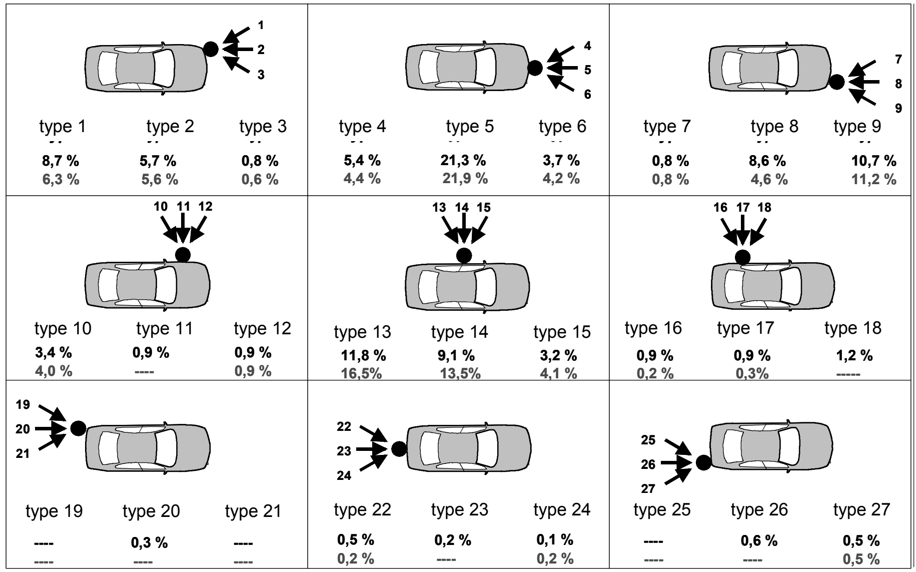


accident frequency

occupants injury MAIS2+

Fig. 4-9: Collision Types Car/Car [OTT97]

It is evident that collisions in the front- and side area of vehicles are most frequent. The driver's side is more often affected than the drivers mate side at side impacts. Frequency distributions like that provide information for the legislative prescribed crash-test-procedures. The frontal crash with an offset of 40 % against a deformable barrier and the lateral pole impact thus came up in Europe.



accident frequency **occupants injury MAIS2+**

Fig. 4-10: Collision Types Car/Obstruction [OTT97]

For the determination of the kind of impact, the accident situation is solely considered from the sight of the considered accident participant. The following collision types can be defined for the passenger car:

- front
- side
- rear
- roll over

The **impact type** describes in which area and to which amount the structure of the vehicle is loaded. The position of the damage and the degree of overlap will be considered for the classification into the different classes.

The claimed body ranges of the accident participants are stated in the **kind of load**. The **load type** refers to the boundary conditions according to the passenger protection. The seat as well as the seating position and the usage of the restraint system are registered. A statistics for the load type at passenger car collisions is shown in Fig. 4-11.

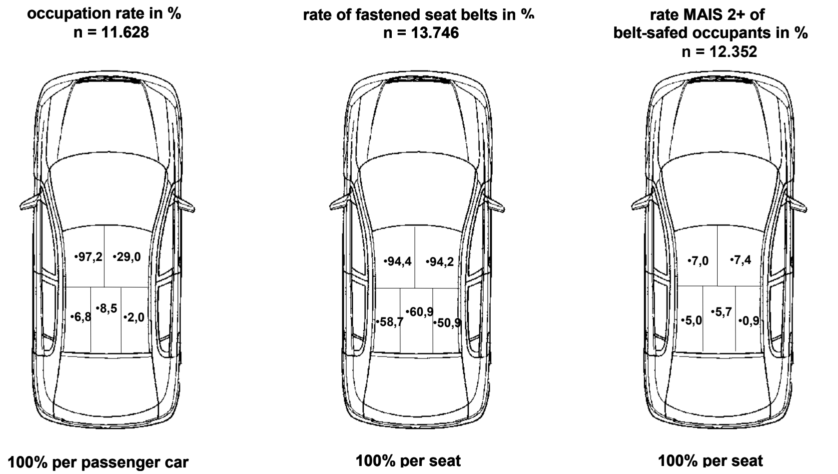


Fig. 4-11: Load Type at passenger vehicle collisions [MHH98]

The **kind of injury** differentiates e.g. between fractures, organic- and vascular injuries. The **injury type** considers different mechanic injury mechanisms. Injuries are differentiated based on

- direct force application
- indirect force application
- inertia forces
- hyperextensions and –flexions (over bending, overturning)

Finally, an evaluation and classification of accidents is necessary due to the injury severity. The definition of this parameter is yet not defined clear without ambiguity. While technical experts often use the physical vehicle load as a criterion, physicians frequently consider the severity of the passenger injuries as the decisive criterion. All influencing parameters for the complete recording of the accident severity are presented in Fig. 4-12.

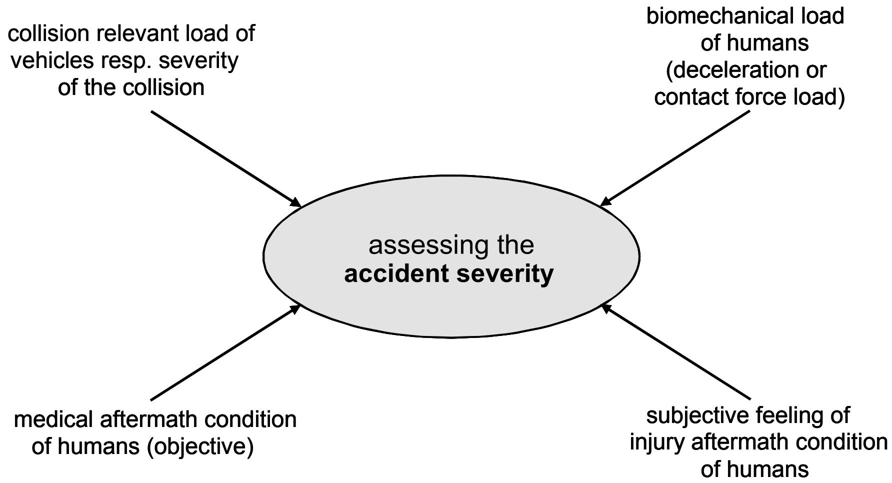


Fig. 4-12: Evaluation of the Accident Severity by means of parameters [BER99]

The collision conditioned load of the vehicle that is also defined as the severity of the collision, can be exemplarily described by the following parameters and characteristics:

- exterior damages
- intrusions into the passenger cell
- speed difference
- energy-equivalent speed (EES)
- average and maximum vehicle deceleration.

The biomechanical loading of the human being is basically determined by the following influencing parameters:

- passenger deceleration under consideration of restraint systems
- contact force
- stiffness and form of impact areas in the interior
- position and mechanical characteristics of the seat

The medical aftermaths for the human being are described by:

- morphology of the injuries
- results of medical tests
- objectively accident aftermaths

The subjectively felt aftermaths of the human being registers the influence of non-objectively medical and psychological findings.

5 Lighting Equipment

Lighting units in vehicles are used for different purposes:

- Front lights
- Tail lights
- Indicator lights
- Main brake lights
- Additional brake lights
- Fog headlight
- Fog taillights
- Limiting and outlining lights
- License plate light
- Backing-up light
- Parking lights
- Daytime driving lights (e.g. Sweden)

In the following section only the front lights are dealt with.

With the design of the headlight systems, the conflicting aims - range of vision and safety have to be considered, Fig 5-1. For the achievement of larger ranges of vision, long-range headlights having a high luminous intensity and a sufficient dispersion on the side and elevation are used; the optical demands being rather small. Further, the low beam must be so designed as to avoid dazzling the driver of the oncoming vehicle. The legislation prescribes a minimum and maximum lighting power, depending on the lit zone in front of the vehicle.

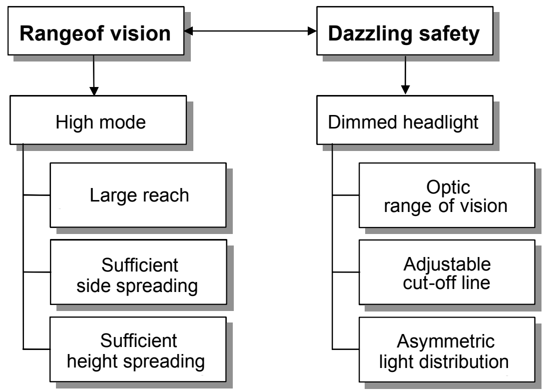


Fig 5-1: Demands on headlights

A characteristic for the asymmetrical low beam headlight is the definition of a light-dark boundary, Fig 5-2. For the right-hand traffic it runs horizontal to the left away from the vehicle axis and to the right it rises at an angle of 15 °. In the longitudinal direction of the vehicle, the light-dark boundary with reference to the headlight centre, moves downward, lowered by 1 %, i.e. around 25 cm over a distance of 25 m.

Above the light-dark boundary is the area of glare. The intensity of light from the low beam should not amount to more than 1 lx, 25 m in front of the vehicle. Within the area of oncoming traffic, this limit value amounts to only 0.6 lx. Below the light-dark boundary, a high intensity of light is desired.

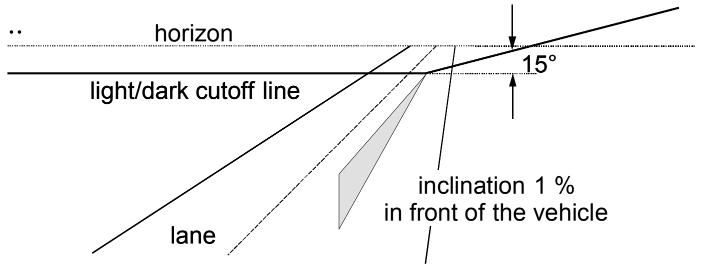


Fig 5-2: Light-Dark boundary for the asymmetrical headlight low beam (right-hand traffic)

Apart from the lighting power, the number and the location of headlights is also prescribed by the law. For example, the headlight low beam in multi-track vehicles requires at least two lights. For the high beam at least two, but at the most four headlights are allowed.

A headlight usually consists of the following essential components:

- Reflector
- Lighting unit
- Housing
- Covering frame
- Cover plate
- Bulb holder

Headlights can basically be differentiated into Reflection systems and Projection systems. In reflection systems the light is distributed by reflectors onto the road. In projection systems a beam of light is projected onto the road by a lens.

5.1 Reflectors

There are four different headlight systems, and these differ due to the form of their reflectors: Paraboloid Headlight, DE Headlight, Super DE Headlight and FF Headlight.

5.1.1 Paraboloid Headlights

In the paraboloid headlights the reflector surface forms a paraboloid, i.e. a parabola turned around its axis, Fig 5-3, in such a way that the light radiated upward is reflected downward by the reflector, about the Z-axis, onto the road. Hence the light is almost parallel up to the point of divergence of the light beam and depending on the size and position of the filament of the lamp. In the headlight low beam a screen ensures the fact that light is radiated only from the upper half of the reflector thus preventing a dazzle to the oncoming traffic. The paraboloid headlight operates on the principle of reflection.

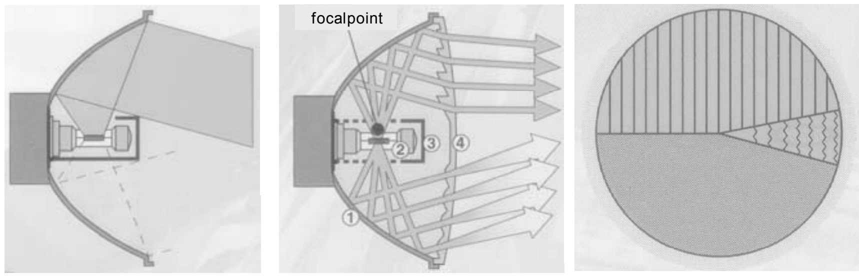


Fig 5-3: Paraboloid Headlight in low beam, source: Hella

Optical elements in the headlight glass cause the distribution of the light, so as to fulfill the legal demands. Cylindrically shaped profiles that are placed perpendicularly cause a horizontal distribution of the light. Prismatic structures located higher in the optical axis disperse the light upwards.

With an increasing size of the reflector the effect of the headlight low beam improves. A construction that is as large as possible results in a large geometric range, but this is however not always possible due to aerodynamic reasons.

The illuminated field is also influenced by the focal length of the reflector. Smaller focal lengths produce broader light beams with a better front and side lighting, Fig 5-4.

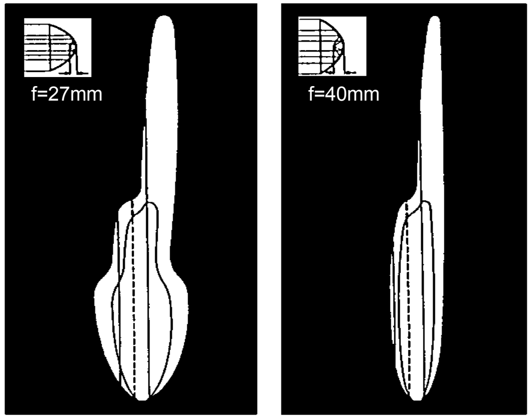


Fig 5-4: Light field depending on the reflector focal length

Due to a larger reflector surface better results can be attained for the high beam in rectangular Paraboloid headlights than with circular designs.

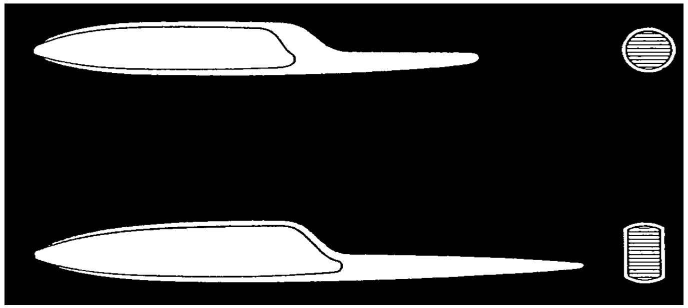
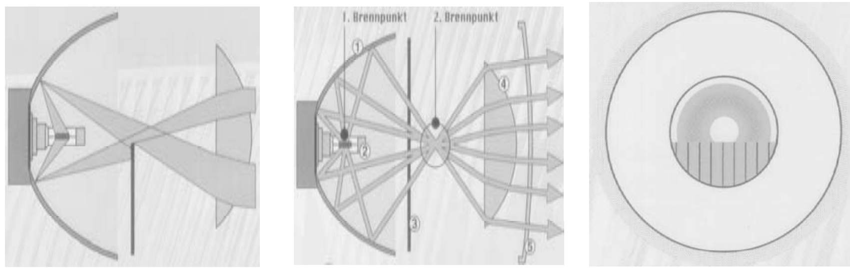


Fig 5-5: Light field depending on the reflector form (High beam)

5.1.2 DE Headlights

The reflector DE headlight has the form of a three-axis ellipsoid (DE). The reflector reflects the light onto the focal point of a lens that projects the light, parallel and onto the road. The outline of the screen behind the lens is projected as the light-dark boundary onto the road. The DE Headlight is based on the principle of projection.



Side view Top view Front view

1: Reflector 2: Shield 3: Screen 4: Lens 5: Glass

Fig 5-6: DE Headlight in low beam, source: Hella

The projection system is very well suited for a deeper penetration during fog, because it can produce very sharp light-dark boundaries. However with the headlight low beam, soft and small proportions of scattered light are desired so that road signs (which are placed at a height above the road surface) are visible.

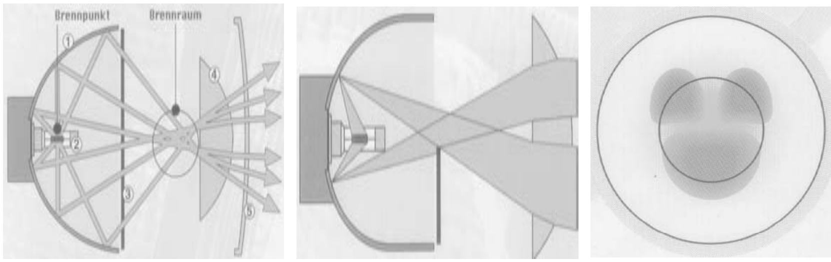
The DE headlight is advantageous when compared to the paraboloid headlight owing to a better lighting performance in the low beam and also requires a smaller mounting space. Long-range headlights however offer no significant advantages.

The variation parameters for adjustment of the lighting characteristics are:

- Size and relation of the focal lengths and axes.
- Position of the glowing filament in the reflector.
- Size and focal length of the lens.
- Optics of the headlight glass.

5.1.3 Super DE Headlight

Super DE headlights are projection headlights, whose reflector surfaces cannot be described by basic mathematical forms, but are formed freely in space. The free spaces are arranged in such a way that the light distribution is no more regulated by a screen but can contribute almost the entire light generated towards lighting. For the design of the reflector surfaces special computation methods are necessary. With the same mounting space the luminous efficiency of super DE headlights is clearly higher compared to that of simple DE Headlights.



Side view Top view Front view

1: Reflector 2: Shield 3: Screen 4: Lens 5: Glass

Fig 5-7: Super DE Headlight in low beam, source: Hella

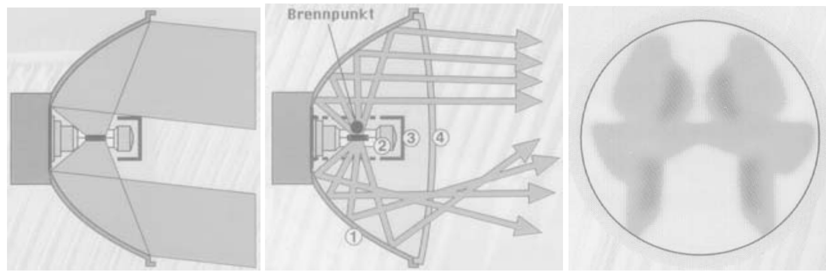
The improvement of the luminous efficiency of super DE Headlights in comparison to the simple DE Headlights is shown as a percentage. The Lighting power of the bulb is hence set to 100 %.

Losses	DE	Super DE
Not emitted from the reflector	13.6%	13.1%
Shaded through Dazzle	39.7%	20.0%
Lens	5.6%	8.0%
Tinted shield	4.9%	7.1%
Luminous efficiency	36.2%	51.8%

Fig 5-8: Lighting losses (power of the bulb = 100 %)

5.1.4 FF Headlights

Free Form (FF) Headlights, similarly, have reflectors freely formed in the space. This type of headlight operates on the principle of reflection, Fig 5-9. Due to the design of the reflector no screen is necessary for the low beam.

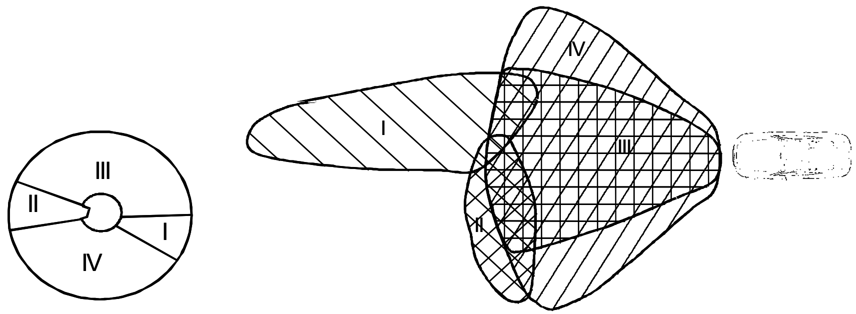


Side view Top view Front view

1: Reflector 2: Shield 3: Screen 4: Lens 5: Glass

Fig 5-9: FF Headlight in low beam, source: Hella

The reflector is arranged in such a way that the individual reflector zones in each case fulfil a certain function, Fig 5-10.



zone I: asymmetric sector - distant zone right road side
zone II: symmetric side - direct beneath the HD - boundary
zone III: nearfield primarily - lane illumination
zone IV: nearfield primarily - culisse illumination

Fig 5-10: Light distribution divided into reflector zones

5.1.5 Comparison of the Types of Headlights

For a comparison of the different headlight systems the relative lighting power is judged on the basis of a circular paraboloid reference headlight of diameter 120 mm, Fig 5-11. For smaller sized lights the ellipsoid headlights have a clear advantage since their lighting power is independent of the headlight size. However if sufficient mounting space is available, then FF headlights with a starting diameter of approximately 170 mm are found to offer a better performance.

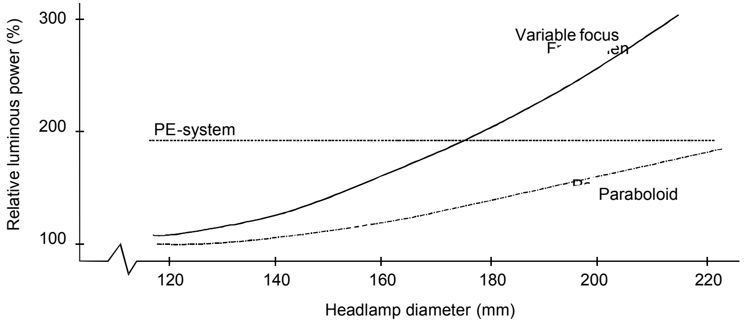


Fig 5-11: Relative lighting power with the same mounting space

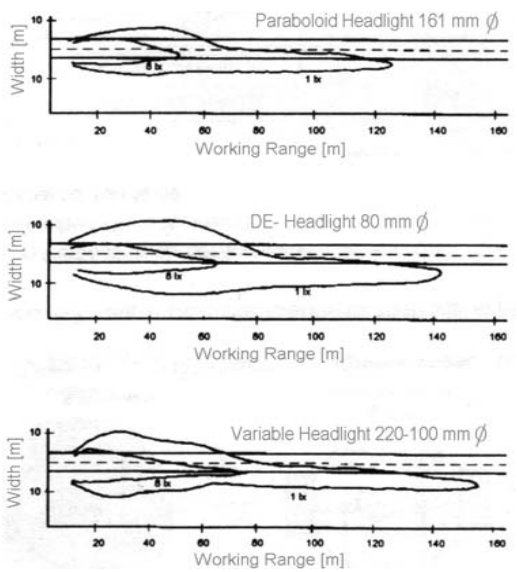


Fig 5-12: Lighting widths

A further criterion for evaluation of headlights is the lighting width. This is the distance at which the density of light drops by 1 lux. In comparison to ellipsoid headlights the FF lights do not possess a higher lighting width and the frontal illumination is, however, homogeneous. Both these systems are clearly more efficient than conventional paraboloid headlights, Fig 5-12.

5.2 Bulbs

Electrical glow filaments, halogen bulbs and gas-discharge lamps are used as lighting bulbs. In all these light sources, electromagnetic radiation is produced due to the outer electron shells (of atoms) becoming active causing them to assume a higher energy level. The transition of these electrons to a lower energy level results in the radiation of electromagnetic waves. The sources of light can be differentiated based on the type of the energy input, which subsequently leads to the excitation of the outer electron shell.

Electrical glow filaments and halogen bulbs are temperature emitters. The energy level of the electron shells is increased by the supply of heat energy, as the tungsten filaments begin to glow. The evaporation of tungsten (melting temperature 3660 K), however, leads to the blackening of the bulb and limits the life span. Glowing filaments are hardly used in today’s headlights.

Halogen lights allow an increased filament temperature due to the presence of a gas. In the proximity of the bulb, evaporated tungsten reacts with the filling gas to form tungsten halide, which is again deposited on the filament by convection. There it decomposes again due to the high temperature and this leads to a cyclic process. The rising gas pressure additionally prevents evaporation and leads to a higher luminous efficiency. The luminous efficiency of halogen bulbs exceeds that of the filament bulbs by approximately 70 %.

In gas-discharge lamps, a bulb filled with a noble gas maintains a gas discharge by the creation of a potential difference between two electrodes. The excitation of the atoms of the radiating gas does not take place by temperature, but by impact. Modern gas-discharge lamps, e.g. type D2S, are equipped with a protective bulb in order to filter ultraviolet radiation. As a rule the life span of modern gas-discharge lamps exceeds the life span of the motor vehicle itself.

Glow lamps are operated in combination with an electronic fluorescent lamp ballast. After being switching on, for igniting the arc, the control electronics produce a sequence of high voltage pulses (10 – 20 kV). Since the glow lamp has a substantially slower response time than a halogen bulb, during the first few seconds of operation the triggering current is increased up to twice that under normal circumstances and hence a separate power-output stage (max. 100 W) is necessary. After approximately 1 s, 50 % of the final value of the current is achieved. If the controller detects a sufficiently stable arc, the electronics then switches to a power and current limiting operation mode.

In order to be able to adhere to the prescribed maximum values of luminous intensity below the light-dark boundary towards oncoming traffic, despite the higher luminous intensity of gas-discharge lamps, a higher importance is attached to the contrast transition in the optical system of headlights. Here projection headlights are particularly suitable.

Conventional halogen bulbs at higher powers reach critical temperature ranges since a majority of the electromagnetic radiation lies in the invisible infrared region. Gas-discharge lamps achieve three-times the luminous efficiency with a substantially higher proportion of light of a shorter wavelength, as a consequence of which the thermal stresses are also lowered by around 40 %. Fig 5-13 and Fig 5-14 compares the characteristics of these two bulbs.

Parameter	Unit	H1	D1	D2S
Luminous intensity	lm	1550	3000	3200
Mean luminance	cd / cm^2	2000	6000	6000
Colour temperature	K	3200	4300	4000
Electrical power consumption at 13.8 V inclusive of the electronic ballast	W	63	40	40
Efficiency inclusive of the electronic ballast	lm / W	25	75	80

Fig 5-13: Light Intensity and electrical efficiency with 13.8 V

The comparison of two ellipsoid headlights with a halogen lamp and a discharge lamp using the D1-Lamp shows the broadened and brightened fore field as well as an increased lighting width, Fig 5-15. The area having a minimum brightness of 0.4 lx, prominent in the picture, is an indication of a soft transition of the light-dark boundary. However the glare from the oncoming traffic, while cornering, lies above the level for halogen headlights. Additionally the glare is increased by the projection principle of the ellipsoid headlight. With the same density of light on the road, as at the headlight glass, an ellipsoid headlight has twelve times the light density of a paraboloid headlight owing to a smaller discharge lens.

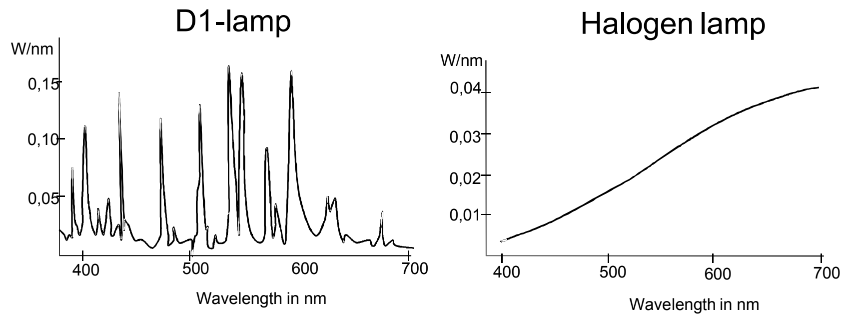


Fig 5-14: Light distribution spectrum

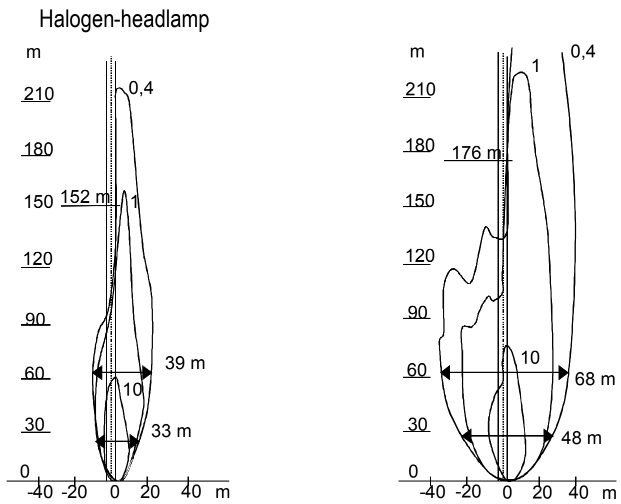


Fig 5-15: Range of ellipsoid headlights with Halogen and D1 lamps

5.3 Headlight Level Adjustment

Apart from the evaluation criteria that can be quantified objectively, i.e. lighting power and lighting range, the evaluation of the subjective parameter that is the visual range is of crucial importance. Due to its dependence on road surface, route guidance, weather as well as the glare from the oncoming traffic, the range of vision is substantially smaller than the lighting width. In two vehicles that approach each other, the range of vision continues to reduce with reducing distance. After such a crossing over, the dazzled eye needs some time for a renewed adjustment, Fig 5-16.

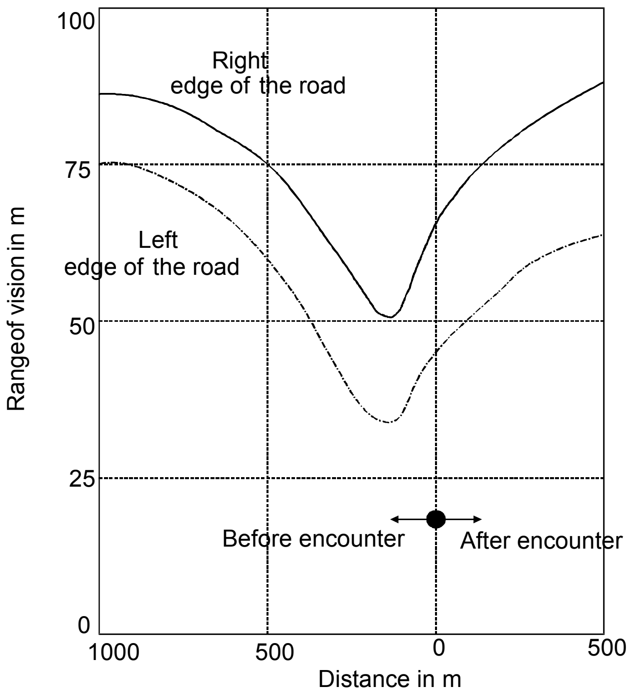


Fig 5-16: Range of vision during approach of two vehicles.

In order to reduce the glare from oncoming traffic, since 01 January 1990, a headlight level adjustment system has been prescribed legally for every vehicle newly registered in the Federal Republic of Germany. In all the designs of lighting width adjustment, the headlight is swiveled around a transverse axis by positioning elements, Fig 5-17. This movement takes place by way of manually operated systems i.e. a switch near the driver or by automatic systems i.e. level sensors on the axles. These level sensors transmit a signal to the positioning element, proportional to the compression. A damping element is inserted in order to prevent an adjustment during rapid level modifications during driving. The angular modification of headlights is achieved by the usage of geared electric motors, vacuum equipment or electrically heated expansion joints.

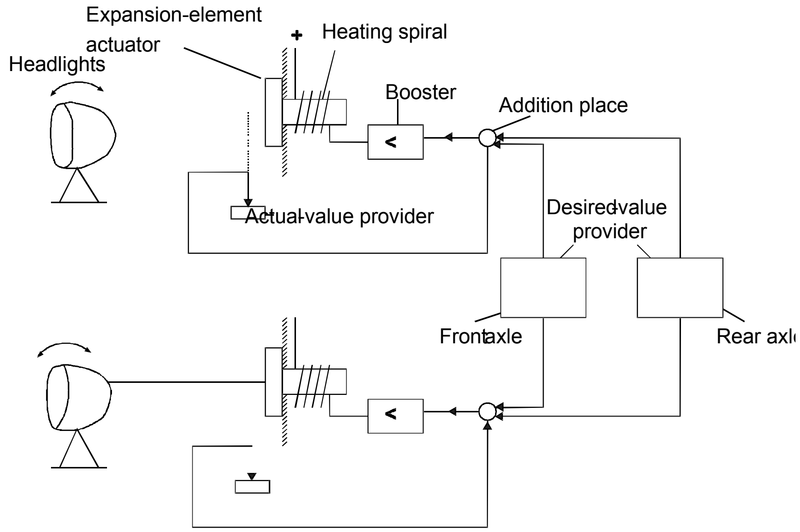


Fig 5-17: Automatic headlight level adjustment.

5.4 Adaptive Front Lighting

The automatic headlight level system, apart from an improvement of the bulb and the reflector technology, also contributes to the increased visibility at night without glare from the oncoming traffic. Advancements in lighting systems have lead to the development of Adaptive Front Lighting.

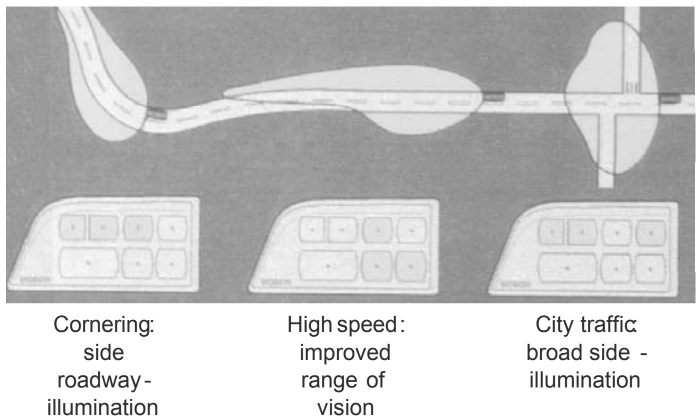
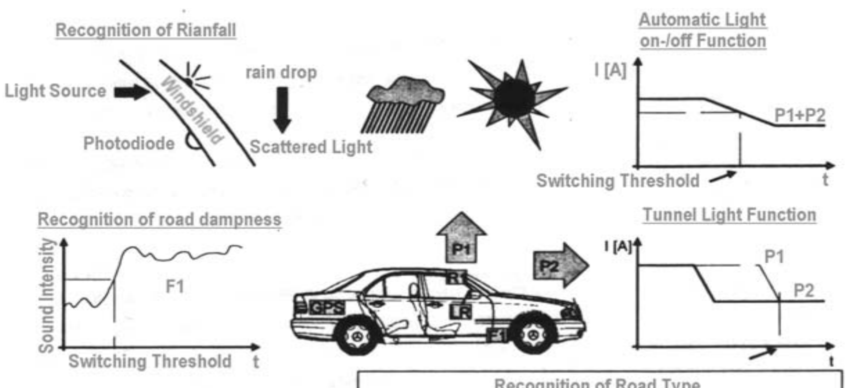


Fig 5-18: Influence of the driving status on the lighting and control principle.

The concept of adaptive front lighting considers different driving and environmental conditions. The dependence of the driving condition on the lighting and the components in a vehicle is shown by Fig 5-18. Illumination in curves is a constituent of the system. This allows a quick and more direct illumination of sharp curves in consideration of the driving speed. At higher speeds the lighting cone is more concentrated, smaller and focused onto the distance. In city traffic a broader side illumination is favourable.

Different electronic components and sensors are necessary for an identification of the driving condition. In addition, rotation sensors and gyroscopic angular acceleration sensors serve to ascertain the turning radius. Information about the driving speed and the position of the vehicle is essential from the point of view of headlight control. The latter is determined by means of the GPS.

Additionally, if the front lighting is to adapt to the environmental condition, light sensors, rain sensors on the windshield, sensors for the identification of the road dampness as well as sensors for the recognition of the degree of pollution of the headlights must provide signals in order to control the lighting. With the help of actuators, the lights can be switched on or off or even dimmed, the headlight cleaning could be operated or the light distribution could be changed.



P1,P2	Light Sensor
R1	Rain Sensor
F1	Moisture Sensor
LR	Steering Angle
V	Velocity
GPS	Position of the Kfz

Recognition of Road Type

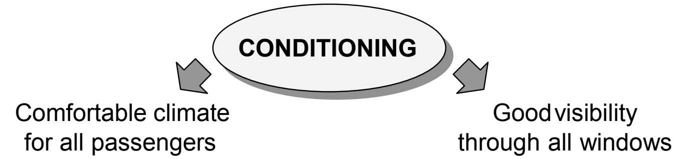
Type	Speed V [Km/h]	Radius of Curve LR [m]
Highway	110 < V	LR > 2000
Federal Road	60 < V < 110	2000 >LR > 500
Country Road	60 < V < 100	1000 >LR > 100
City	V < 60	100 >LR

Fig 5-19: Adjustment of the front light to the environmental condition.

6 Air Conditioning and Glass

6.1 Air Conditioning

A passenger car air conditioning system is used to create a comfortable environment for the passengers as well as ensure a good view through all the windows, Fig. 6-1.



- Temperature and temperature distribution
- Airflow velocity
- Composition of air (particle and humidity)
- Radiation from body elements and the sun
- Temporal behaviour of weather change

Fig. 6-1: Demands on air conditioning in a vehicle.

In order to ensure a good view for the driver in terms of active safety, the windscreen and side windows have to be released from condensation and icing reliably and in an acceptable period of time. Comfort is a highly subjective assessment criterion. It is influenced by:

- Air temperature and air distribution in the interior: The optimum inside temperature strongly depends on the outside temperature. With low ambient temperatures, the necessary inside temperature is higher in order to compensate the heat radiated by the passengers to the cold window areas. In addition to that a stratification of the temperature distribution is necessary, so that the temperature in the floor space is about 4 °C to 8 °C higher than the adjusted temperature around the upper-torso region [REI92].

- Air velocity and flow field: The air is to be introduced into the interior without draught and without the disturbing noises produced by the air stream or by the fan. A direct draught on parts of the body is desired only for a brief duration during some transient exchange processes. For example heating the feet in winter or directing the flow of air onto the upper-torso to avoid excessive perspiration in summer are of importance.

- Constitution of air: Dust particles, exhaust gases and humidity are to be removed from the supplied air. Particle filters or activated-charcoal filters can be used here.
- Solar radiation and component radiation.
- Time response: Variations of the user adjustments for climate are to be implemented quickly and the desired climatic parameters should be achieved within an acceptable period of time after starting the engine. The sensitivity of the adjustment is to be considered as well.

6.1.1 Thermal Load on Humans

The thermal load on humans is described by a comfort index, which is internationally known as the PMV index. The index can take values from -3 (very cold) through 0 (neutral) to +3 (very hot). It was determined with the help of 1300 test subjects.

At PMV 0,95 % of the questioned people feel comfortable in their thermal environment, Fig. 6-2. That is the condition of optimum comfort. PMV 1 stands for a medium thermal load, at which about 30 % of the people are dissatisfied with their ambient temperature. PMV 2 indicates a high thermal load, where approximately 80 % of humans feel uncomfortable. PMV 3 defines an extremely high thermal load, where almost everyone feels uncomfortable. Outdoors, one hardly comes across such loads and therefore they are not shown in the curve.

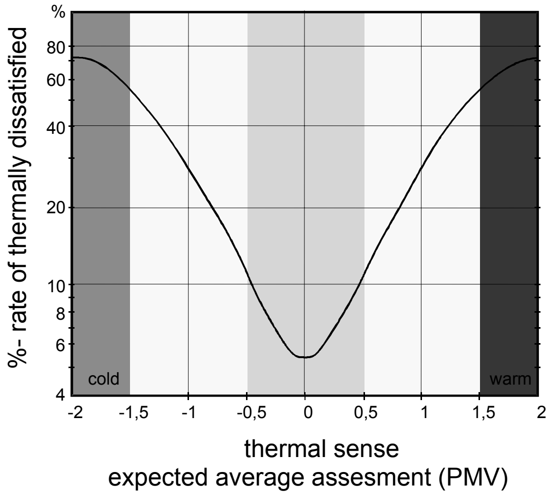


Fig. 6-2: PMV Index

The thermal load on passengers is caused both by the air temperature as well as the direct insolation on the body. In vehicles without air conditioning systems, on warm days, the temperature in the passenger compartment lies between 5 °C and 15 °C above the outside temperature due to the heat-emitting surfaces inside the vehicle and also the heat emission by the passengers. In a parked vehicle that is subject to direct insolation, temperatures of 65 °C to 75 °C develop in the headroom of the compartment.

Above an air temperature of approximately 27 °C, the body can maintain its thermal balance only by evaporation of perspiration. The effectiveness of the body cooling is reduced in a vehicle for three reasons:

- The direct contact of the body with seats prevents the evaporation
- Insulating effect of clothing
- High humidity in the compartment particularly in sultry weather

With a reduced evaporation, the body can no longer maintain its thermal balance and this results in heat stress. Heat stress not only impairs the functioning of the body but also the effectiveness of human actions. This particularly applies to complex activities with a high proportion of mental input like driving a car in heavy traffic. Examples of the effects on driving caused by heat stress are:

- Improper handling of the vehicle due to receding perception and attention
- Overlooking and missing signals
- Reduced attention to auxiliary events, e.g. attention towards speed, siren of emergency vehicles, turn indicator lights
- Rise of the response time (about 22 % with rise of the peak temperature from 21 °C to 27 °C)
- Reduced visual efficiency (sharpness of vision decreases linearly with the rise of body temperature)
- Aggressive handling (for example, aggressiveness can be determined by an excessive use of the horn by a driver)

Accident investigations show that the thermal load has an influence on the number of accidents. Fig. 6-3 shows that the accident frequency rises strongly when the thermal load rises. The thermal load has a stronger influence on the accident frequency in urban areas than in rural areas.

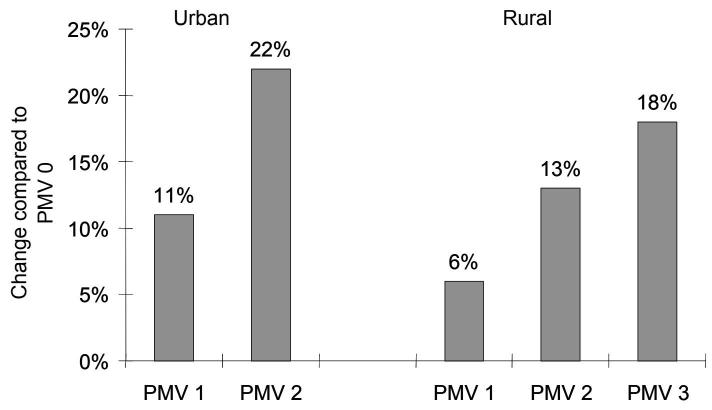


Fig. 6-3: Accident frequency due to thermal load [BAST].

6.1.2 Components of Vehicle Air Conditioning

For the air conditioning of vehicles, engine dependent or engine-independent heaters as well as cooling devices are used. They are both used individually or as combined systems.

The factors responsible for the construction and dimensioning of the components for the vehicle air conditioning are:

- Field of application of the vehicle
- Condition of the body
- Size of vehicle interior
- Number of passengers to be transported

The air flow that passes through the vehicle should amount to approximately 30 m^3 per hour and per person [REI92].

6.1.2.1 Engine Dependent Heating

An engine dependent heating system heats the interior of the vehicle by using the rejected heat that results from the operation of the combustion engine, Fig. 6-4. In engines with liquid cooling, this heat is transferred by the cooling fluid. In engines

with air-cooling, it is transferred by the engine oil. An existing heat exchanger that consists of pipes and ribs possesses a cross-flow due to a flow through of the cooling liquid as well as by the incoming air. The regulation of the heater output can be realised with two different systems: There are water-blending heaters and air heaters.

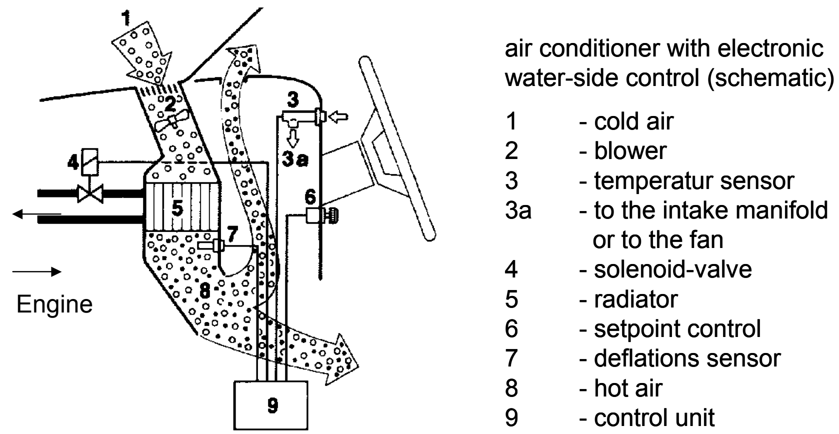


Fig. 6-4: Engine dependent heating [ADL87].

In a water-blending heater, the entire amount of incoming air flows through the heating element. The amount of cooling liquid flowing through the unit is controlled by a valve. Thereby the heater output can be controlled.

In an air heater, the entire amount of cooling liquid flows through the heating element. To control the heater output, the air stream is distributed in front of the heating element. One part of the airflow is conducted through the heating element while the other part is diverted directly into a mixing box where both parts of the air stream are blended again. A continuously adjustable air flap controls the mixing rate of air and therefore the amount of heat withdrawn from the cooling liquid.

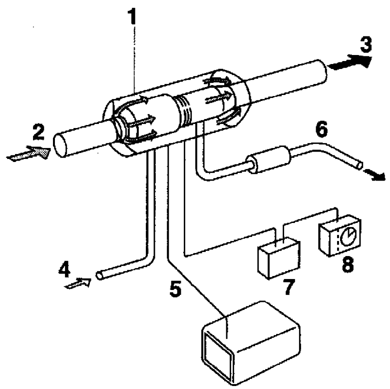
When the heater is turned off, a shut-off valve prevents the heating element from being supplied with cooling liquid, in order to avoid an unwanted residual warming by the hot heating element. By comparing both systems, the water-blending heater represents a smaller constructional expenditure, but it is more dependent on the operating state of the engine than the air heater system. The latter, furthermore, features a better time response and control characteristics. Ventilation is achieved by a multi-speed or a continuously adjustable electrical blower, which is supported by additional dynamic pressure with an increasing velocity.

Particularly high demands on the heater are made by vehicles having a low fuel consumption, for example, direct injection diesel engines. The low transfer of engine heat into the cooling water, results in long delays until a favoured heater output is achieved, especially during cold start of the engine. The heating performance can be improved by the following measures:

- Thermal isolation of the engine
- Increase of the heat exchanger performance
- Optimisation of the air flow in the passenger compartment
- Reduction of the excess air (diesel engine)
- Retardation of the ignition point (petrol engine)

6.1.2.2 Engine-Independent Heating

The engine-independent heating produces the required heat by using an electric or fuel-fired heater and does not use the waste heat of the engine, Fig. 6-5.



1 Air heater with blower for combustion and heating air, combustion chamber and heat exchanger
2 Hot air intake
3 Air intlet to vehicle interior
4 Combustion air intake
5 Fuel supply
6 Exhaust system
7 Electronic control system
8 Thermostat and timer for preselecting switch on time

Fig. 6-5: Engine-Independent Heating [ADL87].

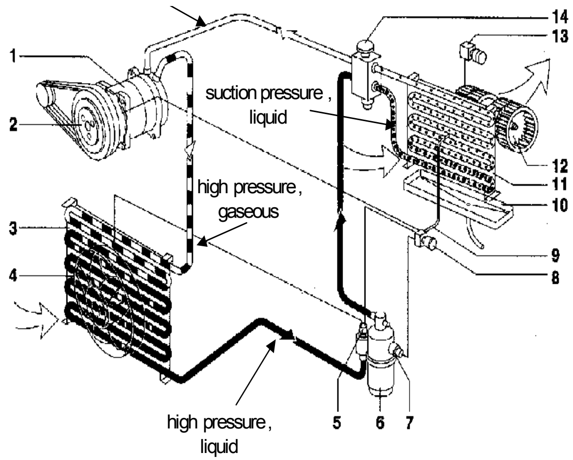
Fuel-fired heaters are operated with the fuel from the vehicle's fuel system. In large vehicles they also use their own fuel system. After the combustion of fuel in the

combustion chamber the hot exhaust gases are supplied to a heat exchanger. Here, either the air for the passenger compartment or the cooling fluid is directly heated. The engine-independent preheating of the cooling liquid also enables a better starting performance during winter.

6.1.2.3 Cooling Devices

Cooling devices perform the task of cooling air and are a central component in air conditioning systems, which consist of a cooling device and a heater, Fig. 6-6. At outside temperatures over 20 °C, the required inside temperatures can only be achieved by cooling the air. Therefore only compression cooling devices are used in vehicles.

The compressor driven by the engine via a magnetic clutch compresses the gaseous refrigerant to approximately 30 bar and heats it up to approximately 100 °C. The medium is cooled down subsequently in the condenser thus causing it to liquify. The heat in the condenser is then discharged to the environment. By an expansion valve the cooled liquid is injected into the evaporator and there it evaporates. The heat required for evaporation is withdrawn from the incoming fresh air, which cools down to approximately 4 °C. The humidity that is carried along with the incoming air is extracted as condensed water. The evaporator is placed in the path of the flow of fresh air and before the heating element of the heater. This is so as to achieve a sensitive heating of the under-cooled air during a roughly adjustable cooling process, i.e. by turning the compressor on or off.



1 - compressor
2 - electric clutch
3 - condenser
4 - auxiliary fan
5 - high pressure switch
6 - fluid reservoir
7 - low pressure switch
8 - temperature switch
9 - temperature sensor
10 - condensate drip pan
11 - evaporator
12 - evaporator fan
13 - fan switch
14 - expansion valve

Fig. 6-6: Air Conditioning System [ADL87]

The cooling process for a cooling device using CO_2 as a refrigerant is depicted in Fig. 6-7. Compared to systems using R134a as a refrigerant, remarkably higher pressures are achieved with the usage of CO_2. CO_2 is gaseous in the complete circuit except after the condenser.

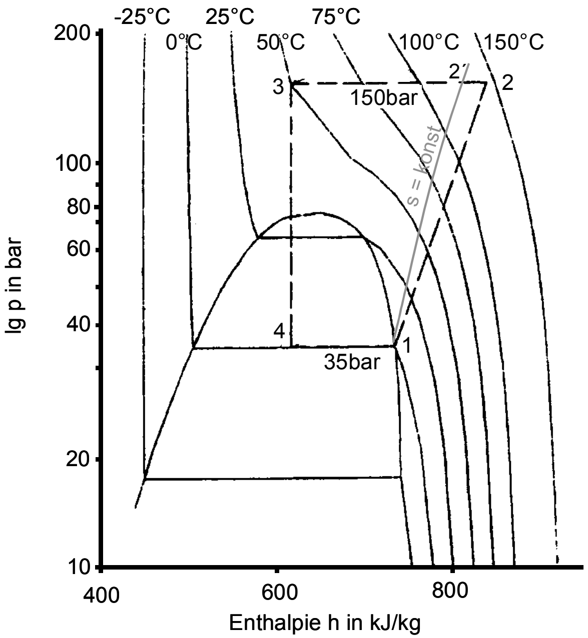


Fig. 6-7: Cooling process of a CO_2 cooling unit.

In simple air conditioning systems the cooling process is regulated roughly by opening and closing the electrical clutch. Constantly switching on and off the cooling device leads to comfort-impairing impacts due to switching. In order to find a remedy here, performance-controlled compressors were developed. These are mostly axial-piston compressors with an adjustable pivoted disc (swash plate compressor). They are integrated into the belt drive system of the engine and are therefore permanently in operation even if the air-conditioning system is not switched on. According to that, especially high demands are made on these compressors in regard to the operational stability and lubrication.

Two different operating modes, depending on the utilised compressor, exist:

- Reheat mode (dehumidifying operation)
- Sliding temperature mode

The Reheat mode corresponds to an earlier used control strategy. Depending on the outside temperature, an evaporating temperature near to the freezing point is adjusted. After that the air is reheated again depending on the required temperature in the heater.

In the Sliding temperature mode, the cooling depends on the actual demand. The running time of the compressor and the compressor output are optimised with regard to consumption. Thereby no more dehumidifying takes place. In a wide range of the outside temperature, the relative air humidity in the passenger compartment conforms to the humidity of the outside air, so that a desiccation of the mucous membranes can be avoided. If the passenger switches on the air conditioning system, automatically all procedures required for a continuous climatic operation without any fluctuations of air humidity and temperature take place in the interior.

A comparison of both operating modes with respect to fuel consumption is depicted in Fig. 6-8. The maximum possible increased fuel consumption during the highest possible cooling output is similar in both modes of operation due to an equivalent compressor power and therefore is defined as the 100 %-point. Referring to this increased fuel consumption, a lower outside temperature, or an increasing re-circulation rate, alternatively a lower inside blower setting results in a reduction of fuel consumption at same driving style also in the Reheat-Mode, since the compressor is switched off from time to time. In the Sliding Temperature Mode, the power of the compressor is reduced in order to raise the temperature of the evaporator. The lower power of the compressor results in fuel economy. With receding demands on the cooling output the effect of economy gets more and more noticeable.

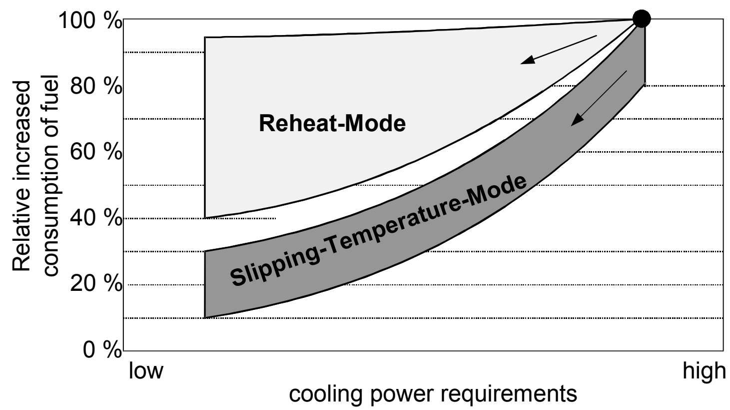


Fig. 6-8: Fuel consumption depending upon operating mode [GEI97]

In former times, the ozone endangering substance R112 was used as a refrigerant. Since 1995 R134a is used. R134a does not contain chlorine and therefore it does not deplete the ozone layer. The substantial technical modifications in the use of the new refrigerant consist in the exchange of lubricants which are easier to be mixed with the R134a as well as the system's layout with higher pressures.

Further on, the use of CO_2 as a refrigerant is aspired for. This refrigerant is already used successfully in stationary devices. Apart from the advantage of a lower influence on the greenhouse effect it also offers advantages in the construction volume and in weight. The disadvantage here is that a new compressor with a suction pressure of approximately 35 bar and a hot-gas pressure of approximately 150 bar has to be utilised (currently the pressure of the hot gas is approximately 30 bar). The system with such high pressures additionally represents a safety hazard, since according to today's technology the evaporator is placed inside the passenger compartment.

6.1.2.4 Compartment Filter

A strong environmental awareness, public discussions about air pollution as well as the increasing number of people suffering from allergies have reinforced the request for clean air inside a motor vehicle. Unpleasant odours are not only perceived as an annoyance, but also are associated with pollutants. Therefore lately more and more vehicles even from the lower segment are offered with devices that clean the inside air [REI92].

Pollutants that appear on the periphery of roads are shown in Fig. 6-9.

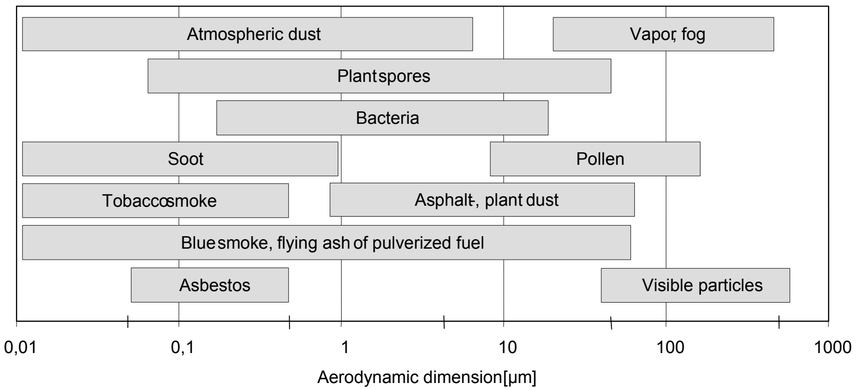


Fig. 6-9: Diameters of atmospheric particles encompassing roads [REI92]

For humans especially, the inspirable toxic particles with a size of up to 2 µm are dangerous, although approximately two third of the inhaled fine particles are exhaled again.

Owing to an increasing number of people allergic to pollen, it is important that the pollen is completely isolated. It has a size of 10 to 100 µm. Particle concentrations from 0,02 to 0,6 mg/m³ air exist in the surrounding air.

One possibility to keep away surrounding dirt and pollutants from the vehicle passengers consists of a recirculation circuit. By recirculating the air present in the passenger compartment, the exchange of air with the surroundings is prevented. Since the quality of inside air reduces the longer it is circulated, and additionally owing to the existence of a danger of fogged windows, the re-circulation mode is only suited for overcoming the temporary contamination that appears in the environment.

In order to clean the inspired air, the following are used:

- Particle filters or
- Activated-charcoal filters

In particle filters, micro fibres of the suspended particle filter form a labyrinth pattern. Here, three effects of separation come into play. All particles that are larger than 10 µm are held down by the strainer-effect. Particles with a size from 0,1 to 10 µm collide with the fibres due to their inertia and cling to them. Those particles that are smaller than 1 µm show a Brownian movement resulting in separation as an effect of diffusion.

Particle filters can hold back dust, pollen, spores and dew droplets almost completely and bacteria, soot, industrial dust, and vapour up to approximately 60 %. Unpleasant odours and toxic gases (that appear in road traffic conditions) such as ammonia, benzene, formaldehyde, hydrogen sulphide, ozone or carbon monoxide cannot be eliminated by particle filters. Therefore activated-charcoal filters are used for air purification wherein highly porous, spherical activated charcoal is applied on a foam carrier with an open network structure.

Activated charcoal has a very high hardness and abrasion resistance, so that no carbon dust is produced by the filter itself. The inner surface of the activated charcoal amounts to more than 1000 m²/g. Various gases are only occasionally stored in the activated-charcoal filter by adsorption and then released by desorption depending on the condition of the air. The concentrations however remain far below the marginal value for odour. Other substances, e.g. paraffin with a higher boiling point, are permanently bound to the activated charcoal.

Not only the unpleasant odours existing in daily road traffic are separated but also toxic gases are almost completely separated. Also smoke particles, gasoline vapours, benzene, diesel vapours and essential oils are largely absorbed. To prevent the activated-charcoal filter from getting blocked too fast it is imperative to place a particle filter in front of it.

6.2 Vehicle Glazing

6.2.1 Buildup, Characteristics and Manufacturing

Definition and Constituents

Glass is an anorganic melting product, which results from the melt by controlled cooling. The basic elements of glass are silicon oxid (SiO_2), sodium oxid (Na_2O) and calcium oxid (CaO). As manufacturing substances for SiO_2, Na_2O and CaO serve glass sand, soda and lime. Silicon oxid with its melting point of 1700 °C serves as glass creator and is with an quotient of 70-72 % the main element of glass. Sodium oxid is used as flux and provides better treatment conditions. Beside calcium oxid, which is fit as balancer, the glass melt is enriched with further additives in form of oxids, like magnesium or aluminium oxid, to improve the physical and chemical properties.

Characteristics of Glass

The most important attribute of glass is its permeability for visible light. This is possible, because there are no interfaces in the inside of the glass, which can reflect the light. Furthermore, the atomic structure of glass does not absorb the visible light.

Concerning mechanical aspects, glass is a very hard and brittle material with a Young's modulus of 70.000 MPa and a compression strength of 800 to 1000 MPa. The characteristic value relevant for the breakdown of glass is the tensile strength, which is divided in theoretical and effective tensile strength. The theoretical tensile strength of glass is about 10.000 MPa. The practical experience shows in contrast, that the practical tensile strength has a maximum value of 30-80 MPa, which means tensile values of about 1 % of the theoretical values. As permanent load there are even just 7 MPa allowed. The reason for this comportment is that glass has no totally regular build-up, but also has bad and bug spots. In addition to that, hardly visible surface splits, which emerge in the manufacturing process as by mechanical and corrosive stress as well, contribute to the low effective tensile stress. It can be increased easily by after treatment, e.g. by thermal or chemical pre-stressing.

The following values reflect the most important physical values of the material glass:

- Density: 2500 kg/m³
- Thermal elongation: 9×10^{-6} 1/K
- Bending strength: $\sigma_B = 50$ MPa
- Tensile strength: theoretical 10.000 MPa / effective 30-80 MPa
- Thermalshock resistance (resistance to differences of temperatures above the panels surface): ca. 150 K (example SSG)
- Slumping temperature: ca. 600 °C (no specific melting point, gradual change from firm to liquid state)

Manufacture of Flat Glass

Flat glass is the generic term for all flat and bent panels, which includes the three main groups cast glass, sheet glass and float glass. The nontransparent cast glass is made by a rolling procedure, the sheet glass (window glass) by a drawing technique and the clear and transparent mirror glass by a float glass procedure. Only the latter mentioned method is relevant for the manufacturing of glass panels in the automotive industry.

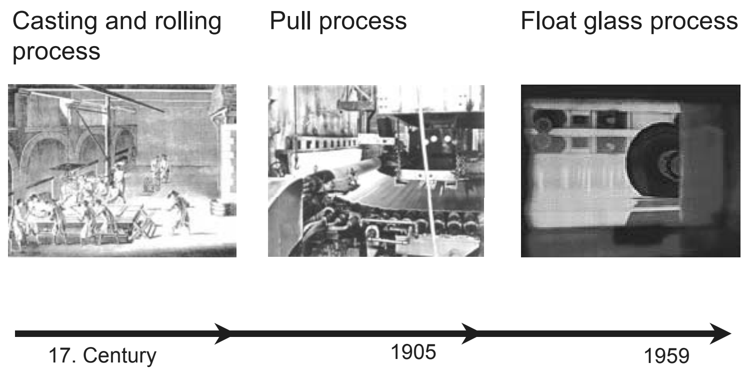


Fig. 6-10: Manufacturing of flat glass

The first industrial application of flat glass manufacturing has been the casting- and rolling technique in the 17th century. Glass has been melted in kettles, lined on a table, rolled and finally smoothed and polished. Automated methods have been developed at the beginning of the 20th century. In the year 1905, a glass panel has been drawn continuously out of the melt for the first time. The Englishman Alastair

Pilkington has had the braking idea in 1959, by leading melted glass over an ideally plan section, so that a very good surface quality was reached. By that the float glass procedure was created and is used successfully all over the world since that time.

Manufacturing of Float Glass

At the manufacturing of float glass, firstly the raw materials glass sand, soda and lime are mixed up. Afterwards the glass melt is led over a liquid bath of tin at an inlet temperature of 1500 °C. Because of the lower density, the glass floats on top of the tin. Contrary to older methods, the melt bears on the tin instead of a hard casting table, so that the lower surface reaches the same faultless quality as the upper surface.

The effect, that the melting temperature of tin with its 238 °C is clearly lower than the slumping temperature of glass is used at the cooling. By that, the glass can freeze as finished plate glass, while the tin remains liquid further on. A slow cooling is the reason for the regular and low stress in the glass. At the end of the process the glass band is tailored to plates.

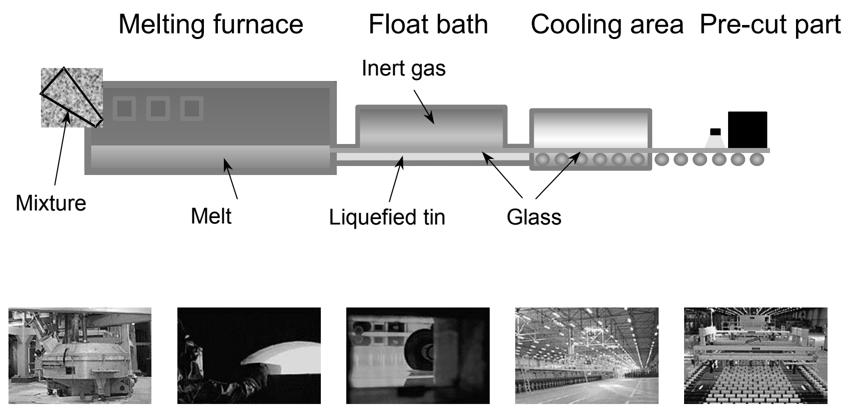


Fig. 6-11: Manufacturing of Float Glass

6.2.2 Demands on Vehicle Glazing

Besides protection of the wind stream, which was the main reason for the implementation of vehicle glazing at the beginning of the automotive history 100 years ago, there are numerous demands on the glazing today. The functional criteria sight and safety are still the most important tasks. A good sight is enabled by huge window surfaces, which guarantee a high transmission of light because of their

transparency; whereby it has to be paid attention that the form of the glass does not lead to deformation of sight or doubled pictures. An overview of the most important tasks on modern vehicle glazing is shown in Fig. 6-12.

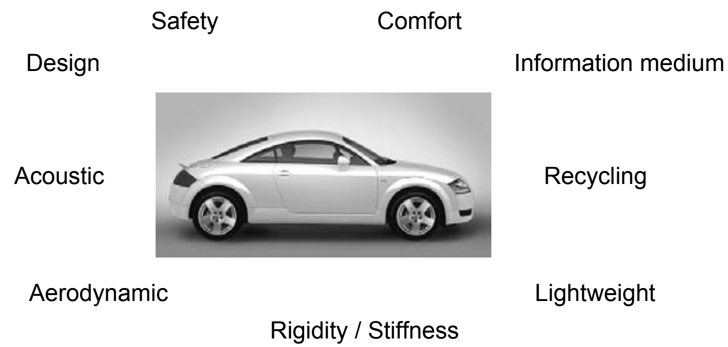


Fig. 6-12: Demands on Vehicle Glazing

In case of a crash, the glazing has a safety function. For example it shall avoid an ejection of passengers or objects out of the interior and ensure a reinforcement of the airbag at the same time. While trying to minimise the risk of cuts at the contact of passenger and glass plate, the safety glass was developed in 1930. At rock slide as another example, at least a guaranteed sight as minimum function criteria has to be ensured. This is succeeded by composite glass windscreens of compound safety glass (CSG). Both forms of glass are described in detail in chapter 6.2.3.

Beside these tasks concerning active and passive security, the breaking security becomes more and more important. By using security glasses, like the mentioned SSG and CSG, more resistible glass plates can be fabricated, which can be destroyed only by a huge expenditure of energy or special tools. Especially this example shows, that the multitude of demands results in conflicts of aims at the development of optimised vehicle glazing. The more resistible the glass is at crashes or braking, the more difficult is the rescuing of the passengers, because a strong glazing complicates the entry to the vehicle interior, which also takes more time.

Further demands on glazing are the reduction of wind sounds, the increase of comfort, the raise of body stiffness, as well as the integration of electronic components. The sounds of wind or acoustical aspects are influenced mainly by the form of the plate. Especially rubber seals or rather points of bonding, so the changeover from the glass plate to the body, are sources of wind sounds. For acoustics, in addition to that, the behaviour of the sound propagation of the bonding in combination with the body structure is relevant. With an adapted construction, a sound damping of the glass plate can be succeeded.

Because the glass surface of modern passenger cars becomes bigger and bigger, the climate of the interior and by that the comfort and the security are influenced increasingly by the glazing. A heated interior for examples causes an enormous loss of concentration, attention and well being. Usages of green glass, sun-protective glass or the meanwhile often serial installation of air conditioning are methods of rising comfort.

The bonding of the vehicle glazing has an essential influence on the body's stiffness. Bonded glasses have an effective function and so they also play a role in the lightweight construction. Today, normally all glass panels except the movable side windows are adhered. In contrast to the windows, installed with rubber seals in earlier times, today the glass plates merge with the body to a carrying unit, whereby they become self-supporting elements of the whole structure and effect a clearly higher body stability.

A trend which has fortified since a few years is the integration of electronic components in the vehicle glazing. While antennas are installed in the windows since 1970, rain sensors are integrated in the windscreens during the last years, too, which control the wiper depending on the weather. In order to avoid fogging or icing of the window, they are also equipped with heating rods. Earlier, you could only find them in the rear window, because the rods were clearly visible, but nowadays they are designed as thin and inconspicuous as possible to prevent an irritation of sight, so that they can also be installed in the front and side windows.

The increasing multiplicity of demands on the vehicle glazing leads more and more often to conflicts of aims. The integration of electronic components for example, has a bad effect on the recycling ability. Solid and hard windows ensure a high level of security on the one hand, but on the other hand they complicate the rescuing procedure after a collision. In general however, the actual development of glass engineering contributes to a raise of comfort and security in the automotive field.

6.2.3 Security Aspects in Vehicle Glazing

Single-Layer Safety Glass

Single-layer safety glass (SSG) has been the state of the art for all glass panels in vehicles from the 30th to the 70th century. Nowadays it is simply used for side and rear windows because of the advantages concerning costs and weight in comparison to composite safety glass. Compared to common glasses, the single-layer safety-

glass has an initial load which is responsible for the characteristic fracture behaviour. The panel is prestressed in such a manner, that compressive stresses occur at the surface and, because of balancing reasons, tensile stresses in the inside (Fig. 6-13). This results in endurable bending loads which can be three or four times as high than at common glasses.

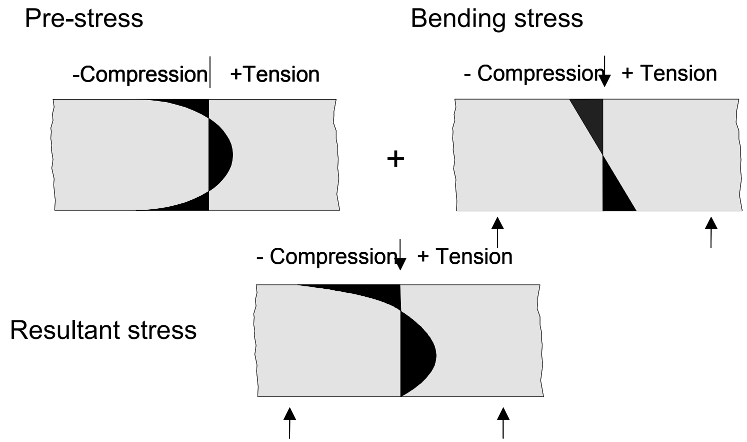


Fig. 6-13: Initial Load on single-layer safety-glass

The initial load is generated by heating the readily formed and drilled glass up to more than 600 °C and then cooling it down quickly by an air syringe. The surface cools down faster than the interior, so that the glass hardens at the outside and remains hot in the inside. The inner layer would contract more and more during the cooling, but is embarrassed by the hard outer layer, so that tensile stresses appear in the inside, while the outer layer gets into compressive stress. Because of this residual stress, at a crash, the glass plate bursts into many little glass peaces without sharp edges.

The production steps of the manufacturing of single-layer safety-glass are shown in detail in Fig. 6-14. The method demands, that all processing steps like tailoring, drilling, grinding, bending and also the integration of heating elements, patterns, antennas or sensors are finished in the run-up. A post processing of the pre-stressed glass panels is not possible.

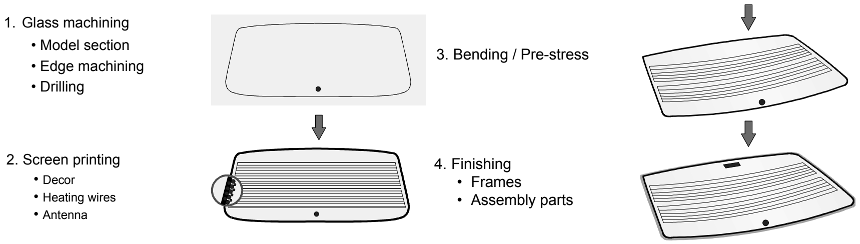


Fig. 6-14: Manufacturing of single-layer safety-glass

A further characteristic of single-layer safety-glass is higher thermo shock resistance of about 150 K compared to float glass.

Composite Safety Glass

Composite safety glass consists of two glass panels, which are combined by a plastics intermediate layer of polyvinyl butyral (Fig. 6-15). Like for the single-layer safety-glass, flat glass is the basic material for the composite safety glass, too. At a breakage of the glass panel, spider web like cracks emerge around the braking point, while the glass is held together by the plastics layer. Contrary to the single-layer safety-glass, the composite safety glass still assures view in distance to the breaking point at smaller damages.

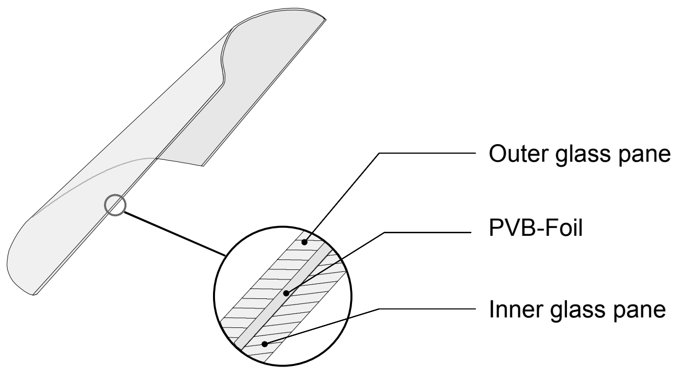


Fig. 6-15: Composite safety glass

In that way composite safety glass features coherence after rock slide, and improves additionally the break-in security. Furthermore composite safety glass decreases the risk of being ejected after a crash, increases the sound damping and allows the

inserting of functional layers (chapter 6.2.6). Just the higher manufacturing costs, the higher weight and the lower self-rigidity affect adversely.

The production steps of the manufacturing of composite safety glass are shown in detail in Fig. 6-16.

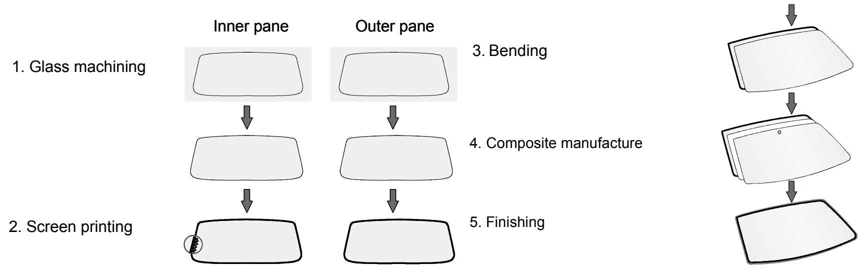


Fig. 6-16: Manufacturing of composite safety glass

6.2.4 Mounting of Vehicle Glass Plates

Beside the Glazing itself, also the mounting of the vehicle glass plates has been enhanced eminently in the last years. While vehicle glass plates had to fulfil basically the viewing function in former times, nowadays they contribute to the body stiffness as self-supporting elements. In the following, the earlier common ways of mounting of the rubber profile glazing and the actually widespread bonding is described.

Rubber Profile Glazing

Earlier, vehicle windows usually have been held into the ceiling by rubber profiles. By this elastic connection the glass plate is decoupled of the body. The compensation of tension takes place via the rubber profile.

For mounting, at first the glass plates are manually fit into the ceiling. Afterwards a band, surrounding the rubber, is pulled out of the seal, whereby an overlap between rubber and ceiling is achieved. In that way, a firm fit of the glass plate is made possible (Fig. 6-17).

An essential disadvantage of the rubber profile glazing is that the installation cannot be automated. The ambition to a modern way of construction and production is in conflict with the dated mounting method. Furthermore, the durability of the rubber profiles is limited. In the course of time they can become brittle and cracked, which means leaky. In addition to that, vehicle glass plates held by rubber profiles cannot contribute to the stability and stiffness of the body because of the elastic connection establishment. Moreover, the distinctive and bulging changeover between body and glass plate cause unfavourable turbulences, which result in increased consumption and acoustic disturbance.

While the former demands on vehicle glazing, namely protection of dirt, wetness, coldness and air stream could be fulfilled by the described way of mounting, modern demands concerning stiffness, aerodynamic, consumption and assembly time are the reasons why the rubber profile glazing is hardly applied in these days.

Glass Bonding

The bonding of glass plates had its beginning in 1963 at General Motors, when the big panorama glasses could not be held anymore by the rubber ceilings. Later on, security determinations, which demanded, that in case of a crash against a concrete barrier at least 75 % of the window's scope have to remain connected firmly with the body, effected a further development of the bonding of glass plates. Compared with the common ceiling technique, the price of this technique has been too high at first, so that in Europe only the export vehicles for the USA have been equipped with bonded glass panels. In the 70th, the oil crisis constrained the automotive manufacturers to fuel savings. With the bonding, the glazing could make a contribution to it by the abolition of the heavy ceiling, as the advancement of the air drag coefficient by an optimised changeover between glass plate and body, too. In 1976, Audi started bonding all still standing windows at the Type C2 (Audi 100), which was the breakthrough of the glass bonding technique.

Fig. 6-17 shows the comparison of rubber profile glazing and glass plate bonding

Fig. 6-17: Rubber profile glazing at the VW Type 2, year of construction 1967 (left) and bonded windscreen and rear window at the actual Multivan (right)

Beside weight saving and the improvement of the air drag coefficient, the bonding has the following advantages compared to profile glazing:

- Clear improvement of the body stability, windscreen and rear window become self-supporting elements of the complete structure
- Bonding and sealing in one process step
- Compensation of tolerances
- Compensation of vibrations and moving
- Large area assembly
- Water- and gas proof
- Assembly of different materials is possible
- Bridging of different thermal expansion coefficients
- Quick, party automated mounting
- No heating of assembly parts
- Eminent increase of passive security

As disadvantages have to be mentioned:

- Higher costs in production
- Changing of glass plates is more difficult, expensive and takes more time

For the vehicle glazing mostly multi component adhesives are used. Beneath the required solvent, the so called cleaner contains activators, which pretreat the surface for the following work steps. The combination of cleaner and activator is called Wipe. The so called primer is an adhesive agent which establishes the connection between the pre-activated surface and the sealing glue.

The long-time constancy of the connection is an indispensable condition for the successful application [BUR00]. Because elastic glues are organic products, they are afflicted with aging. Especially at glass as transparent underground, the UV radiation, harmful for glues, can destroy the sensitive boundary layer between glue and underground at the supreme molecular surface. For this reason, the glued joint is provided with opaque materials (among other things silk screen printing, Fig. 6-14 and Fig. 6-16). Alternatively, the primer is dyed black, to save the sealing glue against the UV radiation.

6.2.5 Climatic Demands on Vehicle Glazing

If you consider the development of the vehicle glazing, primarily design and aerodynamic have influenced the shaping of the glasses. Among other things, cylindrical or spherical bended panels are determining aspects of modern vehicle design in these days. Furthermore, the surface of the window has increased for about 20 % in the last 30 years and the tilt angel has been growing permanently, too.

As a consequence of these changes we have a rising transmission of energy and thereby an increase of the temperature in the interior. You have to consider, that 80 % of the thermal radiation is brought through the windows. The increment of the UV-transmission effects furthermore a lower durability of the interior equipment, therefore a reduction of radiation stress is necessary for modern vehicles. For optimising this radiation stress by technical measures, you firstly have to clarify the physical coherence of the light transmission. (Fig. 6-18).

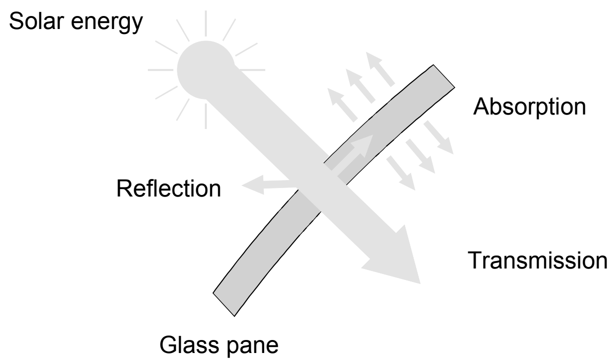


Fig. 6-18: Radiation segmentation at a pane

At impinging of the light onto the window, parts of the light are reflected, absorbed and let through. The sunlight composes of 47 % of visible light, 51 % of infrared radiation and 2 % of UV-radiation (image 1-8). The reflection of light can take place only at interfaces. Because glass has no inner interfaces, the light is reflected exclusively at the window surface. The effect of absorption of light occurs when the irradiated material can gather energy. For this purpose, free electrons are necessary. Tinted glass for example, has more free electrons than clear glass, whereby it can absorb more heat energy. At the transmission of light a total transmission of the visible light with simultaneous reflection, respectively absorption of the UV and IR radiation would be the ideal solution. But this is physically impossible, so that a compromise has to be made at the choice of glass.

Fig. 6-19 shows the segmentation of sun energy as well as the spectral permeability of different glasses.

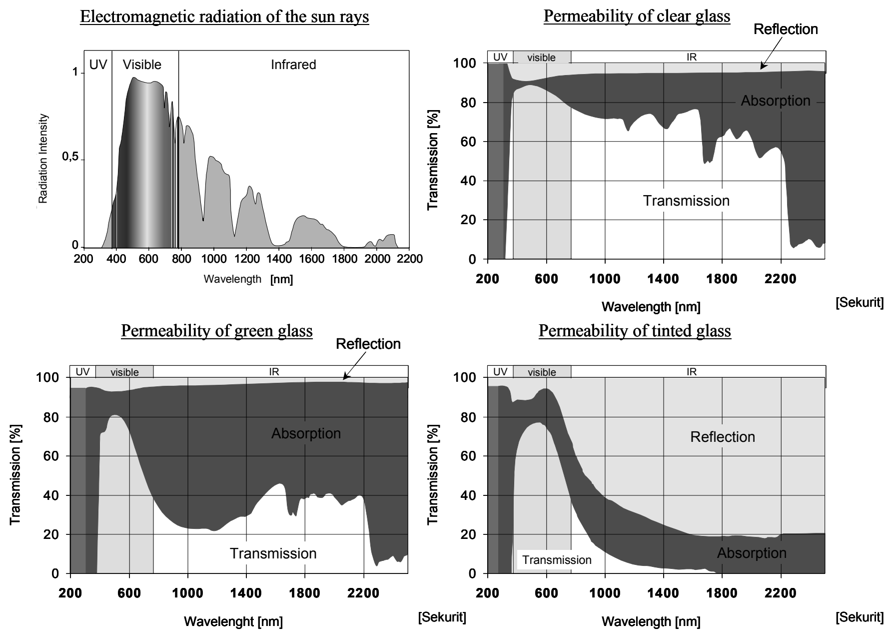


Fig. 6-19: Separation of Sun Energy and spectral permeability of different kinds of glass

In former times, clear glass was very widespread, which has a high transparency in the visible range of light, but which is permeable for IR-radiation at the same time. Furthermore, just a little part of the solar radiation is absorbed or reflected.

Nowadays, almost exclusively green glass is used in vehicles, which is characterised by a high absorption in the IR-range. Because of the colour particles of the tinge, enough free electrons are available for the absorption of energy. The transmission in the visible range reaches a value of about 76 %. The absorption of energy has the disadvantage, that it results in a secondary radiation to the in- and outside, so that heat dissipation is only possible by air stream. A vehicle standing still reaches therefore almost the same temperature in the interior as a vehicle with clear glass. In order to solve this problem, a part of reflection is necessary, which can be achieved by tinted glass.

Tinted glass has the same build-up as composite safety glass, but in addition to the PVB-foil there is also a sunscreen coating (silver-tin-alloy) brought in. Thereby, an extremely high part of reflection at a coexistent low absorption is succeeded. The transmission of visible light is at 77 %. Accordingly, the advantages are a reduced temperature in the interior while standing and driving, a lower radiation stress and a lower cooling capacity of the air conditioning. All these aspects provide an improved comfort.

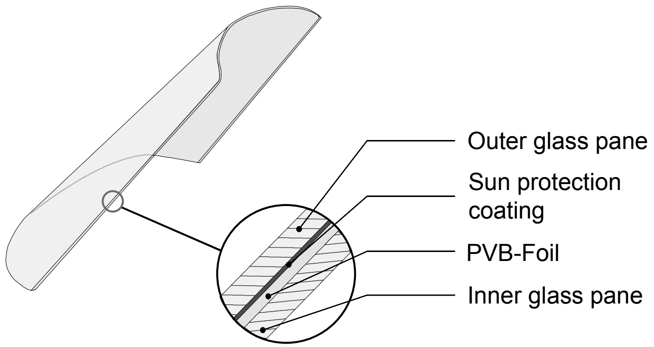


Fig. 6-20: Tinted glass

6.2.6 Trends in Vehicle Glazing

In the following some selected trends of development in vehicle glazing will be described closer. Most of these systems are currently installed serially in higher class vehicles and will be introduced in lower classes later.

Rain Sensor

The raising spreading of rain sensors is an example for the integration of electronic components in the vehicle glazing for increasing the security and ease of use. Rain sensors are mounted at the inner side of the face-plate and they control the wiper self-contained depending on the weather. The basic principle of the sensor is shown in Fig. 6-21.

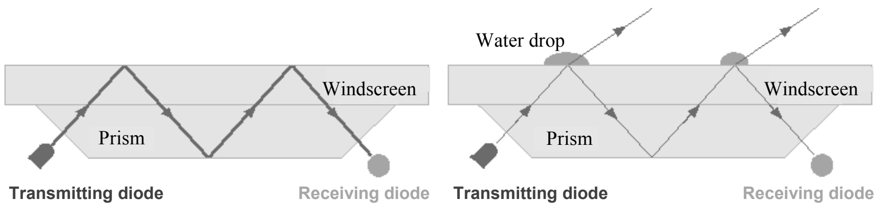


Fig. 6-21: Operating Mode of a Rain Sensor

The light of the sending diode is launched into the panel by a prism, forwarded inside and leaded to the receiving diode. With the grade of reflection, the rain sensor can determine the intensity of rain and control the wiper according to it. In order to prevent misinterpretations because of condensation humidity, an integrated heating keeps the measuring range dry from inside [NIU01].

Head-Up-Display

The Head-Up-Display is a readout-system, which projects important information in the field of view of the user, so that he must not take his eyes of the street. Such systems already exist in jet fighters and as landing help in air crafts for several years. Two years after the first public presentation of a colour Head-Up-Display at the IAA 2001 in Frankfurt, the system of Siemens VDO Automotive has been developed to series-production readiness and is installed in the BMW 5 Series since 2003.

Fig. 6-22: Head-Up-Display in the new BMW 5 series [VDO03]

Beside the speed and revolution indicator, instructions of the navigation system, advices of known hindrances, information about the road condition, the velocity of the vehicle in front or warnings concerning motor and tires can be displayed in the cockpit. By illustrating all these information in common cockpit systems, the driver would be diverted gravely from the traffic, which would counteract to the original intention of increasing the security. Furthermore, the eyes have to be accommodated to the short distance to the instruments, when the view is taken from the street to the armatures.

With the application of Head-Up-Displays this changeover is clearly lower. Moreover, the direction of sight must not be changed, so that the street is in the field of sight further on. The required time for reading off the information can be decreased form one to a half second. For older road users, the gain of potential braking distance is even bigger, because their eyes switch over slower between different distances.

Like looking into a mirror, the driver does not see the image at the surface of the glass panel, but about two meters in front of him, floating freely above the engine hood. This optical effect is reached by turning around the information by four mirrors and a specially adapted windscreen. That way, the drivers' eyes must not accommodate to different distances while reading the Head-Up-Display [VDO03].

Electrochromic Glass

Electrochromic glass makes use of the nano technology for increasing the comfort in the interior of the vehicle. It is about a combination of an electrochomic and a lithium containing electrode with an ion conductive plastics layer in the middle. By landing an electric voltage to the electrode layer, ions of the light metal lithium descend through the plastics layer, serving as conductor, and combine with metal oxides to a complex, which absorbs light [FLA04].

Tinge and transparency of this glass can be regulated individually. Thereby the height of thermal stress in the interior can be reduced on the one hand, and on the other hand the privacy can be increased by refusing the insight to the interior.

Electrochromic glass is an innovation which is almost applied to sunroofs and which can be applied to all backstage windows of the vehicle in the near future. A sunroof of electrochromic glass is currently offered for the Maybach. It shall arrange a comfortable atmosphere in the interior by a diffused light when switching over from transparent to impermeable (Fig. 6-23).

Fig. 6-23: Electrochromic panorama roof in the Maybach 62

Noise-Protection-Glass

The build-up of Noise-Protection-Glass is according to the composite safety glass, described in chapter 6.2.3. In contrast to the single-layered PVB-foil of the CSG, the -Protection-Glass has a triple-layered PVB-intermediate layer. Both outer layers consist of conventional PVB, while the softer inner layer has high damping properties. Thereby especially the high-frequency background noise is absorbed, which results from engine vibrations or sounds of wind in the most cases.

Water Repellent Glass

The surface of water repellent or hydrophobic glass is not coated but refined. Thereby a water repellent molecule is connected with the glass of the panel. Appearing rain water is not able to diffuse extensively, but forms to little drops which expire even at low air streams. The disadvantage of higher costs compared with the common glazing is faced by the following advantages:

- improvement of the driving comfort and security
- reduction of wiper abrasion
- reduced adhesion of sight handicaps (dirt, insects…)
- eased window cleaning

The durability of the refinement is declared to a maximum of three years by the manufacturer.

7 Sight and Control Conception

A safe vehicle guidance can only be assured if the flow of information from the surrounding to the driver and thereby a sufficient view conception is guaranteed. At the same time, a comfortable actuation of the control elements has to be possible in either case. Both aspects shall be illustrated in the following.

7.1 Sight Conception

The most important information to a driver driving a motor vehicle is the visual. Any restriction in getting a proper visual increases the danger of accidents since the reaction of the driver would start late. Along with the vehicle conception, attention has to be paid to reduce the view restriction as much as possible.

Furthermore an obstruction of vision by information indicators (tachometer, fuel level indicator, clock etc.) should be avoided, so that the driver must not divert his view from the road for a long time. Remedy is found by head-up-systems, described in chapter 6.2.6. If the vehicle does not have such a system, the information elements have to be arranged favourable.

Human visual ability can be divided into three areas:

- Visual range
- Field of vision
- Field of view.

The visual range covers the area with which the resting eye (without head and eye movement) can just perceive images but not perfectly sharp enough, Fig 7-1. Sharp viewing is only possible in a field of view of a cone with an opening angle of 4°. The magnitude and the (visual) range depend on the type of view. Here a classification takes place according to the type of perception of a point in the visual range:

- Monocular viewing: Viewing with one eye
- Binocular viewing: Viewing with both eyes at the same time
- Ambinocular viewing: Viewing with one or two eyes (sum of monocular right and monocular left)

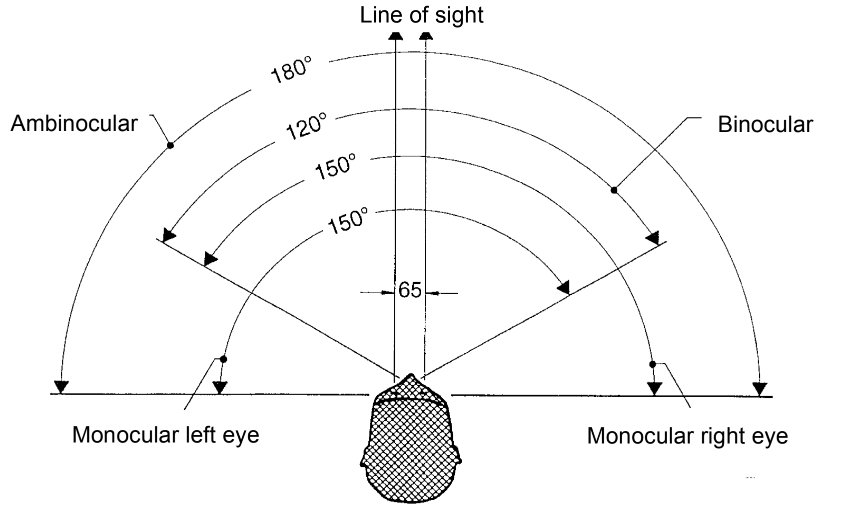


Fig 7-1: Visual range in the horizontal plane

If the representation of the field of view in the horizontal plane is extended spatially, then asymmetrical areas result and these are limited by the eyebrows in the upward direction and by cheeks and nose laterally as well as downwards, Fig 7-2.

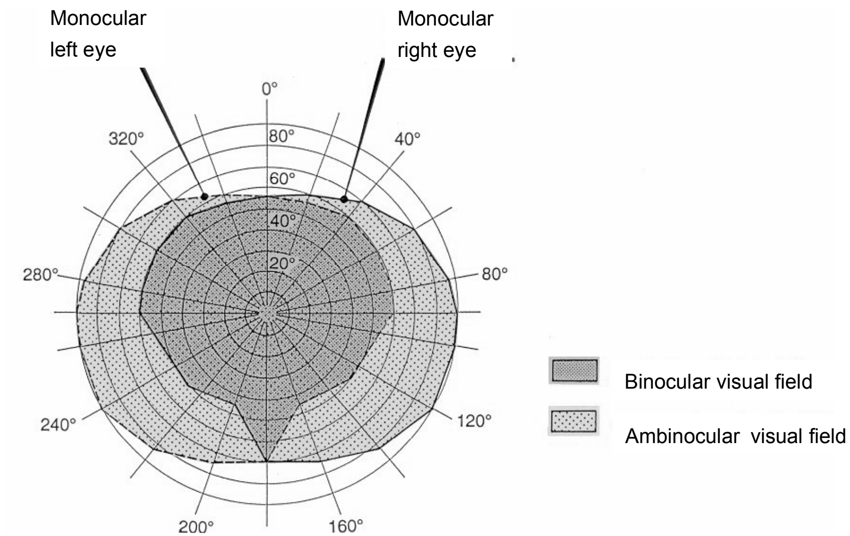


Fig 7-2: Monocular visual ranges for the left eye and the right eye

Since the area of sharp vision is limited, eye and head movements are necessary in order to be able to view the field surrounding the vehicle. The area that can be detected only with eye movements and with a resting head position is called the field of vision. There is a consideration of eye as well as head movement in the field of view.

Fig 7-3 illustrates the range of possible head and eye movements of the driver in horizontal and vertical plane. During the pursuit of traffic, the driver's movement should not deviate from the range of angles within which comfort prevails.

The driver cannot pay attention to the traffic (that is following) by viewing directly (i.e. view in front of the eye level including the view of instruments and display), but however he can do so indirectly with the help of interior mirrors and outer side mirrors. Here the dead angle where the image cannot be captured on the mirror has to be kept as small as possible, Fig 7-4. One of the remedies here is by the usage of aspheric mirrors or convex mirrors.

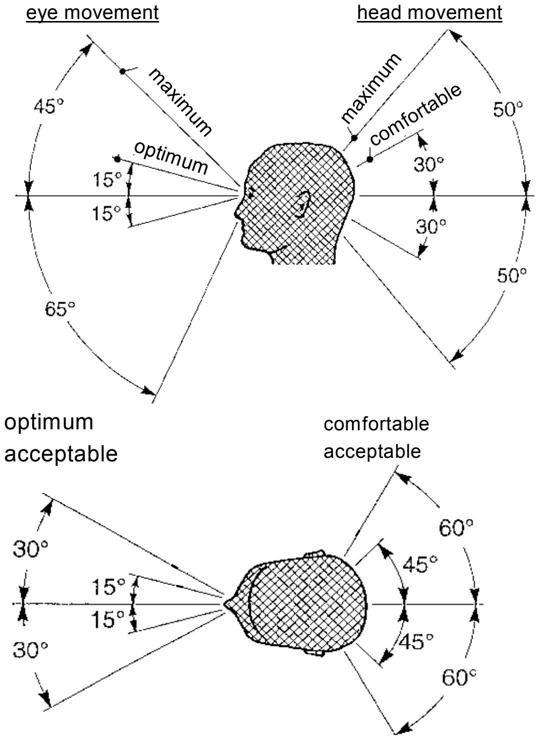


Fig 7-3: Angle areas for head and eye movement

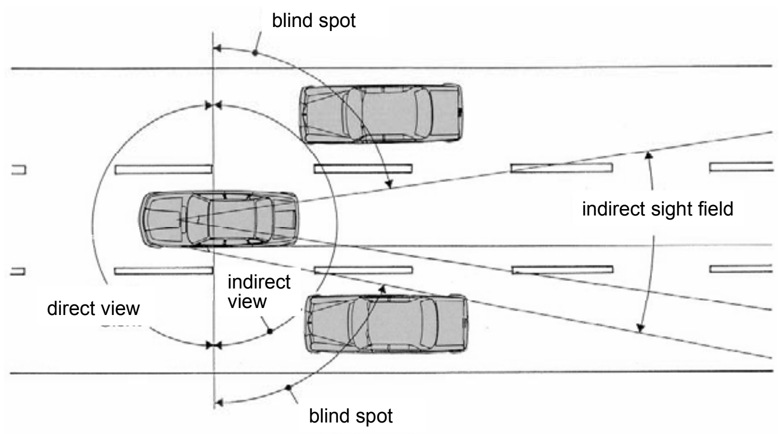


Fig 7-4: Areas of direct and indirect view

An optimised sight conception is realisable in the vehicle only if the eye positions of the driver with reference to the vehicle are known. Here, the eye ellipses serve the purpose of describing the eye positions.

The eye ellipse results out of a set of lines that envelop and thus isolate that area (ellipse). These lines are the ones that divide the measured eye positions into 5 % and 95 % of the area. So, in general, the proportion created by these lines is always P % and (100 - P) %.

The size and the inclination of the eye ellipse depend on the driver population, the seat adjustment range and the position of the eye ellipse i.e. the point of origin of the backrest inclination as well as the position of the SgRP. The eye ellipses are standardized in SAE J 941 A. Fig 7-5 shows a schematic representation of the 95 % eye ellipse.

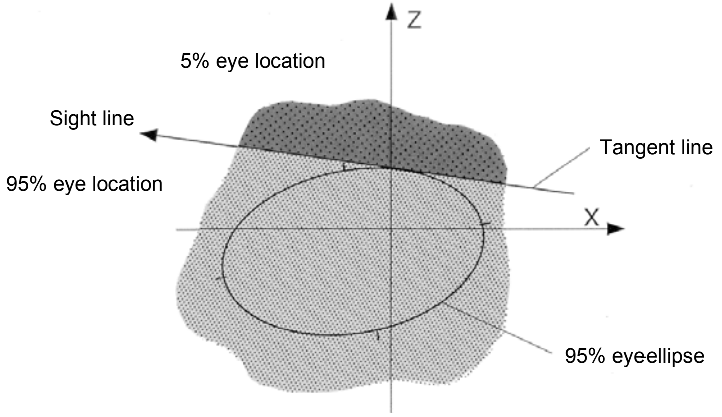


Fig 7-5: Schematic representation of the 95 % eye ellipse

The view out of motor vehicles is obstructed by the body contour, columns, hood, mirrors and wiper. Fig 7-6 illustrates the field of view through the windshield and the obstruction of sight by the interior mirror.

Although the maximum possible viewing angles in the upward and the downward directions amount to 45 ° and 65 ° respectively by virtue of the eye movement, the actual available direct field of view is limited by the dimension of the windshield. The tangents drawn from the opening onto the eye ellipse indicate the boundary for the direct field of view for approximately 90 % of the eye positions. The area within which sight obstruction occurs for these eye positions is characterised by the tangents drawn from these obstructions (a point nearest to the eye) to the eye ellipses and the maximum covering angle for 95 % of the eye positions is included within this beam of sight.

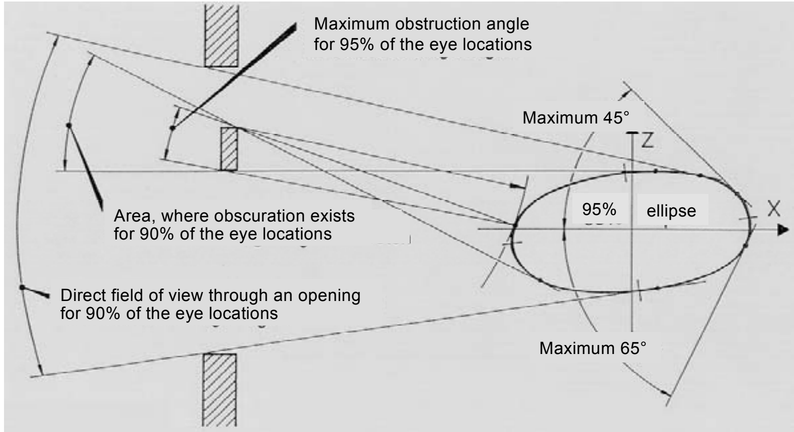


Fig 7-6: Fields of view and sight coverings in the side view

In Fig 7-7, the position of a 95 % eye ellipse defined at the height above the SgRP and also the backrest inclination are shown. In addition to this the purview of sight as a direct sight through the windshield and that upon the instrument panel and also the indirect sight (rear) through the inner mirror are illustrated.

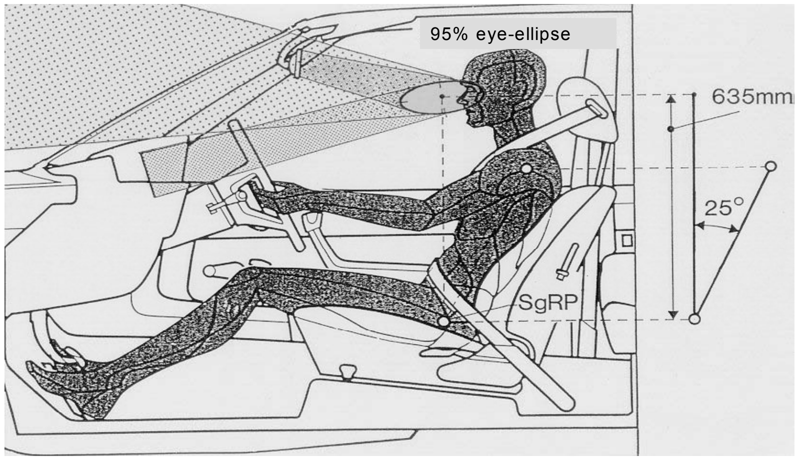


Fig 7-7: Position of the eye ellipse in the vehicle

The legislation permits visual obstructions only within certain boundaries and is defined under § 35b of the StVZO. These boundaries are determined using the 24 m-measurement circle, as shown in, Fig 7-8. The most important demands are:

- The frontal vision boundary to lie within a semicircle of 12 m radius.
- The frontal “Vision wedge” is to cut a chord > 9.5 m on the circle.
- Obstructions may not exceed the boundaries defined in the graph on the right side.
- With vision obstructing sections with a width > 80 mm, the minimum centre distance measured, as a chord, on the vision semi-circle is to be at least 2.5 m.
- A maximum of 2 coverings within the vision wedge,
- A maximum of 6 coverings on the vision semi-circle.

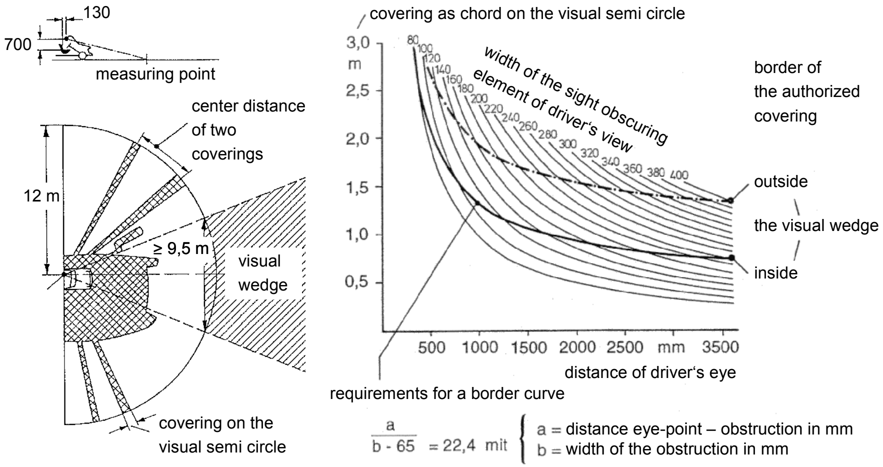


Fig 7-8: View semi-circle, wedge and authorised covering (§ 35b StVZO)

The determination of vision obstruction is carried out in a darkened room where there is a screen on the floor. A laser source kept at the position of the eye scans the view openings in the vehicle and presents the range of vision on the ground or against a wall, Fig 7-9.

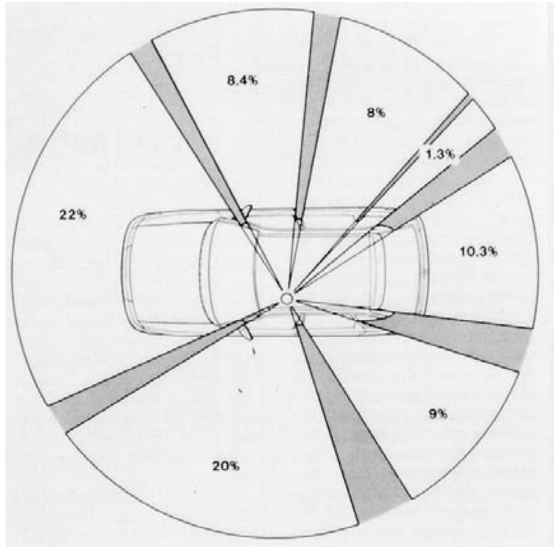


Fig 7-9: Determination of view obstruction on the roadway [OPEL]

The negative consequences of vision obstruction and dead angles in trucks are shown in Fig 7-10. A bad visibility in the side and also at the back is problematic. Children and two wheeler riders are partly or not at all captured in the indirect field of view and this leads to an increased danger of accidents. Adequate mirror systems or newly camera systems produce relief.

Fig 7-10: Vision obstruction in a truck

7.2 Control Conception

Apart from ergonomically favourable seating position and a view restriction that is kept as small as possible, the layout of the driver's place is carried out keeping in mind the optimal fulfilment of all the necessary control processes that are required to drive the vehicle. The target of the control conception therefore is the simple and safe operation of all control elements of a motor vehicle.

Fig. 4-41 shows the requirement criteria.

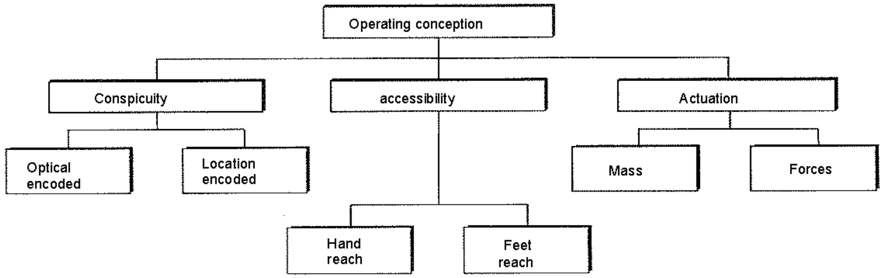


Fig 7-11: Criteria of control conception

The recognition of a control element and the information element is either by the eye or by the sense of touch. Certain possibilities for optical coding are:

- Colour
- Brightness
- Contrast
- Symbols

For testing, the important aspects are:

- Form
- Position
- Quantity
- Separation distance (with associated components)

Warning functions can be additionally emphasized by the usage of special indicators (blinking lights, colour changes).

The display (of variables whose values change rapidly) with analogue or quasi-analogue instruments is generally better and faster than digital displays. Therefore an intermediate trend towards digital displays will not be projected. The usage of an instrument with a conventional pointer over a display avoids the disadvantages of a digital display and also offers the integration of subsequent functions. Fig 7-12 shows a study of instruments that could be used as indicators in future.

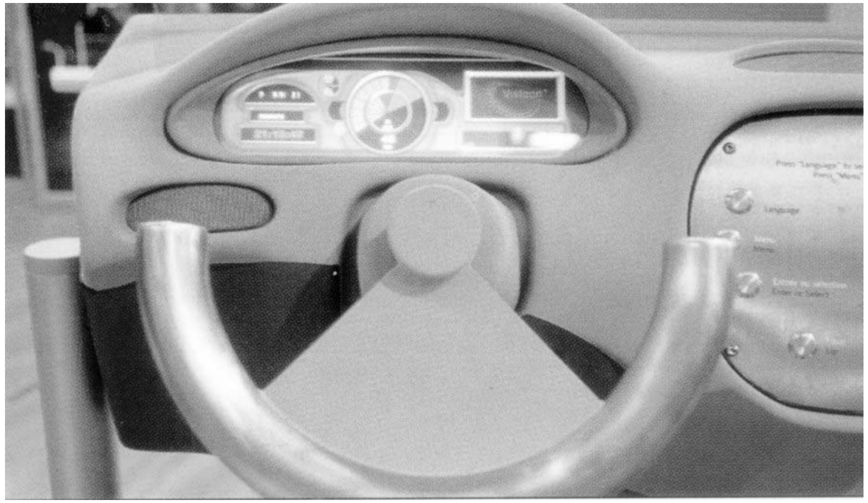


Fig 7-12: Design study of armatures, source: VISTEON

Accessibility depends on the anthropometrical masses and the type of actuation equipment. Push button switches can, for example, be situated farther away compared to devices which must be operated by the whole hand. Accessibility is described as the range which is covered by the driver in his normal seating position. The formation of the field of optimal range is somewhat asymmetrical since the movement of the left arm is constrained by the seat belt. Additionally the computer simulation, which is used increasingly, simplifies a parameter variation (angle modification, seat adjustment).

If one represents the three-dimensional view as a top and side projection for different levels, then it can be seen that the most favourable holding position for the hand is in front and a bit lower than the shoulder level, Fig 7-13. This translates to an arrangement of the hand control within a range of 100 – 450 mm above the H-point. It is apparent from the figure that the right arm has a somewhat larger range than the left arm due to the constraining of the left arm by the seat belt.

The type of operation must be coordinated with the function of the control element. Rocker switches cannot execute certain functions that have to be carried out in a discreet manner, for example, the heater. On the other hand a rocker switch is meaningful if used in the operation of the dipped headlight beam.

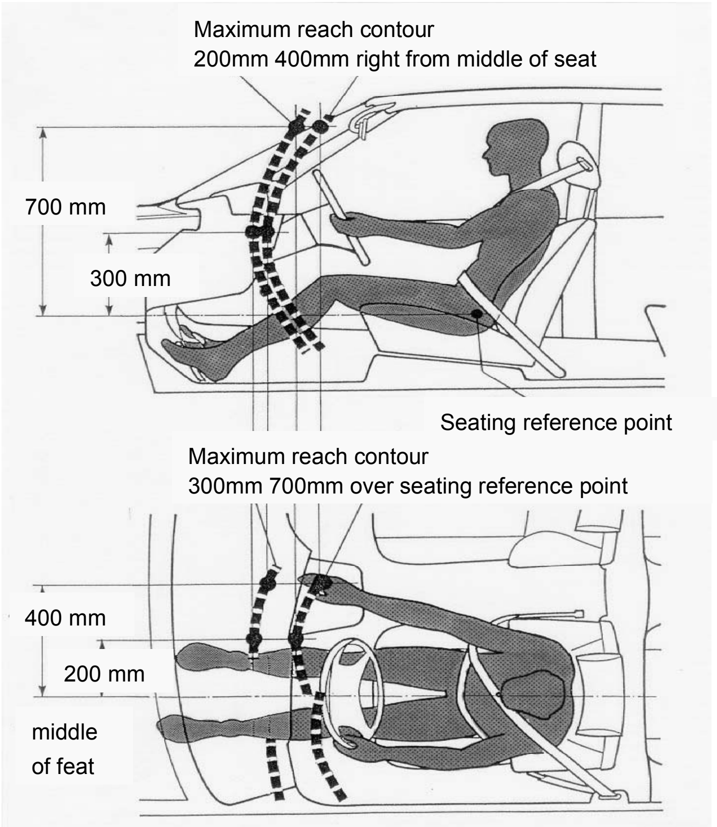


Fig 7-13: Range outlines for control elements

The area covered by the hands, without the movement of the shoulder and the upper body, is limited and for this reason not all control elements can be located within this area. For the arrangement of control elements, priority groups based on operation frequency and function, are formed.

Fig 7-14 shows the frequency of control of a mid segment passenger car considered over a road performance of 100,000 km. Following the sectors that require foot

operation, the gear shift and direction indicators are the most frequently used. In comparison to this, all other processes are of relatively lesser importance.

Coupling		500,000
Foot brake		310,000
Left indicator	Normal	145,000
	Short distance	450,000
Right indicator	Normal	112,000
	Short distance	350,000
Driver`s door		23,500
Starter		15,000
Heated rear window		14,500
Wiper	Stage 1	12,700
	Stage 2	900
Light switch		9,000
High beam		8,600
Horn		3,300

Fig 7-14: Operation frequency with 100,000 km road performance [VW]

Apart from function and the frequency of operation, one can differentiate the hand control elements as those that are used for operation in standstill and for operation while driving. Thus four priority groups can be defined in detail:

I. Important elements that are used while driving and whose arrangement takes place in such a way that the steering wheel (e.g. direction indicators) does not have to be let free as far as possible.

II. Important elements, which are used with lesser frequency, but arranged within the favourable hand range area in the proximity of the steering wheel (the steering wheel may be let free), e.g. headlight on/off.

III. Lesser important or less frequently operated elements, which should also be well reachable, but are of lower importance for driving the vehicle, e.g. elements that influence comfort.

IV. Elements, which are used particularly during standstill and whose operation requires a prolonged deviation of view from the road, e.g. seat adjustment.

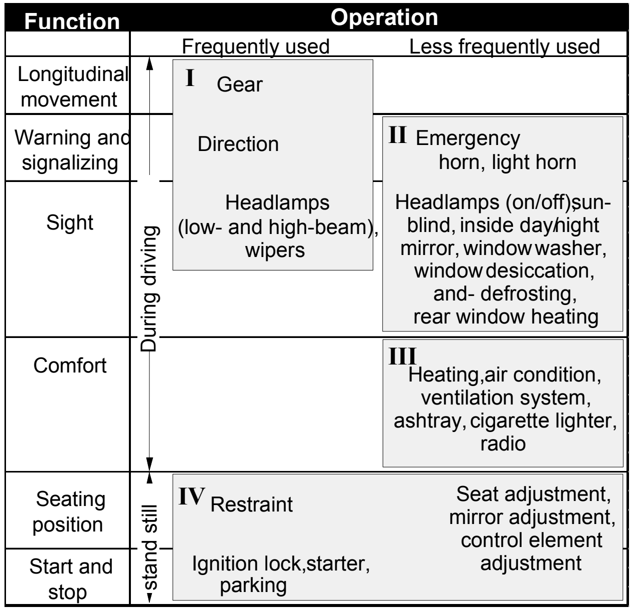


Fig 7-15: Priority groups for hand control elements

When dealing with the actuating forces attention must be paid to the compliance of limit values so that too much is not demanded of the driver. The driver's arm has a higher traction power compared to the thrust force, i.e. the movement towards the body can be better performed than those away from the body.

For the range of operation of the foot, the leg position is determined, to a large extent, by the seat. Since the actuation of the sectors that are operated by foot require the expenditure of some energy, this has also to be considered during the arrangement.

The actuating force that can be applied by the driver depends on the direction and the type of operation (accelerator pedal with foot movement, clutch, operation or parking brake with leg movement). A maximum force (approximately 2000 N) is produced if the force application point is below the H-point, Fig 7-16. In a car, the clutch and the brake pedal should be situated in this area (100 ... 250 mm below the H-point). In a truck, this value is not realisable due to a small cab length. Here the clutch and the brake must therefore operate with servo assist systems.

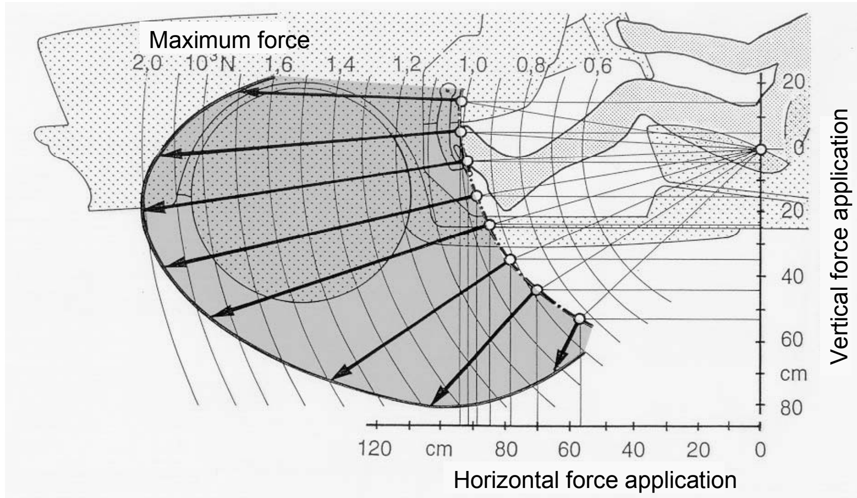


Fig 7-16: Max. forces during different arrangement of the foot operating sectors

While the position of the foot-operated controls is widely determined, there exists no coordination that spans over the entire brand spectrum in terms of arrangement of hand controls. The operation of the basic functions of a new vehicle often requires a study of the instruction manual. At least for the positioning of the elements from the priority classes I and II, a standardised arrangement based on the type of actuation and a direction of operation would be rather meaningful.

8 Driver Assistance Systems

8.1 Introduction to advanced driver assistance systems

In the past of automobile technology the components of a vehicle have been developed separately in the fields of chassis, body and drive train see Fig. 8-1). Due to the increasic traffic dense, the requirements on the driver to route a vehicle safely through these traffic conditions are also increasing. An overall view on the system "traffic" is necessary to understand the complexity of the drivers task. This has to be considered in the development of new measures for the advanced driver assistance and for an active improvement of the traffic and vehicle safety (Fig. 8-2).

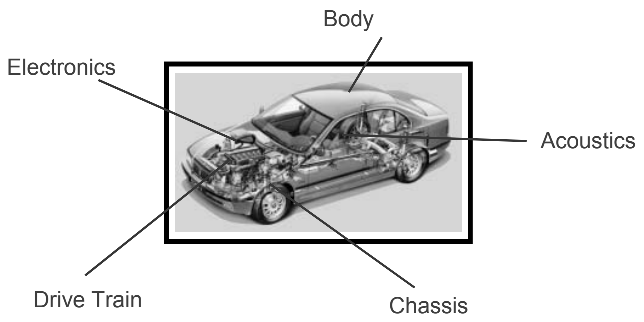


Fig. 8-1: Old view of automotive research: isolated vehicle

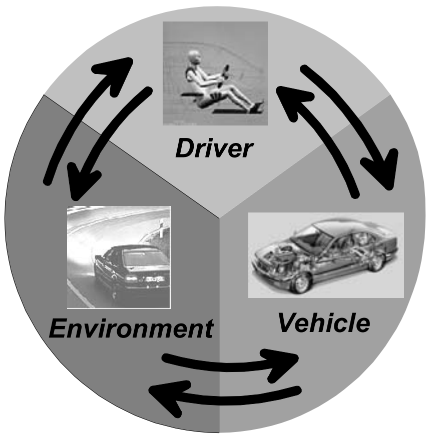


Fig. 8-2: New view of automotive research: vehicle in traffic environment

The system “traffic” can be separated into three elements which influence and interact with each other: the driver, the vehicle and the environment.

- Regarding the actual driving condition and the vehicle environment, the driver decides about the driving strategy (choice of route, velocity and lane). This driving strategy is realised with the use of operating elements in the vehicle (throttle and brake pedal, steering wheel, etc.).
- The vehicle is characterised by its dynamic performance in longitudinal and lateral direction. The driver's influence on each operating element results in the reaction of the vehicle, which is in addition influenced by the environment (e.g. road resistance) but also effects the environment itself (e.g. driving situation).
- The environment includes the surrounding vehicles, the resulting driving situation and also the road condition (progression of curves and hills, road and viewing conditions). The driver reacts and adapts his driving strategy regarding the environmental condition.

8.1.1 The driver in the control loop

As the operator of the vehicle, the driver is in the centre of the traffic situation. It is his task to control the vehicle and to drive safely through the traffic. At the same time he has to cover various driving tasks. As an example he has to pay attention to the driving route, while he is performing a change of lanes. The driver has to adjust the distance to the vehicle driving in front. This task has to be conducted on the new as well as on the old lane, in order to stay in the traffic flow and avoid collisions. Additionally the driver has to observe the surrounding traffic and therefore has to accelerate and to decelerate the vehicle respectively. While performing a change of lanes, the driver has to follow a defined trajectory considering the curve progression of the lanes. These various tasks can be separated into three main driving categories using the three level model shown in Fig. 8-3. The three levels are:

- navigation
- guidance
- stabilisation

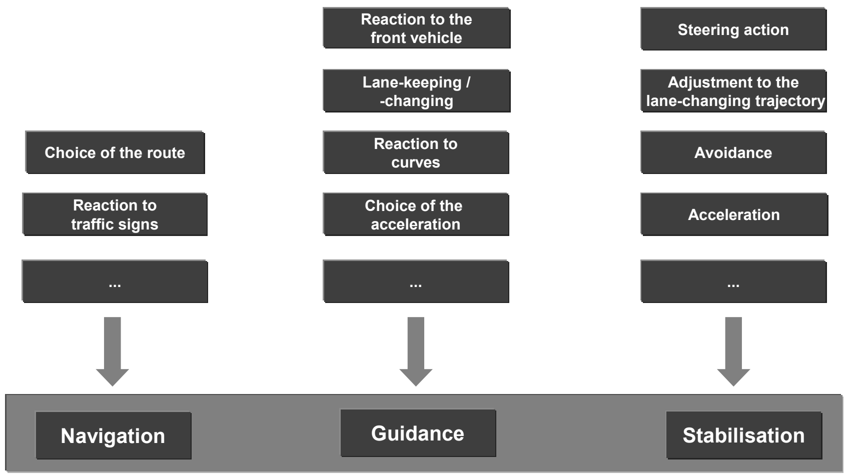


Fig. 8-3: Classification of driving tasks using the three level model

On the navigation level the driver decides about his driving route within the existing road network. The navigation task is focused on the recognition of relevant information in order to follow the intended route (signs, direction hints, name of streets, etc.) during the drive. It may be necessary to adopt the driving route due to changed road conditions (roadblocks, construction sites, traffic jam, etc.). The necessary time for navigational tasks can last up to several hours (time of travel). The minimal time needed is about 30 seconds (necessary time for orientation and for decision on navigation). Driving tasks on the navigation level are usually not critical upon time.

The following of the intended route is conducted on the guidance level. On this level the driver adapts his own driving style, utilising information of the observed road routing and the surrounding traffic. The guidance level includes driving tasks like lane keeping, following, overtaking and reacting to traffic signs. On this level the tasks can be divided into longitudinal and lateral guidance. Lateral guidance includes the avoidance of parking vehicles as well as lane changes. Longitudinal guidance mainly describes the choice of velocity. The necessary time period for driving tasks regarding the guidance of the vehicle is set between two and ten seconds (progress of acceleration, reaction to vehicle in front, lane change). The time needed is still in a higher range than the drivers reaction time, nevertheless it can become critical upon time.

The transfer of parameters from the guidance level into the vehicle movement takes place on the level of stabilisation. Because of this reason the level of stabilisation includes parameters like steering angle, throttle position, brake pedal position and chosen gear. There is a permanent comparison between the desired and the actual value of velocity and steering angle in order to compensate divergences caused by side wind or slippery roads. For the driver "stabilisation" means the avoidance of uncontrollable dynamics of the vehicle. The necessary time period to fulfil the driving task on the stabilisation level can be specified within a time span of under two seconds. Driving tasks on the stabilisation level are always time critical.

The driver can be compared to a controller in the closed control loop “traffic”. This is especially for driving tasks on the level of stabilisation. He compares actual and desired values and tries to compensate deviations with the use of the vehicle's given operating elements like steering wheel, brake and acceleration pedal. The driving tasks on the navigation and guidance level can also be regarded as elements of the closed control loop. Thus the system traffic represents a closed control loop consisting of the driver, the vehicle and the environment (Fig. 8-4).

The main tasks for the driver are:

- information collection,
- information processing,
- and reaction.

The information collection of the drivers results in the following three perception mechanisms:

- optical,
- acoustical,
- and haptical.

The driver collects all necessary information (distance and relative velocity towards other vehicles, own velocity, lane position, etc.) and decides upon these information about his reaction. The determined reaction is transformed by the vehicle actuators such as accelerator, brake pedal, steering wheel, clutch, gear-stick, etc.. At this point the driver acts as a non-ideal controller with a temporally delay (driver reaction time). Furthermore the control depends on defined conditions (leg and hand forces, recognition limits, system understanding, etc.).

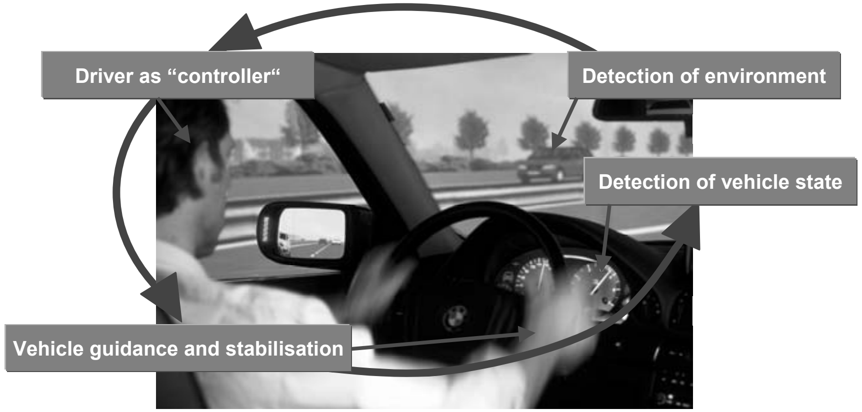


Fig. 8-4: The driver in the closed control loop

8.1.2 Advanced assistance systems for the driver’s support

Due to the increasing traffic volume and growing complexity of the driving tasks, technical systems have been developed in order to support the driver and relieve him of some of these tasks. These systems are so-called **a**dvanced **d**river **a**ssistant **s**ystems (ADAS). Additionally, these systems should relieve the driver from monotonous tasks, so that he can rather concentrate on more important driving tasks. Advanced driver assistant systems should compensate the known weakness of a human driver (inattentiveness, reaction times, etc.).

In order to fulfil these tasks, driver assistant systems are usually interlinked with all of the three elements of the closed control loop "traffic" (vehicle, environment and driver) as seen in Fig. 8-5. But there are also systems that are able to take over a driving task completely and to replace the driver in the defined task. In this case the control loop consists of the vehicle, the environment and the advanced driver assistant system.

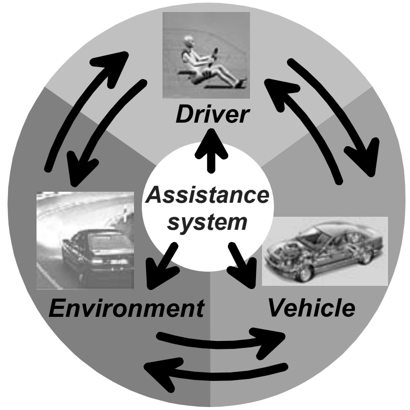


Fig. 8-5: Advanced driver assistance systems in the traffic system

Driver assistance systems can support the driver to achieve some of the following aims:

- Driving comfort: today most driver assistance systems concentrate especially on driving comfort. These are usually systems, which relieve the driver from annoying and monotonous tasks to ease the drive. Those systems do also have a positive effect on traffic safety, but it is only of secondary importance.
- Safety: advanced driver assistance systems can be used to prevent accidents, to decrease accident damages and improve the rescue management. Therefore these driver assistance systems either completely take over the vehicle control or give additional information and some type of warning to the driver (e.g. vehicle in blind spot).
- Traffic efficiency: an improvement of street capacity is expected by the usage of driver assistance systems. Thus traffic jams can be prevented or dissolved faster. In addition the vehicles, which are approaching the traffic jam, can be redirected automatically.
- Environment: the support of the driver in form of technical systems can be used to reduce fuel consumption and noise emissions. The assistance system can give a suggestion for a driving style depending on the situation and the foresight of the traffic in front. For complex drive train structures (hybrid engine) the operating strategy is set to an optimum.

With the takeover of some driver's subtasks, the assistance system becomes a controller or a controller-component in the close loop itself. While the driver depends on his own recognition to collect information, the assistance systems use special sensors (Fig. 8-6). On the one hand the sensors detect the driving condition (velocity, acceleration, yaw rate, etc.) and on the other hand the sensors scan the surrounding traffic situation (e.g. distance to the vehicle in front). The information processing takes place in a micro-controller. Actuators transfer the reaction of the system to the driver. The reaction can be displayed on screens to inform or to warn the driver. Another possibility are actuators which engage the throttle valve or the brake pedal.

The driver activates the assistance system with the help of an appropriate human-machine interface (HMI). In some systems the HMI is limited to an activation switch, while other systems do not have any HMI at all. They are working continuously in the background (e.g. ABS).

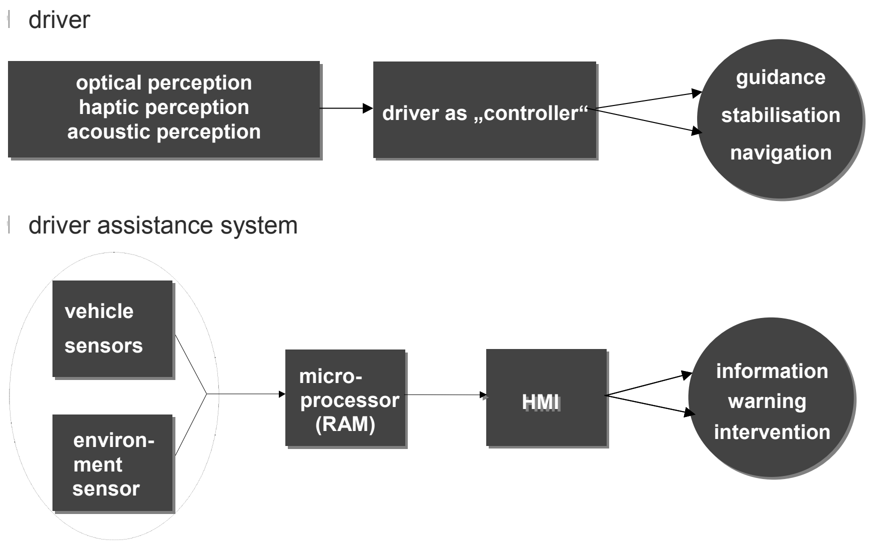


Fig. 8-6: Comparison of the process of vehicle control

Driver assistance systems can be classified depending on different criteria on the main focus of development. In case the technical equipment is important, the systems can be classified into the following categories:

- Systems depending on infrastructure,
- vehicle autonomous systems or
- combined systems (Fig. 8-7).

Vehicle autonomous systems collect the necessary parameters with the help of on-board sensors. Systems depending on infrastructure get the relevant information from the installed infrastructure. A possible application may be for example an information about the allowed maximum speed via vehicle-infrastructure communication. A link between data collected from external and internal sensors is the base for the combined systems. Actuators installed into the vehicle are always necessary to convert the system reaction. This classification is out of date and not very useful, as it is not very detailed and the form of technical information collection is not considered in an adequate way.

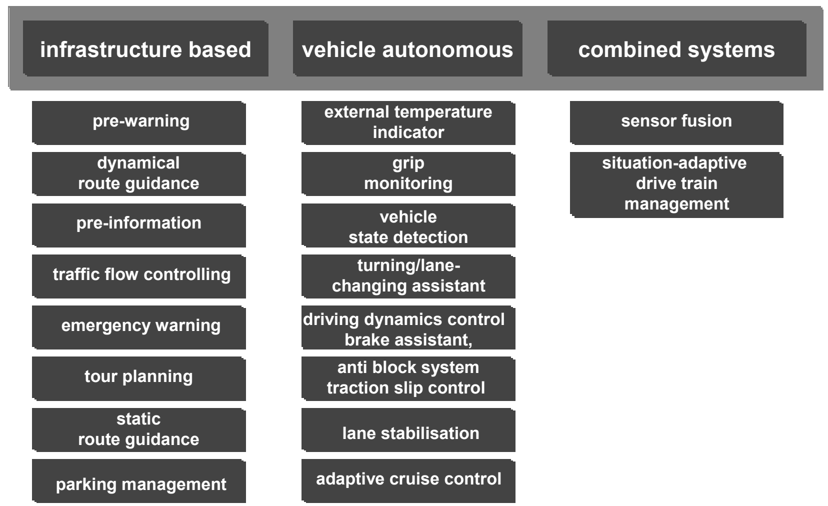


Fig. 8-7: Classification of the assistance function depending on the system architecture

In most cases advanced driver assistance systems are classified into the operating drive-task level, in case the main development focus is on the control itself. (Fig. 8-8). Thus an ACC (Adaptive Cruise Control), which controls autonomously the distance to the vehicle in front, is allocated at the guidance level, while a navigation system belongs to the navigation level and an ESP (electronic stability control) to the stabilisation level. The classification of the assistance systems is also a general description of themselves. Driver assistance systems on the level of stabilisation for example are usually interceding because of their time criticality. These systems are mostly equipped with a possibility to activate or deactivate the HMI. In some cases there is no HMI at all.

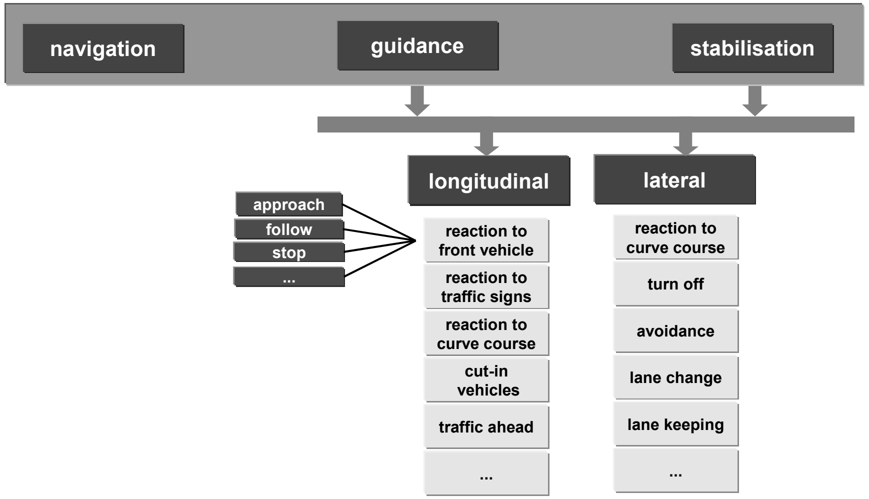


Fig. 8-8: Classification of the assistance function depending on the drive task

The type of support allows another classification level of advanced driver assistance systems (Fig. 8-9):

- informing or warning (optical, acoustical, haptical, e.g. collision warning)
- interceding (e.g. ABS, ESP etc.)
- autonomous (e.g. ACC, lane keeping, etc.)

Both methods for the classification of driver assistance systems are widely spread (type of drive task and type of support). For this reason all systems can be summarised, which are based on a similar mechanism and have to deal with similar problems. Therefore this classification is often used in the development of advanced driver assistance systems.

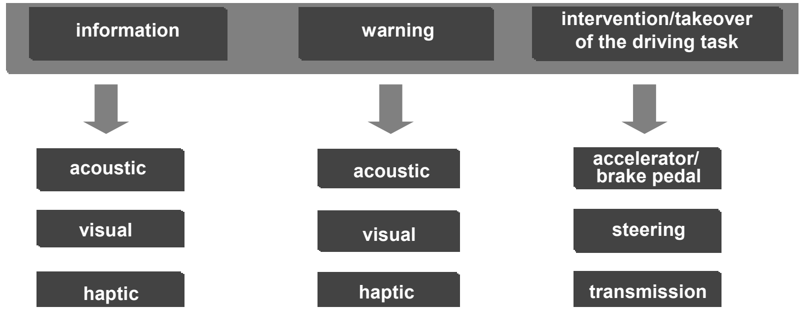


Fig. 8-9: Classification of the assistance function depending on the type of driver support

Another possibility to classify assistance systems is the course of traffic (Fig. 8-10). This approach results out of considering how technical systems can improve traffic safety. The main focus is on traffic safety. This approach of classification is not used by the developers of the systems, but by traffic researchers. They point out already existing control elements and technical support systems to increase traffic safety. With such a method of classification, the impact of a comfort system like ACC onto the traffic safety can be described. The system interacts on the level of a safe course of traffic (homogenisation of traffic flow) and partly on the level of risk avoidance (a too small distance to vehicle in front is generally not adjustable). The safety effect of ACC is therefore just secondary and not directly measurable. This approach of classification summarises all technical control elements on the level of the course of traffic.

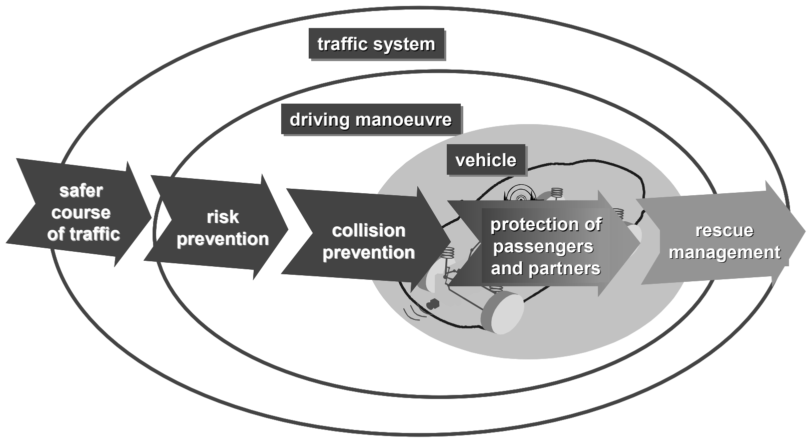


Fig. 8-10: Classification of the assistance function depending on the course of traffic

8.1.3 Historic development of advanced driver assistance systems

Systems, which relieve the driver of some of his driving tasks and therefore can be regarded as assistance systems, have a long history. In 1913 the starter motor was introduced in the automobile industry. The starter motor can be regarded as one of the first assistance system. An automatic gear or a power steering can also be classified as assistance systems. They take over driving tasks or support the driver. An example is the power steering system. The first assistance systems, which interact in the driving process, are ABS, traction control systems and ESP (Fig. 8-11). These types of systems belong to the level of stabilisation. On the one hand those systems do not need any sensors in order to detect the environment, but on the other hand their activation is almost independent of the driver behaviour. They can realize a closed control loop without including the driver. This makes their realisation as part of automotive development just possible, as they do not consider the two other elements of traffic (driver, environment, see Fig. 8-11).

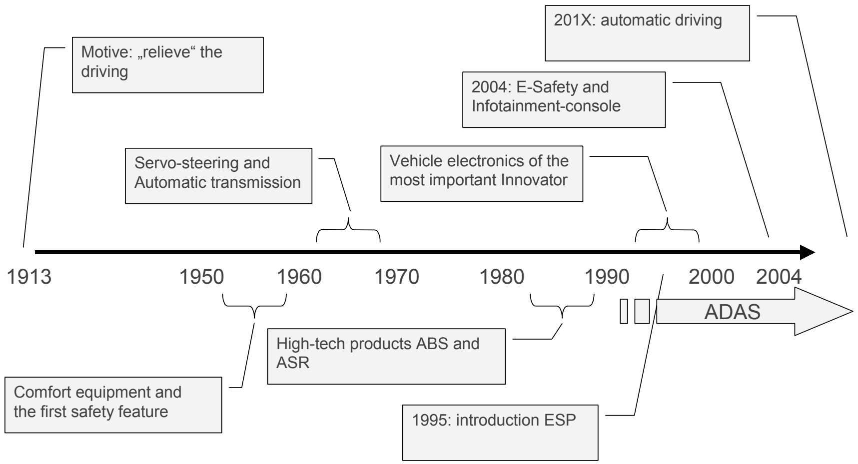


Fig. 8-11: History of ADAS

Modern driver assistance systems (also called ADAS) have to be regarded as a part of closed control loops. Their realisation has become possible within the last fifteen years. In the past the necessary components and technical know-how on sensors and actuators were not available or too complicated. The ideas of today's assistance functions have been already developed in the 50ies and 60ies. Fig. 8-12 for example shows a vehicle equipped with a radar sensor on the roof in the left picture. Today's radar systems have the size of a fist compared to those systems. Fig. 8-12 on the right shows the first approach of inter vehicle communication. The data of the leading

vehicle are transmitted via cable to the following vehicle. With these data the following vehicle can adjust speed and yaw rate to the vehicle in front. Because of the limited cable length this was just an test on a test track. But the potential of such driver assistance systems has been proved with such an approach.

Fig. 8-12: First driver assistance systems to take over driving tasks; left: vehicle with a radar sensor; right: vehicles with vehicle-to-vehicle communication

8.2 Sensors for driver-assistance systems

Sensor systems are one of the fundamental technology for driver assistance systems. The sensors are able to detect the vehicle surrounding and the state of the vehicles. The vehicle surrounding can be divided into a near field and a far field. The near field is a section up to 50 m in front of the vehicle. In this field an object's relative velocity is less important, but the object's distances to the vehicle have to be measured exactly in the centimetre or even the millimetre range. A wide observation angle is substantial. The far field is a section up to 200 m in front of the vehicle. The range of the sensors and the detection of the relative velocity are important factors regarding the far field.

8.2.1 Sensor technology

In most sensor systems the sensor technology for the detection of the environment is based on three principles: Radar (**Ra**dio **D**etection **A**nd **R**anging) Lidar (**Li**ght **D**etection **A**nd **R**anging) or image processing. Laserscanners will be available in the near future. Sensor technology for the detection of the vehicle state (e.g. position, friction coefficient between road and wheel, rain etc.) has been in the centre of attention in the last years.

8.2.1.1 Lidar Sensos

The Lidar sensors which are based on laser technology, use the reflection of transmitted electromagnetic waves for the measurement of distance (ranging). The lengths of these waves are situated within the range of 0,78 µm to 1 µm and thus in the infrared area, invisible to the human eye. The measurement of distance between two vehicles is represented by the measurement of the interval of time between transmission and reception of the reflected signal. The speed can be determined by using the Doppler shift of the frequency of light reflected on a moving object. The frequency variation can be verified by superimposing the reflected or scattered radiation with a reference beam of the same laser, which is a measure for the speed of the target object. Fig. 8-13 shows the operating principle of a Lidar sensor as a block diagram.

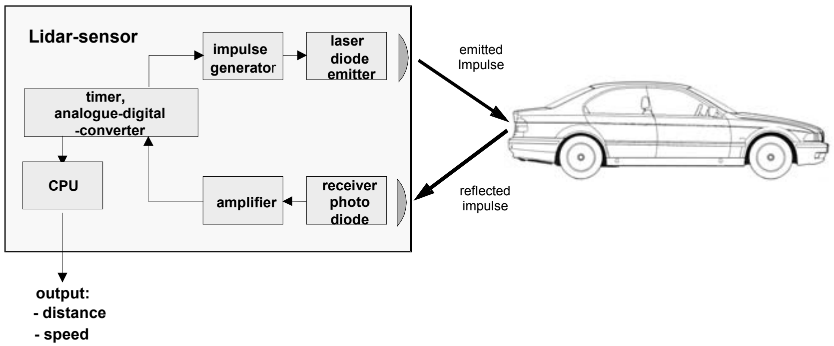


Fig. 8-13: Functional structure of a Lidar Sensor [EHM98]

It is possible to use different detection methods. In automotive engineering two methods are common, the transit-time technique and the Laser-Doppler-shift technique.

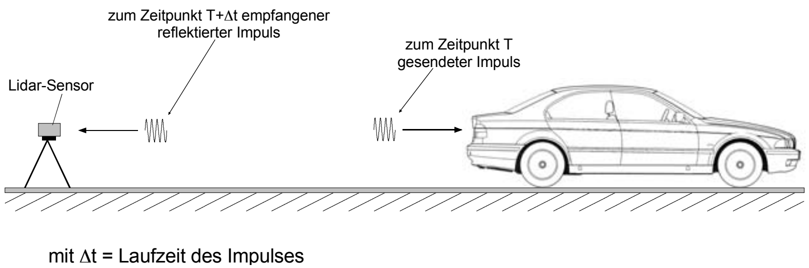


Fig. 8-14: Distance measurement using the transit time technique

The transit time technique is based on short laser impulses being emitted by the laser (Fig. 8-14). The impulses are reflected by the target object and sent back to the laser. The time between the sending and the receiving of the signal is measured. The length of the distance of the measuring section can be calculated using the speed of light and the measured time span. The target velocity can be calculated on the basis of two laser pulses. The velocity can be determined by the change of distance within a defined time interval, e.g. between two pulses.

The velocity can also be measured by using the Doppler shift method of the light frequency during a reflection at a moving object (Fig. 8-17). The frequency shift can be proven by the superposition of the reflected light impulse and a reference impulse of the same laser source.

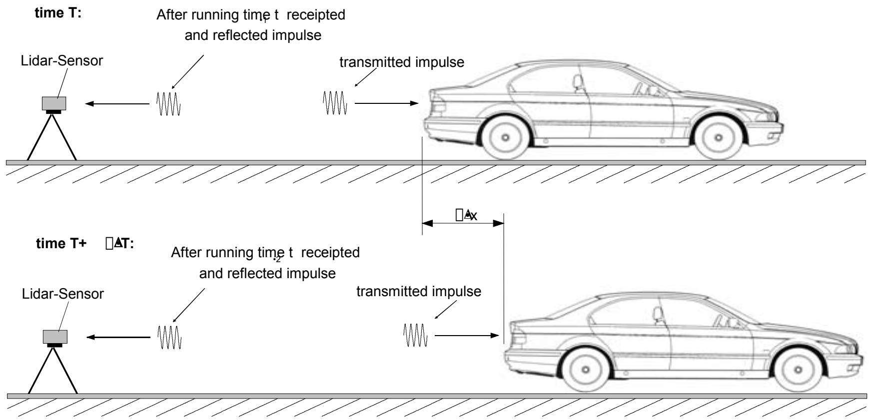


Fig. 8-15: Velocity measurement using the transit time technique

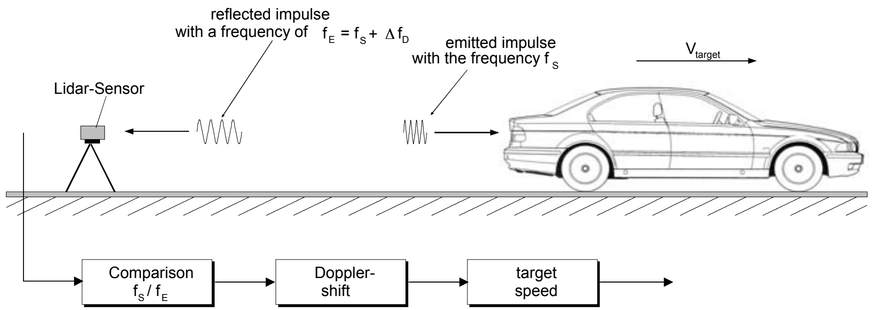


Fig. 8-16: Velocity measurement using the Laser-Doppler-Shift technique

The performance of the Lidar sensor depends substantially on the intensity of the broadcasting laser beam. The intensity must be limited to an upper limit due to safety reasons for the human eye. Therefore a powerful receiver and a powerful signal processing unit are necessary [ANK96].

The sensor needs a free field of view in its wavelength range. Hence, for example, the widely used thermal protection strongly reduces the performance of the sensor. In addition, contamination, rain or fog lead to insufficient reflection, which can affect the performance of the sensor negatively. Fig. 8-17 exemplarily shows a Lidar sensor and its technical data.

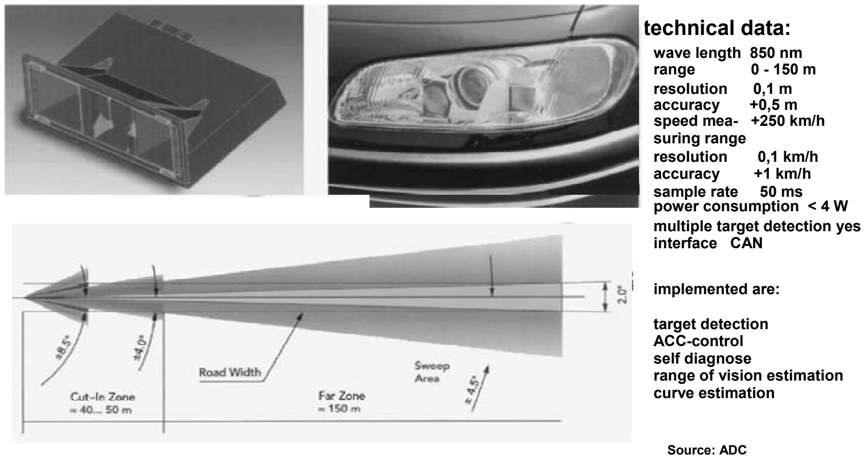


Fig. 8-17: Exemplary sensor concept (Laser)

8.2.1.2 Radar sensors

Radar sensors similar to Lidar sensors operate with electromagnetic waves using frequencies in the centimeter or micrometer area for detection. The legally prescribed frequency for applications of radar in vehicles is approx. 77 GHz. In radar sensors objects are picked up by sending electromagnetic waves and reflecting them over large distances. Some principles may be classified in the radar measuring technique:

The CW (**C**ontinuous **W**ave)-radar emits a continuous electromagnetic wave using an antenna (Fig. 8-18).

The measurement of the distance to the relevant target is based on the phase shift between the transmitted and received signal in the CW-radar. The phase is periodic

and therefore the distance measurement is only distinctive in case the phase shift is less than 2π. This means that only distances in the range of less than a half wave length can be determined exactly. For long range measurement long wave lengths are necessary. The CW-radar therefore has no importance for long ranges, since such low wave lengths are not often demanded. The CW-radar is important for velocity measurement. Many radar systems of traffic monitoring use the CW-principle. In case there is a relative velocity between the transmitter and the receiver a frequency shift occurs between the transmitted and the received frequency. This is the so called Doppler effect. The Doppler effect describes the change of frequency in case the transmitter and the receiver are travelling with a relative velocity. The frequency increases at approach and decreases at removal. The frequency difference depends on the relative velocity, which can be determined based on this effect.

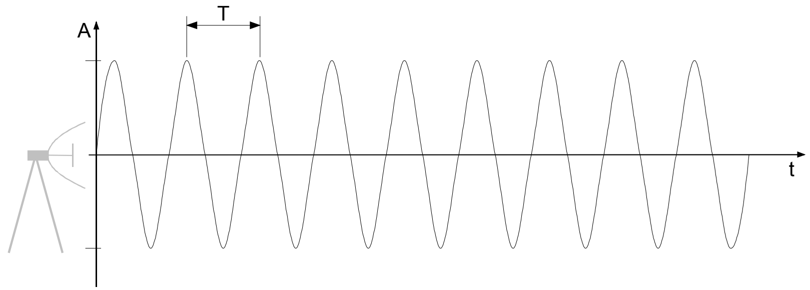


Fig. 8-18: Continuous wave radar

The Frequency Modulated Continuous Wave Radar (FMCWR) represents another principle (Fig. 8-19). Here a frequency-modulated microwave signal with constant amplitude is used. Similar to the pulse radar, the Doppler effect is used for the measurement of relative speed. The distance is evaluated using the frequency modulation: Throughout the signal transmission, the transmission frequency is modulated, which leads to a variation in the frequency between the transmitted signal and the received signal serving as a measure of distance.

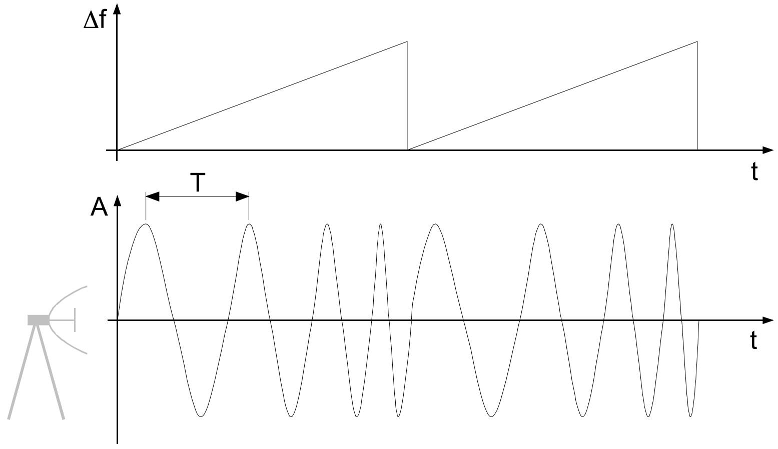


Fig. 8-19: Saw tooth characteristic of frequency modulated FMCW-Radar [DOM99]

Fig. 8-20 shows the block diagram of a FMCW-radar.

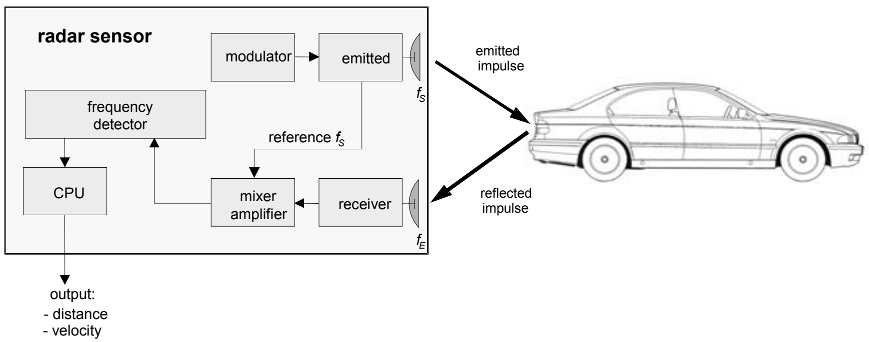


Fig. 8-20: Block diagram of a FMCW-radar (after [BAU85])

The FMCW-Radar principle allows multi-targeting. In addition however, the wide frequency spectrum must be analysed by Fast-Fourier transformation in a post processor. Highly efficient signal processors (DSP), available only in the last few years, make this possible.

The Pulse Radar functions similar to the Lidar sensor where distance is measured based on the time interval between transmission and retrieval of microwave signals. In addition, the speed relative to a vehicle driving ahead can be measured by the

Doppler effect. The sensor is capable of multi target detection, since it recognises different targets at different distances that show different time intervals and thus allow target selection is possible.

The impulse principle transmits a sequence of constant length impulses (T_{pulse}) and constant time distances (T_{follow}) (Fig. 8-21). The impulse is reflected by the relevant target and received from the transmitter/receiver unit.

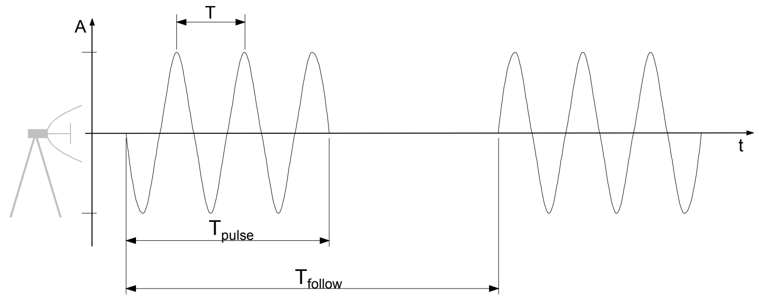


Fig. 8-21: Pulse-radar

The signal's run-time along the distance transmitter-object-receiver is measured at the receiver of a pulse-radar. The duration is proportional to the target distance. In case the velocity of the relevant target object shall be calculated, the variation of the impulses duration can be used.

An additional possibility to measure velocity is the evaluation of the frequency shift between the transmitted and the received impulse. A combination of the impulse and the CW principle is necessary. It is summarized in the **P**ulse-**D**oppler-Radar (PD).

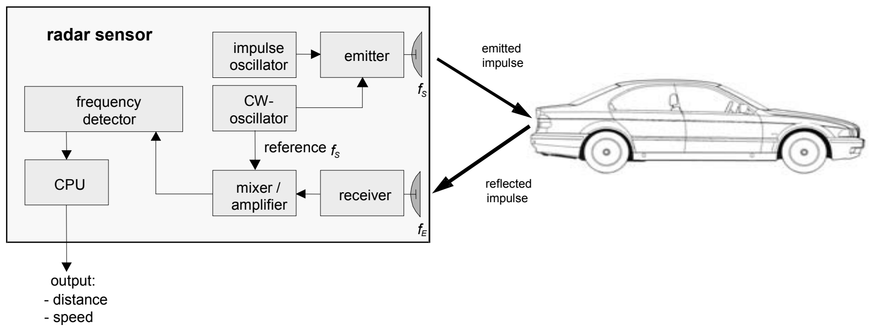


Fig. 8-22: Principle of the Pulse-Doppler-Radar (after [BAU85])

At present the advantages of the FMCW-Radar compared to the pulse radar are lower costs due to a simpler construction. However higher demands are made on signal evaluation, since the separation between the determination of distance and of speed is complex.

In Fig. 8-23 the usual characteristic data for far field and near field radar sensors are summarized.

	near field radar sensors	far field radar sensors
technology	impulse radar	FMCW radar
frequency	24 GHz	60 GHz , 76 – 77 GHz
range	0,2 – 10 m	1-150 m
accuracy	±5 – ±10 cm	0,5 – 5 m
max. velocity	100 – 200 km/h	180 – 200 km/h
velocity resolution	0,2 – 3 km/h	0,2 – 5 km/h
horizontal opening angel	±40° – ± 50°	7° – 16°
vertical opening angel	±10°	3° – 4°
angular accuracy	0,1° – 0,5°	0,1° – 0,5°

Fig. 8-23: Technical data for radar sensors of the near- and the far field

Radar detectors are suitable for the detection of objects in traffic, since they primarily localise metallic and aqueous structures. Sharp edges are favourable for detection of vehicles, since they do not transmit the signals away from the sensors by diffuse reflection.

In comparison to the Lidar, Radar is less sensitive to climatic influences such as rain and snow. A covered assembly is also possible such as, for example behind the radiator grille, as long as no metallic or structured surfaces are situated in the sensor's operation field.

8.2.1.3 Laser scanner

Laser scanners can detect the surrounding area with a high opening angle. The area is scanned using laser beams (see Fig. 8-24). Another advantage of Laser scanners is the possibility to detect the relative velocity of objects in longitudinal and vertical direction. Complex traffic scenarios can be detected and misjudgements (e.g. while driving in a curve) can be avoided.

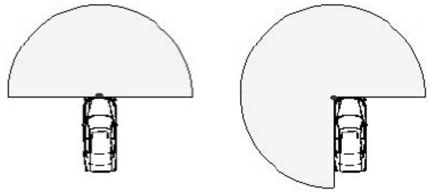


Fig. 8-24: The sensing range depends on the mounting position of the scanner

Laser scanners are based on the measurement of the runt-time of laser beams (time-of-flight principle). In this process light impulses are transmitted continuously. The transmitted beams are reflected by the relevant object. The time between the transmission and the reception is measured as well as the angle to the object. Because of the known constant propagation velocity, the distance, the velocity, the direction and the shape of an object can be determined with high accuracy and high resolution. The laser beams are deflected through a rotating prism in order to perform a 2-dimensional scan. A scanning range of almost 360 ° can be accomplished by using this deflection principle with a rotation head. The average scanning range usually is in the range between 180 ° and 270 ° depending on the mounting position at the vehicle. The remaining possible scanning range is concealed by the vehicle itself (see Fig. 8-24). In order to scan the whole range of 360 ° two or three Laser scanners can be mounted.

The principle structure of the LD AUTOMOTIVE Laser scanner of the IBEO Automobile Sensor GmbH is shown in Fig. 8-25.

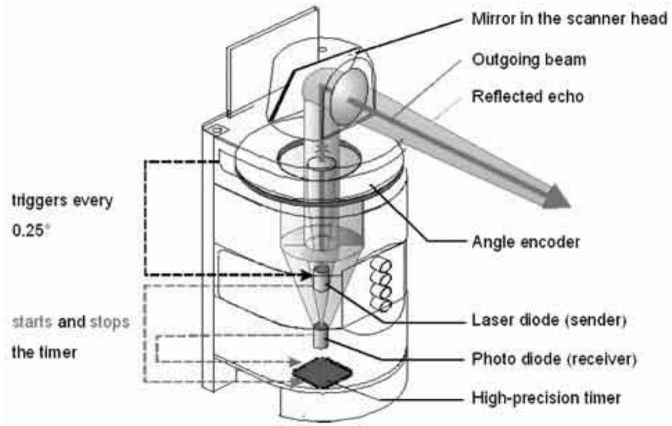


Fig. 8-25: Principle structure of the LD AUTOMOTIVE Laser scanner [IBE04]

The scanner can be used to monitor the field in front of or behind the vehicle. The scanning range of the Laser scanner is limited due to eye safety regulations (laser class 1). Laser scanners can detect an object in a longitudinal range up to 40 m with an object reflexion of 5 % respectively 300 m at high reflexion like for instance rear lights of an vehicle. A single scan consists of 360 distance measurements. Each measurement has an accuracy of ±3 cm to ±5 cm. therefore a truck, which is driving 3 m in front of a scanner is detected with more than 40 measuring points. This means one measuring points each 5 cm. The scanning rate is 10 Hz – 40 Hz, so that all objects can be detected with high accuracy in longitudinal as well as lateral direction. An IBEO Laser scanner and the technical data is shown in Fig. 8-26 [IBE04].

parameter	specification
range	40 m at 5% reflexion; max. 256 m
accuracy	±3 cm
velocity range	0 km/h – ca. 160 km/h
sensing range	180 ° - 270 °
angular accuracy	0.25 °
scanning rate	10 Hz – 40 Hz
laser class	1
weight	3,2 kg

Fig. 8-26: Specification of the Laser scanner LD AUTOMOTIVE [IBE04]

8.2.1.4 Image processing systems

Another possibility to monitor the road space around the vehicle are image processing systems (Fig. 8-27). The first step is to record the road space with an optical device. Next the image data has to be converted into electrical signals. As a data source cameras equipped with semiconductor-image sensors (CCD, **C**harge **C**oupled **D**evice or CMOS, **C**omplementary **M**etal **O**xide **S**emiconductor) are used. The requirements on the lens system are not very high, as a digital image processing is arranged post the lens system. This has a positive effect on the costs and the required space of the optical components. The digital image is analysed using an object detection and passed on the driver assistance system.

All steps of the image processing systems, that are used as an environment sensor, have the task to detect and highlight the relevant objects for the secondary control. A frequently used method in image processing is the method of colour segmentation. In

this method arrays of the same colour are detected and combined. Therefore object borders can be detected, e.g. lane markings of road side objects.

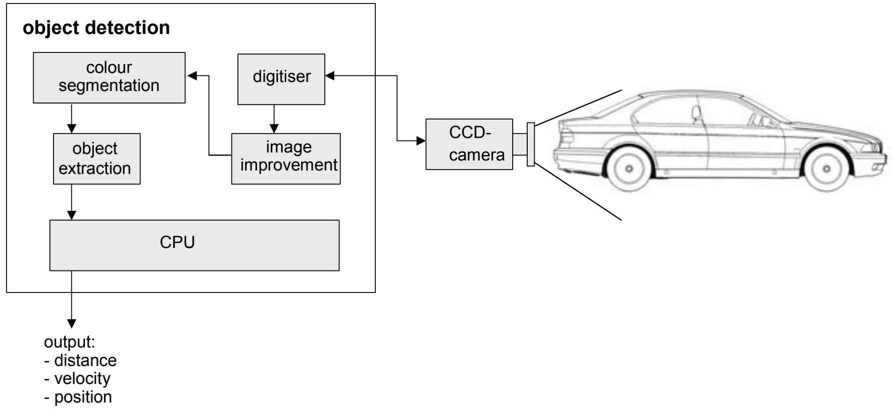


Fig. 8-27: Principle of an image processing unit

A very promising way for image processing systems is the combination with other sensor systems. With the help of the image processing unit, it can be decided if a detected object is the relevant target or not. The course of the road can be exactly determined. Furthermore a image processing system is used in a collision-avoidance system, together with other sensors. Not moving targets on the lane of the vehicle can be detected [DOM99].

The camera is attached behind the windshield in the range of the inside mirror, see Fig. 8-28.

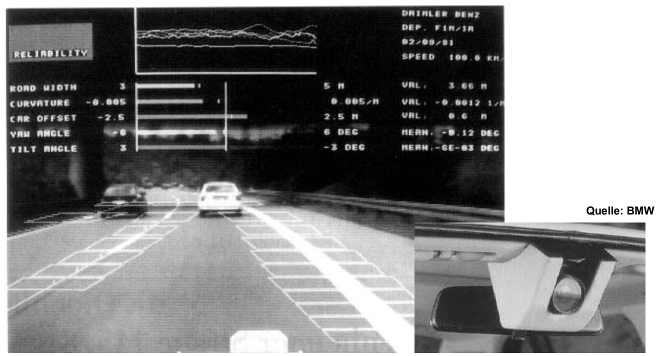


Fig. 8-28: Image processing [MEH96]

For image-processing sensors, the analysis can be designed to any complexity. Here special efforts are being made to develop procedures to carry out the picture evaluation as fast and efficiently as possible. This refers not only to the algorithms for scanning, but also to the intelligence used in the selection of the area of investigation. Thus complex approaches, apart from the identification of the objects in 3-D-Space, pursue an additional trace into time, allowing the development of a virtual world in the computer. Apart from vehicles and road, this virtual world can contain further sufficiently detailed elements which are important for driving. On the one hand these elements are available for control, while on the other hand they enable a faster analysis of the present video pictures due to a prediction derived from time.

Through road recognition an image processing system can determine directly if the detected object is in its own lane. This is particularly advantageous while driving along curves.

The system's vision range corresponds to that of humans. Environmental conditions such as rain, fog or snow limit the range. Large distances make the resolving power of the digital scan more difficult, usually in the curve prediction. Sometimes a second camera with a larger focal length is used in order to improve the resolution. Hence, apart from higher accuracy, the costs of the system continue to rise.

Generally large quantities of data are generated during image processing which can be analysed. This requires high computing capacity, which is presently still expensive. Hence, serial application is still ruled out. As a pure distance sensor, image recognition however is of only limited suitability. The indirect method of distance and speed measurement results in inaccuracies, which can become apparent in vehicle control. Range restriction due to pollution is a further problem.

8.2.1.5 Ultrasonic

The ultrasonic technology is one of the first sensor technologies which was introduced in vehicles as a driver assistance system. Ultrasonic sensors are used for the close-up range object detection, e.g. in order to warn against objects being targeted in the close-up when backing into a parking space. With low velocities up to 40 km/h and low distances (up to 10 m) they offer a good cost/performance ratio.

Ultrasonic detectors are compact and robust measuring instruments. The sensors work with high-frequency acoustic compressional-waves which are sent out into the detection area by an ultrasonic signal transmitter. If the ultrasonic wave hits an objects, the wave will be reflected (echo) and detected by a receiver. Due to the fact that reflection causes loss of energy, the reflected signal has to be amplified. The time difference between sending and detecting can be used to calculate the distance

to the object. The spreading velocity is equivalent to the sonic speed, which is 340 m/s for standard temperature. An ultrasonic wave needs approximately 30 ms for a distance of 5 m to the object and back to the sender.

Ultrasonic sensors are sending compressional-waves with frequencies between 30 kHz and 50 kHz. The maximum measurable distance is approximately 10 m with a resolution of 0,01 m. The sensors in vehicles are fixed to the bumper and have a limited range about 1,5 m. These sensors are mainly used in parking-distance-control systems (see Fig. 8-29).

Fig. 8-29: Ultrasonic sensors from Denso Corp. For the edge- (left) and rear end area (right) [DEN02]

The conventional ultrasonic sensors mounted in the bumper of vehicles are not very flexible. This means that the detection area is fix. The echo-evaluation is simplified and can only be used for the identification and the positioning of one object. For this reason scanning ultrasonic sensors were developed, which enable the construction of a 3-D area of the environment using the direction of the echo, the energy and the Doppler shift of the frequency [BON98]. Therefore automated parking assistants can be realized.

parameter	min.	max
range	0,2 m	1,5 m
measuring accuracy	0,02 m	
relative velocity	-5 m/s	+5 m/s
velocity resolution	0,5 m/s	
observation range	vehicle width ± 30°	
angular accuracy	5°	
object detection time		100 ms

Fig. 8-30: Parameter list of a parking aid system [KUN99b]

The system is based on the scanning of the area with several ultrasonic waves. After a scan is arranged, the time has to be multiplied with the amount of waves which cover the desired area. In order to cover an area of e.g. 90 ° an ultrasonic wave of 30 ° has to scan three times (0 °, -30 °, +30 °). The total time of the three waves has to equal 90 ms. With a simultaneous application of several sensors or sensors with a larger scanning angle (max. 120 ° (±60 °)) a wider area can be scanned in less time. In Fig. 8-30 parameters of a parking-assistant-system are listed.

The general disadvantage of ultrasonic sensors is, that the sensors only identify objects situated in the close sensor range. This means, that everything behind the sensors can not be detected. Furthermore ultrasonic sensors have difficulties with „smooth“ absorbing surfaces. Optically they can not be mounted to the vehicle in a hidden way, because the performance of covered sensors is too low. Ultrasonic waves are sensitive against changes of air density. A change of temperature or wind may influence the echo’s amplitudes. The objects still will be identified, but there are additional algorithms necessary in order to sense these influences.

8.2.1.6 Vehicle-infrastructure communication

Regarding the Vehicle-infrastructure communication, techniques have been established, which are used for the cellular phone network or the broadcasting service. Digital broadcasting techniques such as TMC (Traffic Message Channel) or DAB (Digital Audio Broadcasting) are unidirectional compared to the cellular phone network. This means that data can only be received but not sent by the vehicle The system is not suitable for a complete communication, traffic data (for example) only can be received. Beside this form of communication, the communication through satellites is possible. These satellites are not for rotational position sensing such as GPS, but bi-directional communication satellites.

For the communication through satellites geostatic satellites in the GEO (Geostationary Earth Orbit) or satellites in the LEO (Low Earth Orbit) may be considered. Geostatic satellites are situated in about 36000 km height above the ground so that even a low amount of satellites guarantee a global cover. A very large transmitting power is necessary and the time delay is high because of the distance (>0,25 seconds). Inmarsat is an example for such a satellite system. This system consists of 5 satellites. The transfer rate is about 2,4 kBit/s.

In contrast Iridium or Globalstar are satellite systems, which are situated in the LEO. LEO is the area about 500 – 1500 km above the ground. Because of the low altitude (780 km at Iridium and 1400 km at Globalstar) a large amount of satellites is necessary for a global cover (66 regarding Iridium and 48 regarding Globalstar). Roaming between the satellites, so called handovers, are not unusual. The transfer performance is relatively low and the transfer rate is about 4,8 kBit/s for Iridium and 9,6 kBit/s for Globalstar. Another satellite system in the LEO is named Teledesic and is scheduled for the near future. This system shall consist of 288 satellites in 700 km height above ground with a transfer rate up to 64 MBit/s.

8.2.1.7 Vehicle-vehicle communication

The vehicle-vehicle-communication will play an important role in the future regarding driver assistance systems. The main advantage of this type of communication is that no infrastructural sensors, no powerful host systems and no stationary radio networks are necessary. The information can be sent to the right place quickly.

The vehicles communicate directly with each other in a fast and efficient way in order to exchange important information concerning the traffic situation. Other traffic members can be alluded to the traffic condition, the road condition, important events as well as endangerments. Regarding data transfer along larger distances the vehicles act as network knots to inform as many traffic members as possible. This requires a highly efficient routing protocol, which is able to register the fast changing network topology and which can find possible transmission paths. Another essential requirement concerning the vehicle-vehicle communication is the real-time ability. The data has to be transferred to the receiver without delay.

Various methods of communication technologies with different frequency bands are available today. Those used in different research projects are:

- Wireless LAN IEEE 802.11
- GSM, GPRS, UMTS UTRA TDD
- HiperLAN
- CALM
- Bluetooth
- Independent solutions are based on 434 MHz, 868 MHz, 2.4 GHz, 5.8 GHz, 24 GHz and 61 GHz

In Fig. 8-31 examples for applications of vehicle-vehicle-communication are given. A traffic jam warning behind a curve can be sent to the following vehicles, as seen in the left picture. Regarding the second example, the three vehicles determine the order to cross the intersection using vehicle-vehicle communication and therefore they can pass the intersection safely.

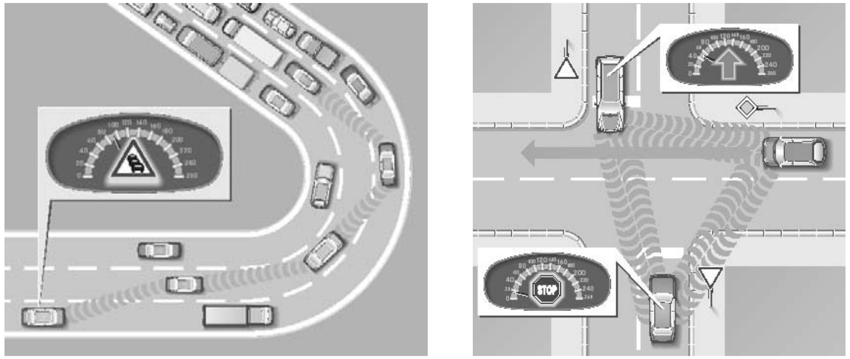


Fig. 8-31: Vehicle-vehicle-communication, danger warning and intersection assistant [DAI01a]

Another application of the vehicle-vehicle communication is the automatic steering of a complete vehicle following another vehicle, which is also known as "electronic tow bar" or “platooning”. Primarily for the growing freight transport the electronic tow bar is a future-oriented method. This procedure allows to reduce the safety distance between linked vehicles from 50 to 12 m. Thus it eases the work for the trucker because the electronic tow bar takes over the driving partially or even completely. Due to the decrease of the distance between the single trucks, more traffic space can be won and the fuel consumption and finally the emissions can be reduced. With the help of the vehicle-vehicle-communication the following vehicle receives information on the driving condition of the leading vehicle, such as velocity, braking actions, steering angle etc.. Therefore it adjusts its driving parameters for the automatical following [DAI02].

Fig. 8-32: electronic tow bar in the PROMOTE CHAUFFEUR 2 project [BON03]

8.2.1.8 Positioning

In the year 1973 the American department of defence commissioned the development of a satellite-based system which should enable the navigation of every single moving or resting object in every weather condition at every location. The result is the „**Nav**igation **S**ystem with **T**iming **a**nd **R**anging **G**lobal **P**ositioning **S**ystem“, abbr. NAVSTAR-GPS, which is known as GPS.

The counterpart to NAVSTAR-GPS is the GLONASS system (**GLO**bal **NA**vigation **S**atellite **S**ystem or Global'naya Navigatsionnaya Sputnikovaya Sistema) which was developed by the former Soviet. The principle of the data transfer and the positioning method is identical to the NAVSTAR-System. At present GLONASS is administrated by the government of the Russian Federation and it is operated by the Coordination Scientific Information Centre (KNITs) of the department of defence of the Russian Federation. Over the last past years many different systems are developed for position finding using the basic GPS-system. In Fig. 8-33 the systems are given regarding their accuracies, costs and the current status.

	position accuracy	costs	status
GPS	max. 10 m for PPS max. 15 m for SPS	cheap	in service
GLONASS		cheap	partially in service
GALILEO	max. 5 m (standard)	cheap	planned 2008
DGPS	max. 1 m	medium	in service
RTK-GPS	centimetre- to millimetre range	expensive	in service
SBAS	max. 3 m	medium	partially in service
INS	ca. 1 m at 30 sec. drive	medium	in service
Map Matching	dependent of map resolution	cheap	development state
SPS	millimetre range	not known	development state
Cell-ID	200 m – 10 km	development state	in service
E-OTD	50 m – 100 m	very cheap	in service
VPS	not known	not known	development state

Fig. 8-33: Systems for positioning

Since 1978 altogether 24 satellites were distributed on six different levels in orbits of 20138 km above the ground. Three of them serve as a reserve, while the other 21 are in permanent operation. Because of the distribution onto the different orbits it is guaranteed that every single point on earth is in the range of view of at least four to eight satellites (Fig. 8-34). As it will be described later, four satellites are necessary for the determination of the exact position.

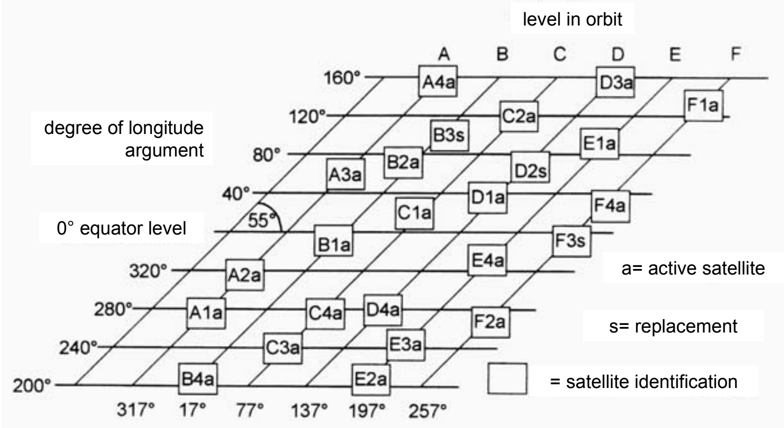


Fig. 8-34: Orbits of GPS-satellites [WOL98]

The GPS enables a three-dimensional position calculation. The orbit data, on which the coordinates of a satellite can be calculated for any point in time, has to be modulated onto the radio signal which is sent out by the satellite and is available for the receiver. The distance between a satellite and the unknown point can be derived from the running time of the radio signal. For this reason every satellite is equipped with four very exact atomic clocks. Those are designed in order to adjust themselves so that the deviations reset each other. Those clocks generate timestamps, which are transmitted together with the orbit data. They document the point of time of the beginning of the broadcast. The GPS receiver measures the arrival time of the signals. The receiver therefore has to be equipped with an additional clock as well. Because of the costs and the lack of space, the use of a highly exact atomic clock can not be considered. Instead a quartz crystal clockworks is used. Because of the inaccuracy and the asynchronous character of the receiver's clock, the „clock error" occurs. For a spatial positioning, the system of necessary equations now consists not only of the three unknown coordinates but additionally also of the retardation. The system has to be completed with another equation in order to solve it (Fig. 8-35). For this reason the data of a fourth satellite is necessary for the positioning system. Regarding the measured signal-run times to the individual satellites, so-called pseudo-distances can be calculated presuming that the signals of the transmitter are spreading with the speed of light.

$$p_1 = \sqrt{(x_p - x_1)^2 + (y_p - y_1)^2 + (z_p - z_1)^2} + \Delta p + e_i$$

$$p_2 = \sqrt{(x_p - x_2)^2 + (y_p - y_2)^2 + (z_p - z_2)^2} + \Delta p + e_i$$

$$p_3 = \sqrt{(x_p - x_3)^2 + (y_p - y_3)^2 + (z_p - z_3)^2} + \Delta p + e_i$$

$$p_4 = \sqrt{(x_p - x_4)^2 + (y_p - y_4)^2 + (z_p - z_4)^2} + \Delta p + e_i$$

$$\Delta p = c \cdot \Delta t$$

p_i	- pseudo-distances to the four satellites
x_p, y_p, z_p	- coordinate axis of the determined location
x_i, y_i, z_i	- coordinate axis of the four satellites
Δp	- deviation of the distances based of the clock error
Δt	- deviation between the clocks (clock error)
c	- speed of light
e_i	- additional error of the system

Fig. 8-35: System of equations for the GPS-positioning

Refraction effects in the ionos- and the troposphere concerning the signal dispersion are present, so that the distance is longer than the shortest connection to the satellite. The receiver adjusts this error with a mathematic error model. The model also needs information about the time of day and the season.

Data sent by the satellites is divided into a civil part (C/A-Code = Coarse/Acquisition-Code), which is available for the public, and into a part which is only used by the military (P-Code = Precision-Code). The P-Code is explicitly more precise regarding the time and the track information. The last one is encoded and only useable with an appropriate military receiver. It enables an accuracy within meter range. Because of political reasons, the civil part of the transmitted data of the satellites had been artificially falsified by the operating company („selective availability") so that the accuracy with a possibility of 95 % was just about 100 m. Since May, 2nd,2000 the public code is transmitted without additional noise so that an accuracy of about 4,11 m is possible today.

In order to achieve a more accurate positioning for the ship navigation in the coastal area, the American coast guards developed the „Differential GPS" – DGPS despite the explained problems. This system is based on the fact that the same positioning accuracy of a permanently installed receiver at location A has to be available for a mobile receiver at location B as well. In case the location of the stationary receiver is known exactly, the receiver can calculate the current difference between the known position and the position being calculated by GPS. It can transmit the data trough radio communication to the mobile receiver. Some assumptions have to be considered (e.g. same atmospheric conditions) in this case. Those assumptions may lead to a lower accuracy for increasing distances between the mobile and the fixed receiver increases. With the help of the DGPS a positioning with an accuracy up to 1,3 m is possible (Fig. 8-36). Actually the necessary correcting signals are broadcasted using a long wave transmitter in Mainflingen/Frankfurt and by the broadcasting corporation of the ARD through the Radio-Data-System (RDS) in Germany.

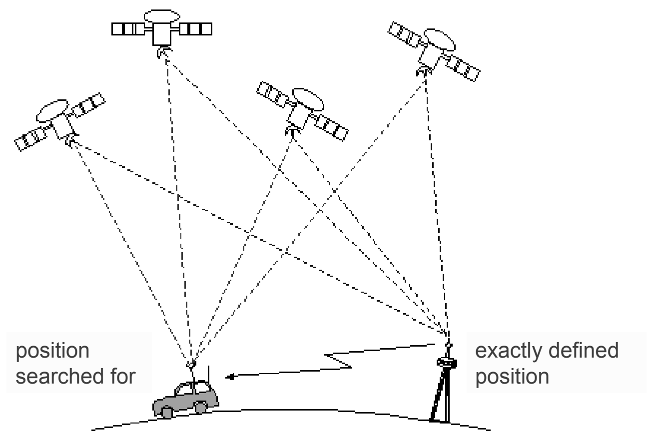


Fig. 8-36: Structure of a DGPS system in vehicle navigation [BAC99]

At the present there is only one global navigation system which is operated by the USA. During crisis situations the USA actually may be the only country to take over the sole usage. Therefore there is a danger of sudden and unattended interruptions for the civil user. At the time many applications are in use, such as aeronautical navigation, which urgently demand further navigation systems for safety reasons. The reliability of GPS is insufficient particularly in regions with a high degree of latitude (partially regions in Europe and in highly agglomerated regions or cities). For this reasons an European satellite navigation system named GALILEO is being developed based on the initiative of the European Union (EU) and the European space agency (ESA). On the one hand the reason is to end the technological dependence to the USA and on the other hand to create a redundancy especially for security applications. The completion of the European navigation system is

scheduled for the year 2008. In contrast to GPS and GLONASS, GALILEO should serve for civil and private reasons and thus it has to be more advanced, more efficient and more reliable than GPS or GLONASS [GAL02].

For the whole system 30 satellites will be delivered in 3 levels of the orbit in 24000 km height above the ground. In every level of orbit a satellite will be prepared as an active reserve satellite which can be moved in every satellite position within the level in order to substitute damaged satellites. The accuracy of about 5 m will be significantly better compared to GPS or GLONASS. A high reliability will be available because the signal carries a integrity notification which informs the user immediately in case of disfunction. The signal strength will be higher compared to GPS in order to improve the usage within buildings. A goal is to let GALILEO work independently from other systems but also to let existing systems complement one another with GALILEO to improve the performance of the satellite navigation. GALILEO will be compatible with GPS and GLONASS. The data will be transmitted on the same frequency in order to communicate with each of the systems. One receiver will be able to receive GPS signals as well as GALILEO signals.

Additional systems

Besides satellite navigation systems there are systems which complement each other or support the navigation systems. Foremost the combination of these satellite navigation systems enables the usage in driver assistant systems. The most important systems will be described in the following chapter.

Map Matching is applied to improve the accuracy of satellite navigation and dead reckoning (e.g. positioning in a tunnel). It is assumed that the vehicle is situated on a street, which exists in a digital map database. At the time a positioning system delivers data which do not correspond exactly to the street on the map, the map matching algorithm corrects the position of the vehicle. Changes of the vehicle direction and vehicle distance are tracked. The route is compared with the road routing to determine the position of the vehicle (see Fig. 8-37).

Map Matching is a pseudo positioning system, because it determines the position with the help of the coordinates of knots (crossing) or points (beginning of a curve or end of the curve) and of the driving distance. If the map's accuracy is better than the positioning system, the positioning can be used with the map matching in the positioning algorithm. Therefore the map accuracy has to be better than 15 m.

There are several types of map matching. One type is named point-to-point map matching. This method uses the current position and tries to bring the position into correspondence with a knot or a point in the database. Another method is the curve-to-curve method. An amount of points are considered at the same time and are adapted to the nearest arc.

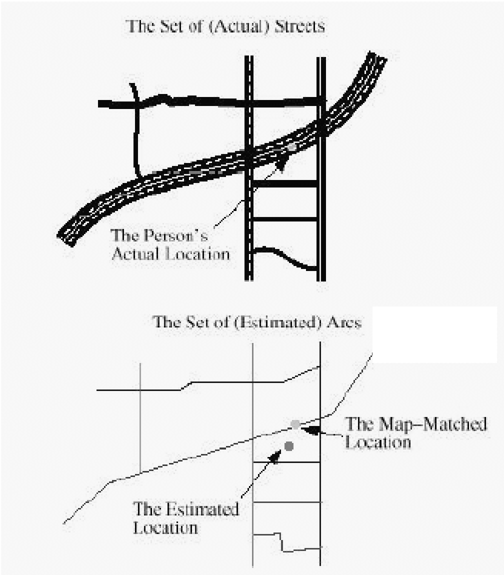


Fig. 8-37: Map matching [KIN98]

Regarding a continuous positioning it is even necessary to cover areas in which GPS is not available because of antenna shading. This means that the intervisibility between the antenna and the satellite is blocked. This can be while driving trough tunnels or driving through thick woodland. A possible solution to this problem is the combination of GPS and further sensors. In this case the inertial-sensor is the most used sensor. This sensor senses the yaw rate and the acceleration of the vehicle. Knowing the driving direction, it is possible to calculate the position with the coordinates of the starting point. This system is the so called inertial navigation system (INS), also named “Dead Reckoning“. INS is able to determine the position in the GPS shading phases. Accuracy decreases with time because of noise. It is possible to calibrate the system by GPS. Indeed INS is not able to find its initial position on its own. Thus GPS and INS form a synergetic relationship. The quality of INS is determined by the quality of the inertial sensors. Using the combination consisting of yaw rate sensor from the ESP and the velocity signal of the ABS it is possible to determine the position of the vehicle up to 30 seconds with an error of about 1 m. Better accuracies can be achieved with more accurate sensors, but they are very expensive.

8.2.1.9 Infrastructure systems for traffic-data acquisition

The acquisition of all traffic relevant data is an important basic module for the reasonable and effective traffic regulation. The acquired parameters are classification and amount of vehicles, lane position, velocity and the time-to-collision between the vehicles. Appraisal criterions are quality and quantity of the measured data, the costs for the realization of the particular principle and the reliability. In the following possible sensors and detectors are listed. The induction loops, the infrared and the laser sensors will be explained furthermore in this chapter.

- induction loop
- magnetometer
- piezoelectric sensors (pressure sensors)
- infrared-sensors
- laser sensors
- millimeter-wave-sensors
- video-image sensors
- acoustic sensors

Induction loop detectors consist of wire loops inserted into the pavement. Those loops detects metal bodies in a strictly defined area see Fig. 8-38.

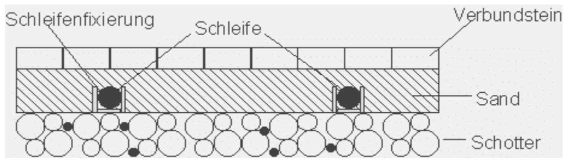


Fig. 8-38: Induction loop wire below the road surface [WEI02]

The operating principle of the loop detector bases on the induction variation of a coil by moving a metal body through the magnetic field of the coil. The wire loop has the inductivity of a high frequent oscillating circuit. A variation of the oscillating circuit’s frequency occurs in case the metal parts of a vehicle moves over the wire loop. The variation of the frequency is evaluated by the loop detector and the information is passed to the vehicle control. The coil is represented by the wire loop inserted into the road pavement.

Induction loops can be applied as single loops or as double loops. For double loops two wire loops are arranged one after another in the driving direction. The single loop counts for example vehicles per hour and therefore it is applied as a basis for traffic statistics and traffic planning. The double loop determines the driving velocity, vehicle type and driving direction. The vehicle type can be divided into nine different classes (passenger car, passenger car with trailer, truck to 3,5 t etc.). Induction loops are established for traffic-light control, monitoring of traffic flow, traffic jams and at entrances and exits of parking garages.

Infrared sensors for traffic-data acquisition work with passive-infrared-techniques (Fig. 8-39). The sensors do not transmit any radiation. The radiation of about 8 µm up to 14 µm is detected. This is invisible for the human eye and is not highly influenceable by atmospheric circumstances (rain, snow, fog). The determined values are independent of the object's temperature, size and surface, but not from their color or the lighting conditions of the environment. The "fast" variations (moving vehicles, pedestrians etc.) are evaluated within a defined field of view of the sensor. These changes also represent the term "dynamic detection". "Slow" changes such as a heating of the pavement caused by changing weather conditions may remain unconsidered. These measurements are named „static detection". Static detection may also be used for the registration of the presence of vehicles (stop line).

Fig. 8-39: Infrared sensor [WEI02]

The range of infrared sensors amounts up to 400 m. The installation can be conducted at existing place such as buildings, bridges, traffic lights etc. The energy demand can be satisfied with the help of solar cells. The data can be transmitted by GSM which would save a complex and expensive wiring.

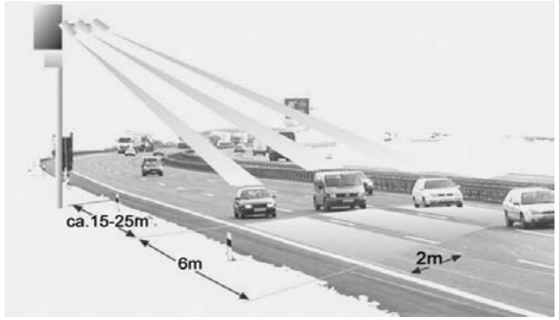


Fig. 8-40: Laser sensors for traffic flow determination

Another appliance for the electronic determination of the traffic flow are laser sensors in Fig. 8-40. Laser sensors are non-contact sensors which are installed mostly at lighting poles or besides the lane at a height of about 4 – 10 m. It is common to monitor more lanes of multi-laned roads at the same time with a high accuracy (+/- 0,5 m). Vehicles can be classified in their length. The velocity of single vehicles can be detected (up to 250 km/h). The detection probability decreases with increasing velocity and distance. The detection probability is about 80 % - 95 %, but the minimum speed has to be higher than 10 km/h to 15 km/h. The laser sensors project a laser field onto every lane with short invisible laser pulses. The signals being reflected by the road or by the vehicles are evaluated by a micro processor. In this procedure the existence, the position, the velocity and the length of vehicles can be determined in real time.

8.2.2 Further Sensors

8.2.2.1 Friction detection

The friction between tire and road is substantial for the driving dynamics and driving safety, since it determines the vehicle's maximal possible acceleration. In the vehicle usually neither information about the friction potential nor information about the friction strain are known. In case action is required concerning the driving dynamics, neither the driver assistance system nor the driver himself can act accordingly to a specific strategy that is adapted to the current friction circumstances.

In order to control the friction value between the tires and the road without attaching forces on the tires, a measurement of all parameters which have an influence on the friction must take place. The relevant parameters must be measured either directly by sensors or indirectly by calculations, characteristics etc.. Therefore a combination of different sensors is used. As one possibility, optical sensors (infrared) are used on the lower side of the vehicle floor in order to determine the road condition (wet, iced, snow-covered, etc.). This principle is based on the different absorptive characteristics of water for different wavelengths within the infrared range. Information about the tire and its condition is acquired by inflation pressure sensors. Afterwards the relevant parameters are combined with the vehicle velocity as input values into a friction model [BAC98]. This model simulates the behavior of the tire/road friction process.

In order to evaluate the friction strain, the current driving condition must be calculated using a vehicle model. Therefore the velocity of all four wheels (ABS sensors), the longitudinal and lateral acceleration (acceleration sensor), the steering angle and the yaw rate are measured. The signals are used to calculate the friction potential as well as the friction demand and the safety clearance.
The sidewall-torsion sensor (Fig. 8-41) acquires the magnetic field changes of the alternating polarized magnetic zones at the tire wall. In case forces affect the tire, the resulting deformation is measured by fixed magnetic field sensors.

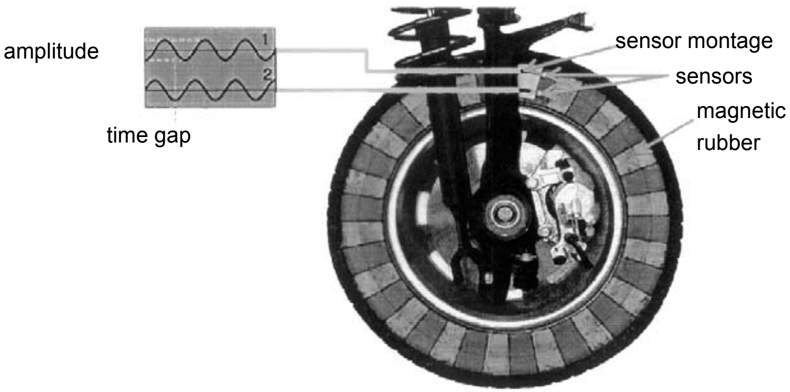


Fig. 8-41: Sidewall torsion sensor by Conti, source: Conti

Another possibility to determine the friction coefficient is being developed by the Technical University of Darmstadt (special field: automotive engineering). A sensor integrated into the tire measures the force between the tire and the road directly in the tire contact area. Based on the tire profile's deformation, the information about the transferred forces as well as the potential of transferable forces are determined. Those information are combined in real time with addition data (inflation pressure of the tire, wheel load, aquaplaning danger), and are available for the driver.

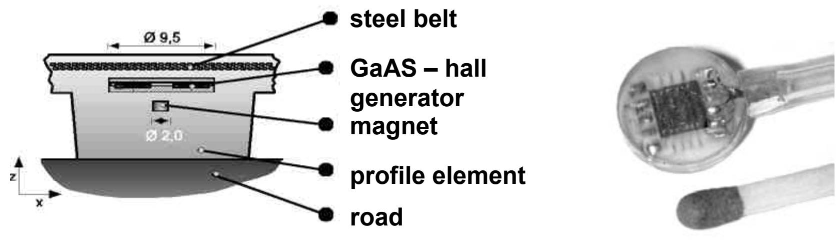


Fig. 8-42: Sensor for friction coefficient determination of the TU Darmstadt, Source: TU Darmstadt

8.2.2.2 Rain-light-sensors

The rain-light-sensor can detect rain and snow on the wind shield. It can automatically start the wiper with an adapted wiping velocity. Another possibly is to automatically close the windows and the sun roof in case of rainfall. The light sensor can control the lightning system. The vehicle front light are activated in darkness or while driving trough a tunnel.

The sensors can be mounted as one unit behind the front mirror in the wiping area of the wiper. The rain drops on the wind shield are detected with an opto-electrical method as shown in Fig. 8-43.

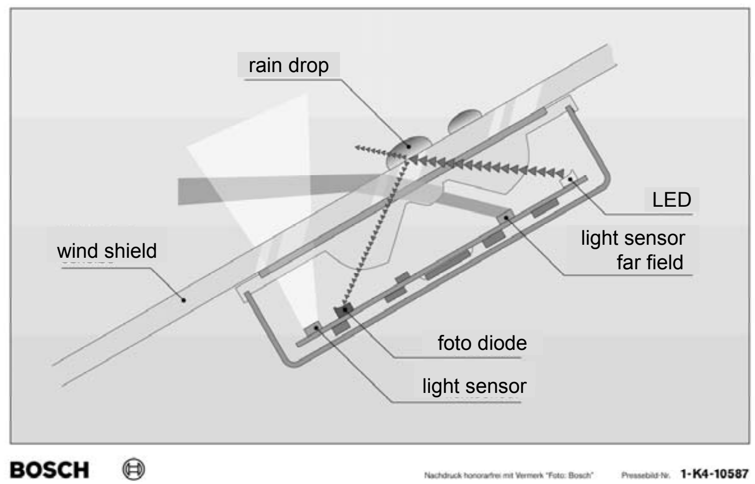


Fig. 8-43: Principle of the rain-light-sensor, source: Bosch

The sensor diode is emitting infrared light, which is conducted through the wind shield and reflected on the outer shield surface. The light is received by different diodes. In case of a dry shield surface the infrared light reaches the receiving diodes with almost full intensity (total reflexion). In case of rain fall the light is refracted and almost does not reach the receiving diode. The electronic unit detects the rain on the wind shield based on the signal difference. As the detection is permanent, the degree of rainfall is also detected by the system [HEL00].

8.2.3 Data fusion

Regarding contemporary radar and lidar sensors many wrong measurements occur. As an example the sensors detect an object on the next lane and classifies it as the relevant target. In another example the sensors recognize an object on the lane being driven too late. The environment and the weather condition also influence the systems.

The rising amount of used sensors in the past few years allows a combination of individual sensor data. This helps to create redundancy factors in order to improve the reliability of the system. Driver assistance systems can be extended in their functionality. Thus there are hardly no boundaries in combining different data sources. As an example the routing of the track on the one hand may be determined by image processing. On the other hand the routing may be determined by data concerning the radius of curves, being deposited into digital maps.

Because of the autonomy of the systems the data fusion of the individual sensor systems nowadays occurs on the object level, as it is shown in Fig. 8-44. Every single sensor has its own evaluation unit and software. After the object acquisition the data is being placed on a shared vehicle bus. This enables the application of different algorithms and components of various manufacturers. The data fusion itself happens in an individual processor unit. The object data has to be available on a standardized time base. The relevant object may be extrapolated out of the sensor data. This procedure is conducted in milliseconds using contemporary computer technology.

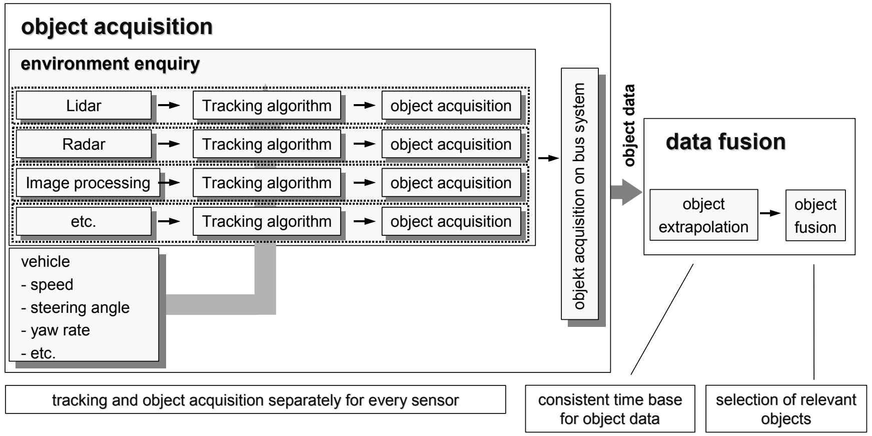


Fig. 8-44: Data fusion within object-level

In order to improve the quality of the signal, data fusion will happen within the raw data level in medium or long terms (see Fig. 8-45). The sensor raw data will be placed directly onto the vehicle bus in order to deliver it to the fusion processor. The data fusion of the individual sensor signals is also executed on a shared time basis. The time basis has to be defined before using the sensors.

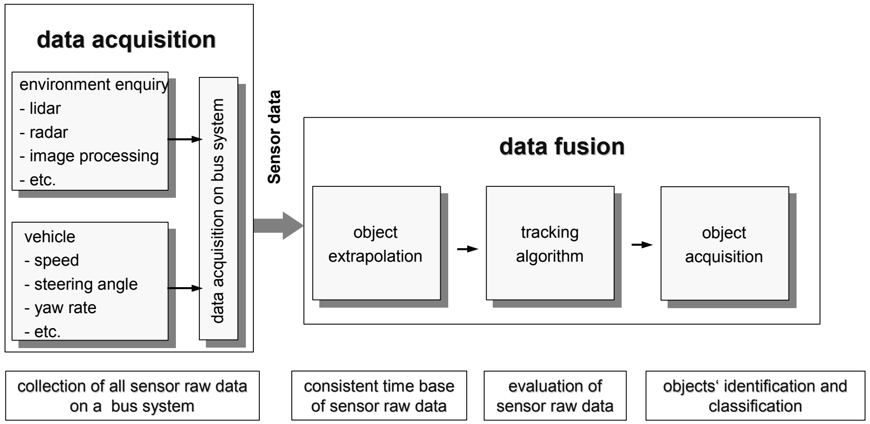


Fig. 8-45: Data fusion within raw data level

The application of the sensor fusion shows a high potential regarding the merging and the supplementation of information. For future generations of driver assistance systems which have to be more reliable and functional such systems will prevail.

8.2.4 Weakness and strengths of sensor technologies

Sensor systems such as Radar and Lidar sensor try to create an image of the reality as real as possible. Regarding Fig. 8-46 a comparison of various sensor technologies is given.

	sensor system			
	Radar	Lidar	Laserscanner	Image processing
wave length	micro wave (77/24 GHz)	near infrared	905 nm	visible light/near infrared
multiple target detection	+	o	+	++
measuring method	reflexion	reflexion	reflexion	triangulation
measuring in bad weather condition/ dirt on sensor	+	o	+	-
hidden mounting possible	yes	no	no	no

Fig. 8-46: Comparison of various sensor technologies for the environmental detection

For a reliable detection a single technology is often sufficient enough. Radar sensors for example are able to measure the distance to the vehicle in front in a very precise way. In contrast image processing systems determine distances with the use of estimation procedures or specific algorithms.

The chart above shows a environmental dependence of the different systems to a greater or lesser extent. Fig. 8-47 shows the environmental influences on the sensors. The source of influence as well as possible effects are presented.

environment influences	reasons	effects
temperature	climate	change of material properties, ageing
temperature change	heat dissipation	tensions, crack initiation, dissolvement of screws
humidity	climate, evaporation of water	condensation, corrosion
water	rain, car wash	short circuits, heat losses, corrosion
salt spray	salt in the air	corrosion, heat losses
air pressure	altitude differences	disfunctions
sand, dust	verge, polluted roads	disfunctions, change of transition resistance
oil, petrol, vapour	service and care	pollution
corrosive, explosive gases	sulfur dioxid, hydrogen sulfide, air-gas-mixtures	corrosion, crack initiation, ignition because of sparks
aggressive liquids	brake fluid, battery acid	corrosion
radiation	sun	ageing

Fig. 8-47: Environmental influences, reasons and effects

The weather influences concerning different technologies of environmental sensor systems is shown in Fig. 8-48 for two optical sensors.

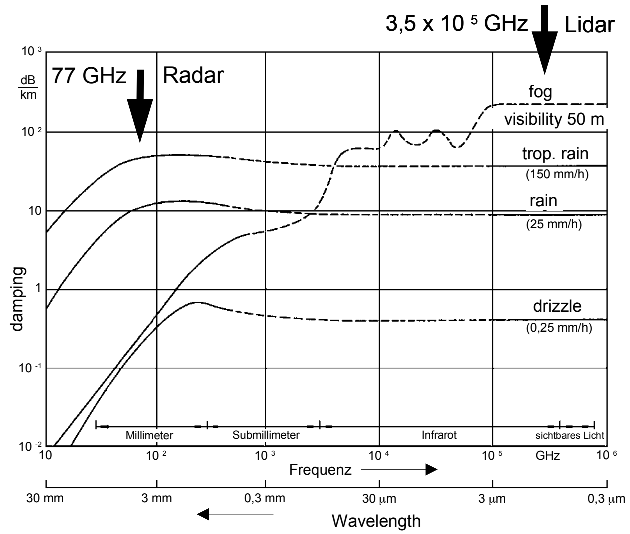


Fig. 8-48: Influences of weather conditions on sensors [DET89]

A 77 GHz radar sensor is compared to a 3,5 x 10^5 GHz Lidar sensor. The abscissa describes the frequency and the wave length of the beams. The ordinate shows the damping of the sensor signal in db/km. The weather conditions fog, tropical rain, rain and drizzle are regarded. The damping of a Lidar sensor is significantly higher than the damping of a radar signal as an example. The radar sensor experiences a higher damping in rain.

The considerations in the diagram show that there is no optimal sensor for environmental detection. Only a combination of different technologies may lead to a safe environmental detection within different weather conditions.

8.3 Actuators

In actuators the input data (input signals) is converted into a physical value in order to influence a technical process. In mechatronical systems the output of the initial value has got a mechanical unit.

The control of an actuator is usually conducted without much power using low power input signals. These input signals are generated by controllers, in which measured signals of technical system are converted into control signals. The control signals are transferred over standardized interfaces. The output value of an actuator is an energy/power, which has to be provided by an energy source. An energy converter is connected to the energy source. The principle structure of actuators is shown in Fig. 8-49 [WAL04].

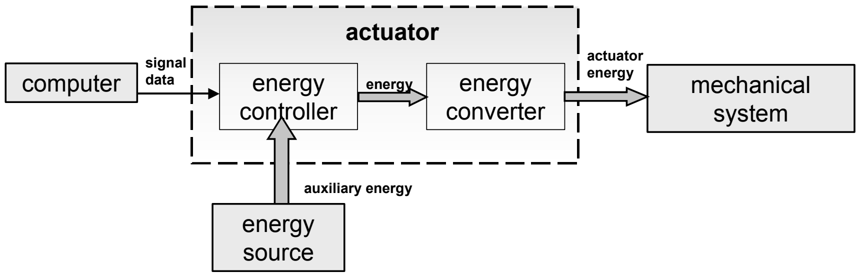


Fig. 8-49: Principle structure of actuators [WAL04]

The actuators of a driver assistance system can be divided into the following groups:

- automatic brake intervention
- automatic steering intervention

- automatic transmission and
- automatic throttle valve manipulation.

Apart from these main groups additional actuators (e.g. curve light, pre-crash etc..) are possible in driver assistance systems.

The automatic brake interference can take place in different ways. Especially the electronically adjustable brake booster is suitable for this. In this section different possibilities of realization are to be presented and evaluated.

An automatic interference into the steering system is necessary for the extension of the lateral dynamic function in a collision avoidance system. The standard power steering can also be controlled automatically using an extended hydraulic system. The possibilities for the realization of an automatic steering system are described in the following chapter.

8.3.1 Electronically controlled brake interventions

The automatic brake interference can be realized on the basis of the following systems: the brake booster, the hybrid brake, the electromechanical brake (EMB), the hydraulic brake, and the electro-hydraulic brake (EHB) and the brake-by-wire system.

Furthermore the electronic parking brake (EPB) is used more often in current models of motor vehicles. This usage replaces the hand brake handled by electronic controlled brake actuators. The cable pull is omitted and thus additional space is available in the vehicle. An automatic braking at a standstill with an upward gradient can be possible using the electronic control of the brake, which eases the following drive off.

Brake booster

The brake booster is able to regulate a desired target brake pressure hydraulically and can therefore accomplish brake applications without the manipulation of the brake pedal by the driver. In Fig. 8-50 the principle structure of the brake booster is shown. The controller of the booster receives the desired pressure requirement and ventilates the brake booster over a valve in a controlled way, so that brake pressure is generated. The current operating condition of the brake system is reported to the controller using a diaphragm way sensor and a pressure sensor [ERK03].

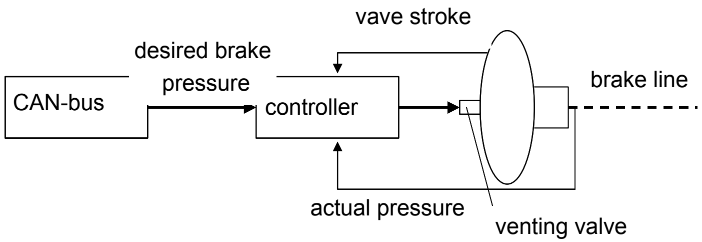


Fig. 8-50: Operating principle of the electronically controlled brake booster [ERK03]

Hybrid brake

The hybrid brake represents a combination of a hydraulic and electro-hydraulic brake at the front axle and a dry electrical brake at the rear axle. An advantage of the hybrid brake is the simplified package at the rear axle by the omission of hydraulic components. The application of the hybrid brake as an electrical parking brake can be realized without further effort.

Brake-by-wire

In a new generation of brake systems the desired deceleration of the driver is electronically passed on to the system. So-called brake-by-wire systems work electrically without a hydraulic medium. This allows a simple electronic interface for driver assistance systems as well as the realization of additional comfort functions and package advantages. Furthermore brake-by-wire offers shorter braking and stopping distances, an optimised braking and stability behaviour and a better crash behaviour. The brake system is to be interlaced easily with future driver assistance and comfort systems. In principle no 42 V electrical system is necessary. It is to be rated as a disadvantage that no direct driver interference is possible. Redundancies are absolutely necessary. A high-quality battery and energy management is necessary, because the brake system works on electronic and no longer on hydraulic basis.

A realized brake-by-wire system is the so-called electromechanical brake actuator. The electromechanical brake system represents a conversion to a perfectly electronically operated brake with dry function for the brake disks. The tasks of the hydraulic components in a conventional brake system are taken over by electrical

and electronic components. This system offers sub-functions for automatic driving (e.g. automatic parking, flow of traffic-dependent speed control, lane keeping assistance or automatic emergency braking).

Fig. 8-51: Electro-mechanical brake actuator

A substantial component of electro-mechanical brake systems is the brake actuator, which is shown in Fig. 8-51. Two principles are favoured as driving motors: on the one hand the brushless permanent-magnet engine and on the other hand the reluctance motor. The very high braking force, which can be produced (e.g. with a emergency brake), requires a high electrical power of P_{max} = 1 KW. In stand-by modus the power consumption amounts to $P_{stand\text{-}by}$ = 30 W during normal drive without pedal manipulation.

8.3.2 Automatic steering systems

The hydraulic power steering was the first step for the development of automatic steering systems. The power steering supports the driver with addition steering power depending on the steering torque. It utilises a hydraulics system in order to create the necessary forces.

A further step in the development of the steering system is the so called Servotronic. The Servotronic reduced the steering support with rising vehicle velocity and therefore offers a light moving steering wheel for parking in the low velocity range as well as a comfortable steering behaviour at high velocity. The increased steering torque prevents nervous steering behaviour within the high velocity range.

Compared to the hydraulic power steering the electro hydraulic steering disposes of an electronic powered hydraulic pump, which enables the propulsion of steering. The control is managed demand-controlled. The propulsion of the used vane pump is usually realized by a V-belt regarding the conventional hydraulic system. In contrast the electro-hydraulic steering is powered with an electric motor.

The electric power steering (EPS) also named servo-electric serves the servo hydraulic power assistance with the help of an electric actuator. The electric motor and the related transmission exemplarily are fixed with the steering column, with the steering gear pinion or with the gear rack. The steering system just needs the auxiliary energy when a steering movement is required - in contrast to previous hydraulic power assisted steering systems which have a permanent power consumption because of the continuous working servo pump. With the help of a suitable control the electric steering serves the possibility of a steering boost with any dimension. Applications are the VW Golf V, the Touran, the Caddy, the Audi A3 and the BMW Z4.

Fig. 8-52: Hydraulic power steering (top. le.), Servotronic (bottom. ri.), electro-hydraulic power steering (top. le.), electrical steering (bottom. ri.)

In the course of the development of steering systems the influence of the steering angle besides the steering torque is desirable with the help of an active front steering. The resulting active front steering is able to apply an additional situation-adapted steering angle onto the current one (Fig. 8-53).

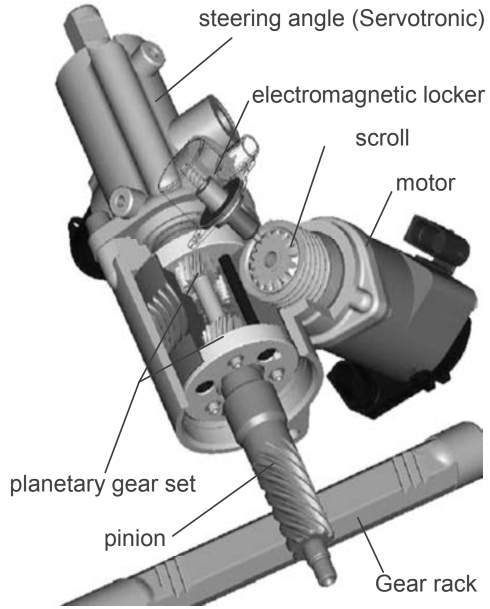


Fig. 8-53: Active front steering with planetary gearbox, source: ZFLS

The additional angle is applied with an into the steering system integrated planetary gearbox. This superposes the driver’s steering intention with any desired angle. The motor angle is transferred with a self-locking worm gear. The steering torque support occurs with conventional systems (hydraulic, electric). With a suitable control of the actuator a variable steering transmission ratio is possible as well as a compensation of lateral dynamic disturbance variable or a stabilisation of the vehicle. The mechanical connection between steering wheel and vehicles tires lead to a direct response about the lateral dynamic driving condition. In the year 2003 this system was named „Aktivlenkung“ (Active Front Steering) and was introduced to the market in the new BMW fifth and sixth series.

For practical implementation of a by-wire steering, the steering-wheel input will be decoupled from the front wheel in a first step. The decoupling can be realized with a mechanically spited steering rod. The example in Fig. 8-50 shows two direct-current motors linked by safety clutches and transmissions. On the one hand the steer angles, which ideally occur because of the controlling can be generated. On the other hand an artificial steering-torque feedback is generated. The motors are designed for steering angles in the ordinary dynamic range.

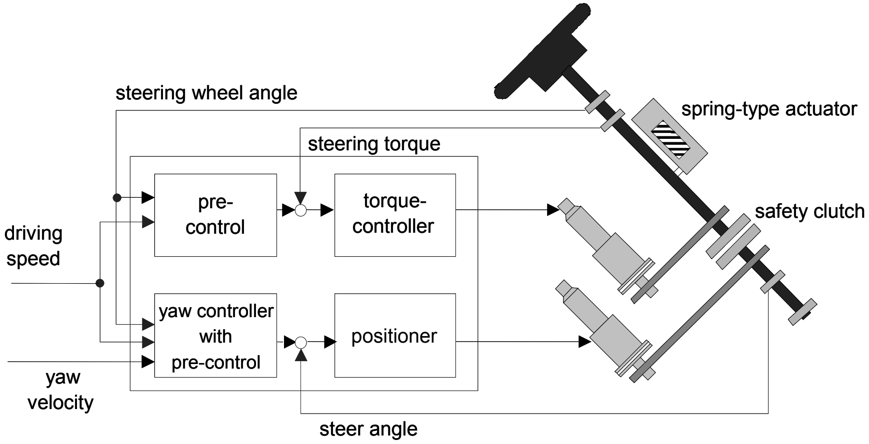


Fig. 8-54: Analysis of an automatic steering regulation with mechanical fail-safe

In case of an occurring malfunction, the conventional functions of a rigid steering rod can be restored, using a spring type actuator with a denture clutch. The motors are separated with magnetic clutches. It is important to mention that the steering construction assures the functionality in the context of researches. It was not optimised concerning fail-safe functions (Fig. 8-54).

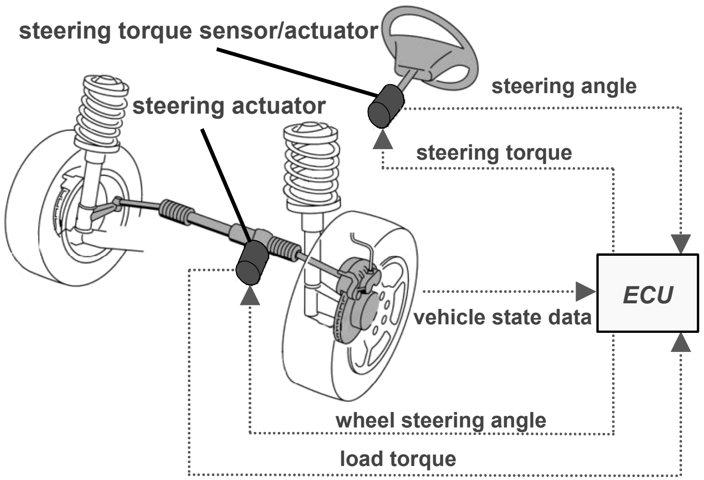


Fig. 8-55: Principle function of steer-by-wire system

The steer-by-wire concept bases on steering without mechanical transfer of steering torque. A mechanical connection between steering wheel and front wheels is not existent. This causes advantages: As an example the steering wheel is not able to intrude into the passenger cell, the installation of the steering wheel is more flexible and additional space is available in the front end section. In order to achieve safety requirements, a complete system redundancy is necessary. The vehicle has to remain steerable, even in the case of a system error. In Fig. 8-55 the operating principle of a steer-by-wire system is shown.

8.3.3 Electronic throttle

An attempt to realize automatic acceleration sequences with the help of an autonomous control is the electronic throttle as it is implemented in the BMW seventh series. In Fig. 8-56 the principle of the unit is shown.

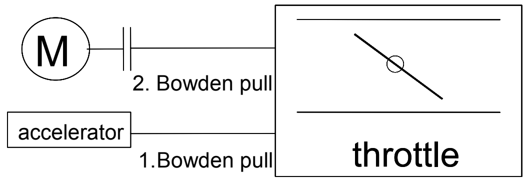


Fig. 8-56: Principle of the electronic throttle[ERK03]

Additional to the mechanical connection between the accelerator pedal and the throttle valve by a Bowden pull, a highly reductive electronic motor is fixed to the throttle by a second Bowden pull. The connection of control motor and Bowden pull is realized with the help of a magnetic clutch within the motor housing. With the clutch being closed, the throttle will open or close. This depends on the current of the motor control. The direction depends on the polarity of the motor. Depending on the voltage associated to the motor control the velocity of the throttle adjustment can vary. The opening velocity depending on the throttle position may measure up to 110 °/s. A complete closing of the throttle can be achieved by opening the magnetic clutch more fast. After an adjustment, the throttle can not be pulled back into the zero position by its return spring, because of the self-locking feature of the motor gear. Even if the motor is switched currentless, the restoring force of the spring is not sufficient enough. The distance of the second Bowden pull can be determined with a potentiometer being installed into the adjusting mechanism. Furthermore the adjusting mechanism is designed so that the throttle is able to be opened further by the driver at every position using the accelerator pedal pull. A temporary take over of the driver is possible. When the driver does not accelerate any more, the throttle will be pulled back into its original position. [ERK03].

In modern vehicles of the upper class electronic acceleration pedals (e-gas) are used instead of a mechanical throttle adjustments. The electronic acceleration pedal is equipped with an electric motor, a pedal sensor and an electronic throttle-position control. The pedal sensor transforms the accelerator pedal position into an electronic signal which is transferred into an appropriate position of the throttle. This happens with the help of the superposed control of the electronic motor. Besides the desired acceleration, the opening angle of the throttle can be adjusted dependant on a high amount of engine-specific measurement data. The concept provides the possibility that driving-dynamics control systems as ESP (Electronic-Stability-Program) or traction-control systems (TCS) can be supported trough a variation of the throttle position so that the engine performance is influenced in a big region systematically thus brake interventions can be abandoned in specific driving situations.

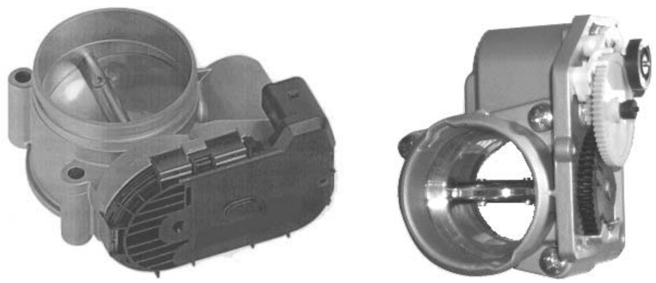


Fig. 8-57: Electrical throttle [WWW04a] [WWW04b]

8.4 Overview of advanced driving assistance systems

A secure course of traffic as a starting point for the traffic-driver-vehicle safety chain reduces the amount of driving situations which are potentially dangerous for the vehicle occupants and other traffic members (see chapter 8.1.2, Fig. 8-10). This also incorporates arrangements for the optimised road layout as well as an aimed influence of the course of traffic because of traffic management. Particularly the decrease of highly dynamic traffic situations and thus a high potential of traffic jams on the autobahn, reduces the amount of potential dangerous driving situations or driving conditions. Traffic control systems with adapted speed limits showed good results in the past: as an example for the effects of the traffic influence [MET98]. In order to prevent traffic accidents, changing traffic signs were installed which enable

active changes of speed limits or traffic jam warnings dependant on the traffic condition. A reduction about 90 % of the stop & go traffic was reached.

In the following overview different driver assistance systems are discussed. The focus is set on a general overview instead of a detailed explanation of single systems.

A group of earlier introduced assistance systems are systems to improve the sight conditions (see chapter 5.4). Those are adaptive light systems which adapt the light distribution variably to the specific driving situation (e.g. „curve light") or night vision systems which projects an infrared image onto the windshield.

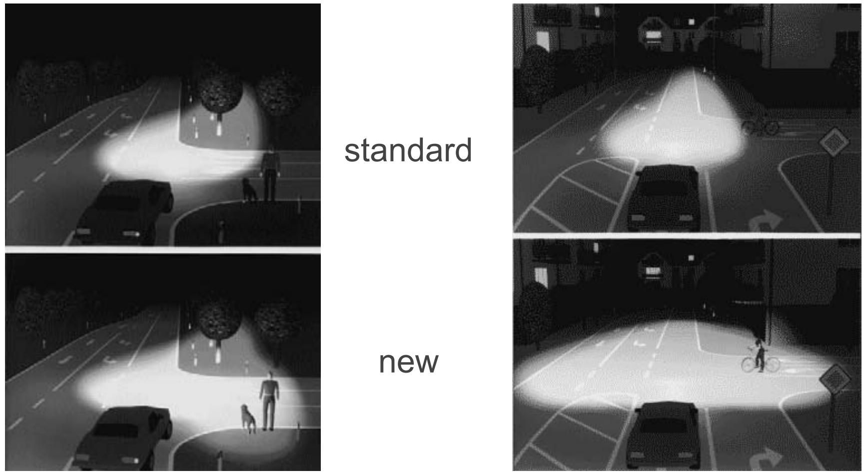


Fig. 8-58: Adaptive light system, source: Hella

Anticipatory safety systems allow the active collision-warning and -avoidance, if sufficient information about the roadway's characteristics and about the traffic situation are available in advance. Assistance systems that are available today, like the ACC (Adaptive Cruise Control, automated distance and differential velocity control) dispose of a very limited view at the course of traffic lying ahead. Even in the ideal case only the preceding car, but not the car which is driving in front of this, can be detected. Therefore ACC-systems which are available today can not be considered as security systems but as pure comfort systems to support the longitudinal vehicle guidance. Only the ACC's future stages of development will be able to provide safety relevant functions to support the driver.

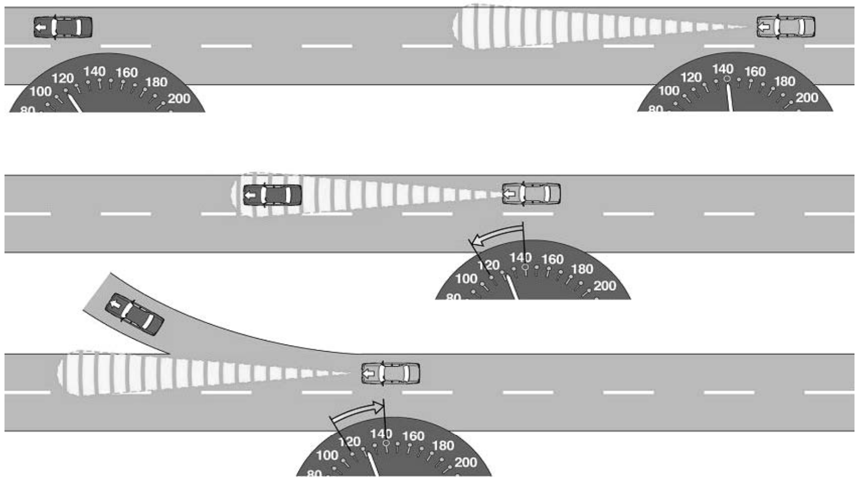


Fig. 8-59: ACC (Adaptive Cruise Control, automatic control of distance and relative velocity), Source: BMW

Besides pure longitudinal driver assistance systems also systems for lateral guidance are being developed. The lane keeping assistant can assist the drivers in staying on the current driving lane [REI95, MEH96]. Another system supports the drivers during the lane change. In this case not only the leading vehicle on the own lane but the whole traffic behind and in front of the vehicle on the own lane as well as on the target lane have to be considered. With the help of appropriate sensors vehicles can be detected in the critical range and the driver can be alarmed by optical (e.g. glow in the outside mirror), acoustical or haptic (e.g. flasher stalk's vibration) signals. In this way a safety critical lane change can be avoided.

The so called "Collision Warning System (CW)" alerts concerning possible collisions and thereby exceeds the pure support. For that purpose also standing targets have to be included in the environmental detection. The situation's interpretations becomes very complex due to the security relevance. Noncritical obstacles like parking cars in urban area have to be distinguished from dangerous obstacles like abrupt ends of traffic jams. Therefore scanning sensors that have a huge sensing range are applied on the basis of radar and lidar. With the data delivered by these sensors obstacles can be detected and their positions can be determined. Nevertheless the braking manoeuvre has to be initiated by the driver. Acoustical and optical alert signals supports the drivers decision to do so. Actuators, which carry the driving manoeuvre out automatically, are not necessary in this development state of the systems.

These actuators are applied in the CW's extension to automatic collision prevention systems (also: collision avoidance = CA). In this case braking and avoidance manoeuvres are initiated automatically. That means, that an automated brake control system (e.g. by electronically controlled brake boosters, brake-by-wire-systems) becomes necessary. The brake's functional principle resembles a lot the ACC brake, but in case of CA it is necessary to brake with maximum deceleration until standstill. The automated steering system that controls the avoidance manoeuvre represent a noticeable enhancement. A parted steering column as well as a steer-by-wire-system or an adaptive front steering system would be possible.

In consequence of the automated implementation of emergency manoeuvres, the standards for predictive interpretation of situations and therefore for environmental sensor detection will rise. In this case especially the combined evaluation of different sensor data (e.g. from active light systems, image processing, radar sensors and lidar sensors) is important in order to have the possibility to process all information and data. It will be possible to make an extensive analysis of the environment by means of light systems and systems for image processing. These information are linked to the radar or the lidar sensor which provide exact data concerning the detected object's movements.

One of the major development objectives are the so called cooperative driver assistance systems. In this context vehicle autonomous systems are combined with systems based on infrastructure. The key role is taken by so called vehicle-vehicle-communication or communication between vehicles and infrastructure. In this case technologies from the area of mobile phones of the 2nd and the 3rd generation like GPRS and UMTS and the "Wireless Local Area Network" (WLAN) which is common for computer networks, are applied. By means of these communication technologies driver-assistance systems can be expanded over the "sight" based evaluation of the vehicle's surrounding so that accidents lying ahead or complex situations at intersections can be dealt with.

The intersection assistance provides a high potential to avoid dangerous driving situations in urban traffic or, if the accident can not be avoided, to minimize the consequences. But it will be a long-term introduction of this driver assistance system. In Fig. 8-32 the merging driver assistance system based on communication technology is shown as an example of a dangerous situation.

The so called park assistant is near the introduction of series production. This assistance system measures the size of a parking gap while passing it und supports the driver in the following parking manoeuvre. This systems can be imagined to give the preset for the steering angle, which has to be adjusted by the driver, or to steer automatically during the parking manoeuvre. Both approaches have in common, that the driver has to carry on operating the gas as well as the brake pedal and therefore the driver still has the responsibility for the parking manoeuvre.

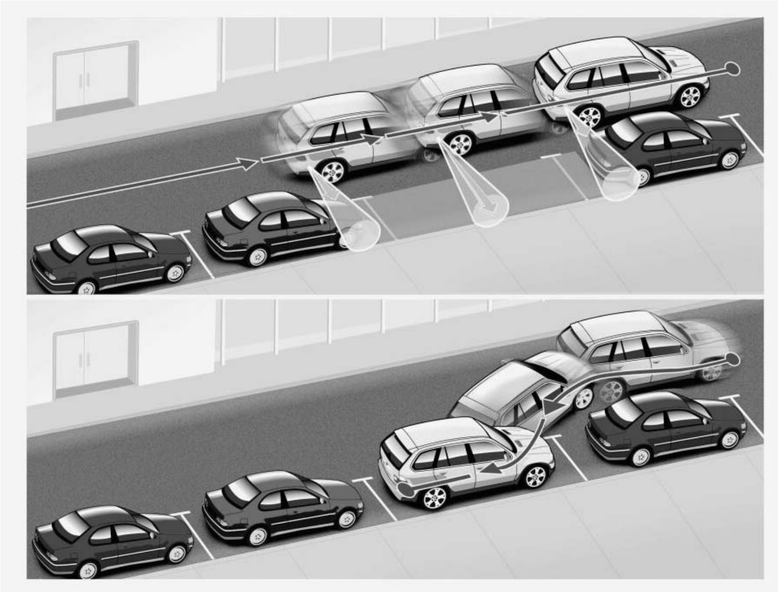


Fig. 8-60: Park assistant, source: BMW

The most important driver assistance systems on the guidance level and the time of their market introduction are shown in Fig. 8-61. As one of the first of those systems the collision warning system was introduced in 1995 in the USA. The system is called EVT-330 and is based on a 24 GHz near-field radar.

The assistance systems shown in Fig. 8-61 represent the requirement for further support of the driver on the guidance level. In a present merging of active and passive safety a multitude of sensors for distance and velocity sensing is used. Fig. 8-62 shows the aim of future assistance systems, the accident free vehicle.

Future assistance system will be transformed from comfort systems to safety systems. Even today distance control systems already help traffic safety, although they have to be regarded as pure comfort systems. Those systems can ease the driving task and support a calm driving style. On the other hand a risk preventive driving is given by the adjustable distances and the control characteristics of the system.

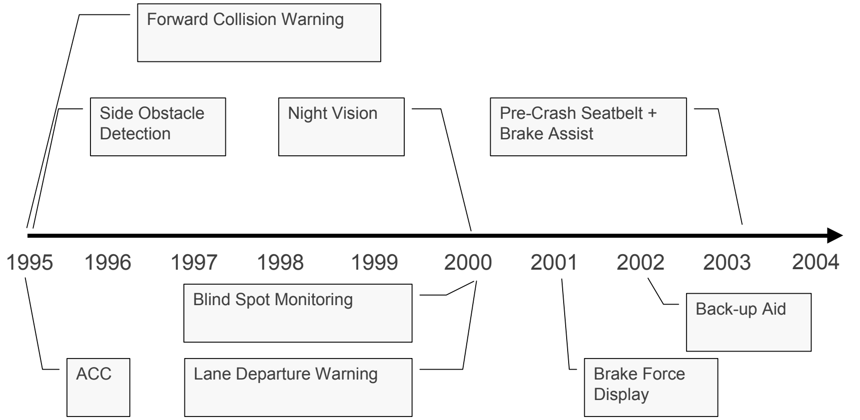


Fig. 8-61: Market introduction of assistant systems

Today the effect of the adaptive distance control onto traffic safety is exclusively indirect, because an active collision avoidance is not possible yet. Nowadays these systems brake in a range which can be seen as a “comfortable” braking range. The performance and the range of the used sensor systems for environmental detection are not dimensioned to work as safety relevant systems.

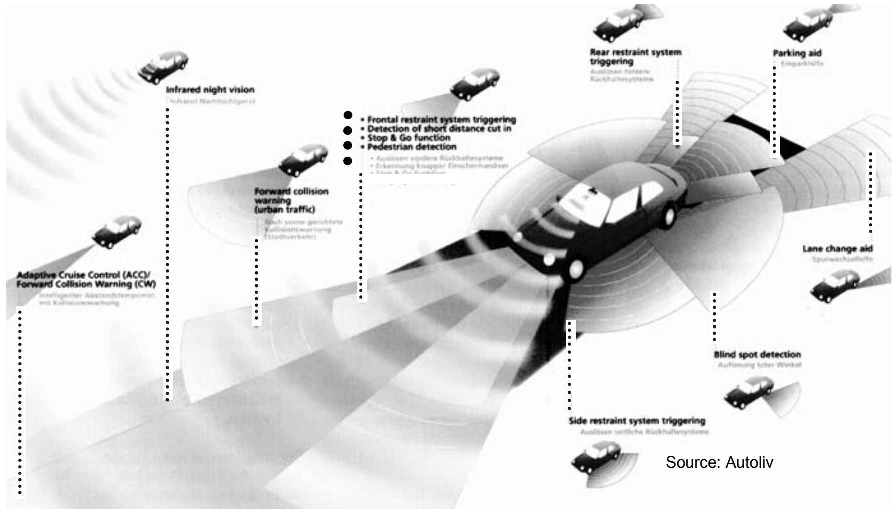


Fig. 8-62: The vision: the accident free vehicle, source: Autoliv

8.5 Development paths of advanced driver-assistance systems

The development and market introduction of driver assistance systems depends on different factors. On the one hand the necessary technical systems (sensors and actuators) must be production ready. This was not the case especially for safety relevant systems. The sensor system must detect the environment and all relevant objects complete and reliable for the assistance function.

A wrong detection which may be caused by ground reflection regarding radar sensors could lead to an emergency stop in autobahn traffic. The system would react according to the so-called phantom target in order to prevent a pretended rear-end collision and thus this could foremost lead to an accident. According to the actuators it has to be guaranteed, that particularly the brake and the steering system are usable even if the system fails. The vehicle has to remain controllable. Those systems have to be designed redundantly if necessary. This aspect is very important regarding x-by-wire systems where no mechanical connection between steering wheel/ brake pedal and the related actuators is available.

Besides this technical challenges which have to be solved further aspects such as costs, legal questions, legal guidelines, user acceptance and other factors are important to the introduction of driver assistance systems.

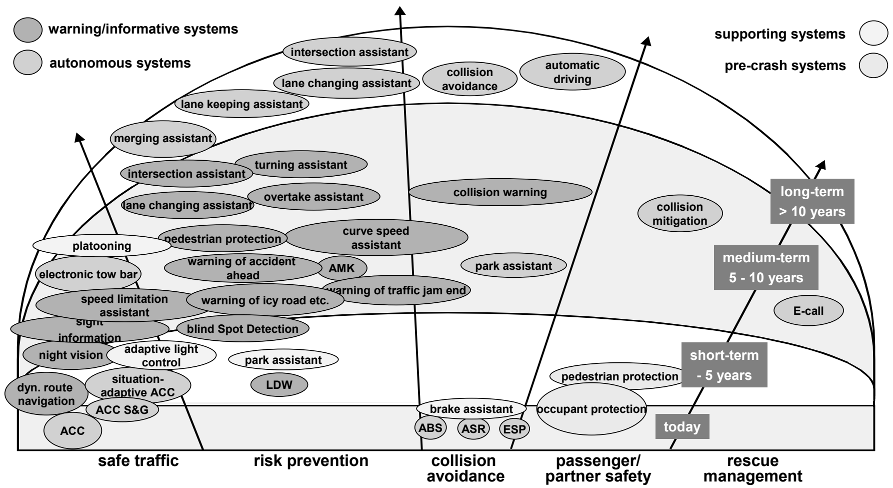


Fig. 8-63: Roadmap of ADAS, field of use and time horizon

Fig. 8-63 shows when and what kind of driver assistance systems could be established in the market. This is presented in form of a "roadmap". The different ADAS furthermore are separated according to the intervention of the safety chain of the traffic system and are classified regarding the kind of intervention of the assistance system.

ADAS may be designed as supporting systems by exemplarily adapting the light distribution of the headlights to the traffic surroundings or to the radius of the curve in order to enable a better sight of the driver to several objects onto and besides the road („Adaptive Light Control“).

Another group of assistance systems which may have a positive influence on the safe course of traffic, provide active warnings or information to the driver. The speed limitation assistant for example detects the current traffic sign regarding the permitted driving speed and shows the driver the permitted maximum speed with the help of an advanced digital map or an image processing system.

Autonomous ADAS take over parts of the driving task permanently or in critical (safety critical) situations completely. The ADAS ”collision avoidance“ for example initiates an emergency brake and/or an emergency avoidance in front of an obstacle, before the time period, that the driver needs to react to the situation, has passed.

Pre-crash-systems intervene if an accident is unavoidable. Airbags and other restraint systems as well as mechanisms for partner protection can be used preventively and adaptive by means of early information regarding the potential collision time and place as well as for the kind of the accident opponent.

In a further roadmap (Fig. 8-64) the safety effect of these assistance system can be seen. It becomes evident that the systems, which promise the highest potential concerning the road safety can be introduced only late into the market due to their complexity. The market introduction of the systems regarding the promotion of the pedestrian and passenger protection can be accelerated by regulations and guidelines provided by the legislator.

As mentioned before the development of driver assistance systems is not only based on safety aspects but also on the resulting costs. Therefore it is tried to adopt build-in sensor and actuator technology for several assistance functions. Development paths of driver assistance systems result from this idea. The development paths show driver assistance systems, which develop one on the other with the extension of functionalities. In principle the development and introduction of new systems is simplified by the presence of other driver assistance systems substantially in the same development path, e.g. due to the use of the same system components (controllers, actuators, sensors, etc.). Assistance systems in the same development path describe similar functionalities, but with a different focus regarding their (increasing) area of application.

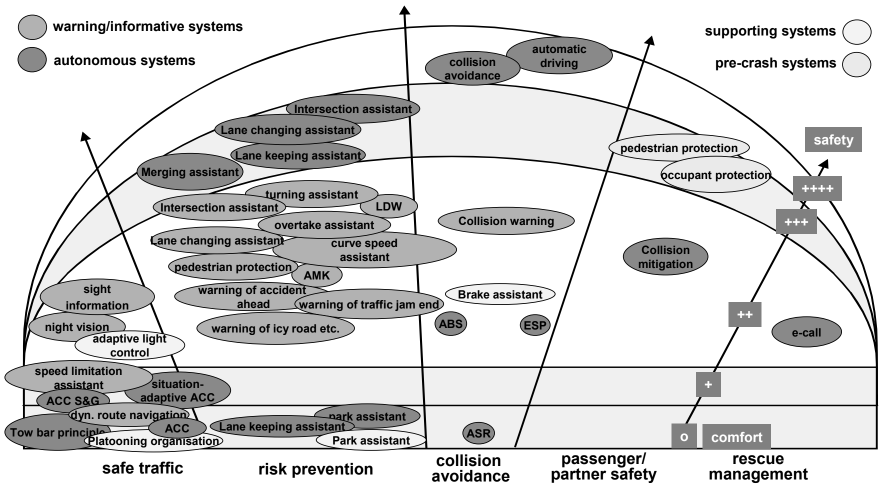


Fig. 8-64: Roadmap of ADAS, field of use and influence on vehicle safety

On the basis of the safety use and the user acceptance (customer use) the following development paths appear probable:

- from ACC over ACC Stop&Go to collision mitigation by braking
- from ACC to collision warning and pre-crash systems
- from ACC over ACC Stop&Go to automatic driving
- from lane departure warning / blind spot detection
  to lane keeping / lane change assistance
- ·from the supporting to the autonomous parking assistance

These development paths are represented in the roadmap in Fig. 8-65.

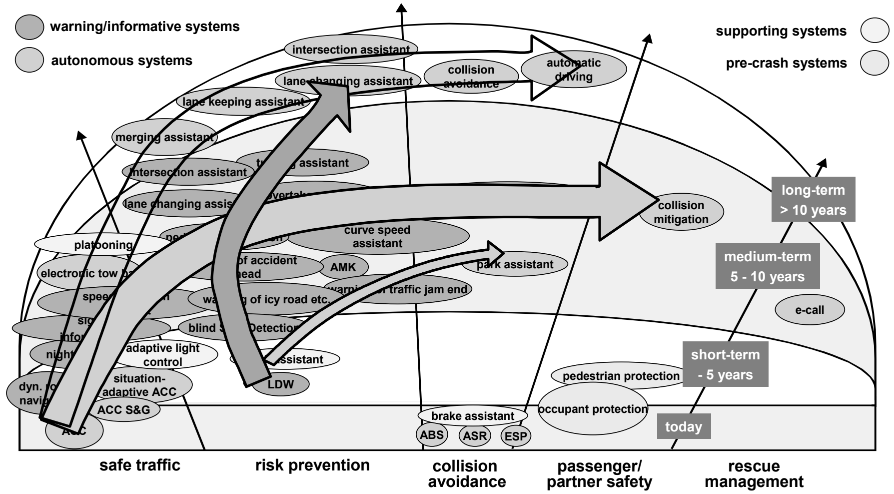


Fig. 8-65: Presumable development paths of ADAS

ACC-functionalities and ACC-components play a key role for future driver assistance system developments. In the ACC-system a sensor is used which determines the distance and the speed differential to the vehicle ahead. Since the ACC-system is a pure comfort system, the driver must intervene himself in case of necessary deceleration of more than approximately 2.5 m/s². The development paths of driver assistance systems show a clear trend from comfort to safety systems. It becomes evident in Fig. 8-66, how ACC can be upgraded to a safety-relevant system by the extension of the velocity and the deceleration range. However a higher reliability during of the object recognition is an important condition for this. It can be obtained with the implementation of several sensors, whose data are fused.

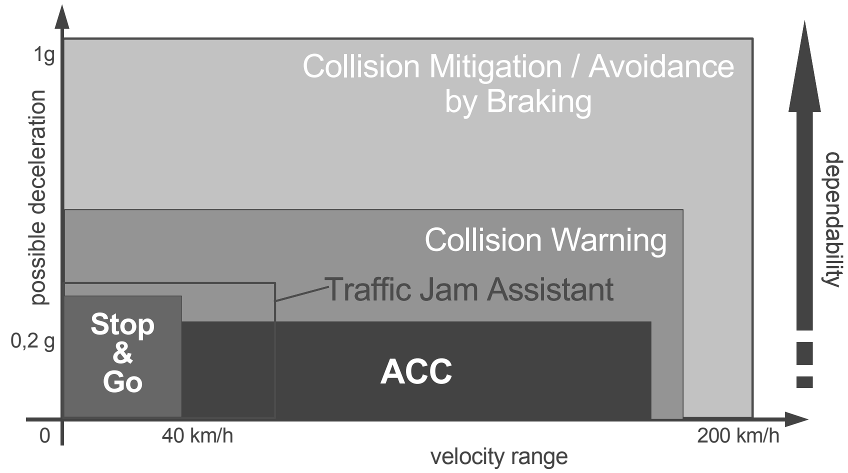


Fig. 8-66: Extension of ACC to a safety system, increase in reliability, increase of velocity and deceleration range

With increasing complexity of driver-assistance systems higher requirements to the system architecture result. The degree of integration of driving dynamics and driver assistance functions has a strong influence on the organization of the system architecture of the vehicle. The effects of rising function-driven integration on the architecture are shown in Fig. 8-67 and explained in the following.

The roadmap shows the steps of development for three time horizons:

- at short notice up to the year 2009
- medium-term up to the year 2014
- on a long-term basis after 2014

On short-term the individual components of driver assistance systems are linked with sensors and actuators. The architecture becomes more complex in the medium-term and on a long-term basis. The cross-linking of the individual components among themselves increases continuously, i.e. several systems access the same sensors and actuators. At the same time the components themselves become more sophisticated. So-called "smart sensors" do not only deliver information about the detected objects, they also examine whether these data is plausible and evaluate the data. In addition they are provided with necessary information such as longitudinal acceleration and velocity by the vehicle. So-called "smart actuators" have simplified

interfaces (e.g. desired longitudinal acceleration) and convert the reaction of the assistance function with consideration of the current driving condition. The further regulation (e.g. necessary brake pressure in order to realize desired longitudinal acceleration) takes place in the actuator itself.

For the increasing information exchange between the individual components today's bus conceptions (CAN bus) are not enough. In particular for safety-relevant applications real timetable bus systems are needed (Flexray), compare to the lecture "Mechatronic Systems in Vehicle Technology".

Also the controllers, in which the algorithms for the assistance functions are implemented, must correspond to the growing requirements. The development tends toward a central controller, on which all necessary algorithms can function. A co-ordinator takes over superior tasks and makes sure that a smooth operational sequence is given. With increasing number of assistance functions these functions overlap themselves more and more frequently, by trying to access the same actuator for example at the same time. In this case the co-ordinator transfers the prioritisation in favour of the more safety-relevant functions and regulates the access to the sensors and actuators.

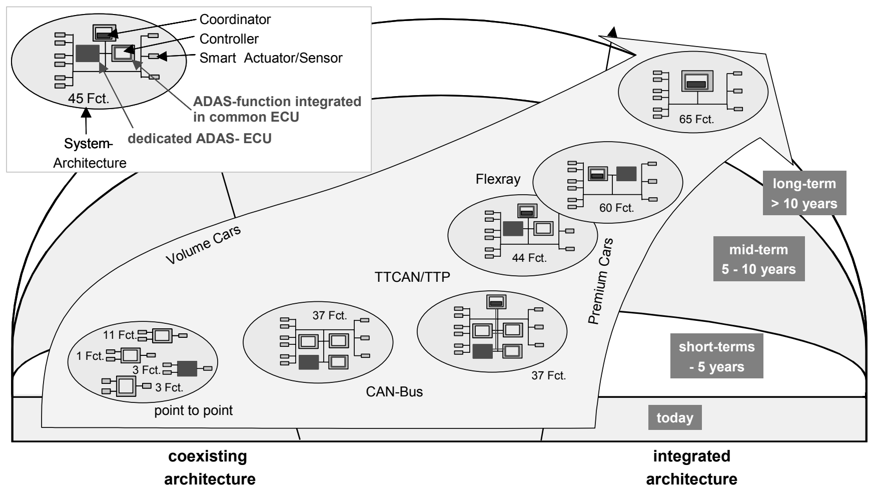


Fig. 8-67: Roadmap of system architecture

In Fig. 8-68 the individual components of the system architecture are shown. The sensor system, the actuators and the signal processing are regarded as the values which take influence on the system. The components signal distribution and energy supply on the other hand can be adopted as reactive values within the necessary technical parameters. Therefore those components have less influence on the design and the topology of the system architecture.

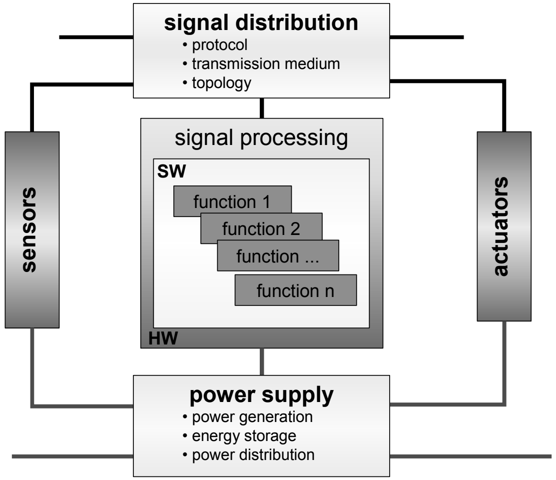


Fig. 8-68: Components of system architecture

The components of the signal processing consists of multiple interacting layers, Fig. 8-69. The fundament is given by the hardware platform, consisting of the controller, the program storage, memory, hardware-I/O-driver, communication driver, protection circuit, signal conditioning, watchdog and back-up controller.

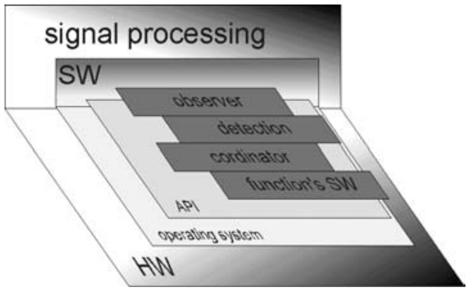


Fig. 8-69: Internal build-up of a signal processing system

The operating system is based on top of this hardware platform. The operating system manages the application, the resources and the memory in real time

(multitasking) as well as abstracts the hardware using software driver for communication and input/output signals. No E.C.U. specific hardware knowledge is necessary above this layer because of the hardware abstraction.

On the next level above the operating system is the so-called middleware. The task of the middleware is to provide all signals in a bi-directional way using standardised interfaces with the function software (top level), e.g. AUTOSAR[2]. This can help to reduce development time for the developer of function software. Furthermore the software modules are more flexible and can be used in different mikrocontrollers.

8.6 Control of advanced driver assistance systems

Regarding the complex development of advanced driver assistance systems the control of the single systems demands more complex algorithms than in the past. As it is described in chapter 8.2 und 8.3 driver assistance systems consist of sensors for gathering information and actuators for the implementation of reactions. Those reactions are determined by an algorithm or by a control unit in consideration of the sensor data and given target values (e.g. distance which must not be fallen short of etc.). The following sections deal with control systems for the intelligent cruise control (ACC) and the Heading Control in a more detailed way. Finally the end of the chapter deals with status control for heading control respective lane keeping.

8.6.1 Adaptive cruise control (ACC)

A production ready driver assistance system is the ACC-system which controls distance and velocity in a semi-automatic way. Being a consequent upgrade of the long used cruise control the system particularly supports the driver on the Autobahn and on country roads being similar to the autobahn helping the driver to keep up safe security distances and velocities. ACC continues the development of the cruise control to an intelligent system: driving on a free lane the velocity being chosen by the driver will be controlled. This desired velocity will be displayed in the speedometer. If preceding traffic is existent which is slower than the desired velocity the system will close the throttle or it will brake so that there will be a distance adapted to the preceding vehicle. Any time the driver is able to turn this function of by pushing the accelerator or the brake pedal.

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[2] AUTOSAR (**AUT**omotive **O**pen **S**ystem **Ar**chitecture) industrial partnership for the development of an open and standardised electronic architecture (www.autosar.org)

Basic item of all ACC-systems are the sensors which detect the environment around the vehicle. These sensors are able to determine the distance, the lateral distance and the relative velocity of every object being registered. Information about the object and the vehicle will be delivered to a control system which controls the throttle (engine management), the gear and the brake by means, that a given distance, mostly dependant on the velocity (in general a time gap of one or two seconds) will not be exceeded. The accelerating and the decelerating behaviour are controlled independently of the vehicle. This happens in order to arrange the accelerating reactions of the vehicle regarding the transition of different driving situations in a smooth and comfortable way. Fig. 8-70 exemplarily shows a ACC-system developed by Bosch.

components

1) controller
2) radar sensor
3) active brake system
4) human-man-interface
5) engine intervention
6) sensors for yaw rate, lateral acceleration, wheel speed and steering angle
7) transmission intervention

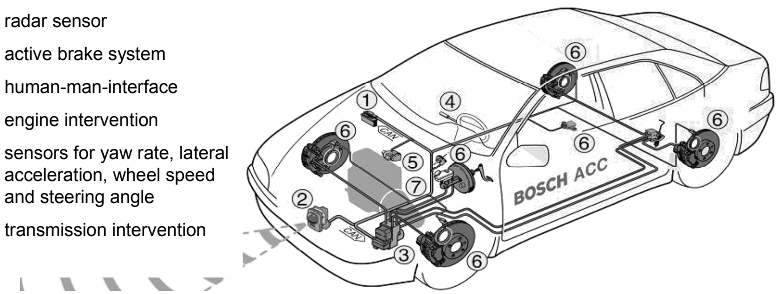


Fig. 8-70: Configuration of an adaptive cruise control (ACC)

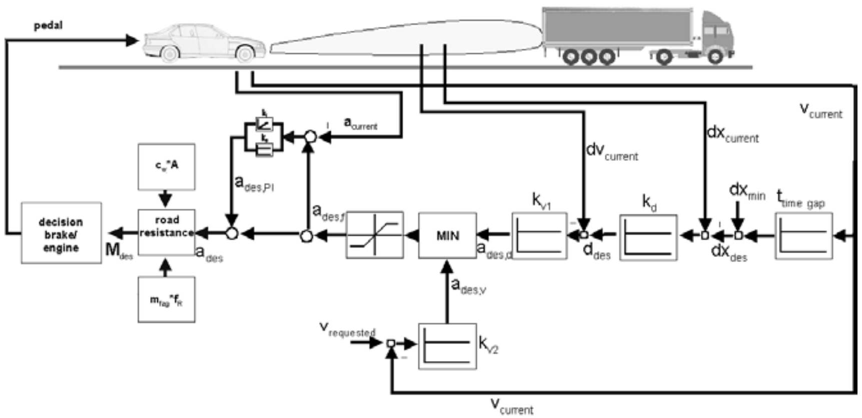


Fig. 8-71: Control parameters of a ACC control loop [NAA99]

In Fig. 8-71 the whole ACC-controller is given with a conventional control.

Input variables like velocity, relative velocity and distance to the preceding vehicle are used to determine the desired pedal position in consideration of the environmental conditions (road resistances) and the driver's wishes (maximum velocity and acceleration). Acceleration profiles or acceleration maxima especially regarding transients between driving situations may be adjusted dependant on the situation with a limitation of the minimum of the desired accelerations, $a_{desired,d}$ and $a_{desired,v}$ from the velocity deviation and distance deviation. The control of the proportion of k_{v1}, k_{v2} (damping of the control loop) and k_d (stiffness of the control loop) enable the consideration of swing-in manoeuvres of near vehicles with little differential-velocity: By reducing the reinforcement k_d of the distance deviation for a period of time an unnecessary strong braking manoeuvre will be avoided in this situation. The velocity of the vehicle swing-in is determining in stead of the temporarily short distance. Regarding the implementation the clever choice of the time span $t_{time\ gap}$ plays an important role because the noise concerning the distance and velocity signals sets boundaries. In order to realize the given velocity and acceleration independently from malfunctions the acceleration controller F_R has to feature at least PI-control response. The parameters k_{v1}, k_{v2}, k_d, $t_{time\ gap}$, a_{min}, a_{max} enable to set nearly every controller characteristic.

The control principle explained above may not be sufficient for an ACC controller in order to accomplish certain functions. So exemplarily distance as well as velocity have to be controlled at the same time. At first these values are independent. The state space theory allows a simultaneous control of different variables.

The description of dynamic systems in the state space is one of the most used attempts in order to solve numerous problems concerning control technology and practice. On the one hand this description has the advantage that systems are able to be described directly with several input and output variables. On the other hand the description based on matrices is a good choice for a further computer-supported procedure which can analyse dynamic models. Fig. 8-72 shows the action diagram of a linear transfer function in the state space. The signal paths represent several signals which are connected by multi-linked blocks and a block with a corresponding amount of integrators.

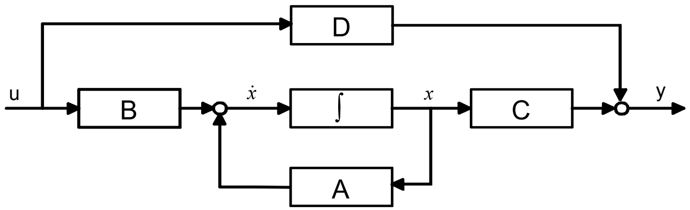


Fig. 8-72: Action diagram of a linear transfer function in the state space [ABE02]

The transmission behaviour of a control loop, in other words the connection between input and output, is described by a system of differential equations of first order concerning the state space. The variables, which occur in the equation additionally to the input and output, are named state variables. So a linear system with the input u, the output y and the state variables x may be described by the following differential equations in the vector form:

$$\dot{\mathbf{x}} = \mathbf{A} \cdot \mathbf{x} + \mathbf{B} \cdot \mathbf{u} \qquad \text{Eq. 8-1}$$

$$\mathbf{y} = \mathbf{C} \cdot \mathbf{x} + \mathbf{D} \cdot \mathbf{u} \qquad \text{Eq. 8-2}$$

Starting from the state space model a control procedure for example may be utilized, the so-called model based predictive control.

The model based predictive control describes a class of model based control procedures which uses a model of the process in order to predict the behaviour of relevant processing values for the future. With this method the future effects of the set variable acting on the process instantaneous may be estimated and may be optimised within the control algorithm [ABE02]. Boundaries of the set, control and state-space variables of the process may be considered.

The aim of the predictive control is to minimise the estimated control differences between the predicted value $\hat{\mathbf{y}}$ which contains the estimated values of the state variable **y** from time k to time k+j and the future command variable **w**. The demand of small variation of the prospective set variable **u** is also considered.

In Fig. 8-73 the structure of an ACC control unit concerning the principle of the model based predictive control is shown. Three state variables are regarded for the control system (ACC-vehicle): the acceleration, the velocity and the distance to the preceding vehicle. These values are the output of the control system at the same time. The input will be the desired engine torque modification and the velocity of the preceding vehicle:

$$\mathbf{X} = \mathbf{Y} = \begin{bmatrix} a_x \\ v_x \\ dx \end{bmatrix}, \quad \mathbf{U} = \begin{bmatrix} dM_h \\ v_{preceding} \end{bmatrix} \qquad \text{Eq. 8-3}$$

The controller can be divided into two components: the state observer and the optimisation. The observer calculates the current state values by means of the process model. The optimisation calculates future desired values by means of the maximal tolerated acceleration and the minimal distance to the leading vehicle.

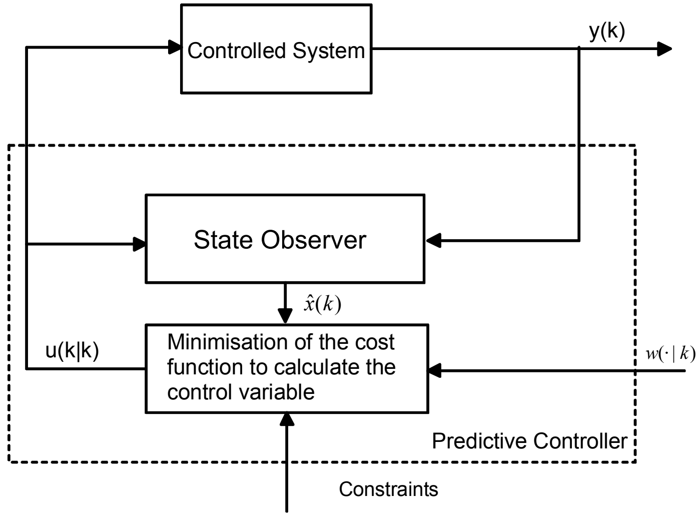


Fig. 8-73: Structure of a preventive control loop

8.6.2 Heading control – lane keeping assistant

The target of this system is it to support the driver in holding the lane. If a driver clearly deviates from the desired standard course, the system tries to make a correction in the steering input. There are various approaches to achieve this:

A steering torque or yaw angle proportional to the deviation of the vehicle from the optimum position is added onto the steering wheel. This can be achieved by means of a electrical servo-motor integrated into the steering column.

The actually driven course with reference to the lane is determined with the help of a simple image processing system. Infrared sensors, which analyse the reflection of road markings, are another possibility for the recognition of the right lane.

By means of certain other parameters (e.g. side slip angle, angular rate of yaw, yaw angle error) the actual driver reactions can be compared with the ideal reactions based on the lane along with the dynamic parameters. As a result, the necessary additional steering force can be calculated (Fig. 8-74).

Investigations show that the system is accepted by drivers and that it is found to be stress relieving. The preferred versions of the system are those where the system reactions correspond as closely as possible to the driver reactions.

An extension of the system to an automatic track holding system without necessary driver intervention is conceivable by increase of the steering forces of the system. The present limitations in image processing however permit only an assistance.

A simple system based on image processing which warns the driver on leaving the track, has been introduced in trucks made by DaimlerChrysler in the USA and in Europe since the year 2000.

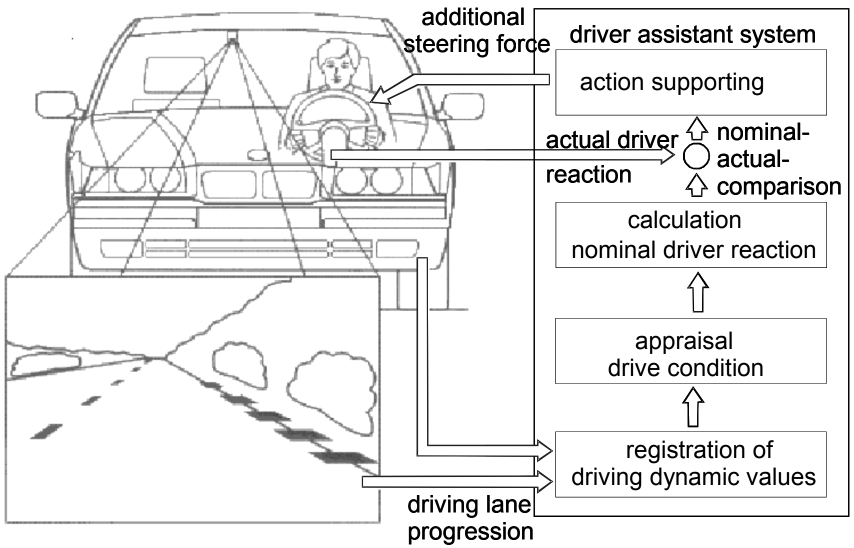


Fig. 8-74: Heading control [LER99]

9 Longitudinal and Lateral Vehicle Dynamics Control

As mentioned in chapter 0 before, the driver's task is divided into navigation, vehicle guidance and vehicle stabilization. Regarding the third of these tasks, the driver acts as a controller with respect to the vehicle's driving stability. With the vehicle as the control travel, interactions between the driver's inputs and the vehicle reactions can be considered to be a closed control loop, Fig. 9-1.

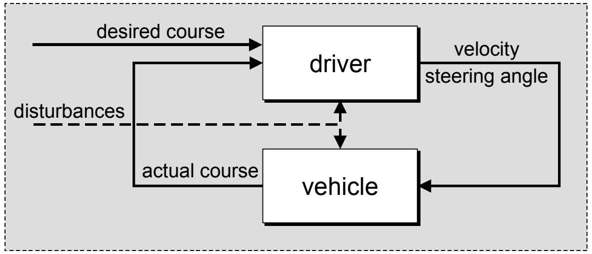


Fig. 9-1: Control loop driver - vehicle

Within this control loop, disturbances become effective for the driver (e.g. relative movements driver – vehicle, poor vision) and the vehicle (e.g. side wind, road excitations). The steering wheel angle, the accelerator pedal position and the brake force / brake pedal position are control variables, which are passed on to the vehicle. Differences between the desired and the actual course are recognized as control deviations by the driver.

The closed control loop is a dynamic system. Due to the fact that the driver's abilities of adaptation are limited, the stability of the control loop for quick corrections due to course deviations under the influence of disturbances mainly relies on the properties of the vehicle behavior.

In modern vehicles, systems for controlling the longitudinal and lateral dynamics are used to assist the driver in his tasks of vehicle guidance and stabilization. These systems are commonly referred to as vehicle dynamics control systems. Their function is to realize an optimized vehicle behavior within the physical boundaries and therefore minimize the difference between desired and actual course. Modern vehicle dynamics control systems thus assist the driver in the cybernetic task of guiding the vehicle on a desired course only.

9.1 Longitudinal Dynamics Control

The transmittable longitudinal tire forces depend strongly on the road surface and the friction coefficient between tire and road surface respectively. The acceleration- and braking forces created by the driver's inputs can exceed the physical limits especially for low friction road surfaces. As a result, the wheel will show a tendency to slip or lock respectively. Beside a risen tire wear, these effects have a negative influence on the transmittable longitudinal tire forces and therefore also on the vehicle's longitudinal and lateral dynamics.

Even for skilled drivers the optimum application of acceleration- and braking forces is a difficult task, since the friction coefficient can not be assessed precisely. Extending the control loop driver – vehicle by a longitudinal dynamics controller, which reduces the tire forces to the transmittable maximum when exceeding the adhesion limit, an essential assistance for the driver is realized, Fig. 9-2.

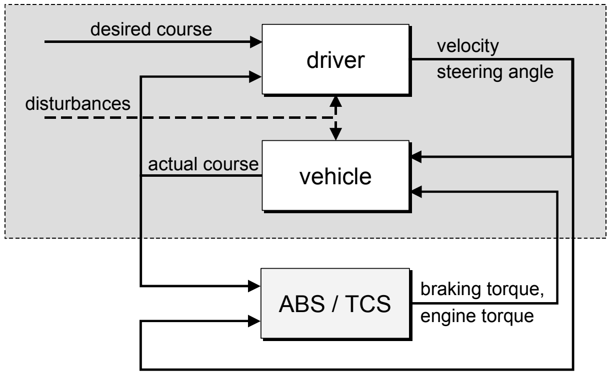


Fig. 9-2: Control loop driver – vehicle – longitudinal dynamics controller

Control systems, which prevent a wheel from locking, are commonly referred to as **A**nti-Lock **B**raking **S**ystems (ABS). An often used expression for control systems, which restrict a wheel from slipping, is a **T**raction **C**ontrol **S**ystem (TCS).

9.1.1 Basics of Longitudinal Vehicle Dynamics Control

The force transmission between tire and road surface in longitudinal vehicle and tire direction respectively essentially depends on the friction coefficient of the road, the wheel load and the longitudinal tire slip. Regarding the longitudinal tire slip, the following distinction between acceleration- and braking slip is made:

$$\lambda_{Acc} = \frac{\omega_{Wheel} \cdot R_{dyn} - v_{Veh}}{\omega_{Wheel} \cdot R_{dyn}} \qquad \text{Eq. 9-1}$$

$$\lambda_{Brake} = \frac{v_{Veh} - \omega_{Wheel} \cdot R_{dyn}}{v_{Veh}} \qquad \text{Eq. 9-2}$$

Fig. 9-3 shows a typical plot of the utilized friction coefficient μ in longitudinal tire direction, defined by the quotient of longitudinal tire force and wheel load, depending on the longitudinal tire slip λ:

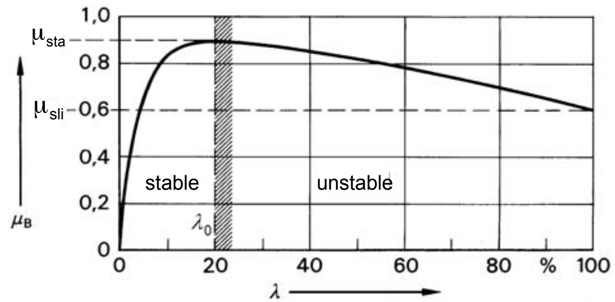


Fig. 9-3: Utilized friction coefficient as a function of the longitudinal tire slip

The figure shows a maximum for the utilized friction coefficient for a longitudinal slip of approximately λ = 20%. The tire becomes instable for higher slip values, since a minor rise in slip causes a locking of the wheel at constant brake force. The tire possesses stable characteristics for slip values smaller than the maximum, for which the friction coefficient gradient is positive.

The influence of the road's friction coefficient on the utilizable friction coefficient is shown in Fig. 9-4. Even though the values of the different maxima vary strongly, the curves show qualitively similar plots, possessing a maximum between ca. 10 % and 30 % of longitudinal slip. An exception is the plot for a snowy road surface, for which the utilized friction coefficient rises slightly near the total tire lock up. This phenomena occurs due the fact that a locking wheel on snow creates a snow wedge in front of the wheel thus increasing the braking force slightly.

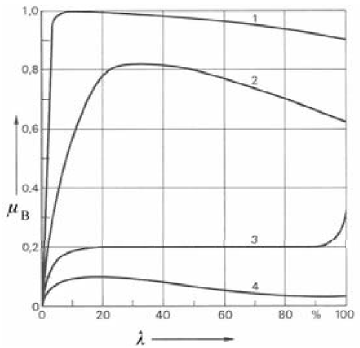


Fig. 9-4: Utilized friction coefficient for different road surfaces: 1 – dry asphalt; 2 – wet asphalt; 3 – snow; 4 – ice

As shown in the figure, maximum utilizable friction coefficients occur independently from the road surface for slip values λ between ca. 10 % and 30 %. Due to this fact, the longitudinal tire slip is a suitable control parameter to influence the longitudinal tire forces and therefore also for influencing the longitudinal vehicle dynamics. For this reason, vehicle dynamics control systems controlling the longitudinal tire forces are also called wheel slip control systems.

Another positive side effect that results from controlling the longitudinal tire slip in a suitable manner can be observed for a superposition of longitudinal and lateral tire forces for different slip values:

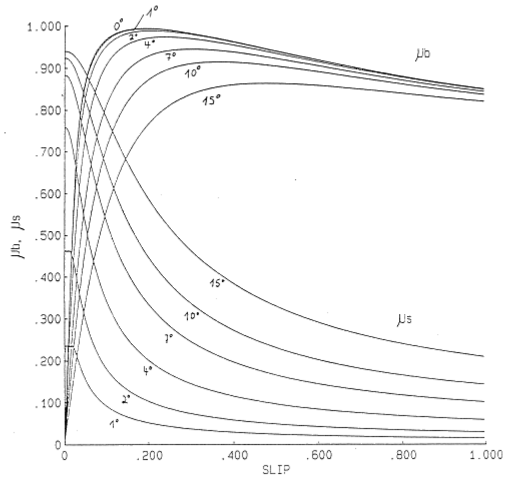


Fig. 9-5: Superposition of longitudinal and lateral tire forces

While the transmittable lateral tire force reduces significantly for a fully locked wheel, relatively high longitudinal and lateral tire forces can be realized for longitudinal tire slip values between ca. λ = 10 % - 30 %. Therefore a suitable wheel slip control maintains the steerability and also the driving stability of the vehicle.

In the following, wheel slip control systems for braking and acceleration forces are described separately.

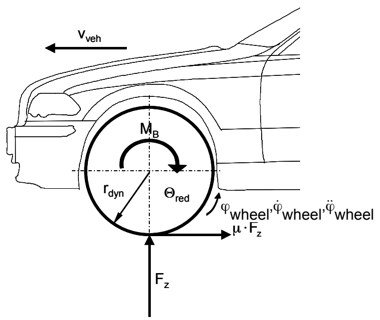
9.1.2 Wheel Slip Control for Braking Forces

The Anti-Lock Braking System (ABS), introduced in 1978, was the first series application vehicle dynamics control system. Its function is to prevent the wheels from locking during braking maneuvers. As mentioned in chap. 9.1.1 , the locking of a wheel (longitudinal tire slip λ_B=1) does not only lead to a reduction of the maximum brake force and thus a smaller deceleration, but also reduces the lateral tire forces significantly. A loss of steerability is the result for locked wheels on the front axle; a risk to oversteer occurs from locked wheels on the rear axle [WAL97].

The longitudinal tire slip created during braking maneuvers is limited to values between 10% and 30% by the ABS, in order to achieve a high deceleration in combination with a high side force potential. The utilized friction coefficient between tire and road surface and thus the transmittable brake force however depend strongly on the make of the tire, the sideslip angle and to a large degree on the road surface properties.

The longitudinal tire slip would be an optimum control parameter for the ABS, since the more or less distinctive maxima of the brake forces occur for identical tire slip values. Due to the fact that the vehicle velocity, which is not measured directly in the vehicle environment, is needed to determine the longitudinal tire slip (Eq. 9-1 and Eq. 9-2), the slip between tire and road cannot be calculated directly. For this reason different control parameters need to be used [SAG04].

The following equation is valid for an equilibrium of moments of a braked wheel:



M_B	brake torque
μ	friction coefficient
F_Z	wheel load
R_{dyn}	dynamic radius
Θ_{red}	reduced moment of inertia
φ_{wheel}	wheel rotation angle
$\dot{\varphi}_{wheel}$	rotational wheel speed
$\ddot{\varphi}_{wheel}$	rotational wheel acceleration

Fig. 9-6: Forces and moments for a braked wheel

$$M_B = \mu \cdot F_z \cdot R_{dyn} - \Theta_{red} \cdot \ddot{\varphi}_{Wheel} \qquad \text{Eq. 9-3}$$

Above a certain threshold, a high brake torque cannot be completely transmitted as a longitudinal tire force $\mu \cdot F_z$ in the tire contact patch. Therefore the brake torque leads to a rotational deceleration of the wheel, especially when the maximum utilizable brake force is exceeded. Due to the sensitivity caused by the different magnitudes regarding the factors $F_z \cdot R_{dyn}$ und Θ_{red}, a high wheel deceleration can be created, which is therefore a suitable control parameter for ABS [SAG04].

The ABS determines the rotational wheel accelerations by derivation of the rotational wheel speed signals provided by wheel speed sensors. Since a moderate wheel deceleration can also lead to a locking of the wheel if applied for a longer period of time, additional control parameters are needed for a suitable wheel slip control.

For this reason the „relative slip“ is used as a second control parameter. An algorithm is used to determine a reference speed, which approximately matches the wheel speed for an optimum brake force at the given moment, based on the wheel speeds of several wheels. The separate “relative” slip values are determined by comparing the actual wheel speeds with the reference wheel speed [SAG04].

In general, the control cycle for all automatic wheel slip control algorithms preventing a lock-up of the wheel based on wheel decelerations is identical. The brake pressure, which is chosen too high by the driver, is controlled in such a way that the wheel decelerations vary between an upper and a lower threshold. The

method, by which the brake pressure is kept within a safe range for optimum brake forces independently from external disturbances, differs between the different types of ABS systems.

As an example, an ABS control cycle which uses the rotational wheel acceleration as well as a relative slip is explained is the following:

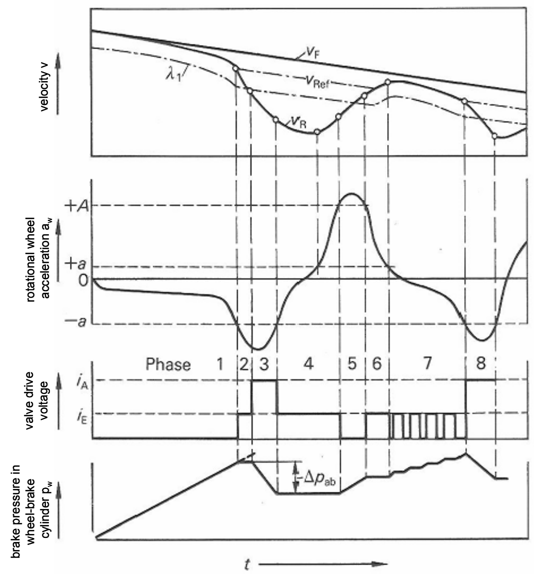


Fig. 9-7: Control Cycle of an ABS system, Source: Bosch

Due to a rise in brake pressure initiated by the driver, the circumference velocity of the tire decreases faster than the vehicle velocity. The brake pressure is held at its momentary value as soon as the wheel deceleration exceeds the threshold “–a”, which is characteristic for the maximum utilizable friction coefficient. In case the wheel speed drops below the slip-threshold s_{B1} in this state, the brake pressure is decreased until the “-a” threshold is reached again. Should the wheel acceleration exceed the “+A” threshold in this phase of constant brake pressure, the brake pressure is increased again. The brake pressure is held at a constant value between the two acceleration-thresholds “+A” and “+a” and then slowly increased until the “-a” wheel acceleration is exceeded again. From this point on a new control cycle begins, for which the brake pressure is however immediately decreased.

In spite of a careful brake-pedal actuation, a wheel with a relatively high moment of inertia or a low road-friction coefficient can cause the wheel to lock without reaching the wheel-acceleration-threshold “-a“. For this reason, the *relative wheel slip* is used as a second control variable. As soon as the relative wheel slip reaches a defined threshold, the brake pressure is also decreased.

The control commands for the decrease, increase or hold of the brake pressure are realized by a hydraulic system. Usually open systems are used, which are operated with two 2/2 two-way valves per wheel. Fig. 9-8 illustrates the operating principle of such a hydraulic system:

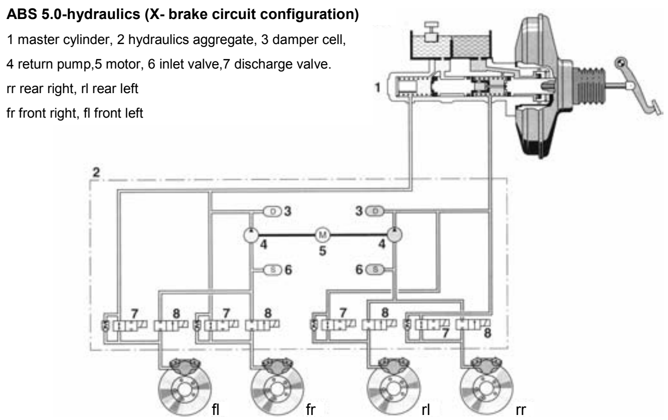


Fig. 9-8: Hydraulic operating principle of the Bosch ABS 5.0

During an uncontrolled brake actuation, the brake-pressure inducted by the driver via the brake-pedal is directly transmitted through the open inlet valve (7) to the particular wheel. The discharge valve is closed.

If the ABS-control unit detects a lock-tendency of the wheel, the inlet valve is usually closed as well, therefore holding the brake pressure at a steady level. If the lock-tendency of the wheel cannot be decreased by holding the pressure, the brake pressure itself needs to be decreased. For that purpose the inlet valve remains closed and the discharge valve is opened. The return pump transfers the discharged brake fluid back to the high-pressure side of the brake (4). Thereby the full hydraulic pressure of the return pump is effective on the inlet valve, so that the brake pressure can be increased again, as soon as the lock-tendency is overcome. Then the discharge valve closes as the inlet valve opens, thus the pressure generated by the return pump increases the brake pressure in the wheel-

brake cylinder. This hydraulic pressure also affects the brake pedal, so that the driver senses a pulsation of the brake pedal.

There are three possible strategies for controlling the brake actuations fort the wheels of one axle:

- select-low control
- select-high control
- independent wheel control

The select-low strategy controls the brake pressure for both wheels of one axle in common. The wheel with the lower utilizable friction coefficient determines the level of the brake pressure for both wheels [WAL97]. The detection of lock-tendencies can be carried out individually for every wheel or on the basis of a single rotational-speed sensor at the axle differential. Due to this control strategy, the maximum transmittable brake force is not realized, as the brake pressure could actually be increased for the wheel with the higher traction. The advantage of this strategy is the remaining high lateral tire side force potential of the tire. The ability to transmit high lateral tire forces is very important especially for the rear axle considering the driving stability: If the centrifugal forces that affect the rear axle exceed the maximum lateral axle-forces, the vehicle begins to skid and breaks away. For that reason the select-low strategy is usually used for the rear axle of a vehicle.

If the brake forces of an axle are controlled using a select-high strategy, the wheel with the higher utilizable friction coefficient determines the common brake pressure for this axle. Therefore a rotational speed sensor for each single wheel is needed. The achievable deceleration is higher than the one achieved with select-low controlled axles [WAL97]. However the wheel with the lower traction can lock easily, which leads to a significant decrease of cornering force. For front axles this decrease of cornering force causes an understeering tendency, which is favorable regarding driving stability. For that reason and due to a higher deceleration, the select-high strategy is usually used for front axles.

If the maximum deceleration possible shall be realized for a vehicle, each single wheel needs to utilize its maximum traction. This is achieved by an independent wheel control strategy, for which each wheel is equipped with a wheel speed sensor and a brake pressure line [WAL97]. The advantage of a maximal deceleration is confronted by a high yaw-moment when braking on asymmetric road surfaces (μ-split), which will be explained in the following.

Another function included in state-of-the-art ABS systems is the so-called "Yaw-Moment-Reduction" (YMR). If a vehicle brakes on an asymmetric road-surface, the ABS controls the brake pressure appropriate to the particular road-friction for both sides of the vehicle. That generates a yaw moment around the vertical axis of the vehicle, that needs to be compensated by countersteering of the driver.

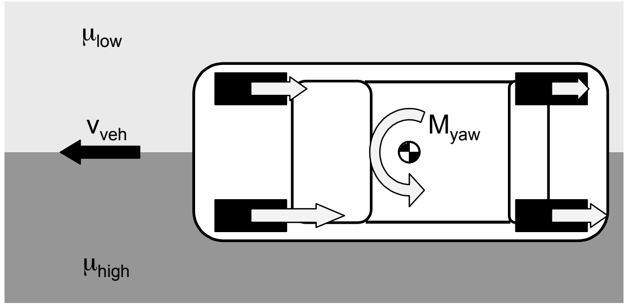


Fig. 9-9: Yaw moment while braking on an asymmetric road surface

The necessary steering corrections due to braking on asymmetric road surfaces, often referred to as "μ-split-braking", demand advanced driving skills from the driver. This raises the risk of a loss of control for vehicles equipped with conventional brake systems as well as ABS without YMR. In order to avoid such dangerous situations, YMR-systems increase the brake-pressure for the wheels on the high-friction surface with a reduced gradient, as soon as a significant difference in road-friction between the two wheels of an axle is detected. As the rear axle is normally controlled by a select-low-strategy, the principle of YMR is mostly used for the front axle only. The YMR-strategy leads to a slower build-up of yaw moment around the vertical axis, which can be compensated much easier by countersteering of the driver.

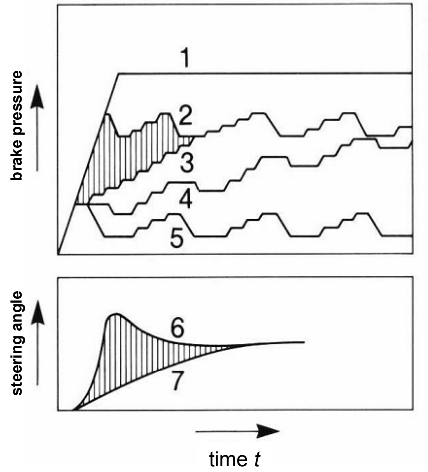


Fig. 9-10: Brake pressures and steering angles during μ-split braking without and with YMR

9.1.3 Wheel Slip Control for Acceleration Forces

Analogous to brake forces, traction forces that exceed the force-transmission potential between a tire and the road, generate wheel-spin, longitudinal slip and a loss of lateral-force transmission. This loss of lateral force leads to an understeering tendency and a reduction of steerability for front-wheel driven vehicles and to an oversteering tendency and possibly a loss of vehicle stability for rear-wheel driven vehicles respectively. To meet the requirements of good longitudinal dynamics and a high side force potential, modern vehicles feature traction control systems (TCS, ASC, etc.).

In general, the task of a TCS can be described as that of an inverted ABS: The TCS shall reduce longitudinal slip due to high traction forces to values near to the maximum value of utilizable force transmission. Concerning the control strategy there are however differences between TCS and ABS: Whereas ABS usually uses the wheel acceleration as a control-variable, this is not suitable for TCS due to the high inertia moments of driven wheels. Also the drive torques are much more dependent on the rotational wheel speed compared to brake torques. For those reasons the wheel acceleration is not used as a control variable in traction control systems [ZAN03].

Contrary to braking procedures, for which all four wheels of the vehicle are decelerated and therefore build-up longitudinal slip, a propulsion concept with only one driven axle allows a precise determination of the vehicle speed during acceleration. Since the non-driven wheels roll freely, they practically possess no longitudinal slip, which allows a determination of the vehicle speed according to their rotational speed. Thereby the longitudinal slip λ for the driven wheels can be calculated reliably with Eq. 9-1. The ABS wheel-speed sensors can be used to measure the wheel speed for the TCS-algorithm. Due to the possibility of precisely calculating the longitudinal tire slip, this parameter can be used as a TCS-control variable.

Since all-wheel-driven vehicles can show high wheel-spin for all four wheels simultaneously, the evaluation of the driving speed needed for the calculation of the longitudinal slip is considerably more complex. Therefore TCS has not been applied to all-wheel-driven vehicles until ESP entered the market, which is also dependent on an exact evaluation of the vehicle's longitudinal speed [ZAN03].

Basically the TCS-control strategy differentiates between two cases: Driving of an axle on a homogeneous and on an asymmetric road surface. For a homogeneous road surface, both wheels of an axle can transmit the same traction force for identical wheel loads. When the TCS detects wheel-spin, it produces an intervention into the engine management. The TCS can be decrease the engine torque by different measures. For Otto engines, these are:

- Throttle adjustment (only for EGas)
- Ignition-timing adjustment
- Suppression of several ignition pulses
- Suppression of several injection pulses

For Diesel engines the engine management decreases the engine torque by controlling the injection pump and decreasing the quantity of injection.

The TCS reduces the longitudinal slip to values between 10% and 30% by the use of an adequate engine-torque reduction and thus prevents wheel-spin, in order to improve the traction.

If an axle is driven on an asymmetric road surface, the axle differential causes the traction forces of both wheels to be nearly identical. The low-friction (μ-low) wheel begins to spin as soon as the traction force exceeds its maximum utilizable value, whereas the high-friction (μ-high) wheel can only transmit the force defined by the friction coefficient of the low-μ-side due to the effect of the axle differential. Since the μ-high-wheel is able to transmit a higher traction force, the TCS individually brakes the μ-low-wheel to thereby support the higher driving torque. By this

measure the longitudinal slip of the μ-low-wheel decreases with a nearly constant longitudinal force transmission for this wheel, whereas the μ-high-wheel transmits a higher traction force, Fig. 9-11:

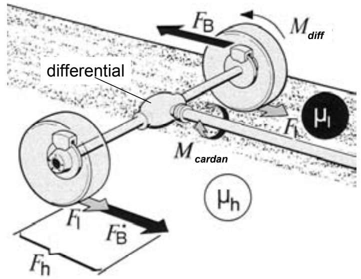


Fig. 9-11: Wheel individual TCS braking on an asymmetric road surface

By designing the brake-force control accordingly, nearly identical wheel speeds for the μ-low- and the μ-high-side are achieved. An appropriate control strategy is important to avoid differential-damage due to high differential strain at high rotational-speed differences under load. The described function is often referred to as "Electronic Differential Lock".

While accelerating on asymmetric road surfaces an additional decrease of the engine torque is not carried out until the traction force of the μ-high-wheel exceeds its maximum value, causing this wheel to build-up significant wheel-spin.

Extensive or often occurring TCS-brake interventions on asymmetric road surfaces can lead to high brake temperatures. In order to avoid brake-fading or damages, the brake-temperature is evaluated using a theoretical model. If the evaluated brake temperature exceeds a defined threshold, the brake interventions are temporarily interrupted [ZAN03].During this operation mode, the TCS uses interventions of the engine management only, which can lead to a reduced traction.

Under certain circumstances, the TCS can also increase the engine torque moderately. A release of the accelerator pedal without disengaging the clutch causes an engine-drag torque, which produces a braking torque on the driven axles. On low-friction road surfaces this can cause high longitudinal slip on the driven wheels, which can affected the driving. In order to avoid unstable driving conditions, the TCS is able to increase the engine torque to a defined, moderate maximum value after detecting the described situation. This function is often referred to as "engine-drag-torque control".

Fig. 9-12 illustrates the implementation of an TCS-system into a vehicle environment. As TCS and ABS partially use the same components, both algorithms are normally combined in one electronic control unit:

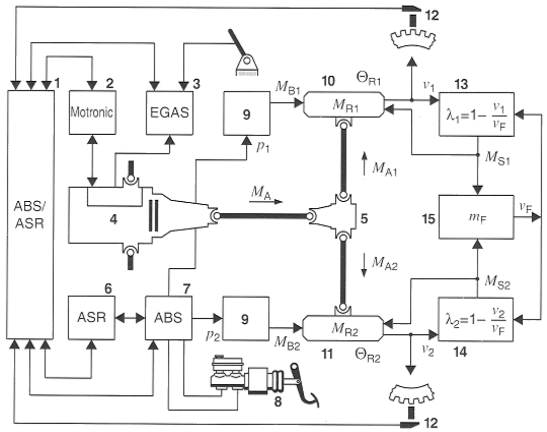


Fig. 9-12: Implementation of TCS in a vehicle environment

9.2 Lateral Vehicle Dynamics Control

An improvement of driving stability and a compensation of disturbances, which affect the vehicle behavior, can be achieved by adding a vehicle dynamics controller (VDC) to the control loop driver-vehicle (Fig. 9-13). The vehicle dynamics control compares the vehicles actual course with the desired course which is calculated from the steering angle and the vehicle speed adjusted by the driver. In the case of a critical driving situation, the vehicle dynamics controller can stabilize the car by reduction of the driving torque, by selective brake interventions or by additional steering angles at the front wheels [HOL00].

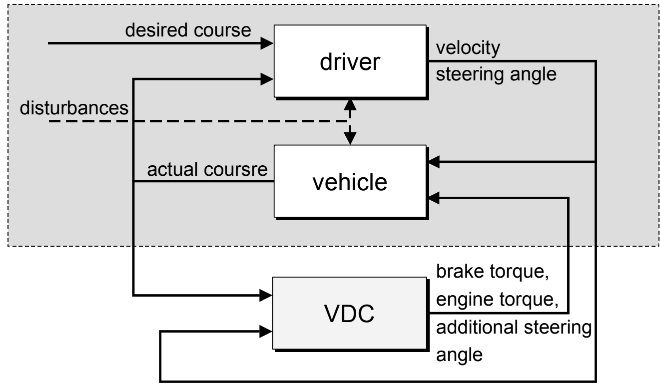


Fig. 9-13: Control loop driver-vehicle-vehicle dynamics control

Other common descriptions for vehicle dynamics control systems are ESP (Electronic Stability Program), DSC (Dynamic Stability Control), PSM (Porsche Stability Management) or VSC (Vehicle Stability Control). All these systems rely on the basics described in the following chapters.

9.2.1 Basic Elements of Vehicle Dynamics Controllers

The structure of a vehicle dynamics controller can basically be divided in the three blocks observation of the driving condition, identification of the driving condition and control of the driving condition [CON97] (Fig. 9-14).

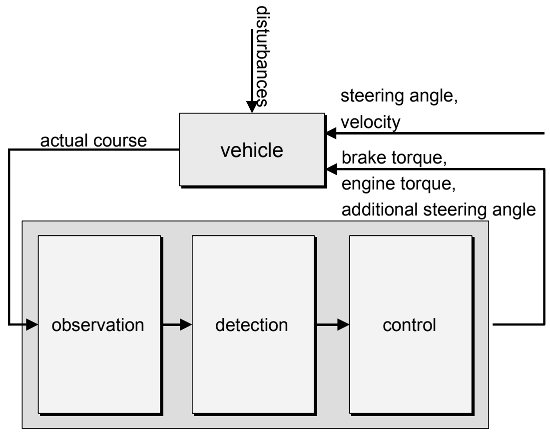


Fig. 9-14: Basic layout of vehicle dynamics controllers

A controlled lateral dynamic vehicle movement requires information about the current movement and the desired movement of the vehicle. The block *observation of driving condition* calculates or estimates all required variables by using the signals of the applied sensors as well as models of vehicle and tire behavior stored in the control unit. Depending on the specific functions, variables such as longitudinal speed, lateral speed, attitude angle and side slip angle are calculated or estimated from the measured variables. A linear single track model allows the calculation of the desired yaw rate from the variables driving speed and steering angle. By comparing the calculated or estimated actual variables with the desired driving condition, a critical driving situation can be subsequently detected in the block *identification of driving condition*.

The task of the block *identification of driving condition* is the detection of all critical lateral dynamic driving situations and the activation the block *control of driving condition.* The vehicle enters a critical situation when it no longer follows the desired course as set by the driver and either oversteers (exceeding of utilizable lateral force transmission at the rear axle) or understeers (exceeding of utilizable force transmission at the front axle).

The demands on the identification of driving condition are:

- Permanent, self-acting monitoring of the transfer behavior yaw rate / steering angle.
- Fast detection and identification of critical lateral dynamic driving situations.
- Function independent from the actual force transmission between tire and track.
- Function independent from the actual driving condition.

The results of the *identification of driving condition* serves the *control of driving condition* during the activation of the control process. A compensational yaw moment can be calculated from the deviation between the desired values and the actual values of the yaw rate (and if necessary the attitude angle). State of the art vehicle dynamics controller generate the compensational yaw moment by individual brake interventions for each single wheel. These systems control the lateral dynamics as well as the longitudinal dynamics

9.2.2 Observation

In normal driving situations the absolute value of the vehicles lateral acceleration does not exceed 3,5 m/s² during 95 % of the driven curves [RIS91; MIT91]. For this reason it can be assumed, that normal drivers usually experience a driving

behavior similar to the behavior described in the linear single track model, because this model is valid in the described operating range. This consideration leads to the following definition[MIT91]:

“The vehicle shows a critical lateral dynamic driving condition, when the transfer behavior yaw rate / steering angle clearly differs from the field of experience of a normal driver. The field of experience of a normal driver generally references to a linear system behavior.”

Therefore the control strategy of common vehicle dynamics control systems is to realize a vehicle behavior as linear as possible even close to the lateral dynamic stability limit. The driver shall not be overstrained with the control and the reaction of the vehicle.

Under this aspect, a desired yaw rate is calculated from the variables steering angle and driving speed using the linear single track vehicle model.

$$\dot{\psi}_{des} = \frac{v_{veh}}{l \cdot \left(1 + \frac{v_{veh}^2}{v_{vhar}^2}\right)} \cdot \delta_{driver} \qquad \text{Eq. 9-4}$$

The characteristic driving speed v_{char} combines the dependencies of the single track model and the values

- Position of the center of gravity defined by l_f and l_r
- Side slip stiffness $c_{\alpha f}$ and $c_{\alpha r}$
- Vehicle mass m_{Veh}.

in one value:

$$v_{char} = \sqrt{\frac{c_{\alpha f} \cdot c_{\alpha r} \cdot l^2}{m_{veh} \cdot (c_{\alpha r} \cdot l_r - c_{\alpha f} \cdot l_f)}} \qquad \text{Eq. 9-5}$$

By combining these values in one value, which depends on the particular vehicle, the installed tires and the current load, the real vehicle behavior can be described by the single track model.

At constant driving speed, a linear dependency as described in Eq. 9-4 exists between the desired yaw rate and the front wheel angle,. The limiting effect of the maximum force transmission between track and tire on the yaw rate is not taken into account in this formula.

To consider the influence of the maximum force transmission, the desired yaw rate is limited depending on the friction coefficient of the road. Nowadays it is not possible to measure or estimate the actual road-friction coefficient precisely during the ride. Therefore a yaw rate limitation is executed in consideration of the actual lateral acceleration. Starting from a pure yaw motion without an attitude-angular velocity (steady-state), the maximum yaw rate results from the centrifugal force, which is the only horizontal force to transmit in this case:

$$a_y = v\left(\dot{\psi}_{veh} + \dot{\beta}\right) \approx v \cdot \dot{\psi}_{veh} \qquad \text{Eq. 9-6}$$

$$v \cdot \dot{\psi}_{veh} \approx a_y \le a_{y,max} = \mu \cdot g \Rightarrow \dot{\psi}_{max} = \frac{\mu \cdot g}{v_{veh}} \qquad \text{Eq. 9-7}$$

In Fig. 9-15 the friction-dependent limitation of the yaw rate is displayed on the basis of two yaw rate curves according to Eq. 9-4 with constant steering angle (45° and 90°) as well as on the basis of curves of constant lateral acceleration (Eq. 9-6).

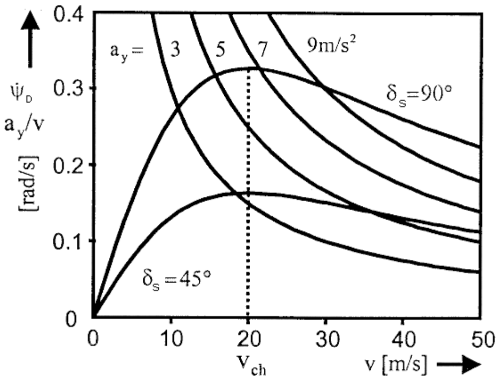


Fig. 9-15: Road-friction dependent limitation of the desired yaw rate

If the vehicle drives on a snow-covered road (road-friction coefficient μ = approx. 0.3) a maximum lateral acceleration of approximately 3 m/s² is possible. Between 0 m/s and 10 m/s the yaw rate follows the line δ_S = 90°. At the point of intersection with the line a_y = 3 m/s² the maximum lateral acceleration is

reached. With a road-friction dependent limitation, the yaw rate follows the line of constant lateral acceleration a_y = 3 m/s² when the driving speed increases. This complies with the real vehicle behavior. Thus it appears that the lines of constant lateral acceleration form the limit which can be reached according to the particular road-friction. Points below this line can be reached with the vehicle, whereas points above this line cannot be realized.

9.2.3 Identification of driving condition

This module of the vehicle dynamics control system performs the task of identifying critical lateral dynamic states and activates the control of driving condition.

A critical lateral dynamic state is reached when the actual yaw rate clearly differs from the calculated desired yaw rate. The desired yaw rate is enclosed with a range of tolerance according to [P4305] and [WIT95]. When the actual yaw rate exceeds this range of tolerance, the control of driving condition is activated.

The yawing movement of the car is divided into right-hand and left-hand curves. A positive yaw rate represents a left-hand curve in the already introduced system of coordinates.

The vehicle behavior properties “oversteer“ and “understeer“ are defined according to the following definition:

- Understeer: The absolute value of the desired yaw rate is bigger than the absolute value of the actual yaw rate
- Oversteer: The absolute value of the desired yaw rate is smaller than the absolute value of the actual yaw rate.

This classification leads to the following diagram (Fig. 9-16), which describes the possible driving conditions.

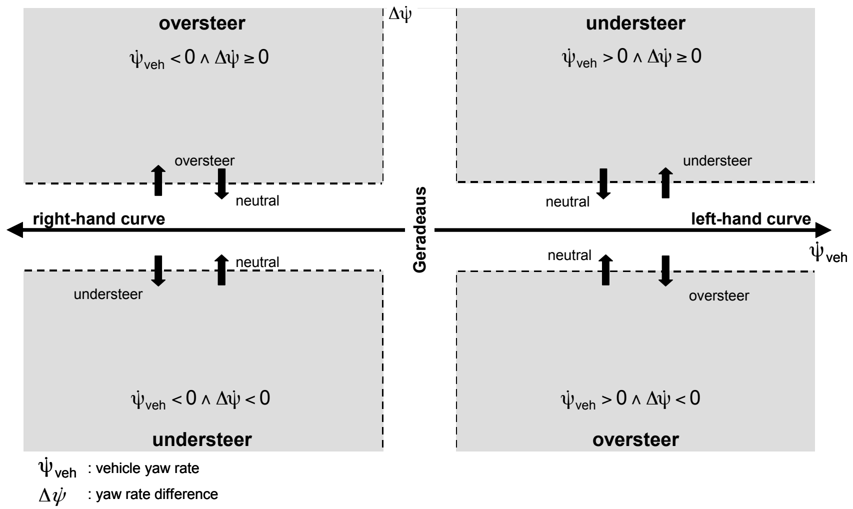


Fig. 9-16: Classification of driving conditions

Where necessary, some special driving conditions have to be detected, for which the controller needs to be deactivated. As an example, the controller has to be deactivated during

- Cornering on a high-banked curve (e.g. at a testing facility)
- Rearward driving
- Running the vehicle on a roller dynamometer.

9.2.4 Control of driving condition

The driving condition controller calculates a compensational yaw moment, which is generated by individual brake and engine interventions. Usually a yaw rate regulation is used in combination with an attitude angle limitation.

9.2.4.1 Yaw Rate Regulation

If a vehicle understeers during cornering, the exceeding of the utilizable of lateral tire forces on the front axle leads to a reduction of the absolute value of the yaw rate. The vehicle can be stabilized by a compensational veering-in yaw moment, which can be generated by a brake intervention at the inner rear wheel for example, Fig. 9-17. The single-side brake force generates a yaw moment, which

turns the vehicle towards the center of the curve, thus compensating the understeering behavior.

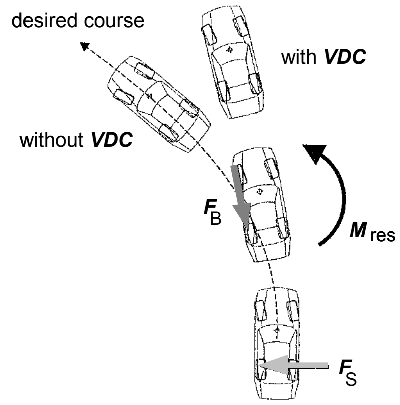


Fig. 9-17: Brake intervention for an understeering vehicle

State of the art vehicle dynamics controllers use an interface with the combustion engine to throttle the driving torque before initiating the brake intervention for an understeering vehicle. Brake interventions are only carried out for massively understeering vehicles, because the overall extent of brake interventions has to be minimized for comfort reasons. Furthermore an engine throttling leads to several positive effects, that stabilize the vehicle:

- For front-wheel-driven vehicles, the front wheels do not have to transmit driving torque, allowing more lateral force to be transmitted. This effect stabilizes the vehicle.
- The deceleration of the vehicle causes a dynamic wheel-load transfer towards the front axle; thereby higher lateral forces can be transmitted by the front axle.
- The dynamic wheel-load transfer reduces the wheel load and therewith the lateral forces at the rear axle. The combination of the increasing lateral force at the front axle and the decreasing lateral force at the rear axle generates – independently from the drive concept –a yaw moment which turns the vehicle towards the center of the curve.

If a vehicle shows an oversteering behavior, the yaw rate quickly increases and the rear end of the vehicle tends to break away, Fig. 9-18. In this case the vehicle dynamics control system initiates a brake intervention on the outer wheels, for example at the outer front wheel. The resulting yaw moment counteracts the yaw movement of the car and thereby prevents a further break away. Also, the brake intervention leads to a loss of lateral force at the front wheel, which also supports the desired movement of the vehicle.

Nowadays the brake-intervention strategies of different vehicle dynamics control systems vary considerably. Modern systems initiate brake interventions for one or more wheels during over- or understeering situations. Due to this variety of existing systems, specific control strategies shall not be described here.

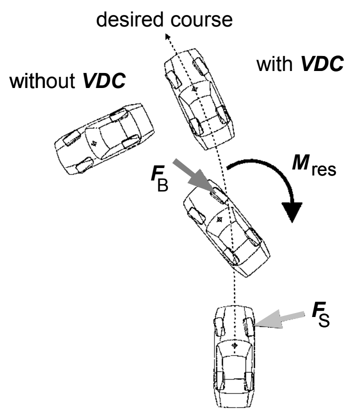


Fig. 9-18: Brake intervention for an oversteering vehicle

9.2.4.2 Limitation of the attitude angle

In addition to the yaw rate control, all modern systems include algorithms with the intention to limit the attitude-angle. The attitude angle is defined by the angle between the horizontal speed vector and the vehicles longitudinal axis. To substantiate the necessity of these algorithms, a cornering maneuver of a vehicle is described for different road-friction coefficients and for different control concepts, Fig. 9-19.

Curve (1) shows the course of the car in case of sufficient road friction. The remaining potential regarding lateral force transmission ensures an identical desired and actual course. In this case, the vehicle performs a steady state cornering according to the driver's intentions. If the road friction does not suffice for reaching the lateral acceleration as defined by the driving speed and the

steering angle, the vehicle will normally understeer and follow a greater corner radius (2).

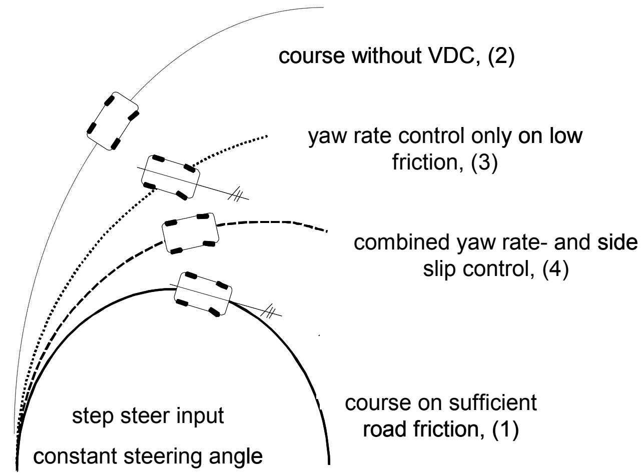


Fig. 9-19: Cornering on high and low friction coefficient road surfaces with different control concepts [VAN96a,b,c]

If the vehicle features a dynamics control system without a limitation of the attitude angle (3), this situation would be identified as a strong understeering tendency, causing the controller to initiate a brake intervention at the inner rear wheel. A suchlike intervention would correct the yaw rate but would also lead to a great attitude angle. Overall, the use of a yaw rate control only on low friction coefficient surfaces can generate instable driving conditions, if the driver does not react accordingly by decreasing the steering angle quickly enough.

Therefore a stable vehicle movement also requires a limitation of the attitude angle beside the yaw rate control. Using such a combined control systems, the vehicle will travel stable on a curve which represents the physical maximum regarding the lateral acceleration (4).

9.2.5 Structural Design of vehicle dynamics controllers

As described on the previous pages, the basic design of a vehicle dynamics control system consists of the three modules observation, identification and control. Modern systems, such as ESP, contain further elements, that shall be described here briefly.

Being a highly safety relevant system, a vehicle dynamics controller requires a sophisticated safety concept. All incoming sensor signals need to be made checked for plausibility and a deactivation concept has to be implemented to shut off the controller, if errors occur.

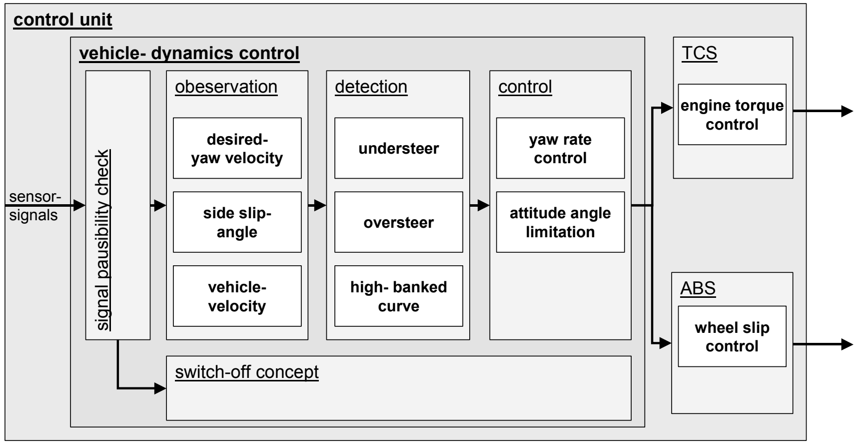


Fig. 9-20: Simplified structure / layout of a vehicle dynamics controller (ESP)

The signal plausibilisation monitors and provides the signals which are used by the different algorithms and functions. The following evaluation methods can be used for the monitoring of signals:

- Single-signal plausibilisation
- Redundancy-based plausibilisation
- Model-based plausibilisation

The signal plausibilisation provides a qualifier for each signal, which describes the state of the particular signal on the basis of the evaluation method used.

The information provided by the signal plausibilisation are evaluated by a deactivation concept. The controller is activated and deactivated according to this evaluation.

Two other subordinate controllers are working in coexistence with the vehicle dynamics controller. The engine controller adjusts the engine torque, whereas an enhanced ABS calculates a desired-slip value from the compensational yaw moment calculated by the VDC. This desired slip is generated by the “ABS-valves”.

9.2.6 Components

The vehicle dynamics control clearly exceeds the possibility of ABS or ABS/ASR-systems. It uses advanced components of ABS and ABS/ASR systems and affords highly dynamic active braking for all wheels. Usually the antilock system and the traction slip control (ABS and ASR) are subordinate to the actual vehicle dynamics controller.

The vehicle dynamics control system uses several sensors to evaluate the momentary driving condition, as shown in Fig. 9-21.

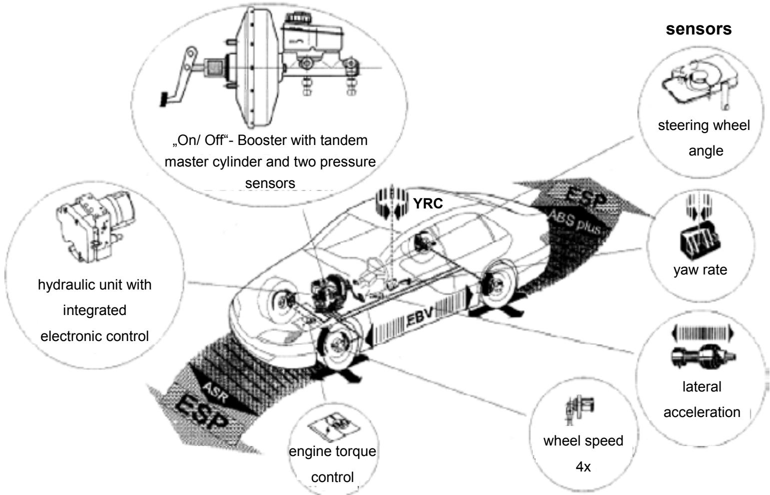


Fig. 9-21: Sensors used by the vehicle dynamics controller [FEN98]

Besides the acquisition of the wheel speeds and the steering angle, the yaw rate and the lateral acceleration of the vehicle are measured.

A hydraulic system is needed to generate brake interventions independently. For that purpose a storage pump is integrated into the hydraulic circuit, which is able to provide high brake pressures for each individual wheel with a very quick response time. The other components of the hydraulic system correspond essentially to a wheel-individually controlled ABS, since every wheel requires an independent brake-pressure control. Fig. 9-21 shows an example of an ESP hydraulic circuit:

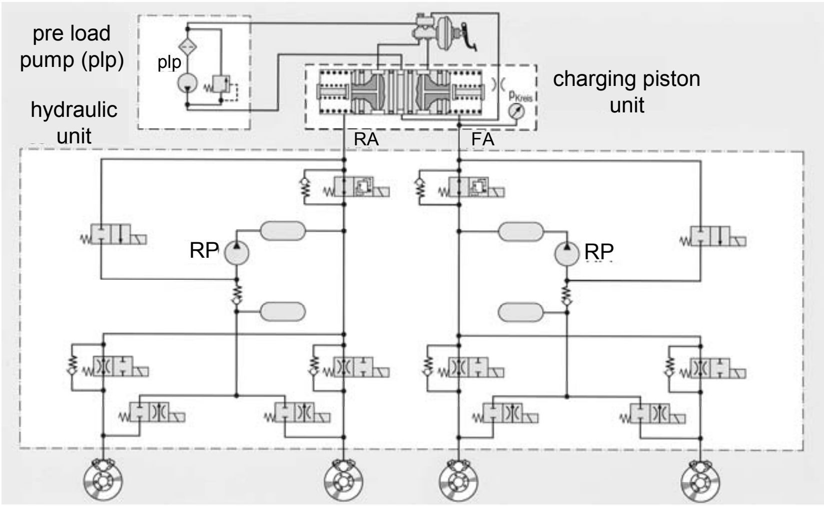


Fig. 9-22: ESP hydraulic circuit

In addition, the vehicle dynamics control system possesses an interface to the combustion-engine controller. Similar to the hydraulic system, the vehicle dynamics controller uses components of a subordinate traction control system (ASR) to control the engine torque.

9.2.7 Simulation Results with and without Vehicle Dynamics Control

In the following, simulation results with and without an active vehicle dynamics control system are shown. The driving maneuver used is a typical ISO-double-lane-change ("elk-test"), which was simulated using a numeric driver model.

As seen in the curves, the vehicle dynamics control system stabilizes the car using selective, wheel-individual brake interventions. Thereby the VDC-controlled vehicle maintains a stable state, whereas the uncontrolled reference-vehicle becomes instable at the end of the maneuver.

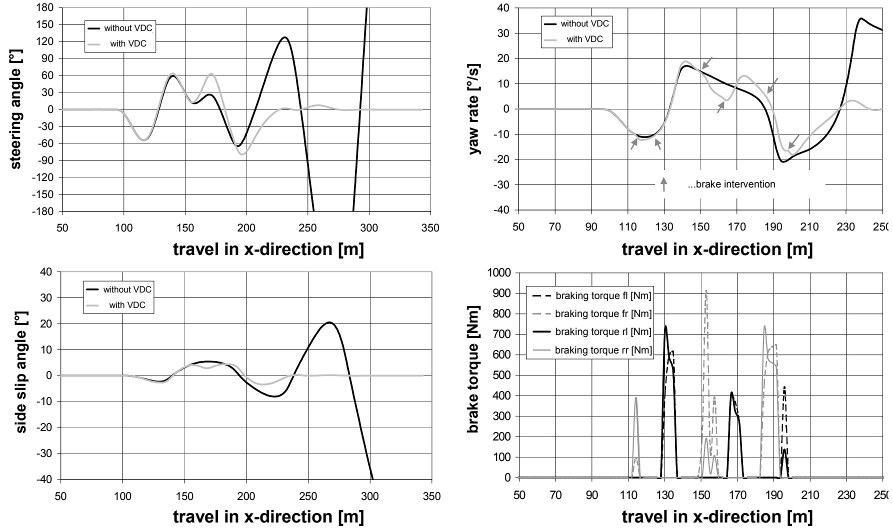


Fig. 9-23: ISO double-lane-change with and without vehicle dynamics controller

10 Biomechanics

Biomechanics means the description of the mechanical performance of the living body and its parts. A static and dynamic description of the analytical processes is made. Therefore biomechanics is called the connection of biology and applied mechanics in the science of engineering.

10.1 Functions of Biomechanics

With the knowledge of the extra-endangered parts of the body from the accident analysis, the function of the biomechanics is to determine the load capacity of these parts of the body and to find adequate protection procedures to proof the efficiency of safety measures at the vehicle. The development of the protective criteria is based on load limits which are defined by tests with animals and dead bodies. Criteria are e.g. fractured bones and organic impairments.

A real problem is the direct determination of the load limits, because volunteer tests can only give information on the consequences of low decelerations. Beside ethnic objections, tests with animals show no representative results because of the anatomical differences even between humans and apes. PMTO (postmortal test objects) can be used as well in tests with extreme decelerations, but the age and the impairment before the tests allow just unprecise conclusions for the performance of living bodies. The calculation of the load by evaluations of real accidents is only possible, if all accident parameters are known exactly. Deviation errors can lead to completely different decelerating behaviours and injury levels.

The strain of the body during the accident is divided into:

- strains, which can be suffered without or with reversible injuries and
- strains, which lead to irreversible or fatal injuries

The limits are determined and called injury criteria. Out of these, the protective criteria are defined by using a safety distance. They represent the limits of mechanical load figures (forces, accelerations), which are measurable and are not allowed to be exceeded. The determination of the legal safety criteria is based on biomechanical limiting values, but lies below these biomechanical load limits. So even for physically handicapped persons a chance of survival exists and a safety distance to the not exact diagnosable biomechanical limits is kept.

In the following section the anatomy of the single parts of the body, their injury mechanisms and the legally determined safety criteria are explained individually.

These criteria are generally defined for concrete dummy tests, to guarantee a good reproducibility of the tests.

10.2 Head

The most endangered part of the body in traffic accidents is the head. Because of the usage of airbag technologies the number of vehicle occupants with serious head injuries decreases strongly. At pedestrian accidents head injuries are still the most frequent cause of death. Life-threatening injuries mostly occur at skull and brain. The anatomical formation of the skull is described in Fig. 10-1.

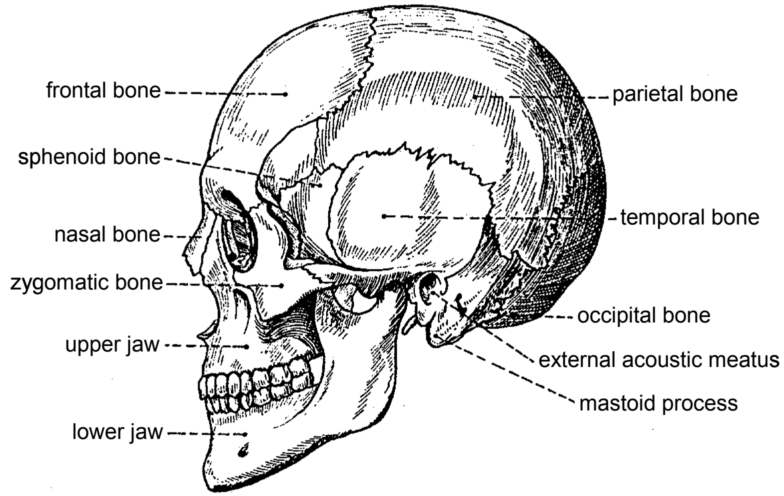


Fig. 10-1: Anatomical formation of the skull [KRA98]

The bone structure of the skull can be roughly divided into facial and skull (cranial) bones. These two areas are completely coalesced only at adults. Children do not have this connection, so that a relative movement between the bones can occur. This fact needs to be looked at closer in the case of biomechanics concerning children and adults.
The carnial meninx membrane is situated underneath the 4 to 7 mm thick carnial bone, which consists of several layers like the skin of the head does (cp. Fig. 10-2). Between the skin layers there is nutrient fluid, which in addition has a shock absorbing function concerning exterior vibrations. The brain itself consists of grey brain substance in the outer areas and white brain substance in the inner areas.

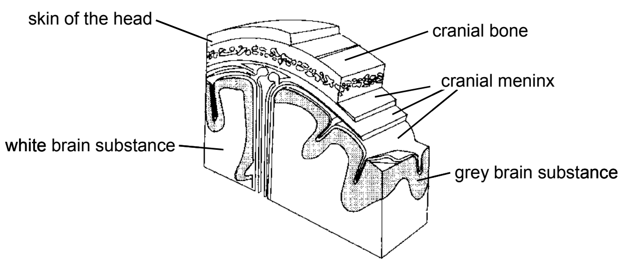


Fig. 10-2: Cross Section [KRA98]

10.2.1 Injury Mechanisms of the Head

The impact on hard structures of the passenger cell (passenger) or the outer skin (outer traffic member) of the vehicle is the most often reason for head injuries. With an increase of the injury severity lacerations and cuts, haematomas and skull bone fractions take place. Brain injuries nearly only happen together with skull bone fractures. The injury mechanisms for skull and brain injuries are shown in Fig. 10-3.

In the left side of the figure it is shown, that the direction of the fractures normally corresponds to the direction of the affecting force vector. The breaking point is reached at an deceleration of 80 g during a time period of not less than 80 ms. If this period gets clearly exceeded, comminute fractures of the skull bone occur very often.

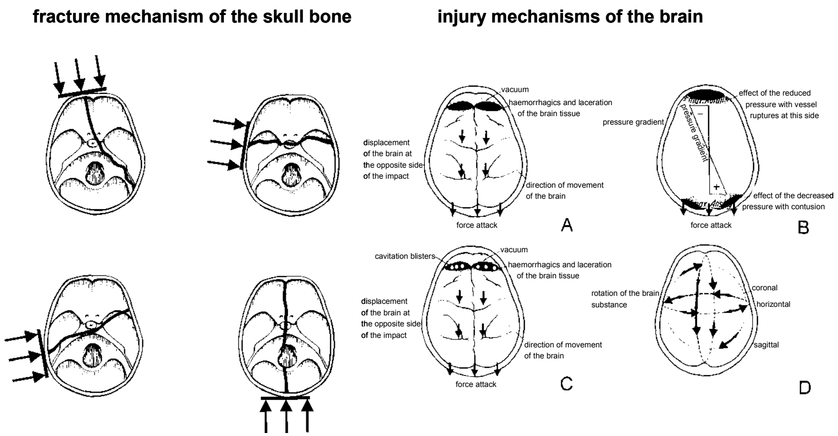


Fig. 10-3: Skull and brain injuries [PUD46]

The right side of the figure shows the injury mechanisms of brain injuries. In general the injury formation can be divided into the following four theories:

1. Impact/rebound (figure A): contusion injuries (injuries of the brain caused by crush in the exposure area). At the non impact side (centre-coup) brain injuries can be caused by vacuum.

2. Pressure gradient theory (figure B): Two areas of negative and positive pressure develop. The pressure dissipates from the impact pole to the rebound pole as a pressure gradient. So the pressure increases at the impact pole with the same amount as it decreases at the rebound pole. Contusions occur in the exposure area because of the overpressure, in the rebound area vessel ruptures are the consequences of the abrupt pressure drop.

3. Cavitation theory (figure C): Because of the vacuum on the rebound side a formation of blisters in the cerebral vessels occurs (pseudocavitation). As a consequence the cerebral vessels rupture.

4. rotation theory (figure D): If the impact is eccentric, the skull bone rotates with a certain angle. As a consequence the brain substances moves relative to the skull bone. So movements of adjacent brain areas as well as dislocations and destructions of vessels and tissues occur.

Brain injuries that happen frequently can be as well classified into four groups relating to their heaviness:

1. Unconsciousness: The injury severity and the appearing long-term consequences grow proportional with the duration of the unconsciousness.

2. Brain contusion: See above

3. Haematoma and interossei pressure increase (ICD): The occurring blood blister presses on the brain substance and causes brain dysfunction.

4. Diffuse Axonal Injury (DAI): (Injury of the brain by high pressure and shear forces): Major deformations and twists in the inner brain arise. These injury mechanisms can be followed by a complete collapse of the brain function.

10.2.2 Injury Criteria of the Brain

The anatomy of the head described above has a load capacity in dependence on the occurring accelerations which has to be considered for the definition of injury and safety criteria. The brain can sustain extremely high accelerations without the danger of remaining impairment for a very short duration; the continuous load capacity though amounts just about 40 g. In the so called Wayne-State-Curve this dependence is shown (Fig. 10-4).

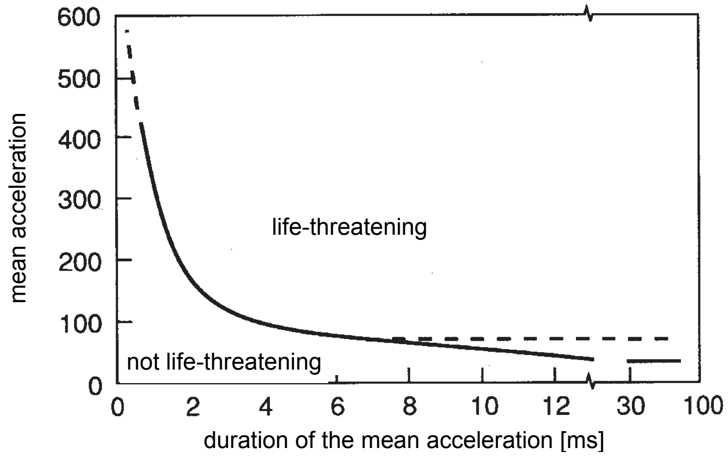


Fig. 10-4: Limiting values of the head (Wayne-State-Curve)

By using logarithmic axes this curve approximates a straight line with the gradient 2,5. Here from the injury criteria in form of the SI Severity Index, HIC (Head Injury Criterion) and HPC (Head Performance Criterion) are deduced. The two latter criteria are both calculated as shown in Eq. 3-1. The different nomination just results from different standards made by law.

$$HIC = HPC = \max\left\{\left[\frac{1}{(t_2 - t_1)} \cdot \int_{t_1}^{t_2} a(t)dt\right]^{2,5} \cdot (t_2 - t_1)\right\} \leq 1000 \qquad \text{Eq. 10-1}$$

t_2-t_1: time window in s from the beginning of the head contact for which the calculated figure becomes maximal

a: acceleration of the centre of gravity of the head, as a multiple of the gravitational acceleration g

For the calculation the resultant acceleration must be used as a multiple of the gravitational acceleration g. t_1 and t_2 define an optional time window in s from the beginning of the head contact for which the calculated figure becomes maximal. Thereby the time values have to be filled in s.

The legal limiting value is at HIC 1000. For motor vehicles today this figure is no big problem any longer, because well adjusted restraint systems provide figures clearly below 500. Apart from this parameter, the resultant head acceleration is limited to 80 g by law. Exceptions are short acceleration peaks, which are not allowed to exceed 3 ms.

The less common SI for evaluation of head and chest decelerations is calculated by

$$SI = \int_0^t a(t)^{2,5} dt . \qquad \text{Eq. 10-2}$$

The integration is made for the whole decelerating interval, so that the influence of single acceleration peaks is not that big.

10.3 Spinal Column

The spinal column (columna vertebralis) consists of many small vertebral bodies which are related to the above depicted regions. The vertebral bodies are ring-shaped bones through which the spinal cord runs. Between the single bodies there exists a jointed connection. The intervertebral disks serve as a cushion and thus as a vibration absorber. There emerge neural furcations out of the spinal cord which lead to the different body parts. A destruction of single nerve cords often occurs in connection with injuries in the area of the spinal column.

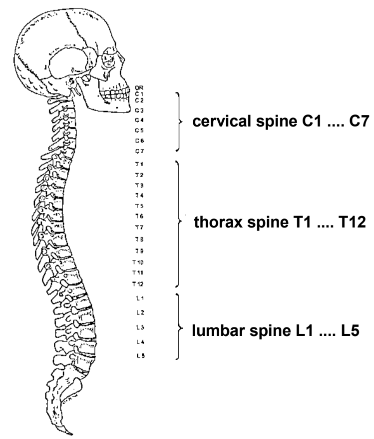


Fig. 10-5: Anatomy of the spinal column [KRA98]

The anatomy of the spinal column as well as its connection to the head is shown in Fig. 10-5. The medical terms of the single vertebral bodies result according to the segmentation of the spinal column into the parts cervical spine (C1-C7), thorax (T1-T12) and lumbar spine (L1-L5). The lower process consists of the five sacral bone vertebrae which adhere to the sacral bone and four to five rudimental and often coalesced coccyx vertebrae.

Because injuries of the cervical spine on the one hand play a decisive role in terms of traffic accident statistics and on the other hand show a complex mechanical behaviour, this part is described more detailed in Fig. 10-6.

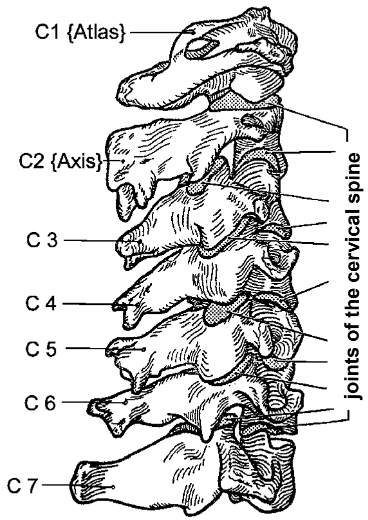


Fig. 10-6: Detailed view of the cervical spine [KRA98]

Three of the seven cervical vertebrae are named separately due to their special medical importance. The first vertebra (C1) is called Atlas, the second Axis (C2) and the seventh (C7) is called Vertebrae Prominens (projecting vertebra) due to its clearly palpable dorsal process.

The cervical spine carries and supports the head and guarantees the necessary movability. Furthermore it takes over an assisting function in the supply channel together with the neck musculature and the cervical musculature in order to connect the structures of the head with thorax and pelvis (air tube, gullet, main blood supply, spinal cord with vital nerve cords).

The movability of the cervical spine is limited by the structure of the joints between the vertebral bodies and the maximum possible dilation of connected muscles and ligaments. While rotations around the vertical axis are easily possible due to the anatomy of the collateral joint connections, other movements of the cervix are partly very restrained because of the joint-surrounding joint capsules. Furthermore there is the restrained possibility of compression of the intervertabel disks as well as the limited dilation of the ligaments.

Rotations of the head are made possible by the swivel joint between Atlas und Axis, nodding is realised by a movement between head and Atlas.

10.3.1 Injury Mechanisms of the Cervical Spine

The cervical spine is very vulnerable to injuries caused by dynamic loads, because it represents a relative weak connection between two body parts with each a high mass (head and torso). Due to affecting accelerations and with it occurring inertia effects, large forces appear in the muscles and ligaments that surround the vertebrae. If strong over expansions thereby happen, e.g. occurring at frontal or rear collisions (cp. Fig. 10-7), the flexion of the cervical spine can lead to splinter fractures of the vertebral bodies.

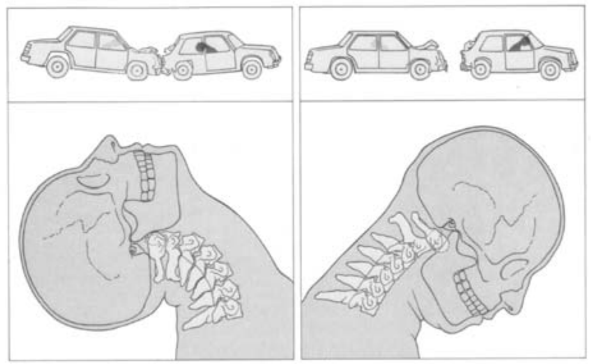


Fig. 10-7: Injury mechanisms of the cervical spine [KAL98]

The initiator for suchlike fractures is often the fact that the strong ligament connected to the spinal process tears away the slim part of the Atlas bow (C1). There from result the depicted injury forms shown in Fig. 10-8. Thereby it occurs either a bow fracture at the rear vertebra caused by shear/compression load (right) or a Jefferson-Fracture caused by pure compression load (4 fracture segments).

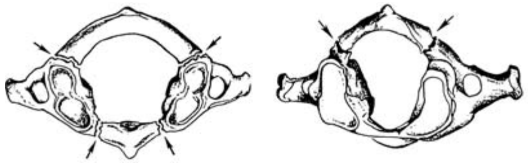


Fig. 10-8: Typical fractures of the cervical spine [KRA98]

Apart from the above described failure due to flexion and extension of the cervical spine, injuries caused by inclination and rotation as well as by axial relative movements between head and Atlas are distinguished between. The latter named form of injury is mostly imminent fatal and often occurs at a vehicle-pedestrian-accident. Exceeding rotations lead to massive ligament injuries in connection with massive vertebrae dislocations without nameable damages of the bones.

The rotation between Atlas and Axis happens around a spinous process of the vertebra belonging to the Axis (Dens). Fractures of the Dens mostly occur due to extreme forward displacements of the head relative to the cervical spine.

Severe injuries in the area of the spinal column are often combined with damages or divulsions of the out coming nerve cords, which lead from a failure of single body functions up to a paraplegia.

10.3.2 Limiting Values of the Cervical Spine

The limiting values for the area of the cervical spine for a frontal collision are summarised in the NIC (Neck-Injury-Criterion) by the European Enhanced Vehicle Committee (EEVC). Apart from the force characteristic depending on the exposure time of the load shown in Fig. 10-9, a maximum bending moment of 57 Nm is permitted for the area of the cervix.

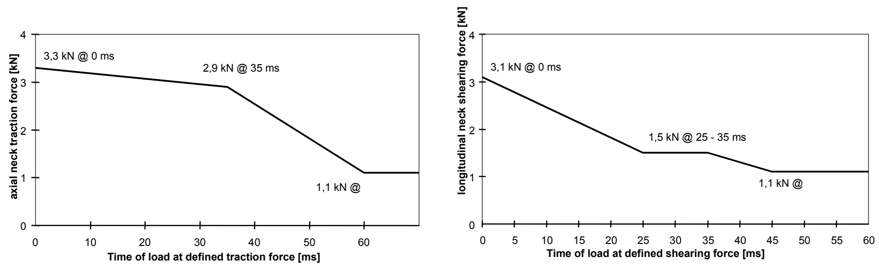


Fig. 10-9: Neck Injury Criterion (NIC)

The determination of injury criteria for the area of the neck at frontal collisions is not proven though, because today's vehicles are equipped with three-point seat belts and airbags and due to this neck injuries are rather seldom in real accident details [SEI97].

10.4 Thorax, Abdomen and Pelvic Region

Legal limiting values exist in these areas, in the context of this lecture bock though this chapter is not looked closer at

10.5 Lower Extremities

To vehicle passengers injuries are caused by the foot controls or by intrusion of the bulkhead. A special relevancy of leg injuries is noted in the case of pedestrian accidents. Injuries of the lower extremities normally occur at contact with the front end of the vehicle. From a sideways acting impact force, superposed by an additional axial torsion force in the leg area, a multitude of injuries can result. The mostly appearing kinds of injuries are bone fractures, knee injuries and ankle dislocations or ankle fractures. Fig. 10-10 illustrates a schematic depiction of the frequently appearing fractures at a lateral vehicle-pedestrian-collision. The impact on the vehicle's front and the following acceleration of the lower extremities of the pedestrian leads to a complex injury mechanism. The lateral shearing stress and bending stress of the lower extremities were recognised as essential injury reasons.

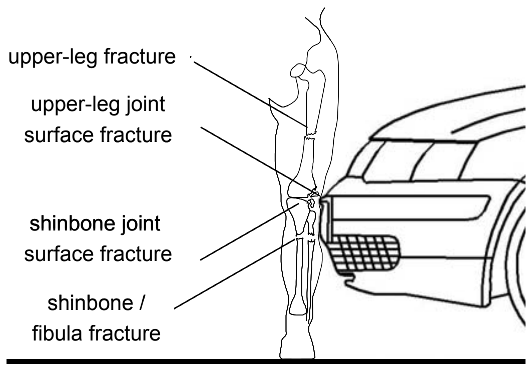


Fig. 10-10: Focal points of injuries in the area of the lower extremities

The bumper and the edge of the bonnet are the main reasons for fractures of the shinbone, calf bone and lower leg. The most injuries of the shinbone are caused by the bending moment, which occurs when the bumper catches the leg laterally. From the bending of the shinbone results a compression stress at the side of the force application and a tensile stress at the opposite side of the shinbone. The fracture of the shinbone is a result of inflated strains. This injury mechanism due to the bending can also lead to a fracture of the calf bone, whereat upper-leg fractures caused by the impact on the edge of the bonnet additionally emerge.

The resistance of the tubular bones has been investigated for different loading conditions. Upper-leg fractures appear at peaks of the impacting forces amounting 3-10 kN and a torque of approximately 320 Nm [KRE93]. Shinbone fractures emerge at impact forces of 2,5-8,0 kN [BUN83].

The knee injury normally results directly from the bumper impact as well as indirectly from the power flow through the joint of the knee. The reaction strains in the knee can be contemplated as a combination of a shearing force and a bending moment. The bending moment emerges due to a tensile stress in the area of the ligaments (crucial ligaments and inner/outer collateral ligaments) and a compression force, which acts on the contact surfaces of the joint connections in the area of the articular fossa, Fig. 10-11. When the leg is hit laterally in the height of the knee, the joint of the knee is subjected to a shearing dislocation of the joint surfaces by the delayed occuring movement of the upper leg. This shearing dislocation leads to an extension of the ligaments area in the knee and a concentration of the contact force between the joint bodies. The resistance of the knee towards this dislocation is in the first place dependent on the contact of the upper-leg bone with the joint surface of the head of the shinbone and the protuberance of the joint plateau.

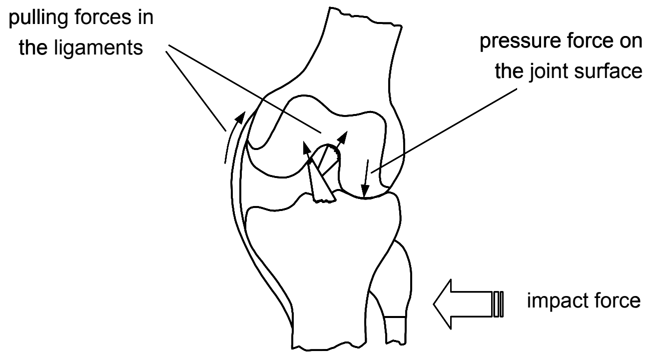


Fig. 10-11: Acting forces on the knee joint during the lateral impact

Because the musculature underlies an extension due to the pulling force, muscle-fibre ruptures can occur. The failure of the knee area is caused by the exceeding of the tear resistance of the ligaments on the tensile stress side and by exceeding of the pressure resistance of the bones on the pressure stress side.

The maximum bending moment is declared with 123±35 Nm [KAJ93] at a velocity of 20 km/h and with 331±79 Nm [KAJ97] at a velocity of 40 km/h. The limiting values of the shearing force amount 2,5±0,5 kN according to [KAJ99].

10.6 Assessment criteria of the injury severity

To allow the comparison of different injuries, characteristic numbers are used very often. Therefore all kind of injuries are categorised.

The most known characteristic number is the AIS (Abbreviated Injury Scale) where the weighting of the injury severity is made concerning the probability of survival. Remaining impairments of body functions and economical resultant costs are not regarded to.

Some examples of the classification by AIS are shown in Fig. 10-12. Dependent on the state of knowledge in medicine the classification of some injuries can be changed. (Example: Before liver rupture was AIS 6, because the soft liver tissue could not be stitched. Today it is just AIS 5, because the liver tissue can be cured by laser.) At the moment a revision of the AIS takes place every five years.

If several injuries occur the highest injury severity determines the maximal AIS (MAIS). The AIS chart just informs about the severity of one injury, interactions with additional damages of other parts of the body and their influence concerning the chance of survival are not regarded to.

The Injury Severity Score (ISS) is used to pay attention to those connections. Therefore the body is divided into several areas and the highest AIS figure from every area is determined. The ISS-figure is the result of the summation of the square of the three highest figures. The result of this calculation is the ISS-chart with figures from 0 to 75. By using statistical research limiting values for a chance of survival of 50% depending on the age of the injured persons is determined [BAK74].

AIS	injury	examples
0	none	
1	slightly	abrasion, cuts, contusion
2	moderately	deep flesh wound, brain concussion with unconsciousness less than 15 min., uncomplicated bone fractures
3	seriously, not life-threatening	crown fractions without brain injuries, spinal column dislocation underneath the fourth cervical vertebra without spinal marrow participation, loss of one eye, multiple rib fractures without paradoxic breathing
4	very serious, life-threatening, survival probable	brain contusion with or without crown fraction with unconsciousness less than 12 h, paradoxic breathing, bladder rupture, loss of one leg above the knee
5	very serious, survival unsure	spinal column fractions underneath the fourth cervical vertebra with spinal marrow participation, rupture of the intestine and the heart, unconsciousness longer than 12 h with bleeding into the inner brainpan
6	very serious or deadly, survival improbable	fractures of the cervical vertebra above the third cervical vertebra with spinal marrow participation, extra-heavy open injuries of chest and abdominal cavity
9		unknown injuries

Fig. 10-12: Classification of the injury severity by AIS

11 Pedestrian Protection

After the safety of vehicle passengers was noticeably improved by crash-optimised vehicle structures and improved restraint systems, since the beginning of the eighties also stronger efforts in the field of pedestrian protection are perceivable. Therefore at the optimisation of passive safety in modern vehicles, the importance of pedestrian safety gets increasingly relevant. The European Commission has recently passed an European law, which envisions the examination of pedestrian safety at new vehicles using a testing procedure with testing bodies such as heads, hips and legs.

11.1 Importance of Pedestrian Protection

In the last decades environmental aspects and the safety of traffic have more and more come to the fore due to an increasing number of vehicles on the roads. From these new focal points also again new difficulties result. For example, a frontal collision with a mini car, which can be considered as ideal regarding environmental aspects, states a problem of compatibility when crashing into a high class vehicle. Due to its lower mass and its significantly lower energy absorbing deformable zone, the survival chances of the mini car driver are clearly constricted without a specific safety construction of the vehicle.

Such kind of compatibility problems occur more and more often in the field of vehicle development due to a steadily growing traffic density and a growing number of vehicle designs. In Fig. 11-1 the injury risk for the different traffic participants is compared with their masses and weights in a qualitative way. Simplified, the following general statements can be revealed:

- the risk of injury falls with an increasing mass
- the higher the distance between the two collision partners, the higher the injury risk for the lighter and smaller collision partner

The pedestrian, as the weakest member in the chain of traffic participants, is affected in a special way by this problem. He is exposed to the impact nearly unprotected, because no really deformation areas for the absorption of energy exist. By that the risk for pedestrians of suffering severe or fatal injuries is extremely high, even in traffic accidents with low velocities. A purposeful vehicle concept for the protection of pedestrians is not easy to develop due to the considerable differences regarding size and stature in the pedestrian population.

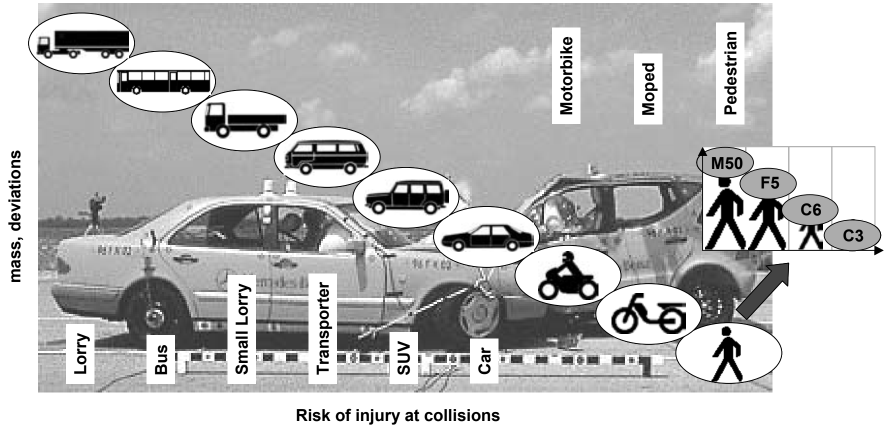


Fig. 11-1: Compatibility at collisions of different traffic participants

To analyse the pedestrian accident at first a detailed contemplation of long-term developments in the field of accident details is necessary. Fig. 11-2 shows that the number of killed and injured pedestrians in road traffic is strongly decreasing since the seventies. In the first place, the appearing reduction of the total accident numbers is caused by traffic-organisational measures and not by constructional developments of the vehicles themselves. These organisational measures are e.g. the installation of traffic-calmed areas and bypass roads, in order to reduce conflict points between pedestrians and other traffic participants [MAI99]. Furthermore, the developments of vehicle design and aerodynamics and the so resulting streamlined designs of the vehicles' fronts lead to a reduction of injury severity in case of pedestrian accidents in the contemplated period of time.

In statistics moreover it can be seen that about 90-95% of all pedestrian accidents happen in urban areas. Out of these collisions also 90-95% of all injured persons result. The share of killed people in urban areas is clearly lower with 65-70%. The injury severity and the number of killed pedestrians is as expected articulately higher in rural areas due to the occurring high collision velocities. There from it can be followed that apparently the velocity of the participating vehicle has the main influence on the injury severity of the involved pedestrian. It can be derived that for the layout of vehicle-side pedestrian protection structures velocities of 30-60 km/h can be classified as suitable, because most severe pedestrian accidents occur in this range and there are still good possibilities for an effective mitigation of accident after-effects given by measures from the field of passive safety. Exacter accident analyses show in fact that approximately 75 % of all vehicle/pedestrian

accidents occur at collision velocities of up to 40 km/h [OTT98]. At velocities of over 70 km/h there exist nearly no survival chances for pedestrians [BER97].

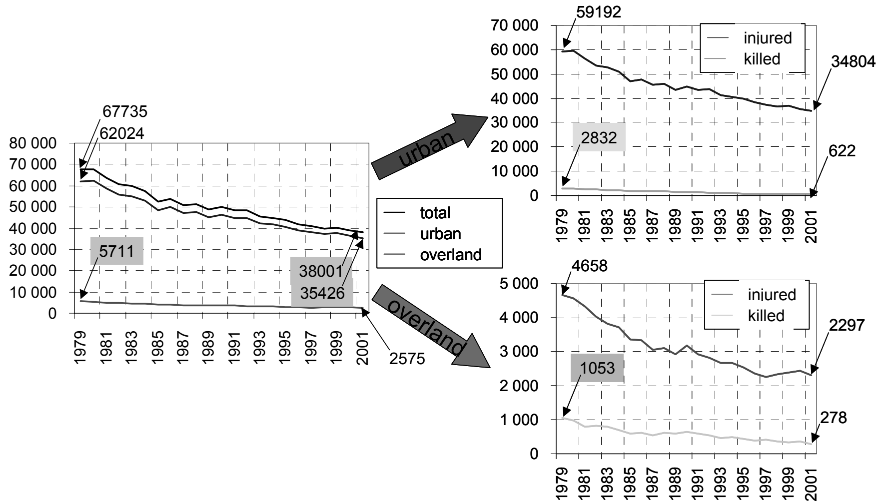


Fig. 11-2: Injured pedestrians/casualties in traffic accidents [STA02]

The potential of organisational measures is not inexhaustible, so that the amount of injured or killed pedestrians, at unvarying traffic density, will approach an invariable value in an asymptotic way. Thus there is further action needed to be taken in order to lower the injury severity of pedestrians by constructive measures concerning the vehicles. A vehicle-side, passive pedestrian protection though can only lead to a reduction of pedestrian loads in a limited way so that a simultaneous reduction of the collision velocity is necessary, e.g. by further development of active safety systems.

11.2 Accident Kinematics

The movement of the pedestrian when colliding with a vehicle can be divided into the three phases depicted in Fig. 11-3. When impacting on the vehicle, the body is accelerated nearly on the vehicle's speed by the primary bump. The thereby absorbed kinetic energy is successively relieved again in the further accident details:

1. Contact phase pedestrian-vehicle:

It occurs a direct contact between the accident vehicle and especially the lower extremities of the pedestrian. At the so called first contact, the contact between knee and bumper, the main impact mostly happens underneath the body's centre of gravity. By that an angular moment is exercised on the body which leads to an impact of the torso onto the bonnet and the impact of the head onto the bonnet or the windscreen. Amount and direction of the angular moment though are strongly dependent on the pairing of the geometry. A higher vehicle front can also lead to a rotation of the pedestrian away from the vehicle.

2. Contact phase pedestrian-vehicle or flying phase:

   In regular this is the phase in which the pedestrian moves away from the vehicle or again impacts on the bonnet of the vehicle with the upper extremities or thorax and shoulder. The flight path of the body is strongly influenced by the velocity of the collision. The now following flying phase of the pedestrian ends with the secondary impact onto the accident environment.

3. Contact phase pedestrian-road, resp. slipping phase:

   At the impact on the road or the environment of the road multiple injuries of the head, spinal column, chest, thorax and extremities are possible. The impact is followed by the slipping phase which lasts until the body comes to stop.

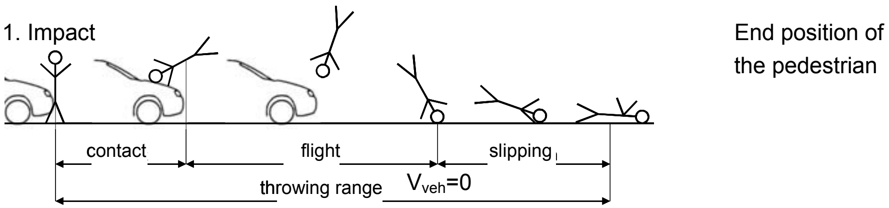


Fig. 11-3: Classification of the accident phases [KÜL80]

When evaluating the pedestrian accident in terms of accident research and the analysis of real collisions, it can not always be assigned which injuries of the pedestrian result from which accident phases. At the moment discussions between experts take place, in which it is talked about how much the injury severity of pedestrians can be lowered by constructional measures of the vehicle front. A reduction of appearing injuries in the third phase though is not to be expected by such modifications.

Especially in the first phase of the collision the occurring kinematics is substantially dependent on the outer shape of the involved vehicle. Furthermore it is useful to contemplate the outer shape of the vehicle in combination with the body size and the proportions of the pedestrian. For a description of kinematics a distribution in various categories depending on the position of the main impact point of the pedestrian and the relation between front-end height and pedestrian size is reasonable, Fig. 11-4.

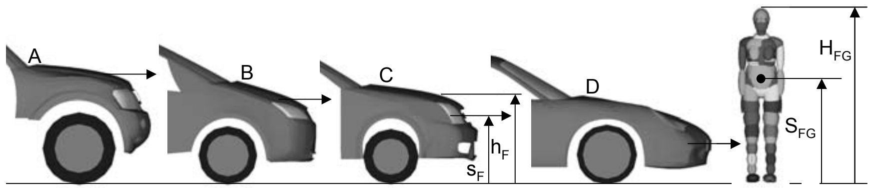


Fig. 11-4: Geometry pairing and impact point positions at pedestrian impact [KÜL80]

11.3 Injury Severity

An evaluation of the occurring injury severity is visually possible by a classification of the accident details in different kinematical groups of which the definition is made by the appearing impact areas of the vehicle, Fig. 11-5. For a judgement of the accident severity it is differentiated between moderately severe up to severe and life-threatening injuries.

At collisions that are assigned to the kinematical group 1, only an impact at the frontal area of the vehicle occurs. From this leg injuries result, which lead to high subsequent injury costs but are regularly not life-threatening.

A categorisation in group 2 follows, when the first impact takes place in the area of the vehicle front and a second impact occurs on the bonnet. Collisions at which a rotation of the pedestrian around the frontal edge of the bonnet takes place due to high collision velocities belong into this group. The upper leg and hip area is strained. Because especially hip injuries are mostly combined with large blood losses, these injuries often are life-threatening.

The further constellations according to the present classification are combined with a head impact of the pedestrian, which mostly causes severe injuries of the pedestrian.

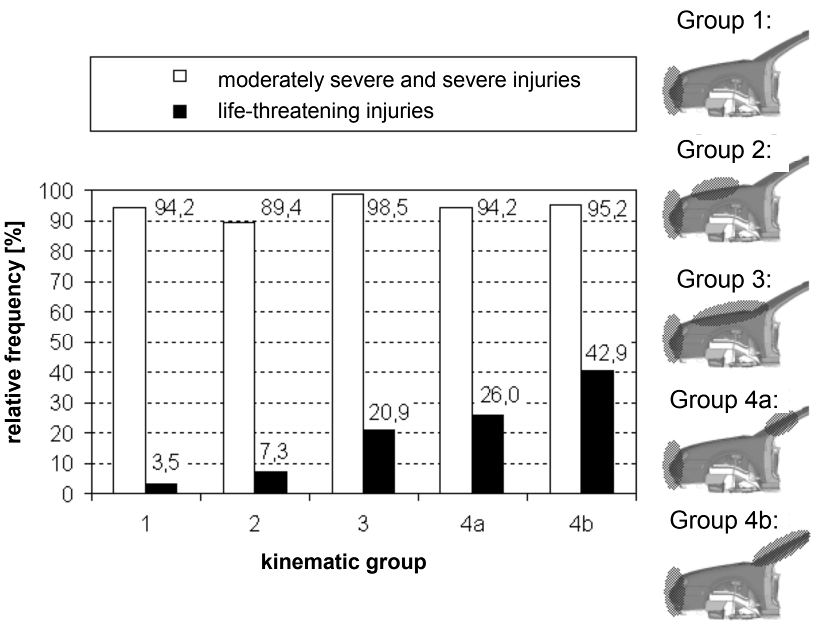


Fig. 11-5: Injury severity at different kinematic groups [LAN03]

At kinematical group 3 it occurs a further impact onto the bonnet or in the transient zone of the windscreen after the first crash in the area of the vehicle front, while in group 4 the second impact point lies exclusively in the field of the windscreen. Thereby it is further differed between an impact onto the windscreen glass (4a) or onto the windscreen frame (A-pillar, 4b). In case of an impact onto the frame of the roof mostly very high collision velocities are present, which in combination with the rigid structure of the impact area lead to a large number of life-threatening injuries. When contemplating the moderately severe and severe injuries it can be generally seen, that these injuries appear at almost all versions

11.4 EU-Guideline

Various suggestions from different sides have been presented in the last years regarding the discussion for a useful testing method for vehicle fronts. Some approaches base on the accomplishment of computer simulations with detailed models of the pedestrian and the to be evaluated vehicle as well as on experimental tests with pedestrian dummys [KRA02]. Due to the many to be

expected problems, e.g. regarding inspection costs and certification of calculating models and simulation software, these suggestions were not able to be realised. On the one hand, the numerical simulation with detailed models would be to time-consuming, on the other hand experimental tests with dummy technology would be too cost-intensive. The established testing procedure of the European Commission (EC) is based therefore on component tests with sub-systems for the body parts head, upper-leg and leg which are used for investigation of the vehicles, Fig. 11-6.

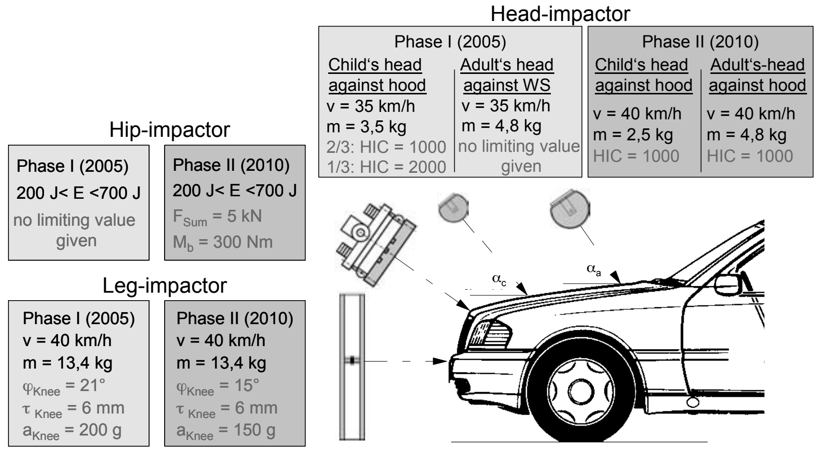


Fig. 11-6: Requirements of the European guideline for pedestrian protection

The definition of testing bodies and boundary conditions is based on a collision, in which a pedestrian that crosses the street, coming from the left or from the right, is thereby laterally hit by a vehicle. The testing bodies are shot onto the vehicle's front and muss comply with defined load limiting values during the crash. By doing so, the energy absorption behaviour of the vehicle fronts at pedestrian accidents can be evaluated in a qualitive way. Especially due to the very good reproducibility of the results this procedure is widely considered as useful. The choice of the testing points that are hit by the impactor is determined by the position of the critical areas, at which components of package are positioned that form so called hard points at which no further deformation is possible. This is the case at e.g. the engine block or the top of the spring leg (comp. Fig. 11-7). The different sectors for adult's head, child's head and hip are defined in the testing routine and lead to conflicts of aims in terms of optimisation of the front structure due to the different requirements.

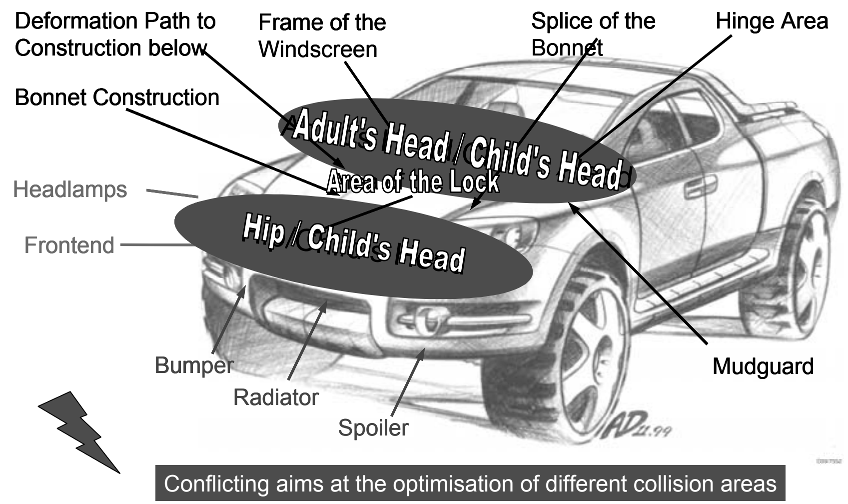


Fig. 11-7: Critical impact areas and concerned components

The introduction of the law shall occur in two steps in 2005 and 2010, whereby the demands will be intensified during this time. In the first phase the limitation of loads is restricted on tests with head and leg impactors. Additionally monitoring tests with the hip and the adult head impactor against windscreens are executed. In the second phase binding limiting values for the tests with all the three testing objects are initiated. The verification of the efficiency of the implemented methods for the pedestrian protection of the respective vehicles takes place at test benches for tests with head, leg and hip impactors. Fig. 11-8 shows an impacting piston test bench for researches on head impacts on engine bonnet and windscreen. Active and passive pedestrian protection systems can be evaluated thereby and different testing procedures can be developed, evaluated and reengineered.

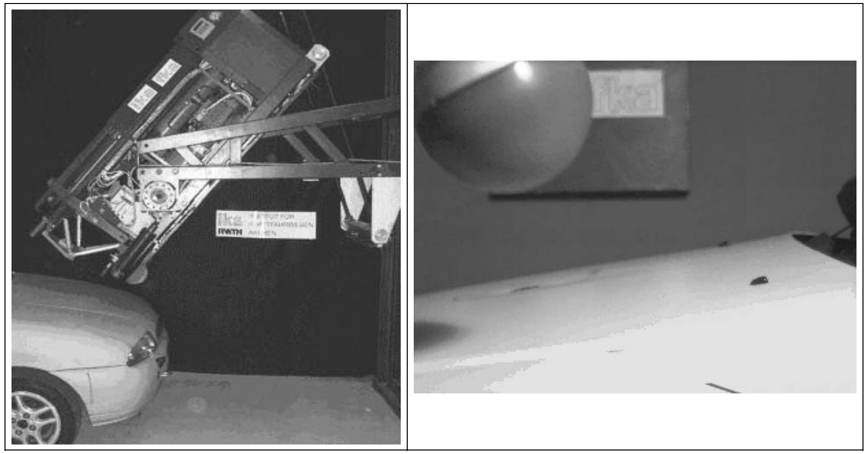


Fig. 11-8: Impacting piston test bench

11.5 Constructive Possible Solutions

Currently discussed pedestrian protection systems can be divided in active and passive solutions. For the passive optimisation, an improvement of the impact behaviour is aspired by profound modifications of the package. At active systems, the enlargement of the deformation distance or the airbag activation follows by actuator technology, which is activated by corresponding sensors. Sensor problems ("Pre Crash") currently prevent the application of active systems in the impact area of legs and hip, so that active measures are just conceivable in the area of the head impact. The combination of active and passive measures is imaginable, too, whereby a passive optimisation of the structures is indispensable also for the application of active systems (e.g. bonnet raising mechanisms).

The prevention of geometrical incompatibilities, for example because of protruding or sharp edges, is nowadays almost nationwide realised at modern vehicles. Therefore the basis of a further improvement of the pedestrian friendly vehicle construction has to be seen at the range of the passive security, fundamentally in a purposeful constructed zone of deformation. Thereby the absorption of energy occurs at force levels which are bearable for all of the impacting parts of the body.

Because of the impact areas defined in the testing procedure the optimisation of the head impact is concentrated on the engine bonnet at many common vehicles. The lateral bonnet gaps and the assembly points of the bonnet are especially critical. The rear end of the bonnet is not regarded in the actual testing procedure.

The passive optimisation of the bonnet structure is shown as an example in Fig. 11-9 by using computer aided topographical optimisation. Basing on pretended loads, this program can derive a design proposal for an optimised strut arrangement. By application of the optimising tool a slim construction of the inner panel ribs at a maximum of bonnet stiffness can be achieved. Thereby the critical points for head impact with their high stiffness in the range of the ribs can be improved clearly. Basing on the results of the computer optimisation, at first different rib build-ups are designed. An avoidance of crossings and a regular distribution all over the bonnet are aspired. After choosing one version, the optimised rib structure is implemented in the FE-model.

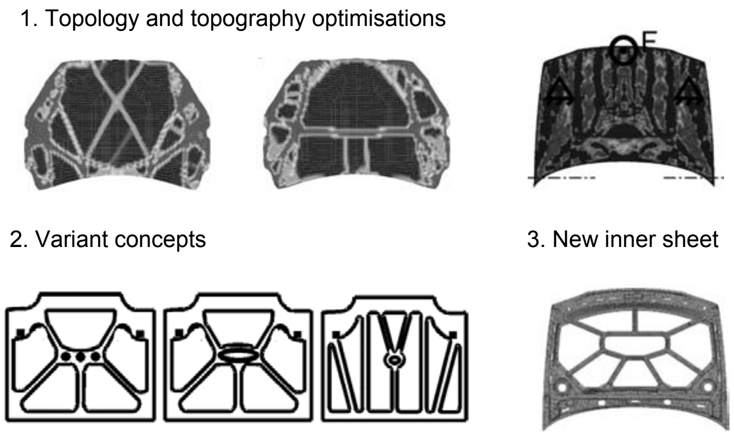


Fig. 11-9: Passive optimisation of the bonnet structure

Nevertheless, a reduction of torsional and bending stiffness of the engine bonnet often can not be avoided. Thereby an individual evaluation of each vehicle is required, regarding how weak a structure can be.

As further fatal problems in this content the assembly points of the bonnet and the package of the front end have to be seen. Because the available space in the engine bay is decreased anyway by bigger and additional aggregates for example, especially at high-motorised vehicles it is difficult to provide the required free space for the absorption of energy at the pedestrian impact. Fig. 11-10 shows by example the impact scenario and a possible constructive intervention at the modification of the hinge by a shear bolt.

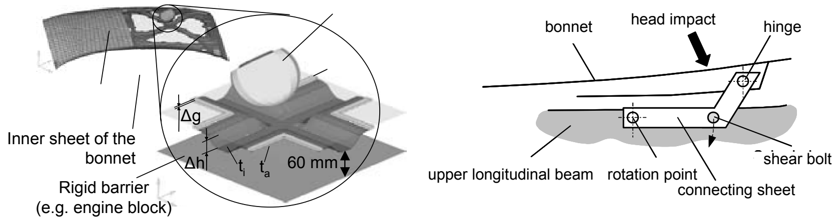


Fig. 11-10: Passive optimisation of the engine bonnet

As an example for an active solution in the head impact area the active bonnet raising mechanism has to be mentioned (comp. Fig. 11-11), by which the distance between bonnet and engine can be increased. The detection of the pedestrian follows by a pre-crash-sensor.

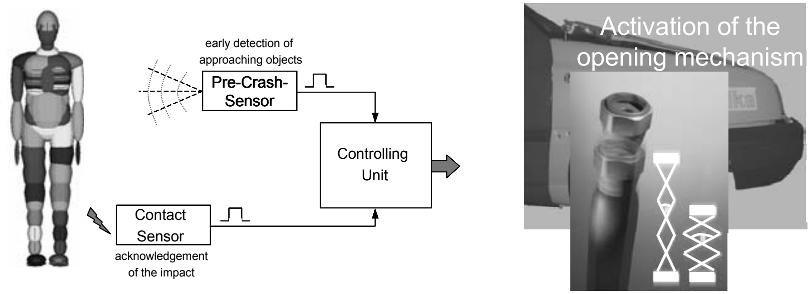


Fig. 11-11: Active bonnet raising mechanism

After the real impact of the pedestrian is certificated by a contact sensor, the clap is activated by a spring mechanism or a pneumatic actuator for example. The rotation point of the bonnet is near to the bonnet lock, whereby the raising exhibits its maximum gain of deformation distance at the cowl panel.

By regarding the development of the vehicle population (comp. Fig. 11-12) it has to be diagnosed that head injuries still play an important role concerning frequency and intensity. Because of the changed kinematics at the pedestrian accident due to the modern vehicle design the area of the A-pillar and of the windscreen play a more and more important role. The upper leg and hip injuries clearly decreased admittedly due to a changed vehicle design. Statistics demonstrate that the hip impact is not relevant anymore for modern passenger cars with aerodynamic design.

1975 **heute**

Fig. 11-12: Development of the vehicle population

The frequency and intensity of lower leg- and knee injuries still has to be evaluated as high, the relevance on accident details is given furthermore. The economic damage by knee and knuckle injuries is moreover high and justifies thereby intensive activities concerning the leg impact.

In the area of the leg impact, actually just passive systems can be regarded because of sensor problems. For the impingement of the leg impactor, a maximum tibia acceleration of 150 g is pre-determined in phase 2 of the European guideline. The bending of the knee elements is not allowed to exceed 15 degrees and the shear distance is limited to 6 mm. Fig. 11-13 shows a principle of solution and the varying parameters.

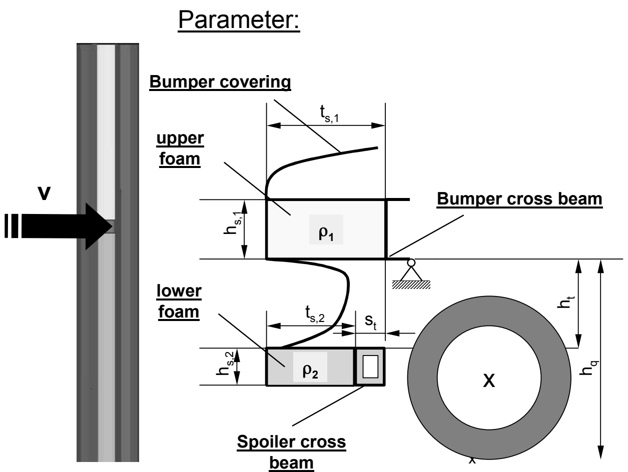


Fig. 11-13: Principle of solution in the area of the leg impact

For keeping the determined limiting values the application of polymer foams for defined energy absorption is conceivable. Often EPP- or PUR foams with densities between 30 g/l and 75 g/l are employed, which are already used in bumper systems of other series vehicles. The resulting buckling stress at the deformation of these foams is between 0.1 and 1 MPa at bucklings of 10 to 80 %.

11.6 Foresighted Pedestrian Protection

If the risk of a vehicle-pedestrian collision exists, an intervention in the vehicle control is possible by so called active security systems. Such collision avoidance systems (Fig. 11-14) shall avoid the contact with pedestrians or at least decrease the impact speed by an active intervention in the vehicle dynamics, and thereby prevent the accident consequences.

A fundamental aim at the development of pre-crash systems is to identify suitable indicators for a possibly imminent collision. Furthermore, an aimed activation of the active security systems in the areas of leg, hip and head impact can follow due to the pre-crash information.

Fig. 11-14: Detection of the pedestrian by collision avoidance systems

Therefore experimental analyses at the three levels sensor-, system- and user test are necessary. Tests on level 1 supply data concerning the reliability of the used sensor system. Nearby the exactness of the delivered information (e.g. distances, velocities etc.), statements concerning the rate of detection can also be made. Level 2 and 3 evaluate the capacity of the system due to its functionality, whereby the third level especially includes the user into the test. For the implementation of the tests, definite, reproducible and realistic testing conditions are required.

They can reproduce the accident details on cut off test courses, in testing equipments or even in the real traffic. An example of the section testing is the testing configuration for analysing different sensor data on crash facilities (e.g. point acquisition in proximity at fast changes of movement, distance characteristics or relative velocity), shown below (Fig. 11-15). By using a flexible employable deceleration device different deceleration characteristics can be realised. The testing configuration allows to approach the object high-dynamically to the still-standing barrier to a distance of 0.5 m and with a defined deceleration (60-0 km/h < 1 m). A damage of the used sensor systems is not possible.

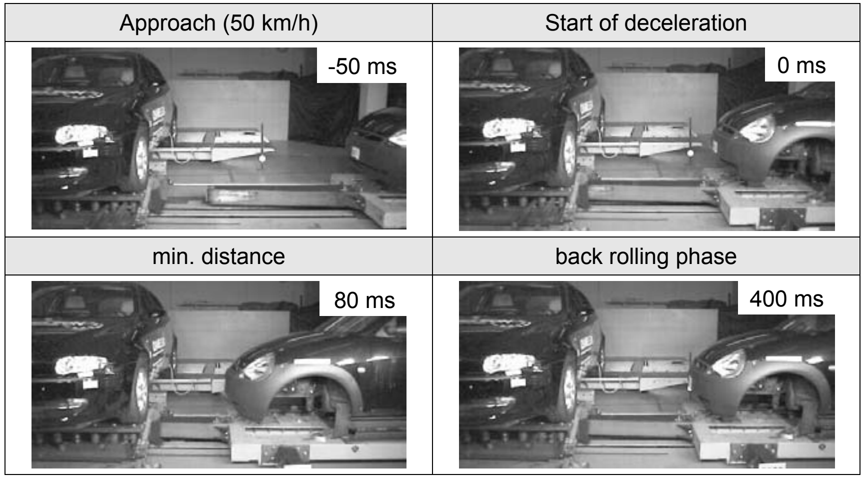


Fig. 11-15: Testing of sensor systems

12 Passenger Protection Systems / Restraint Systems

A favourable configuration of the vehicle structure is not sufficient enough to ensure passenger survival in case of an accident. Unsecured passengers are not subjected to impact on the interior parts during vehicle deceleration and thereafter are exposed to very high accelerations. Restraint systems (RS) provide for a linking of the passenger to the vehicle deceleration and thus for bearable, survivable loads. Fig. 12-1 clarifies the differences in the movement of unsecured and secured passengers at a simplified model.

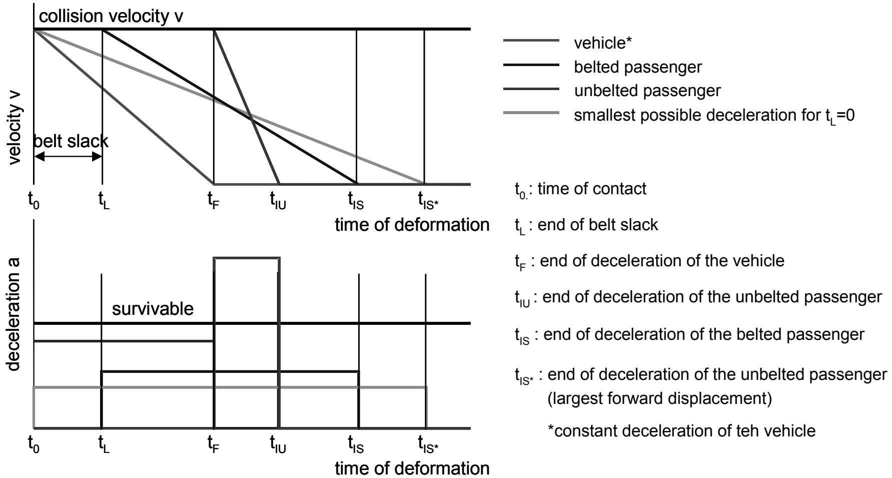


Fig. 12-1: Motion Behaviour of Vehicle and Passenger at Frontal Impact

At start of collision (t_0), the vehicle in this model would be decelerated with constant deceleration till standstill (t_F) and a maximum deformation of s_F.

Until the response of the restraint system with t_L, the secured passenger first moves forwards with unreduced initial velocity v_0. From this results a relative movement to the vehicle of 50 to 80 mm (so called belt slack). Subsequently, the middle passenger deceleration is smaller than the deceleration of the vehicle, so that the driver and front seat passengers can use the available free forward displacement space (approx. 450 mm). The passenger forward displacement is therefore defined as the difference between the maximum deformation of the vehicle and the maximum movement of the driver or front seat passenger (s_{IS} - s_F).

In contrast the unsecured passengers move forward with unreduced initial velocity v_0 of the vehicle, until they meet at a very late time point t_H at an obstacle, e.g. the steering wheel, instrument panel or windshield. Since these components are substantially more rigid than the restraint systems and deform less strongly, unsecured passengers are retarded in a very short time up to standstill; the passenger load substantially decreases faster than with the secured passengers.

A restraint system without belt slack represents the ideal case, which uses the entire available forward displacement. Thereby results the minimum possible passenger load.

Summarized below are the demands of a restraint system:

- early binding of the passenger to the cell deceleration, i.e. small belt slack
- optimal utilization of the available forward displacement
- lower wide area restraint forces affecting the passenger
- adherence to the permissible biomechanical limit values
- comfortable operation regarding high acceptance

In regard to the restraint systems, one differentiates between active systems, which must be applied by the driver himself and passive systems with which the passenger is protected without self-manipulation (Fig. 12-2). All systems hold the passengers back in the area of the head, thorax, pelvis and knee thigh.

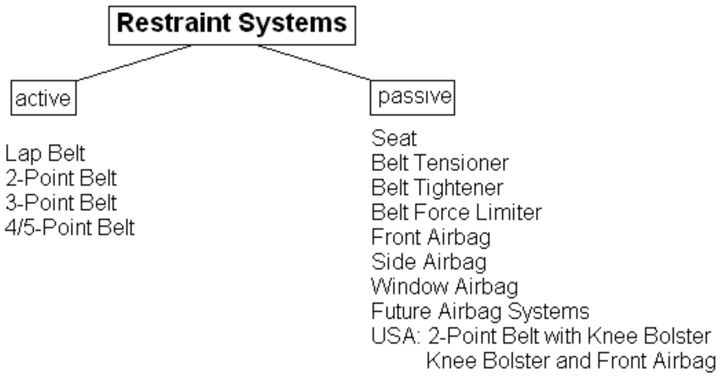


Fig. 12-2: Classification of Restraint Systems

12.1.1 Vehicle Seats

Vehicle seats provide the connection between the vehicle and the passenger. Its tasks apart from an ergonomic, comfortable and fatigue-free positioning of the passenger in the vehicle also exist in the binding of the passenger to the structure, for load transmission in case of an accident. With the help of flexible upholstery, a wider contact area to the passenger is established. Thereby also loads in thighs and pelvis can be introduced by forming out a seat ramp in the transverse direction (Fig. 12-3).

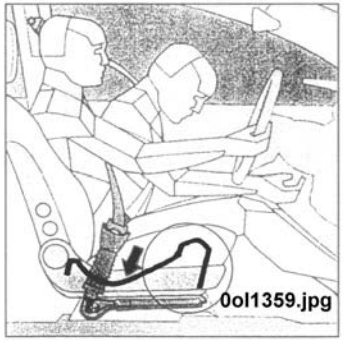


Fig. 12-3: Representation of a Seat Ramp

In combination with a belt, this part of the passenger movement can be acquired by the deformation of the upholstered seats, and sub-marining, slipping through of the passengers under the belt can be successfully prevented.

In America, in regard to this background knowledge, investigations with actuator seats were made which actively or passively moved upwards and with small biomechanical loads held back the passenger with a lap belt by one tiltable seat face into the embryo position. Due to the necessary place for a tiltable seat, a realization of this system in the passenger car is questionable.

But also different developments try to integrate the seat more strongly into the restraint system. One example is the adjustment of the lower belt coupling point at the front seats is mandatory. With Cabrios or Sport Coupes without B or C-pillars, so called integral seats are used frequently, with which also the upper belt coupling point and the buckle and retractor mechanics are integrated into the seat structure. An optimal belt guidance, independent of the figure of the passenger, is thereby guaranteed. This construction requires a particularly sturdy seat framework, since the deceleration of the passenger is fully affected by the seat. Fig. 12-4 shows an integral driver's seat.

Fig. 12-4: Integral Seat (DC)

Besides an optimised belt guidance the integral seat offers further safety advantages:

- improved lateral restraint of the torso during side collisions
- improved support function in case of turnover
- head restraint function coupled at shoulder belt adjustment
- smaller belt stretch and smaller film reeling effect of the rolled up belt due to the overall shorter belt
- increased transverse rigidity of the vehicle during side impact by basic seat framework

Also under the aspect of arising comfort as a result of the use of integral seats due to some improvements:

- high buckling up comfort by optimal accessibility
- ideal belt stretcher comfort by gentle looping without slip
- increased entering and leaving comfort into the rear with two-door passenger car - increased adjustment comfort in the seat, because of no relative movements between the belt and the passenger during seat

adjustment in buckled conditiondisadvantages are the increasing costs and high weight of such an integral seat.

A further integration of the seat into the restraint system is possible by the rear seated integrated child seats - new future developments will be weight reduction (basic version: 11-12 kg, seats with electrical adjustment: max. 18 kg), sensor mats for passenger recognition, integrated belt systems as well as among other things electrically adjustable head impressed restraints.

An additional protection with rear end collisions is offered by an Anti-Whiplash seat (Fig. 12-5), which reduces the long-term movements of the neck spinal column injuries (NSC injuries) for the front passenger. Here the back seat adjustment mechanism consists of a template transmission with integrated deformation element. In case of severe rear end collisions, first a pin is cut and afterwards the deformation element is deformed by the absorption of energy. This causes a rotation of the backrest at the start of a parallel backward motion, thereafter rotation over up to 25 °.

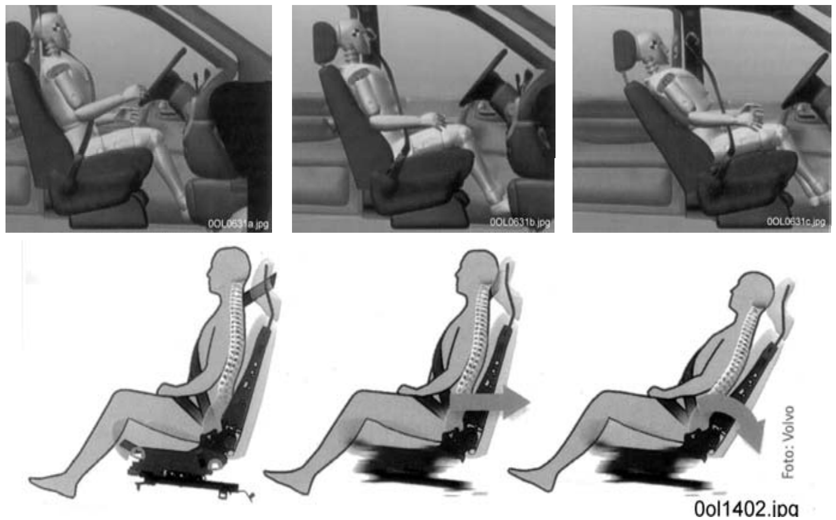


Fig. 12-5: Anti-Whiplash-Seat (Volvo)

With still increasing load, nevertheless a stable support function is guaranteed. A similar function is possible by the installation of energy absorbing deformation elements at the seat track. A deformation sheet metal between seat track and floor and/or seat framework is installed, which is deformed during a rear end collision controlled from the seat till energy absorption.

12.1.2 Head Protection

Direct height adjustable fastened to the vehicle's seat are the head restraints. They became generally accepted despite an marginal obstruction of vision for the driver even on the rear seats. With the use of these, an inadmissibly high pitch head angle to the rear, in case of accidents, can be avoided by correct positioning. Fig. 12-6 documents this effect of head restraints on the basis of crash tests with and without head restraints. The neck angle increases substantially without suitable support for the back of the head. For comfort reasons, the head, in case of normal driving, does not rest against the head restraint.

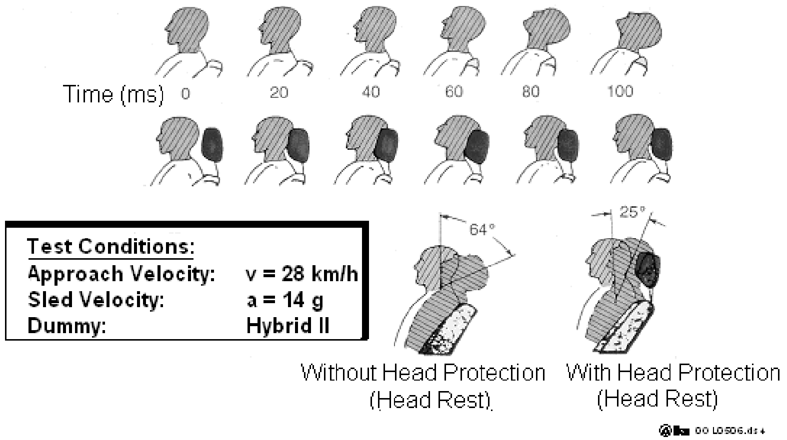


Fig. 12-6: Influence of head restraints on the movement behaviour of the head

According to a Swedish study from 1970 to 1990, the number of the NSC-injuries doubled, scarcely 50 % of all expenditures within the range "Personal Injuries", refer to this cause. For a further reduction of the spinal column load, active head restraint systems are used which intercept the head more effectively and more promptly.

A mechanically realized system of SAAB works in cooperation with the Anti-Whiplash seat and a head restraint spring-tensioned link before the crash. Released in case of a crash is the support of a bowden cable coupled with the deformation element at the back's seat verse plate, so that it is moved rapidly upwards and towards the head, with the goal that the distance from the head up to the head restraint is kept as small as possible (Fig. 12-7). A system of Volvo uses a split air cushion in the head restraint and in the backrest (preferably for rear passengers). In case of an impact of the body, the high pressure in the lower chamber opens a valve between both chambers so that air can flow into the

chamber in the head restraint. Thus an indulgence and an early activation of the head restraint can be made possible for the back seat and also at the same time to the head of the passenger. The airbag in the head restraint stabilizes the head and avoids a NSC trauma.

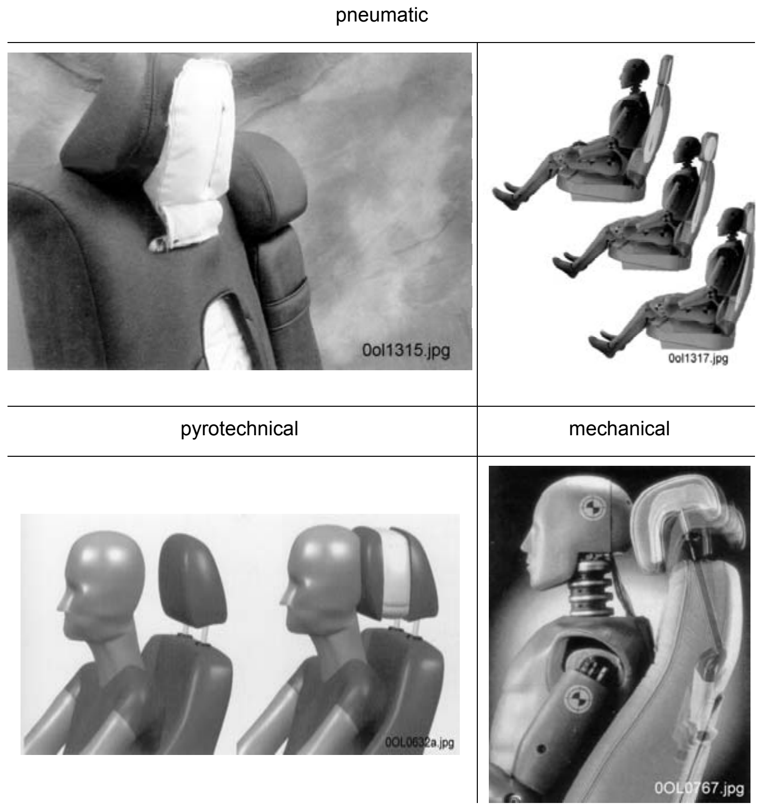


Fig. 12-7: Active Head Protection Systems

Apart from a pneumatic function mode there also exists the possibility of reducing the distance between the head and the support with the help of a firing device or further by means of a mechanical mechanism. This shifts the head restraint forward if defined imprinting of the backrest takes place.

Fig. 12-8 describes the principle construction of pyrotechnical head protection system. In the basic housing of the support, a so-called "Snap-in-housing" is positioned that functions as the receiver different components as the generator, airbag and finally the frontal pad.

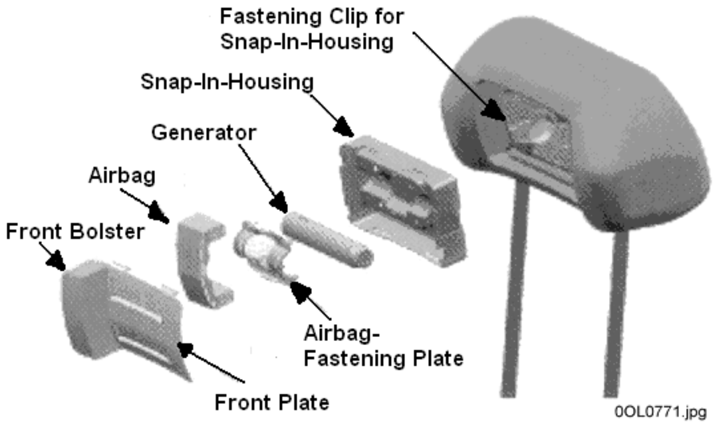


Fig. 12-8: Construction of a Pyrotechnical Head Protection System

12.1.3 Belt Restraint Systems

Today the basis of each restraint system is a three-point retractor belt with a width of about 10 cm that holds back the torso and the pelvis. On the tunnel side, the belt runs a locking part, which is usually fastened to the seat in the centre of the vehicle. On the opposite side, the belt is led over the B-column with a fastened return fitting into the retractor. The belt length amounts to approx. 2300 mm and can stretch up to 8 % under load.

Lap belts are used only on the middle rear seat banks in passenger car or in busses, since the upper coupling point here is missing. They hold back, as the name says, only the pelvis and are used as static and inertial retractor belts.

4-, 5- and 6-point belts due to their firm adjustment of the passenger at the seat and the restrained carrying and applied comfort are thereby only used in racing applications. With minimum belt slack, the passenger here follows the deceleration of the vehicle without using the possibility of free forward displacement.

In the USA, some belts with kneepads were installed rather than the passive belt systems. Here, the upper belt coupling point was fastened to the door so that the passengers is forced to enter with the belt inside the vehicle. The missing support strength in the pelvis range was introduced by a knee pad at the instrument panel.

During the layout of belt systems, the usual driver population is considered from 5 % woman to 95 % man. Due to the different seating levels of the passengers and their positions relative to the point of return at the B-column, the belt fits optimally only with a small proportion of the passengers. Too high positioned belts and backwards placed points of return (two-door cars) lead to the degradation of the passenger ratings, furthermore with small persons, the cervical artery can be hurt by unfavourable belt guidance. Belt vertical adjustments adapt the belt guidance of the physiognomies of humans by the shift of the upper coupling point at the B-column and today mostly sit under a smooth cover in order to minimize the injuries of the head in case of side impacts. A seat release fastened to the seat provides for an optimal positioning on the opposite side.

Injuries of rear passengers are caused e.g. by a roof impact because of a vehicle turnover or by the forward displacement against the front seat backrests. With side impacts, there is a possibility for the unsecured passengers to be thrown out from the cabin. Three point static belts at the rear seat places protect not only the rear passengers but also serve for the protection of the driver and the front seat passenger, because of the load in addition to the forward displacement, the backrests could break. Also a collision of two heads can lead to fatal injuries for the passengers.

In this context, the use of static lap belts at the rear seat is to be criticized. On the one hand, their accurate attitude is very much uncomfortable on the body size as with all static belts and is therefore rarely implemented correctly, on the other hand its protective function is reduced, since one prevents only a throwing out of the passengers, while a large forward displacement becomes certified. The middle passenger on the rear seat is endangered by the use of a lap belt not directly as the persons sitting in the front, however with a barrier impact speed of 50 kph on a firm wall, the forward displacement is so large that its head can impact on the transmission selector lever.

In order to improve the restraint function, today additional components belong to the belt system. First to name is a retractor mechanism, by which the so called inertial retractor belt system can be taken off and put on easily by its defined quiescent condition. In comparison to the static belt, here a clock spring adapts the belt by its retractor strength to the respective body form, holds it at the body under tension more easily and provides the possibility of a large freedom of movement by taking the belt off against the retractor spring. The belt extraction is however only possible in a defined position of the retractor, otherwise a ball closes the mechanism and the passenger is held by the belt for example after turnover. This ball is additionally used for sensing the crash heaviness (see chap. 12.1.4.2). A centrifugal force weight, besides the belt starting, blocks from a certain extraction speed e.g. in case of an accident. It is on this blocking that the restraint effect of the belt is based.

Since however only a limited passenger forward displacement is available, the system response time must be as small as possible for the delimitation of the deceleration. With belt systems, the response time can be lowered by the decrease of the belt slack.

A reason for too large belt extraction lies in the fact that the rolled-up belt in loose courses lies on top of one another. Therefore it can completely wind itself under load despite the friction between the film reels and release the belt strap inadvertently (film coil effect). Thereby one gets larger belt slacks and the restraint effect sinks. Over a mechanical belt clamp in the retractor of the belt, a mechanical blocking of the belt with a blocked belt coil can be used to prevent this.

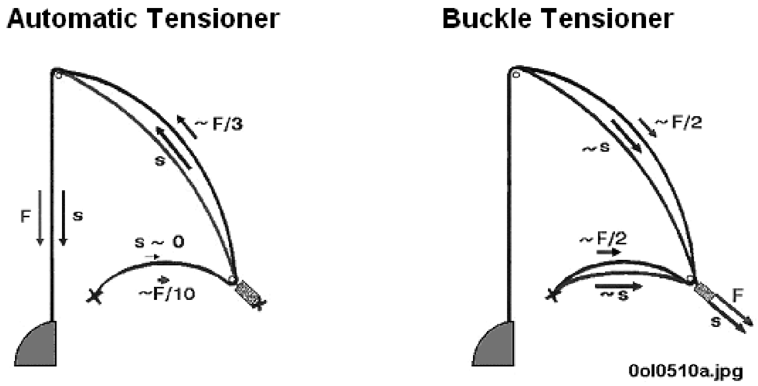


Fig. 12-9: Pre-Tensioning Function with Buckle- and Automatic-Tensioner

In addition, the belt slacks can rise by wearing thick clothes or an exposed seating position of the passenger. Often the lap belt with such clothing lies over the abdomen and can lead to heavy injuries of the belly organs. A belt system equipped with a belt retractor therefore stretches the belt within approximately 10 ms in case of an accident over a linked up spring or with the help of a pyrotechnic propellant for a given distance, so that the belt fits tightly to the body. Here, one differentiates between the design of the buckle and the automatic tensioners. The buckle tensioner has the advantage that, by the movement of the seat harness release, the pelvis and the shoulder belt slacks are reduced at the same time. Shoulder and lap belts are thereby pre-tensioned for instance till the

entire amount of the buckle misalignment (vectorial addition of the tensioning effect). With the use of an automatic tensioner, however only the simple pre-tensioned displacement is available for the entire belt. In addition, substantial force losses arise by the detour of the belt so that only the shoulder belt is nearly tightened (Fig. 12-9).

The force for tightening the belt can be produced by means of a mechanical system over a linked-up spring or with the pyrotechnical solution using a small gas generator that is filled with solid propellant in granulates form. The release of the system can be made mechanically by the use of centrifugal mass or electrically by means of an ignition impulse that is generated from an electronic controller. With the mechanical seat harness release tensioner, a spring-mass-system serves as a sensor, which reacts to crash specific vehicle decelerations. With smaller decelerations, the sensor mass is back pressed by the sensor spring again into the rest position. With the lever ratio in an accident of 2000 N, the linked up retractor spring is released, which pulls the seat harness release over a push-pull cable diagonally downwards to the rear. A bolting device system, with the layout of the belt force, finally blocks the seat harness release in each retractor position (Fig. 12-10, left). During pyrotechnical execution, the retractor force is produced by a small pyrotechnic propellant that uses the gas pressure on the piston in a pipe and a steel cable for the course movement of the buckle (Fig. 12-10, right).

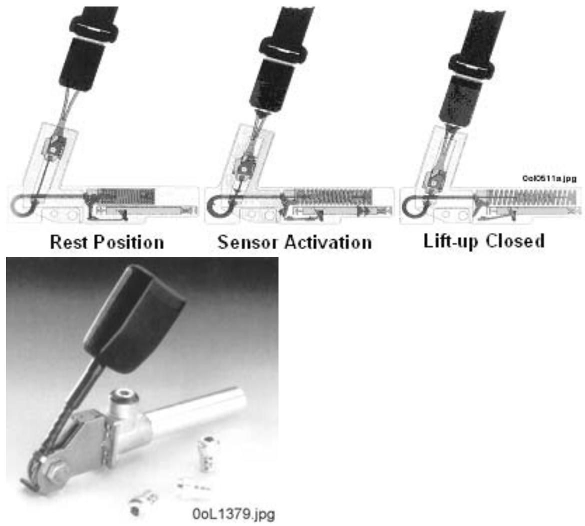


Fig. 12-10: Buckle tensioner

With the automatic tensioner, all the various designs relate back to a pyrotechnically produced tension, working at the belt role of the retractor. Here the gas pressure moves pistons or steel balls in tubes that are directly connected with the coil role by steel cables or gear wheels (Fig. 12-11).

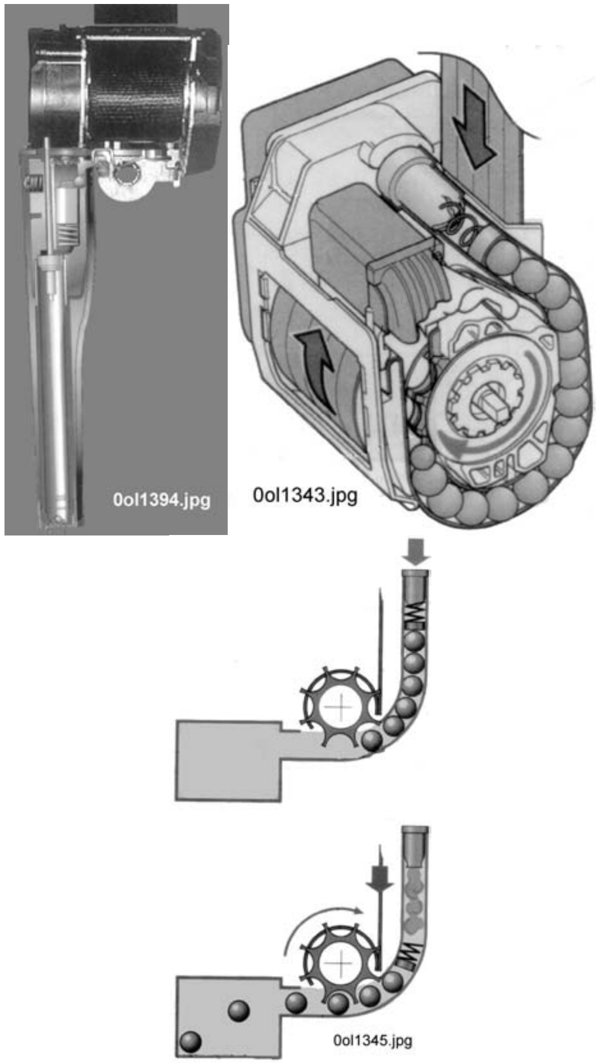


Fig. 12-11: Automatic Tensioner

Because of the smaller belt resiliency, attention is to be paid with the installation of a belt tensioner for the adherence to the biomechanical load limits of the head and the chest. With lighter and smaller female passengers, whose injury borders are clearly under the legally specified borders of an average 50 %-man, complete feed of the belt to high chest loads can be achieved.

The employment of the belt force limiters can clearly reduce the danger of injury. At first, this function was realized by tearing seams at the belt ends, which failed above the tearing up force and released a belt loop of approx. 1 cm each loop. However attention is to be paid to limit the available passenger deformation travel. The employment of a torsion bar in the role of the inertial reel belt is a further possibility of not letting the belt load rises further with the increase of the designed fixed torsion load (Fig. 12-12).

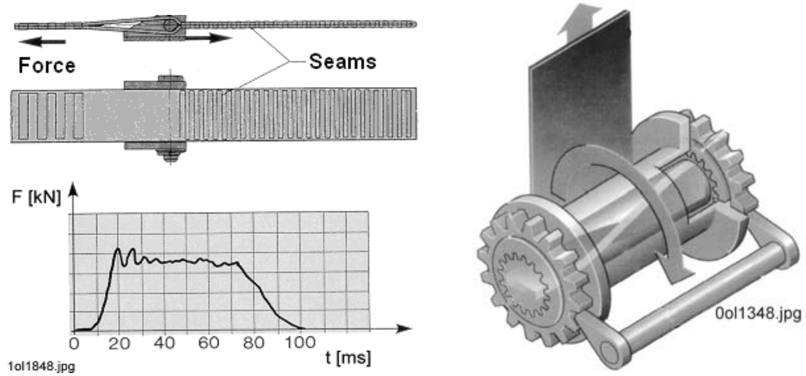


Fig. 12-12: Belt Force Limiter

Due to the demand for adaptive restraint systems, which adapt to the passengers at the respective accident, it became necessary to develop adaptive belt tensioners and belt force limiters. By means of a multi-stage belt tensioner, the necessary restraint force is produced only for the respective accident. In Fig. 12-13 an adaptive belt tensioner is represented operating according to the Wankel-principle. As a Wankel-engine, the belt tensioner has three combustion chambers that are arranged around the rotary circular piston. With the ignition of up to four propellants, the belt force can be regulated by the tensioned displacement. Since the costs of this complex construction are not insignificant, on the market there are also solutions with unregulated tensioners and multi-stage force limiters.

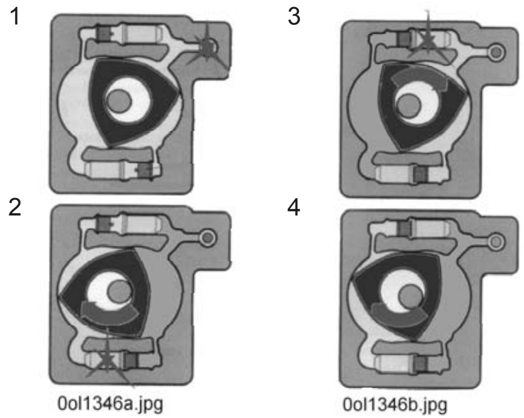


Fig. 12-13: Multi-Stage Belt Tensioner

With the system shown in Fig. 12-14, the belt force is shifted by a pyrotechnical shift of a switching element on a thinner torsion bar and the belt force level is lowered. In the starting position always the higher belt force level is active. The reason is to be able to obtain maximum restraint effect. Thereafter only a decreased effect follows, if necessary.

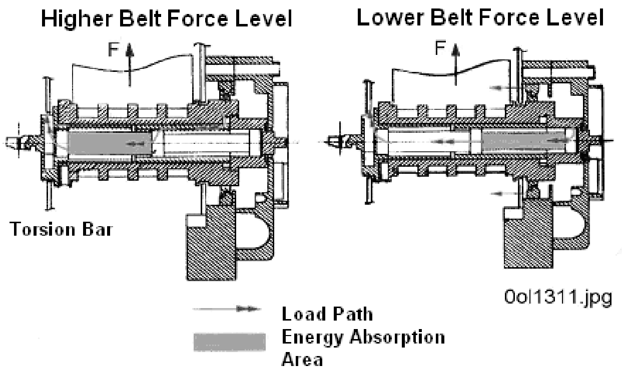


Fig. 12-14: Functional Sketch of a Pyrotechnical Belt Force Limiter

12.1.4 Airbag Systems

Further safety components for the increase of the passenger protection are airbags. Also in contrast to the belt and in addition to the torso, the head can be

held back by these systems. Over the large available airbag surfaces and the form adapting to the body surface, the deceleration forces can be conducted much more effectively and less injury-critically. The neck load sinks by smaller overstretching of the neck due to the force application on both sides of the neck.

For the driver, the airbag unit is integrated into the steering wheel and consists of the components gas generator, airbag and cover plate. The gas generator is electrically connected to the airbag controller unit. As soon as the ignition impulse of the crash sensor and controller reaches the gas generator, gas fills the airbag. The cover plate on the steering wheel hub breaks open at the intended position and the lens-shaped airbag is blown up in a maximum of 40 ms to its full size. Thereafter the head and the torso are retarded by driving the gas out (Fig. 12-15). Airbags have the advantage of very uniform head decelerations without pronounced acceleration points, since no hard impact is to be feared on parts of the interior equipment. Also the chest deceleration altogether collapses somewhat earlier.

Fig. 12-15: Driver Airbag

The front seat passenger airbag must be activated due to the larger distance of the passenger to the interior. Because of the range at the seating position it is substantially more voluminous than the driver side's. It is inserted above the glove compartment. One or two gas generators that are ignited with temporal misalignment, blow-up the airbag. Due to the large distance to the passenger that can be protected, the entire igniting and blowing up procedure takes place in around approximately 10 ms later than with the driver airbag. The important times of the blowing-up procedures are displayed in Fig. 12-16. The ignition of the driver airbag takes place in about 20 ms, that of the passenger in about 30 ms after the impact.

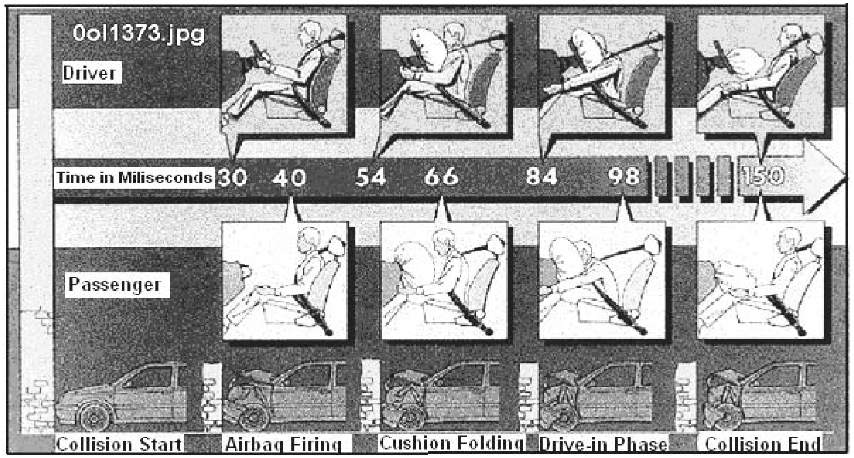


Fig. 12-16: Schematic of Airbag Firing Process

In dependence to the other components of the restraint systems, in each case, two sizes of airbags on the driver and front seat passenger side are installed. The small so-called “Euro airbag” is meant as an addition to the legally prescribed belt system. The airbag here mainly serves for the prevention of the head and torso impact on the steering wheel or the instrument panel. The otherwise usual “US Airbag” has a substantially larger volume, since it is laid out as an exclusive restraint system and thus the entire kinetic energy of the body striking it must be absorbed. With the US bag, the ignition times are much earlier by the large forward displacement of the unsecured passenger than with the Euro bag in former times.

With optimal functioning of the entire restraint system, the injury risk for head and chest is substantially reduced by the additional use of airbags (Fig. 12-17). The head injuries, also in very severe accidents, decrease with airbag, while without airbag, already with moderately severe accidents, moderate injuries arise and in very heavy accidents critical injuries are caused which amount to about 10 %. The magnitude of the injuries within the chest range is altogether on a higher level than with the head injuries. However a clear improvement here is also possible by the employment of airbags. The danger of rib fractures is substantially reduced. Eyeglass wearers can however, in case of impact, carry light injuries by the breaking off of the frame and the glasses.

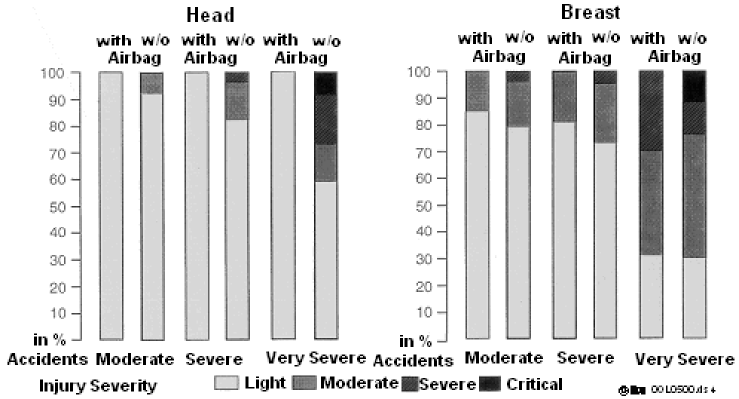


Fig. 12-17: Injury risks with and without Airbags

Nevertheless frontal airbags offer no protection with side impacts and turnovers. Therefore, particularly for this accident configuration co-ordinated systems in the door and in the roof range of the vehicle are used. Also with multiple collisions, as they arise with mass collisions, the frontal airbag offers protection only once. Therefore the use of airbags is meaningful only in connection with belt systems.

Near the driver and passenger airbag additional airbags are in use that take over other protective functions.

The passenger in the back seat in the future will be protected by the lap belt of the three-point static belt fastened airbag against an impact of the torso on the front seats. This large airbag of about 60 l content will be filled by means of a hose from the gas generator at the floor and would unfold away from the passengers between torsos and thighs (Fig. 12-18).

Fig. 12-18: Airbag for Rear Seat Passengers

The restraint effect in the vehicle is to be optimised in the future by additional airbag systems that at present are still under development. Inflatable airbags within the knee impact range of the instrument panel should hold back the hip of the passenger over the introduced force on the one hand; on the other hand they should also reduce the impact at the instrument panel. This knee airbag system is partly equipped with load distributing cover plates. An airbag system in the knee area is to raise the seat front edge by blowing up a pad and pull the injury endangered lower leg parts from the danger zone of the shift pedals. The risk of injury of the feet is to be decreased by inflatable pads under the interior carpet (Inflatable Carpet); the generated high bending angle of the foot joints by the floor panel and their accelerations over air cushion, penetrating with the frontal crash into the passenger compartment, are reduced. The head, during an accident, protects itself by resting onto the back of the head protection airbag. These airbags reduce the distance between head and head restraint, usual in normal driving, by air cushion and as a result decrease the neck loads in case of head impacts.

12.1.4.1 Construction of Airbag Systems

For a timely blowing up of the airbags, so-called gas generators are used, which produce the necessary gas flow rate. The ignition takes place via an electrically

heated glow filament, which as a small firing pellet ignites the specific propellant. With older airbag systems, a solid fuel (sodium azide) in the form of small pellets became stimulated from the firing pellet due to sudden burning under gas generation. In order to adapt the blowing up speed of the airbags to the desired target curve and to cool down the gas volume, the gas flow is retarded by auto body sheets and filters, cooled down and is retained of the burn-up arrears. The appearing gas temperatures are so high that they nevertheless can hurt the passengers. The gas generators inserted in the steering wheel have a round, plate shaped structure (Fig. 12-19), and the modules inserted at the front seat passenger side consist of several of these round generators or are installed as a tubular design (Fig. 12-20).

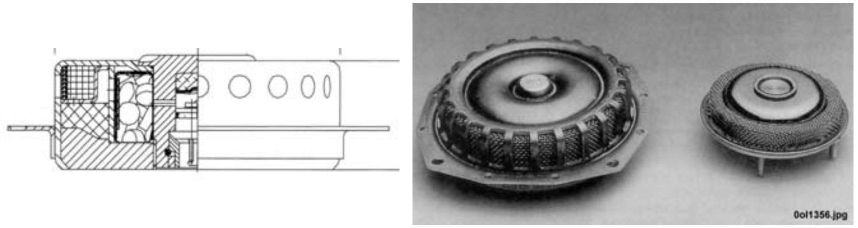


Fig. 12-19: Construction of Driver Airbag-Gas Generators

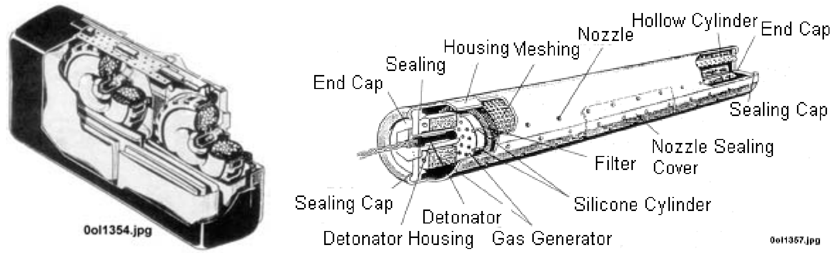


Fig. 12-20: Construction of Passenger Airbag-Gas Generators

Since the used fuel exhibits a bad environmental compatibility (water-endangering, toxicity) and besides a larger quantity of explosive in the vehicle represents endangerment, hybrid generators are used increasingly. As the name already suggests, here two different concepts are combined. The ignition of the generator is again made electrically by the burning of a firing pellet. The pressure developing thereby in a pre-chamber breaks open a burst plate, which locks the connection to a compressed gas reservoir filled with highly compressed nitrogen (398 bar). A second burst disc is opened by the increase of the pressure in the reservoir and the leak out of the gas fills the airbag. So as not to cause the freezing of the discharge openings during the sudden pressure decrease, a small additional quantity of solid fuel is simultaneously ignited as the heating charge. Thereby this generator design has the additional advantage, which is to a large extent independent of the filling of the airbag at ambient temperature. Also plate or tubular hybrid gas generators are again used here depending upon place of work. The assigned explosive quantity is thereby clearly reduced (Fig. 12-21).

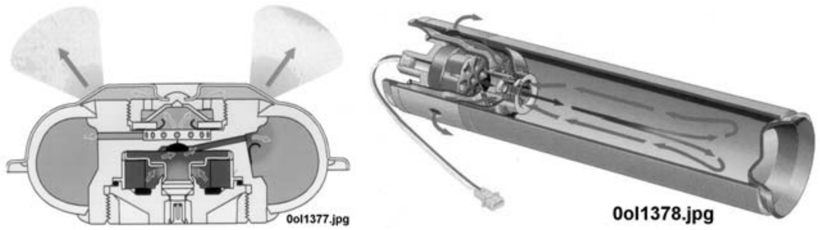


Fig. 12-21: Hybrid Generators

The sizes of airbags vary in relation to the vehicle, in which they are installed. Typical characteristic values for airbag systems are represented in Fig. 12-22.

	Volume		***Explosive***
	US-Bag	***Euro-Bag***	
Belt Tensioner	-		1 g
Firing Pellet Airbag	-		2 g
FS-Airbag	80 l	35 l	120 g / Hybrid 15-30 g
BFS-Airbag	120-140 l	70-80 l	200- 340 g
Side Airbag	12-25 l		60 g

Fig. 12-22: Characteristic Values of Front-Airbag Systems

12.1.4.2 Sensing and Triggering of Restraint Systems

For all pyrotechnical belt tensioners and airbag systems, ignition decision and an optimal ignition point as a function of the accident must be determined. This is realized with special sensor technology, whereby one differentiates between two constructional methods of sensors.

Mechanical sensors sense only the excess of the fixed threshold value. They are used only for the release of belt tensioners or as a redundant sensor with electronic airbag disengagement. Their structure consists for example of units containing spring-mass-, magnetic-iron-mass or gravity force-mass systems. To sense the threshold value, the seismic mass is deviated by the arising deceleration against the force of a spring, a magnet or the force of gravity from the rest position. With delays below the minimum trigger level, the seismic mass is pressed back again to the initial position after deflection by the counter acting force. With the exceeding of the minimum trigger level, however it comes to the closing of a contact, which activates the RS (Fig. 12-23).

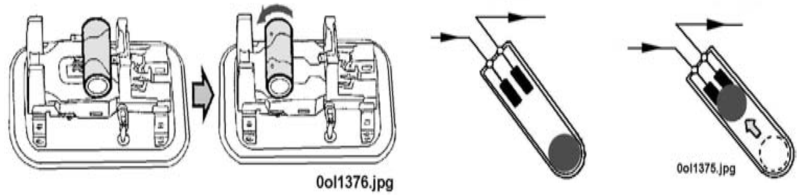


Fig. 12-23: Mechanical Threshold Value Sensors

In order to be able to acquire the entire deceleration process, electronic sensors are used whose seismic masses are deviated by the deceleration. Thereby the charge between two condenser plates changes or with piezo-resistive **w**ire **s**train **g**auges (WSG), the occupied bridge of the seismic mass reacts with change of resistance (Fig. 12-24). The discharged electrical signal here is proportional to the deceleration. By means of a sensor signal, time-optimised ignition of all pyrotechnical components of a RS is possible.

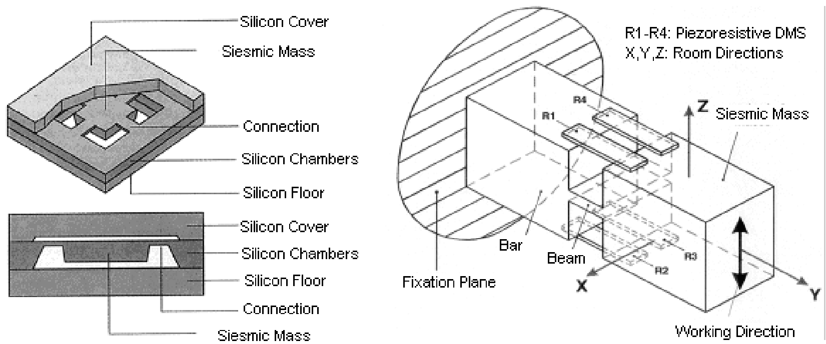


Fig. 12-24: Electronic Deceleration Sensing

During the contemplation of the motion behaviour of vehicle and passenger, one can distinguish between a fixed and a vehicle-lateral moving coordinate system. Shown exemplarily is a vehicle, which with its initial velocity hits against a stiff obstacle, whereby in Fig. 12-26 is represented the measurement of the deceleration process. From this (Fig. 12-26), results the likewise represented speed and deformation process. Due to an incomplete plastic impact, a small return motion takes place. A non-secured passenger does not experience deceleration up to an impact at vehicle components. Its speed remains the same as the initial velocity, the travelled distance rises linearly.

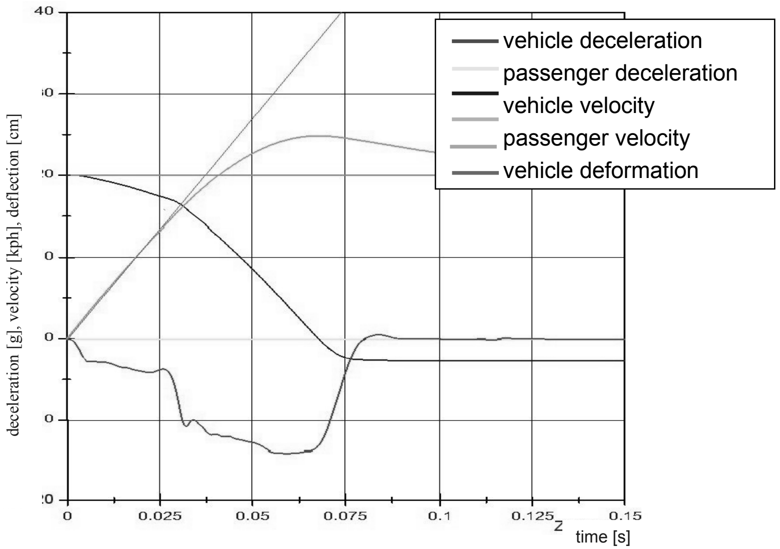


Fig. 12-25: Motion Behaviour Vehicle and Passenger

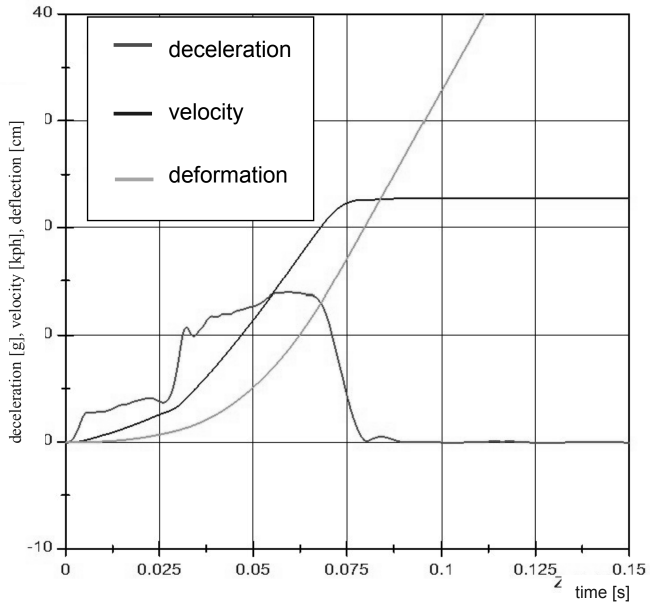


Fig. 12-26: Deceleration, Velocity and Deformation Signal of the Passenger

For the passenger, however only the relative movement to the vehicle is of importance. If the vehicle is slowed down with the same deceleration, the speed and the deformation process for the unsecured passenger results relative to the vehicle in Fig. 12-26 in the vehicle-fixed coordinate system.

The passenger is accelerated with the vehicle deceleration relative to the vehicle. At start, no speed difference exists till deceleration. The stronger the working deceleration becomes, the faster the increase of the speed difference rises up to the initial velocity, as well as the deformation difference between the vehicle and the passenger.

Due to the fact the passenger is not allowed to impact the vehicle interior, a restraint system must be released quite early, according to the crash heaviness. This takes place over a subsequent treatment of the incoming sensor signals in the airbag control unit. Here on the one hand, a clear distinction between ignition and non ignition relevant impact procedures must take place, also on the other hand, the correct ignition point (TTF, **t**ime **t**o **f**ire) for the appropriate accident configuration must be determined.

As a characteristic for the accident, the change of speed Δt is referred to the impact. In Fig. 12-27 a process for a change of speed is represented for a 40 % offset crash at a speed of 45 kph against a deformable barrier. As a result of the soft front structure of the vehicle to protect weaker accident opponents and the deformable barrier, timely deceleration, up to an explicit rise of the change of speed, typical for the accident, arises. The following upward gradient of the curve is thereby a measure for accident severity.

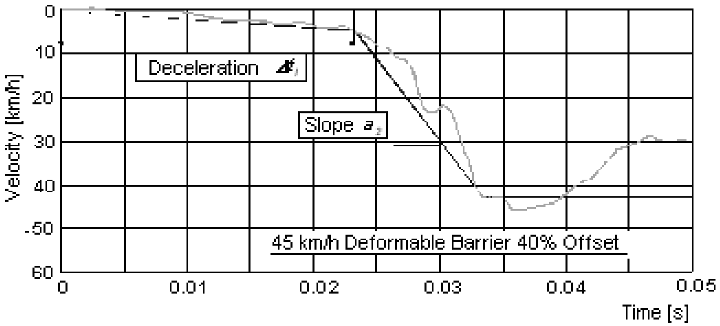


Fig. 12-27: Velocity Change for an Offset Crash

On the basis of specific decelerations and the upward gradient of the curves, different impact configurations can clearly be separated (Fig. 12-28). With reducing deceleration Δa and increasing upward gradient “a”, the processes increase the accident severity for the restraint system.

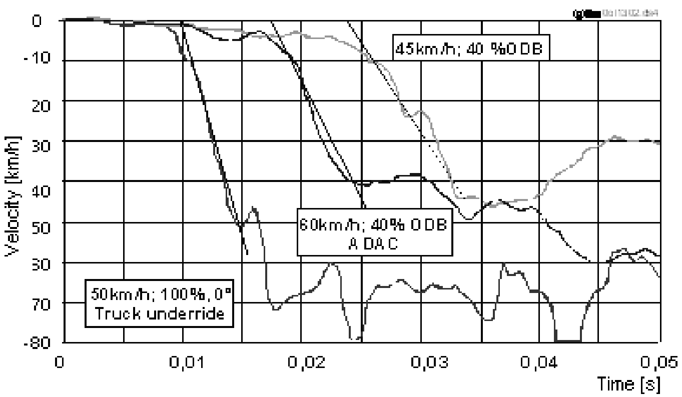


Fig. 12-28: Velocity Change for different Accident Configurations

The wide impact on the nearly non-deformable rear end under-ride protection of a truck is substantially more critical than the two 40 % offset impacts with different velocities against a deformable barrier.

In order to determine the change of speed, decelerations affecting the body in the relevant directions are usually acquired by means of acceleration sensors. As soon as a small fixed load limit is exceeded, the controller shifts into the alarm condition, and the detailed deceleration signal is internally processed in two separate computation routines as shown in Fig. 12-29. On the one hand, shown above, it is integrated in order to determine the process of the change of speed from the start of the accident. This starts at the beginning of the accident with zero and then sinks during the accident process towards negative changes of speed.

Secondly, the acceleration signal is filtered, in order to be able to neglect unwanted peaks of the body oscillations or short impacts (falling rocks). The filtered deceleration process is transferred to a minimum trigger level and made more sensitive by being re-valued with high current decelerations over a specific factor. This factor is stored in a characteristic diagram from the well-known deceleration processes. From the intersection of the minimum trigger level and the determined change of speed, the appropriate component is ignited. For rising decelerations (high accident severity), a smaller change of speed is thereby necessary until release (earlier ignition). For each pyrotechnical component of the restraint system, its own theoretical minimum trigger level for this time point is calculated (Fig. 12-29).

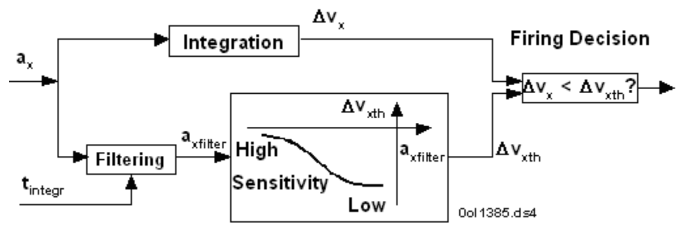


Fig. 12-29: Processing of the Acceleration Signal

The starting point of each minimum trigger level based on a vehicle-dependent offset is shifted towards negative changes of speed, whereby the minimum trigger level with increasing accident severity quickly rises. With smaller accident severity, both the upward gradient of the minimum trigger level and the reduction of the change of speed are too small than that of the two curves which would intersect with the given negative offset. With increasing accident severity, first ignited is the belt tensioner, whose minimum trigger level exhibits a smaller offset and another evaluation process of the airbags takes place. With further increase of the accident severity, the upward gradient of the minimum trigger level and the change of speed, which leads to an earlier intersection of both the curves and an earlier release of the restraint systems, rises. By means of the adapted characteristics, first the belt tensioners and later the airbags are activated. By means of these adaptive systems, the airbag can be ignited on recognition of a non-secured passenger in the vehicle at the minimum trigger level of the belt tensioner, in order to improve the restraint effect (Fig. 12-30).

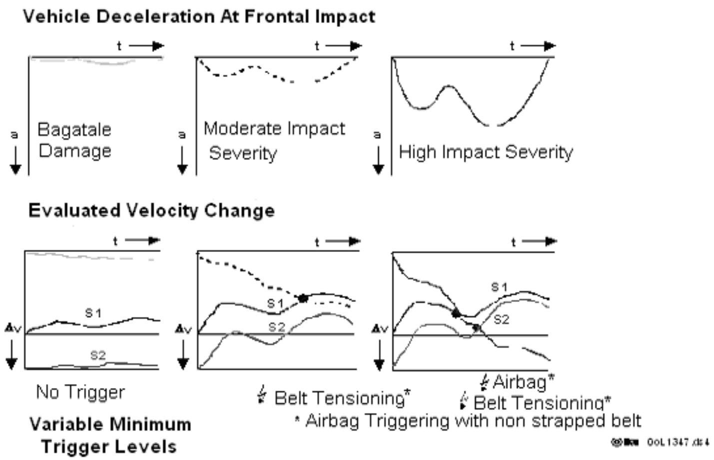


Fig. 12-30: Variable Triggering Thresholds

By means of offsets and evaluation routines of the filtered acceleration signals, the restraint systems can be adapted to the different body characteristics in different accident configurations. In order to reduce the risk of false signal initiations, additionally a parallel switched mechanical sensor must be guided from its rest position by the deceleration and an electrical signal must be transferred to the controller for the ignition of the systems. By this second sensor, also only partial initiation of the subsequent treatment of the input signals takes place.

The ignition of the airbags should take place so early that the blowing up procedure of the airbag is completed at the impact of the passenger in order to retard him by pressing out the gas gently from the discharge openings (vent holes). Thus result the possible times for the ignition of the airbags as a function of filling time and the deformation travel of the passenger (TTF). Until this time, a

safe distinction between ignition relevant impact and uncritical misuse boundary conditions must take place.

By means of the accident boundary conditions e.g. the structurally rigid accident opponent, the offset or the upward gradient of the change of speed, additionally make a distinction between an ignition and a non-ignition relevant accident more difficult. With a central sensor attached within the range of the vehicle centre of gravity (CCS, **C**entral **C**rash **S**ensing), no clear distinction of the signals until TTF (here 30 ms) can be realized. A solution for this are vehicles with asymmetrical impact configurations (Fig. 12-31).

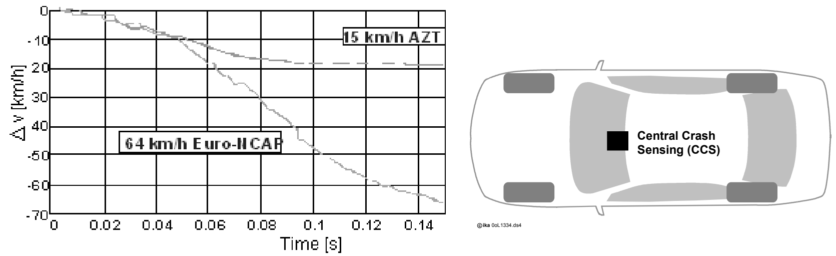


Fig. 12-31: Velocity Change using CCS

By the use of additional satellite sensors (UF, UpFront Sensing) within the direct impact range, on the one hand an early distinction of the signals is made possible by the short signal transmission distances and, on the other hand conclusions can be drawn for the possible offset crash configurations using a direct comparison of the data with several sensors (Fig. 12-32). For the same reason, in the side impact range, satellite sensors are used in the proximity of the doors.

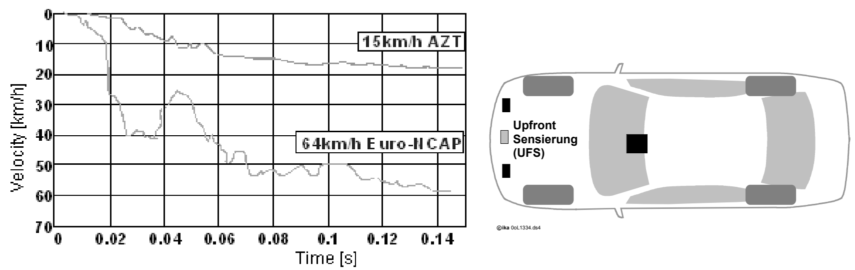


Fig. 12-32: Velocity Change using UFS

12.1.4.3 Out of Position (OoP)

The use of airbags in vehicles can however in exceptional cases also cause additional injuries. From USA cases are well-known wherein, persons sitting in front of the steering wheel, unturned passengers or children in wrongly used child seats were killed by the unfolding of the airbag. A majority of the killed passengers were not buckled and by brake applications before the impact (Pre-impact braking) were thereby moved into the installed range of the airbags. The two typical causes of death thereby are (Fig. 12-33):

Punch-Out: The impulse transfer and the flap contact at the beginning of the development phase in the chest range. The short and high thrust force developing thereby compresses the human chest so fast and so strong that multiple rib fractures and tear in of the heart muscle and adjacent veins can develop.

Membrane Effects: Production of relative motions between the individual body parts during the blowing up procedure of air bag system (head, neck and torso). Skull fracture and injuries of the back can be caused due to neck overstretching.

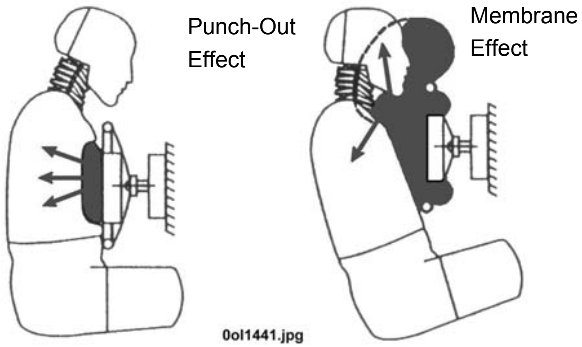


Fig. 12-33: Injury Mechanisms in OoP Configurations

Therefore in USA, laws were issued for the use of adaptive airbag systems to reduce the endangerment by a situation-adapted blowing up procedure e.g. to reduce the generator over-performance. Represented in Fig. 12-34 are examples of such situations, in which no release of the airbags takes place. Release is either not necessary or otherwise a weakened release is wanted for e.g. normal ignition.

However, since the system response time become longer and heavy passengers can additionally be endangered, additional efforts must be done in order to acquire all relevant accident boundary conditions. For this, amongst other things,

information about the passengers and their positions must be known. So-called OC-systems (Occupant Classification) close this information gap in several detailing stages.

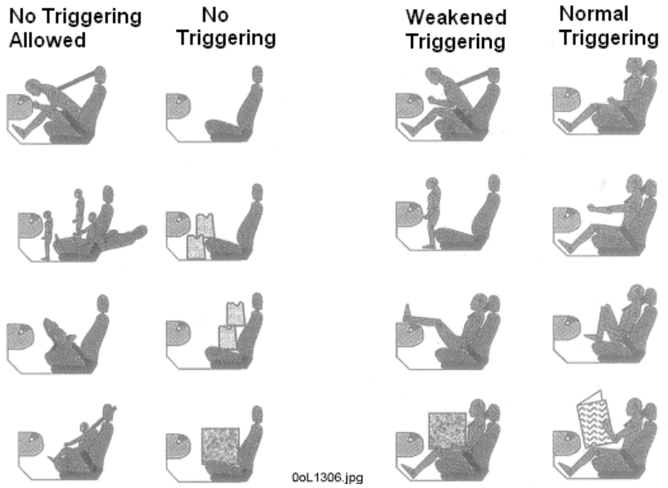


Fig. 12-34: Situations for Adaptive Airbag Firings

The first stage represents the seat allocation recognition, which excludes an unnecessary ignition of airbags and the developing costs thereby. It works in cooperation with pressure-sensitive mats under the upholstered seat, which activates the airbag at a fixed limit. In connection with belt recognition, an adjustment of the airbag characteristic can take place. If the system fails, the airbag remains active.

In the second stage, child seats and their adjustment over internal sending and receiving units in the seats can be recognized. They likewise prevent an ignition of the concerned airbags. If the system fails, the airbag is switched off.

In the third stage, differentiation can be made by additional sensors between passengers and objects as well as the passengers' weight and size. This takes place by the measurement of the single seat force and also by the pressure distribution under the upholstered seat positioned pressure-sensitive mats. So an adjustment of the airbag performance for the passengers takes place.

In the fourth and last stage, one determines the current seating position of the passenger using optical or electromagnetic sensors.

Here one distinguishes between static systems, which acquire the position with a small frequency before the crash (stages 1-3), and high-dynamic systems, which allow changes, even during the impact procedure, into the release strategy (stages 3-4). With a possible endangerment of the passenger, the restraint system is adapted or is not ignited at all.

For ignition in a weakened form, on the one hand, the increase of pressure gradient in the airbag can be reduced (de-powering; over a bypass) or the maximum pressure can be lowered (de-energizing, staged gas generator), see Fig. 12-35.

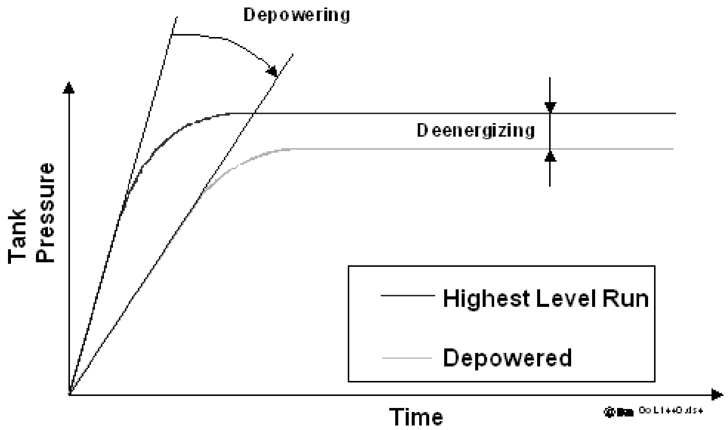


Fig. 12-35: Pressure in Gas Generator with Adaptive Systems

The adjustment is further made by multi-level gas generators, with which several propellants can be individually shifted temporally or ignited together. Likewise the belt tensioner and the belt force limiters can be adapted by means of multi-level execution during a crash. An adaptive ignition then occurs as shown in Fig. 12-36.

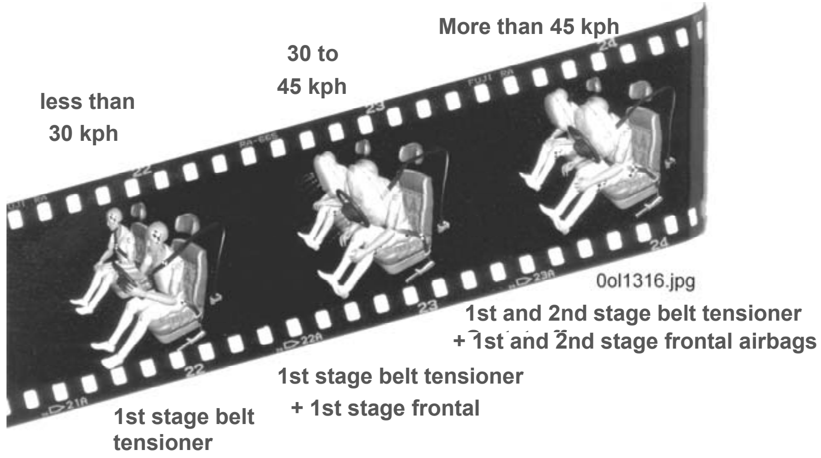


Fig. 12-36: Adaptive airbag firing

Another possibility for reducing the endangerment of airbags is an optimised folding of the airbags and an adapted filling technology. Thereby one can directly avoid a larger surface with full pressure and also the accelerations affecting on the passengers (Fig. 12-37, left). By means of the so-called Petri-Folding, the individual positions are subjected from the inside towards the outside by gas pressure. In addition, the gas pressure is not conducted central on the entirely folded airbag surface, but supplied over a small centrally arranged fire-place diffuser (Fig. 12-37, right). The fabric moving out from the airbag module thereby forced upon, acquires an additional development direction perpendicular to the passenger. Thus, by the use of easy airbag fabric, the OoP loads can also be clearly reduced without multi-level execution of the gas generation.

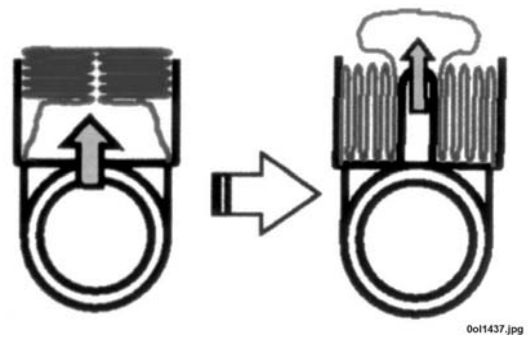


Fig. 12-37: Alternative airbag folding (PETRI)

12.1.5 Child Seats

Child restraint systems (CRS, children restraint system) adapt the seat form and restraint performance of the existing belt systems to the needs of the differently large and heavy children. Actually available are child restraint systems with different concepts.

Newborn children and infants due to their not yet fully developed neck and neck musculature are usually transported in baby pods or reboard seats against the driving direction. The child in these seats in the case of a frontal impact is pressed against the backrest and the head and the back is supported over a large surface, without this, it can come to an overstretching of the spinal column. The belt of the child seat serves for the adjustment of the child during travel and prevents high skidding of the child during impact. However, the attachment of the seat over the vehicle belt is not always easily accomplished error free, the space requirement for reboard seats is not sufficient in small cars, and when assembling on the passenger seat an endangerment develops with the non disengageable airbag. As a result of the attachment of the seat with the vehicle belt, double belt slack results.

Other seating systems are likewise installed at the standard seat belt and work in the driving direction with or without the impact barrier within the belly range of the child. The absorption of energy during impact results via controlled deformation of the impact barrier and via the belt integrated at the child seat. It is mostly implemented as a 5-Point-Belt. Also with these systems, the problem of double belt slack results, but additionally large head forward displacements result for the child by the missing restraint. An advantage is that they need less place in the vehicle and can even be used for larger children.

To minimize the possibility of failing during the assembly of child seats, the ISOfix system was developed (Fig. 12-38). The basic frame of this CRS is directly fixed without belt slacks with pressings at the vehicle body and thus follows the deceleration process of the vehicle during impact. Smaller load values can be obtained by early deceleration of the seat than with the other systems with optimal tuning of the other seat components. A further usage of the ISOfix system has been prevented so far by the European and the national legislation, since they prescribe examinations of the individual seats for each car model, type-related due to the different front car designs, which is connected with immense complexity.

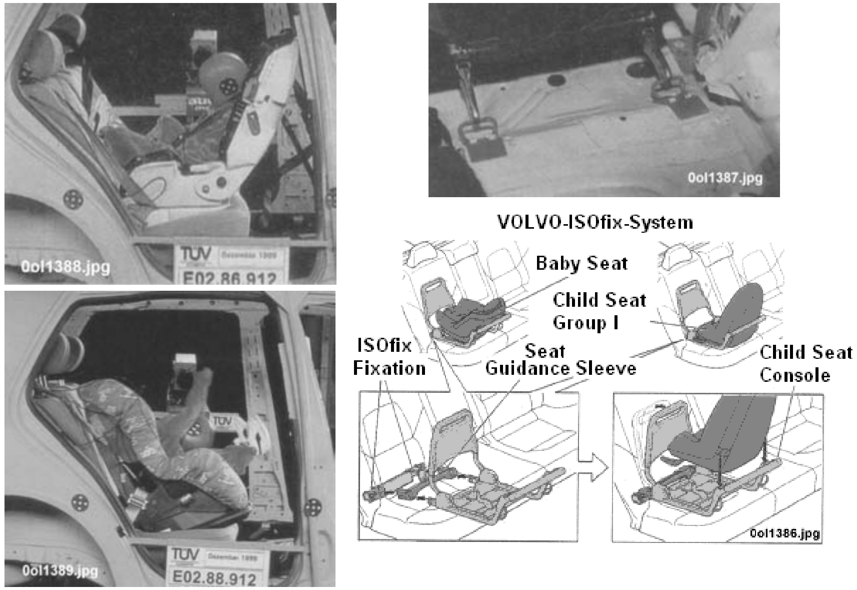


Fig. 12-38: Child Restraint Systems

12.1.6 Restraint Systems in Light Commercial Vehicles and in Busses

For trucks and busses, legally prescribed is the installation of belts with new vehicles. However, the belt usage rate for trucks is well below 10%, although the belt can straight away prevent the throwing out of the driver by the broken windshield with critical truck-truck accidents (Fig. 12-39).

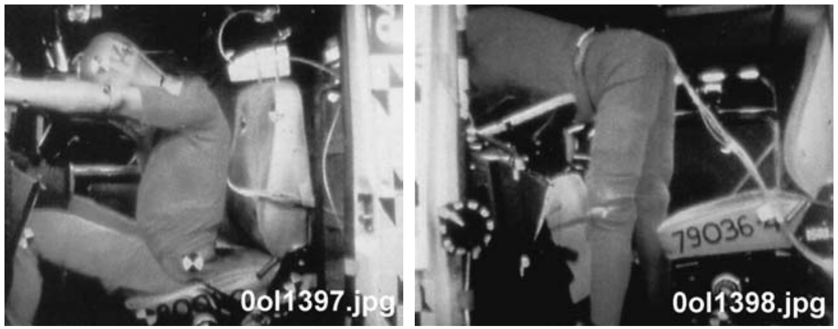


Fig. 12-39: Belt Systems in Light Commercial Vehicles

In busses, the absorption of energy takes place over deformable seat components at the feet, similar to an Anti- Whiplash seat, and by the use of pelvis or 3-point belts, an impact with the passengers is avoided on the frontal backrest in frontal accidents. At the drivers seat, as also with trucks, an additional airbag protection system is generally provided (Fig. 12-40).

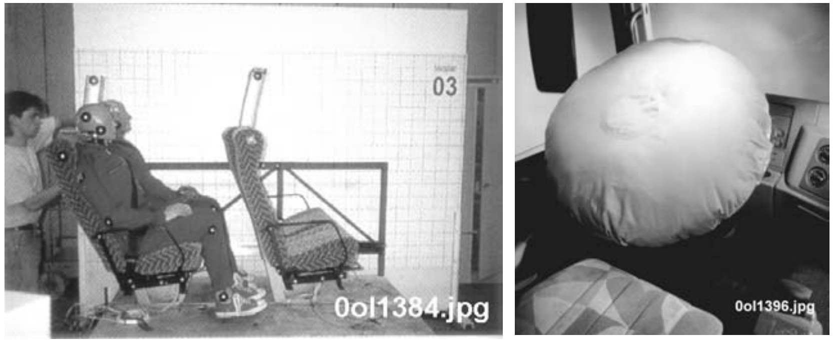


Fig. 12-40: Restraint Systems in Busses

12.2 Side Impacts

The side impact, after the frontal impact, belongs proportionally to the most frequently occurring kinds of collision [WAL98, SEI92]. The proportion of severely injured humans at this accident configuration, seen relatively, takes constellation due to the lasting improvements of passive safety during frontal accidents in particular after the introduction of the frontal airbag systems [HAC99a].

With impact processes against the side of a passenger car, deformations arise directly at the passenger space because of the missing crunch zone in comparison to the frontal crash. It substantially restricts the lateral free space and creates sharp edged impact ranges for the passenger.

The injuries of the laterally impacted passenger certainly are caused by [OTT98]:

- the relative movement of the body to the vehicle
- the design of the inner compartment where the possibility of impact exists
- the biomechanical loads resulting due to the occurrence of jerks and accelerations

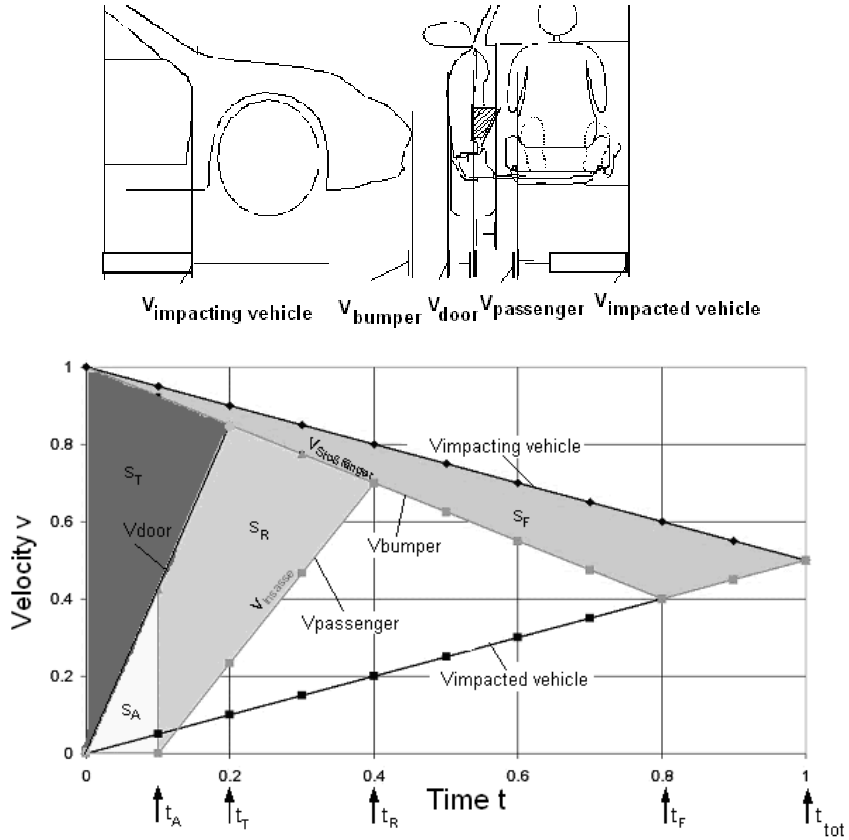
The increasing relative injury rise with side impacts in the last years led to an intensification of the side impact preventive measures. So standard bending

resistant carrier structures are integrated in all doors, and a majority of the manufacturers meanwhile offer energy absorbers in the side trims (paddings). Beyond this, side and head airbags are used in all vehicle classes.

12.2.1 Restraint Systems for Side Impacts

To minimize the passenger injuries during side impacts, the movement and impact behaviour must be changed by coordinated restraint systems in such a way, that the biomechanical values are clearly reduced. For explaining the fundamental interactions between the two vehicles involved and the passenger inside, the boundary conditions at the example of a 90°-Vehicle-Vehicle-Side impact for the absorption of the energies are more nearly described in Fig. 12-41 on the basis of a velocity time graph. One proceeds using simplifications such as constant decelerations and linear speed processes.

At time t=0, the impacting vehicle with a speed of $v_{bumper,veh}$ impacts at the exterior of the standing vehicle ($v_{resting,veh}$=0). After the impact, the speed of the bumper v_{bumper} and of the impacting vehicle of $v_{impacting,veh}$, as a function of the initial penetration resistance of the side door, decreases. The velocity difference between both of them arises as a result of the deformation of the vehicle front s_F. Further velocity decrease is then increasingly determined by the penetration resistance of the columns, the sills and the floor. In order to be able to reduce the velocity of the impacting vehicle more strongly, side door, columns, sills and floor must be reinforced. In this way, the deformation travel s_F can be increased and the load on the impacted vehicle can be reduced.



t_A = Contact between passenger and Sideairbag doorbolster

t_T = Time point for the largest relative velocity between the Passenger and the Door trim

t_R = Time point for the same velocity between the Passenger and the Door trim

t_F = Time point for full side structure deformation

s_A = Free Passenger Room

s_T = Deformation Door

s_R = Deformation Bolster/Airbag/Passenger

s_F = Deformation of vehicle front

Fig. 12-41: Velocity-Time-Graph with Side Impacts

The acceleration of the impacted vehicle begins at time t=0, while the passenger acceleration starts at time t_A only after the free deformation travel s_A via the contact with the door inside and has its maximum within the range at t_T. At this time, the relative velocities between the passenger and the door are the largest.

The shortening of the time between impact and contact to the inner door leads to a reduction of the passenger loads. The run of the passenger velocity graph within the range between t_A and t_R, which should be uniform and without acceleration points, can be changed by additional padding measures (padding) or airbag systems. The thickness of the upholstery, which affects the length of the deceleration distance line, is mostly limited by the close building area in the range of the side door. With use of airbag systems, the free deformation travel s_A until deceleration can additionally be reduced apart from the extension of the deceleration distance line.

Starting from time t_R, the door width and the deformation possibility of the upholstery and the restraint system is limited, so that the speed of the bumper v_{Bumper} corresponds to the speed of the passenger $v_{passenger}$. The relative velocity between the passenger and the impacted vehicle thereafter becomes ever smaller until the end of the side impact, when all speeds are equal. The improvement of passenger safety can thus be reached by constructional measures by the vehicle side structure, by upholstery or by adaptive airbag systems.

12.2.1.1 Side and Thorax Airbag System

The side airbag system of the actual development level consists of the so-called thorax or side airbag and a window bag, which protects against head injuries. In Fig. 12-42, the two designs used for the thorax airbag are represented, the left airbag is integrated in the door trim and the right one is integrated in the backrest. With systems in the backrest the inflation direction results perpendicular to the passenger, and with the installation in the door lining, results a inflation direction towards the passenger as well. This leads to an increased hazard potential e.g. for small passengers.

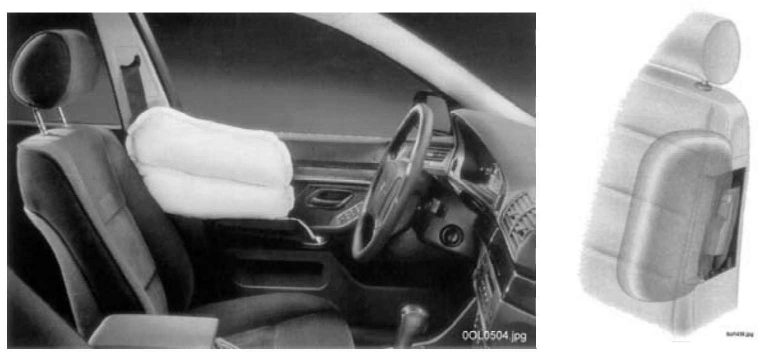


Fig. 12-42: Constructional Forms of Thorax and Side Airbags

Both of the thorax airbag systems are unfolded between the door frame and the passenger into the pillar or door. This causes an enlargement of the load application on the surface and a simultaneous absorption of the impact by driving the air out from the air cushion. Side airbags usually have a volume of 15-20 l and like the frontal airbags, they can be filled by gas generators with solid fuel (about 60 g fuel) or by hybrid generators (2 g of ignition pellets, 15 g heating charge and pressure bottle).

The timely operational sequence of the blowing-up of a side airbag is represented in Fig. 12-43.

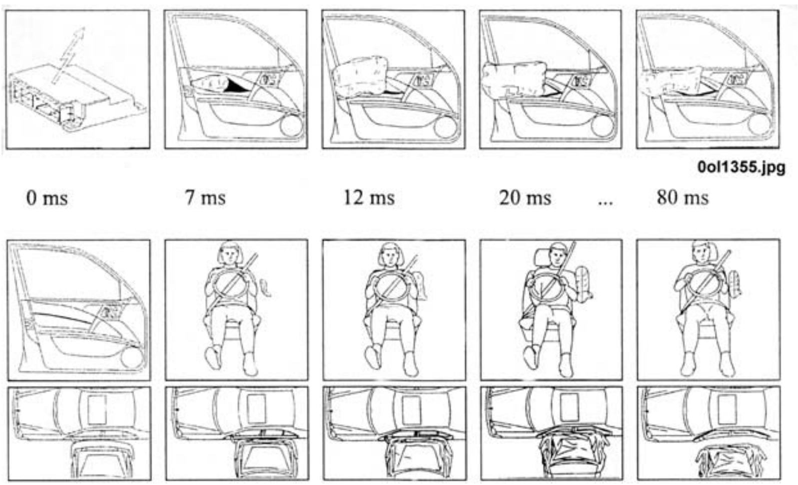


Fig. 12-43: Blowing up procedure of Side Airbag

Compared to a frontal airbag, the ignition impulse of a side airbag after impact must take place within 5 to 10 ms depending on the opponent's velocity. The reason is the small existing deformation zone and which does not allow 20-30 ms until ignition as the driver airbag system does. The complete blowing up must be finished after further 15 to 20 ms (driver airbag 85 ms), since it otherwise leads to a direct contact between the penetrating door and the passenger.

The maximum impact speed, with which the pasenger's protection can still be provided, is dependent on the needs of the reaction rate of the system up to the ignition impulse and the system-dependent blowing up time of the airbags.

12.2.1.2 Head Airbag Systems

Fig. 12-44shows two different forms of head airbag systems. On the left a window-bag is represented that opens in the form of a curtain at the side windows extending from the A- to the C-pillar. The window-bag accommodated in the roof frame is filled by a tube generator installed at the back window framework or in the C-pillar. In Fig. 12-44, on the right the ITS system side is represented (**I**nflatable **T**ubular **S**tructure) and it shortens the unfolding of the window-bag between the head and the disk. In this case, the window bag is implemented as a flexible tube. By the internal pressure, the existing wound out fibre hose shortens and stretches between the outside mirror and the upper edge of the rear side window. Thereby an adjustment is provided for the different passenger sizes. Both systems are used in combination with a thorax airbag and blown up to remain for longer time in case of an impact.

Fig. 12-44: Head Airbag Systems, Window airbag left and ITS System right

12.2.1.3 Sensing Concepts

With the side airbag, as with the frontal airbag, in dependence to the number of airbags, different sensing concepts were realized; they are represented in Fig. 12-45 from left to the right:

- a central sensor in the middle tunnel
- two sensors in the range of the side sills and one in the central control unit of the frontal airbags which are electronically released
- sensor in the central control unit and two sensors at the rear door sills
- four sensors distributed outside at the seats and an integrated control unit at the central tunnel

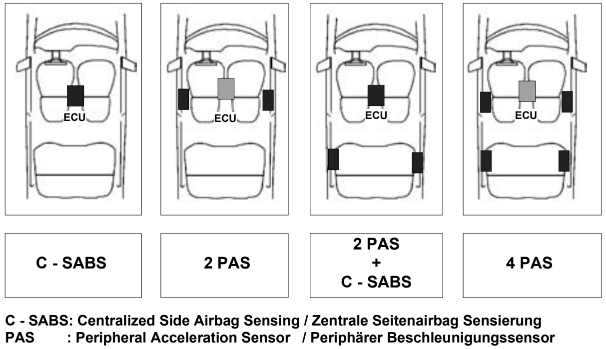


Fig. 12-45: Sensing Concepts for Side Impacts

As sensors silicon acceleration adaptors are used and in addition, pressure sensors in the B-pillar or deformation sensors on the side impact protection in the door.

Central Side Impact-Sensing

The quality of the determined signal (here the acceleration signal) strongly depends on the distance and the relative position of the sensor to the place of impact. The computation of the characteristic values and the output of an ignition impulse retards, the longer the transmission path and the larger the absorption on the transmission path gets. Additionally the positioning of a sensor in an oscillation-sensitive zone can, by the excitation of the impact, lead to incorrect signals (Fig. 12-46). Therefore the sensors should be positioned as near as possible to the impact zone (see Upfront sensing frontal impact).

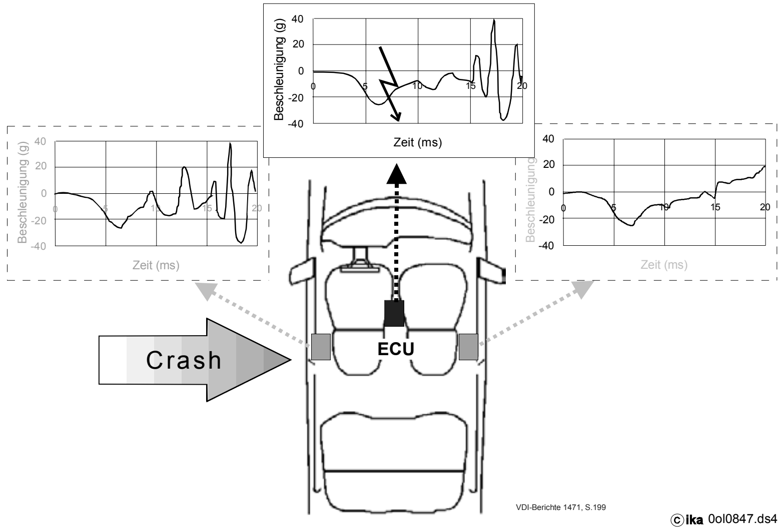


Fig. 12-46: Central Side Crash Sensing

Decentralized Side Crash-Sensing

With the use of four sensors, an exact location of the place of impact is possible, so that, as a function of accident weight, only one side airbag or both the side airbags of the concerned side are ignited. A central sensor at the central tunnel would not have received useful signals for a release in the case of decentralized impact and in case of the resulting turn of the vehicle (Fig. 12-47).

In order not to provoke double release from the front and the side airbags during diagonal impact, frontal airbags activate up to an impact angle of ±30° to the driving direction and the side airbags only at an impact angle starting from 35° to the driving direction.

Also with the side airbag, the seat allocation and the child seat recognition influence the possible ignition of airbags.

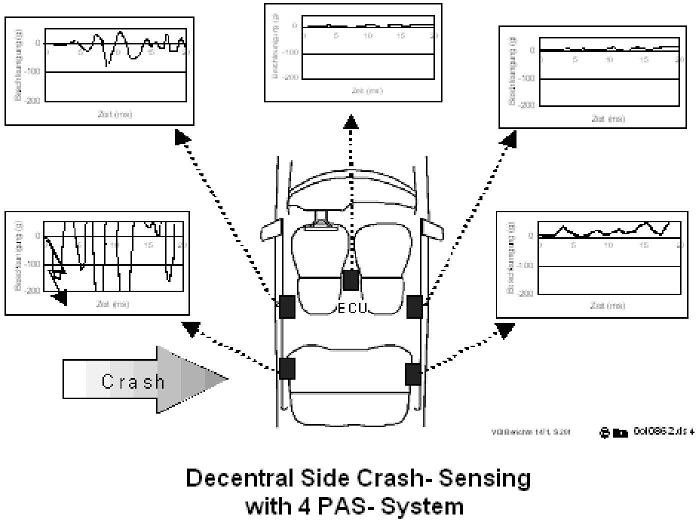


Fig. 12-47: Decentralized Side Crash-Sensing

12.2.1.4 Misuse-Boundary Conditions

But even when using sensors within the impact range, so-called misuse boundary conditions (not release-relevant impact procedures) can, with high decelerations of the body, lead to false signal initiations by the short gate trigger time areas. Apart from the development of the system weaknesses, also inadvertent releases are therefore analyzed at a later stage. Besides an impact of a cyclist and a hard door-slam, also the lateral impact against a curbstone represents a misuse boundary condition for the side airbag sensing. Despite high vehicle accelerations, the passenger loads with a curb impact is so small that a side airbag solution is not effective. In order to be able to reproduce such an impact and the preceding slide procedure, sled tests similar as in the case of the pole impact are accomplished.

For this, a test vehicle is set up on a component sled on two friction linings transverse to the driving direction. With this test, the entire test set-up is accelerated and only the sled at the crash impact block over the deformation elements is slowed down, whereby the test vehicle slips freely and laterally on the linings. At the sled a curb weight is attached in the form of high metal bases with a height of 10 cm in desired position for simulation purposes, against which the vehicle hits sliding with a fixed speed (Fig. 12-48).

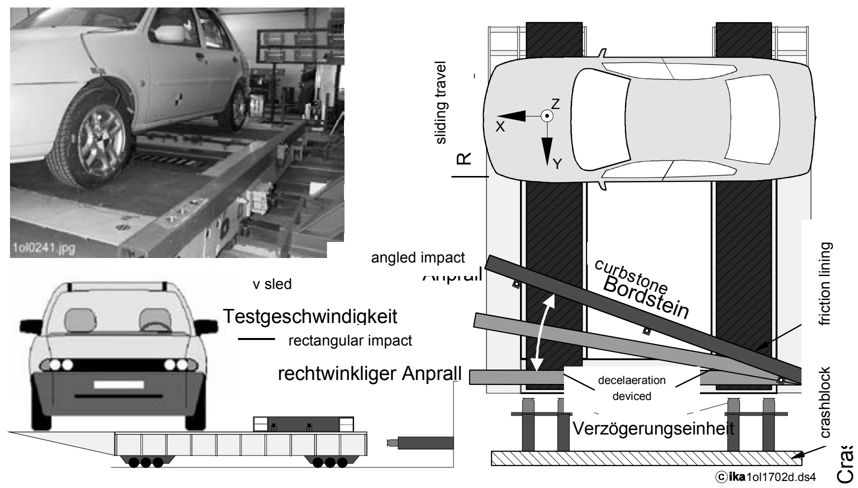


Fig. 12-48: Test Setup for Sled Tests

At the impact block, the deceleration mechanism for the sled is installed as a buckling brake tube assembly, and a rebound movement of the sled is prevented by a roll back brake.

Due to the inertial mass, the vehicle begins to slip after the impact on the sled surface. Depending upon the friction value of the lining, more or less strong lateral distortion of the chassis is caused during the slide phase. For the maximum deceleration of the vehicle, both of the wheels must impact at the same time at the pavement. After the impact, a rotating motion of the vehicle is developed around the longitudinal axis. During the test, the acceleration signals at the sensor positions of the side airbag systems are noted. Fig. 12-49 shows an impact against the pavement with a speed of 11 kph.

Fig. 12-49: Process of a right-angled curb impact

Due to different test boundary conditions, a purposeful influence of the vehicle reactions and the sensor signals is possible, which can be increased up to a provoked false releasing of the side airbag systems. At the approach speed of the sled and the length of sliding, the impact speed of the vehicle against the pavement can directly be changed. A pavement and an adjustment of the vehicle made under an angle make a deferred impact of the front and rear wheels possible. A change of the distorting chassis is realized by different friction values of the used platforms. The form and the height of the used pavement represent a further parameter for curb impacts.

12.2.2 Alternative Door Concepts

For the improvement of side impact protection different door concepts were developed and realized in a special research branch of the BMFT.

For the improvement of the side impact protection an alternative concept is represented in Fig. 12-50 in opposite to a steel door, which was developed using GRP components materials, consisting of a laminated interior and outer shell, which are filled with a foam core and stuck with one another. Additionally, both on the course and on pressure side, a loadable element is integrated between the hinges and the bolt for additional reinforcement. Contrary to a conventional steel door, the danger of injury by sharp edges or fragment within the range of the internal door has to be excluded by an upholstery of the inside panel.

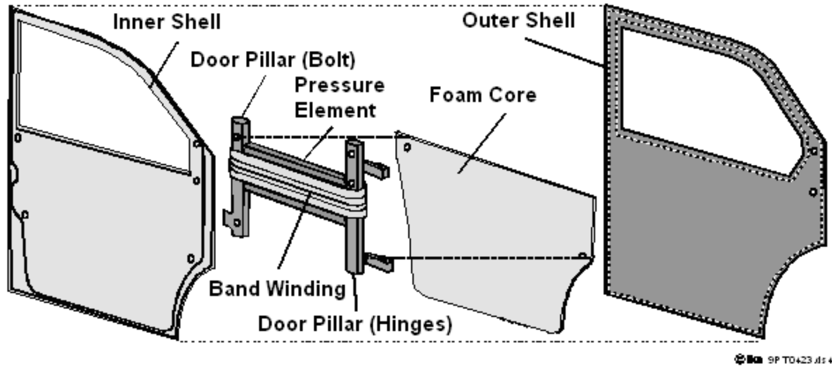


Fig. 12-50: Side Door made from Fiber Composite Material

With a direct comparison of the plastic door against a conventional steel door, an improvement of the maximum dynamic intrusion of 15 % could be achieved in the case of the lateral pole impact at a speed of 25 kph (Fig. 12-51). Due to the highly flexible portion of the door, also the available rescue area for the ambulance becomes larger by the door's springback.

steel door plastic door

Fig. 12-51: Intrusion after Dynamic Tests with Steel and Plastic Door

Fig. 12-52 shows determined load-deflection graphs of a sandwiched/strain related component and a door impact bracket made of steel for quasi-static examinations according to FMVSS 214.

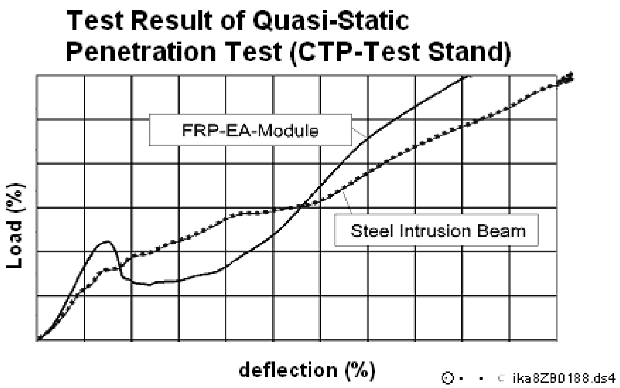


Fig. 12-52: Load-Deflection-Diagram for different Impact Beams

13 Pre-and post-crash systems

Present safety systems can be classified considering the criteria of active and passive safety. Active safety systems support the driver in accident avoidance. The grade of support ranges from acoustic or visual warnings to interventions in the break or steering system (e.g. ESP II). Passive safety systems can be understood as protecting mechanisms which contribute to the reduction or the avoidance of the accident consequences (e.g. restraint systems and airbags). A classification considering the activation timing in the accident process results in active systems, which are activated before the accident, and passive systems, which are activated after the accident.

Pre-crash systems are a combination of active and passive safety systems. Until now the primary approach in the vehicle safety was the reduction of accident's aftermaths. The sensors didn't provide any information for personal protection for available safety systems until the accident happened. However for an improved activation strategy information from a so called pre-crash phase shortly before the collision are useful. Fig. 13-1 shows the classification and a categorization of the introduced safety systems on a timing scale.

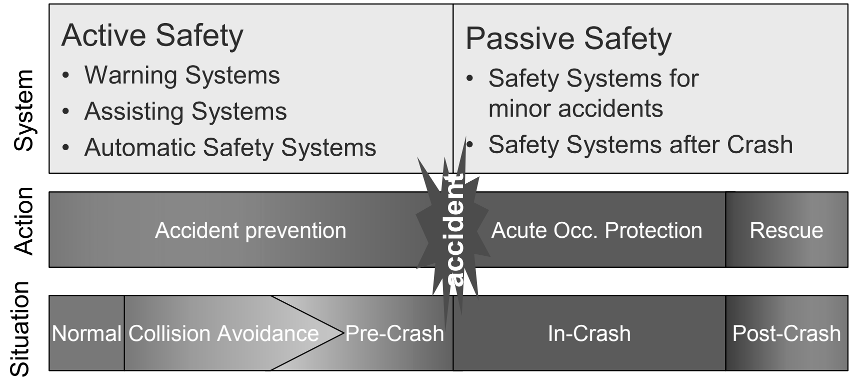


Fig. 13-1: Classification of active and passive safety

The task of the conventional protection systems is the detection of the type of accident during the collision. An estimation is made concerning the severity of the accident. Furthermore the corresponding measures of personal protection systems are triggered, e.g. the activation of airbags. For these tasks there is usually only the fractional amount of one second available.

Fig. 13-2 shows the results of investigations of the Mercedes Benz research on accidents regarding the length of the pre-crash-phase. The evaluation of 371 accidents resulted in the fact that 59 % of the collisions precede a longer pre-crash phase, which already permits conclusions on the following impact. The conclusions are available already before the collision.

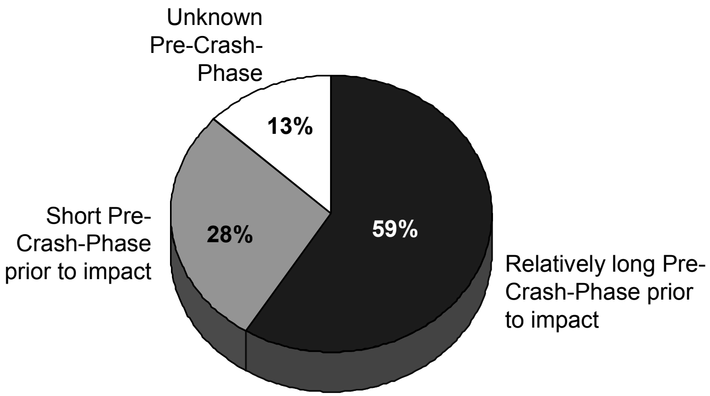


Fig. 13-2: Investigation of the pre-crash-phase by Mercedes-Benz [JUS99]

The requirements for the exact timing of the release of restraint systems (airbags, seat-belt pretensioner etc.) are derived in front-crashes primarily from the magnitude of the crash. In case of the central sensor sensing, the installed sensors are to be found in the central of the passenger compartment (see chapter 12, Fig. 12-31 and Fig. 12-32). As a result of the impact-absorbing deformation zone of a vehicle, a relatively small speed reduction arises at the point of the central crash sensor in the vehicle at the beginning of the crash phase. A necessary classification of the crash for passenger protection systems is not possible within the first 50 ms. However the airbag activation must take place within the first 30 ms after the crash. To fulfil this requirement further information about the crash have to be used. In addition upfront-sensors and pre-crash-sensors are needed [LAN99].

The upfront-sensors are built into the deformation zone of the vehicle. An early prediction of the magnitude of the crash is possible in comparison to the central sensor version. The upfront-sensor is located ahead of the central-sensor. The reduction of velocity is possible due to earlier recognition. It is evident that an even earlier recognition of the collision allows a further velocity reduction and also leads to an improved passenger protection. The use of pre-crash-sensors permits a

premature detection of an accident and represents a kind of fictitious sensor in front of the vehicle.

13.1 Definition of pre-crash-systems

The aim of the pre-crash systems is an improved passenger and partner protection in case of an inevitable collision. Pre-crash-sensors already detect an inevitable collision of the vehicle with another object before the impact. The remaining time interval up to the accident (time to collision) can be used in order to take situation-suitable preventive protection measures. Those activate relevant safety systems for the passenger protection and reduce accident aftermaths for the passengers and accident victims.

Fig. 13-3 shows accident details with and without the use of pre-crash-systems. For pre-crash-systems the remaining time interval between the time of the first recognition and the time of the accident is crucial. Here the arising accident must have been recognized, before the first velocity deceleration of the vehicle due to the accident is measurable [DOM02].

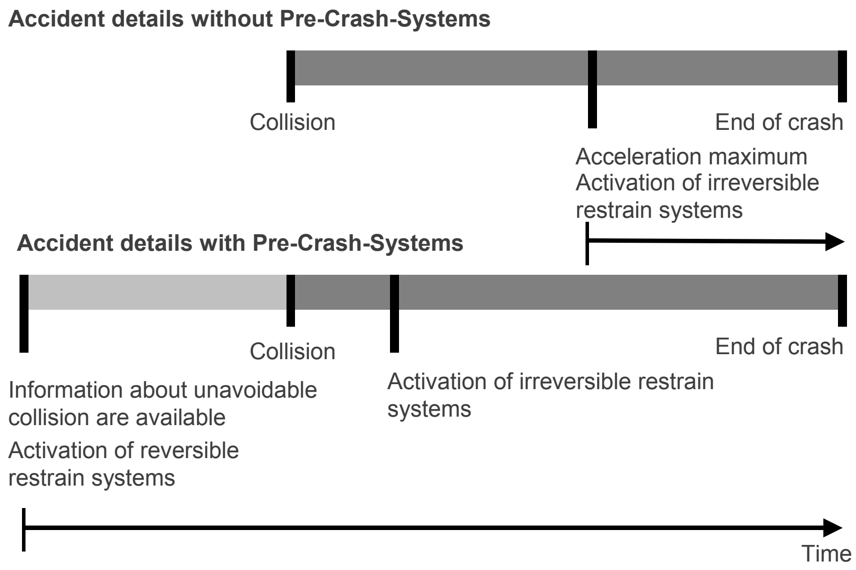


Fig. 13-3: Accident detail after a collision with and without pre-crash system after [DOM02]

In the project CHAMELEON, which was supported by the European Union, a necessary pre-crash-period of 100 ms was taken into account, in order to activate the protection mechanisms early enough [FUE01].

In the pre-crash phase of an unavoidable collision processes can be activated as for example:

- Driver warning (optical, acoustic, haptic)
- Activation of reversible restraint systems
- Initiation of measures for driver protection (seat adjustment to a favourable position, closing of the sliding roof and the windows, extendable protection cushions, knee airbags)
- Intervention of the systems in the vehicle guidance (automatic brake, brake force reinforcement)
- Disengagement of reversible energy absorption systems (building up additional crush zone, material stiffening)
- Activation of an accident recorder
- Early activation of irreversible restraint systems (airbag, seatbelt) after the confirmation of the collision
- Activation of measures to active partner protection (active engine hood, active bumper, external airbags).

Pre-crash systems are subdivided into three different function levels. The principle function is shown in Fig. 13-4.

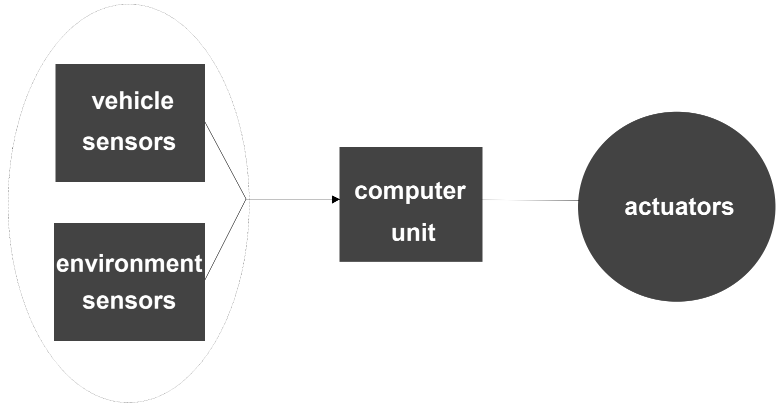


Fig. 13-4: Principle function of pre-crash-systems

Different sensors detect the vehicle state and observe the environment surrounding the vehicle. On the basis of different characteristics of the objects, for example velocity, distance, direction and classification of the objects, a micro-controller analyses the data and identifies the risk of collision, the severity of the collision and if necessary, the accurate point of time of the collision. With the data from these sensors, the relevant safety systems can react to the danger situation.

The data of powerful sensors, for example Laser scanners, Lidar sensors and Radar sensors as well as camera systems are fused in a computer. The redundancy can be used to ensure a reliable environment detection. The data fusion play an important role in the development. Fig. 13-5 shows the result of the data fusion for pre-crash-relevant systems.

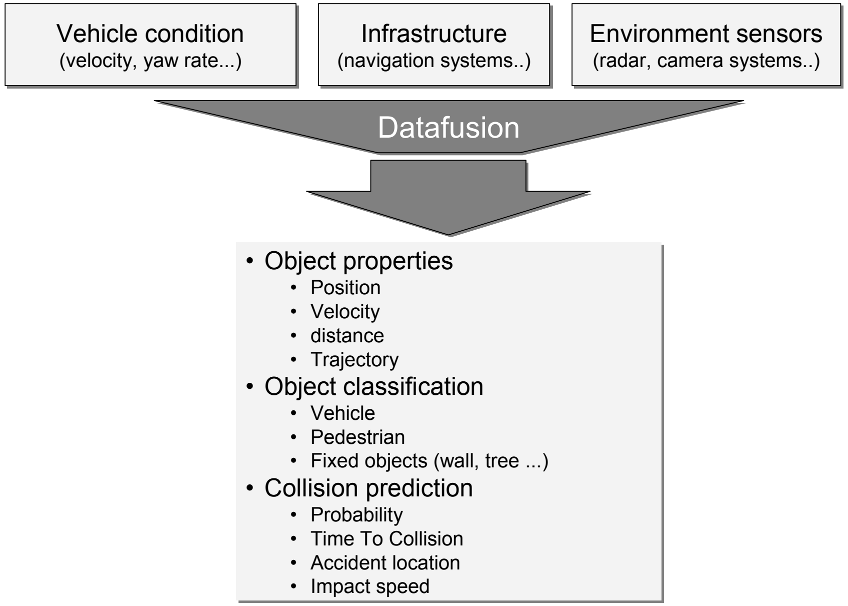


Fig. 13-5: Data fusion of different sensor systems

The microprocessor analyses the fused sensor data and predicts the collision regarding the probability of collision and the direction of impact relative to the own vehicle on the basis of the relevant object properties and the object classification.

The activation electronics of the restraint systems as well as further protection systems are activated by the corresponding information from the microprocessor. Information about the severity and the progression of the accident can be transmitted, so that the corresponding actuator for example belt pretensioner or airbags can contribute effective to the mitigation of the accident consequence.

13.2 Pre-crash developments

In the following chapter the pre-crash components, which are already introduced in the market or still in the development phase, are described more detailed. The production ready complete systems are subsequently introduced.

13.2.1 Pre-crash components

A pre-crash system consists of three significant pre-crash components: sensors, microcontroller and actuators. The sensors can be subdivided into environment sensors and sensors for the detection of the vehicle state. The most important sensors like Radar, Lidar, Laser scanner, infrared and image processing systems for the environment detection as well as the sensors for the vehicle state where already introduced in chapter 8. The necessary microcontroller and the essential signal processing are described within the lecture “Mechatronic Systems in Automotive Engineering”.

13.2.1.1 OC-systems (Occupant Classification)

Beside the already used vehicle sensors for longitudinal and lateral dynamic vehicle systems and crash sensors, the position of the vehicle occupants can be detected using sensors or seat weight detection. These information can be used additionally for airbag activation suitable to demand of the occupant.

Fig. 13-6: Occupant classification for optimal airbag activation [WES02]

In many cases vehicle occupants, who suffer severe or deadly injury caused by an unfolding airbag during a collision, are sitting too close to the airbag at the time of activation. This situation can be due to different possibilities. The unconsciousness of an occupant during the collision, a hard brake before the collision, multiple collisions by several vehicles, wrong installed child seats or a late activation of the airbag can be reasons for the necessary application of position detection.

The seat occupation detection represents the first stage of occupant classification systems. It prevents the unnecessary activation of airbags in case of an unoccupied seat. The system works with sensitive pressure mats located under the seat cushion, which activate the airbag over a specified limit. Associated with a seatbelt detection an adjustment of the airbag characteristics can additionally take place. In case of a system failure the airbags remain active.

In the second stage the child seats and their direction can be detected via internal sending/receiving units in the seats, which prevent the activation of the involved airbags. In case of a system failure the airbag is deactivated.

In the third stage the occupants are distinguished from other objects in the vehicle. Different occupants weights and heights are also specified. This is conducted by measurements of the body forces and pressure distribution with pressure-sensitive mats in the seat cushion. An adjustment of the airbag strength towards the occupants can thus be carried out.

In the fourth and the last stage, among the other things the sitting position of the occupants is identified by optic or electro-magnetic Sensors. The sitting position and the location of the occupants can be taken into account during the airbag disengagement, or the other restraint systems can be activated before the disengagement of the airbag. This brings the occupants into the optimal sitting position [NEU01].

13.2.1.2 Restrain systems

Pre-crash restrain systems for personal protection can be distinguished between reversible and irreversible systems. Irreversible systems are nowadays activated via pyrotechnics, so that the desired protection measures are available in split second (see also chapter 12).

The vehicle must be maintained after every activation of irreversible systems. The maintenance results in additional costs. Moreover incorrect activations can hurt the occupants and lead to dangerous traffic situations (e.g. sight interference by false airbag disengagement during driving). Therefore the activation threshold of the irreversible systems is set significantly higher then that of the reversible systems. The requirements to the corresponding pre-crash sensors to ensure a reliable collision detection are thus also significantly higher then the requirements to the sensors of reversible systems. Nowadays reversible systems are driven by electric motors or via fluid techniques. The resulting principle-conditioned time span to the complete activation requires an early accident detection by the pre-crash-sensors. The activation threshold of reversible restraint systems can be set significantly lower, because although the driver is distracted from the driving task in the conflict situation, he is still able to accomplish his driving task. After an incorrect disengagement the reversible systems are ready for use after a short time span.

Another field of restraint systems are seat belts. In case an upcoming collision is identified by the pre-crash system, new-developed seat belt systems can be reversibly pre-tightened. The belt loose is drawn in by an electric motor and the belts are fastened closely against the body of the occupants. This is especially advantageous with thick winter clothes, which normally allow too much seat belt loose.

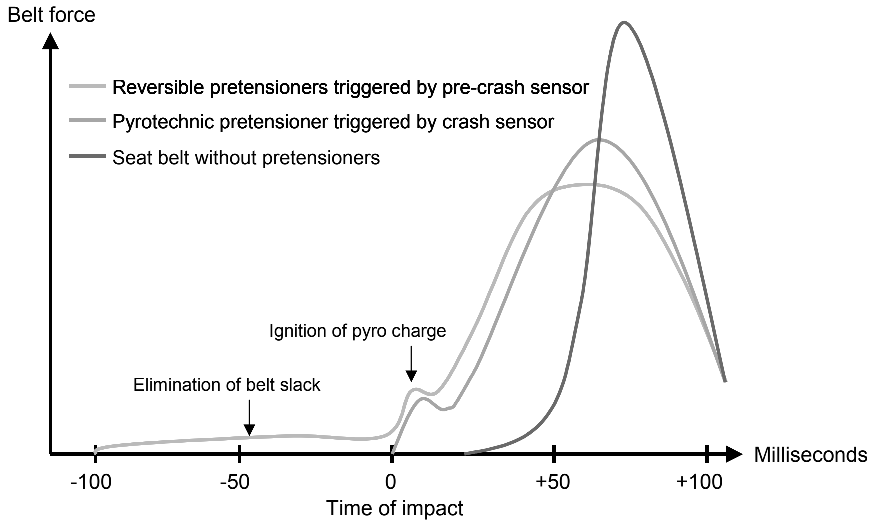


Fig. 13-7: Belt forces due to different belt systems [WES02]

Fig. 13-7 shows a comparison of the belt forces between seat belts with and without pre-tightening over a time span of 100 ms before and after the collision. Additionally it is distinguished between reversible and irreversible seat belts tightened by crash- and pre-crash-sensors. The level of maximal belt forces with pre-tightening is significantly lower in comparison to the level without pre-tightening. Besides an optimised sitting position for the airbag systems, a reversible seat belt with pre-tightening in comparison to a system without pre-tightening can also reduce the belt forces on the occupants body. Furthermore the temporal characteristics of the belt forces of the reversible restraint systems can be improved by using pre-tightening and the belt force acts earlier on the body.

Fig. 13-8 shows some examples for reversible per-load belts, which can be tightened via electric motors. These are nowadays already applied in pre-crash-systems e.g. of DaimlerChrysler, Toyota or Nissan.

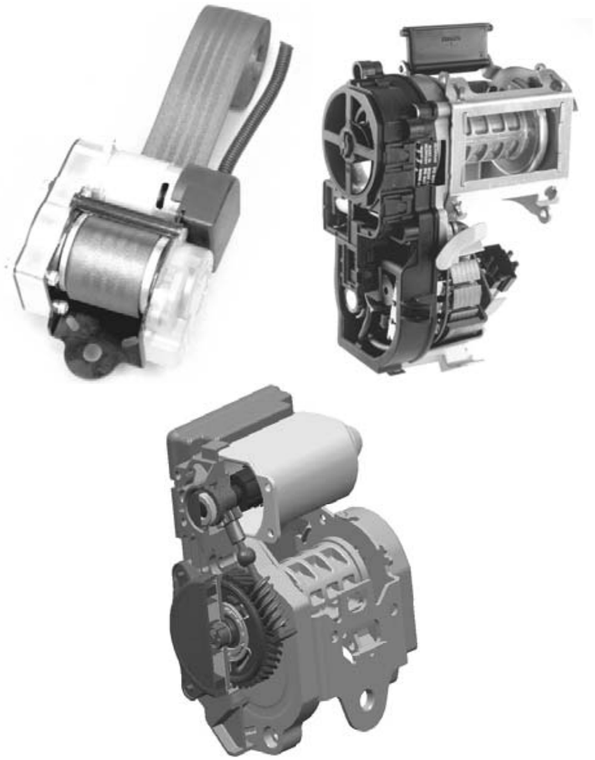


Fig. 13-8: Reversible restraint systems of Denso, DaimlerChrysler and Autoliv

Another field of restraint systems is represented by airbags. The development of irreversible airbag systems for the application in pre-crash-systems is not far proceeded yet. Based on available sensor information it is possible to realize an earlier activation compared to the present airbags, so that the risk of airbag injury can be minimized. The subsystems of multi-level airbags can also be activated before the collision.

External airbags as active crash-structures as well as external airbags for active partner protection are to be discussed in the following chapters.

13.2.1.3 Active protection of partners

Active pedestrian protection systems were already partially detailed introduced in chapter 11. Besides the active engine hood as a safety solution for the head impact area, other systems are still in development (Fig. 13-9).

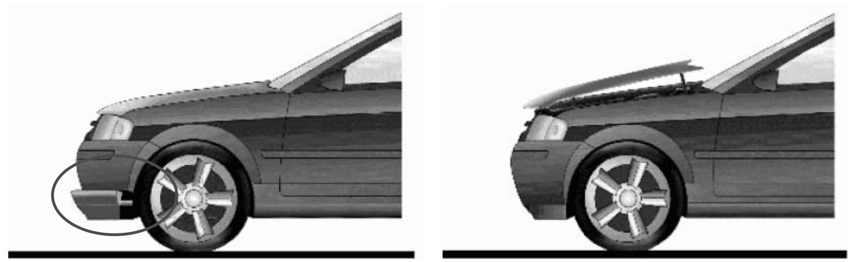


Fig. 13-9: Active bumpers and active hood for pedestrian protection [HOF01]

In case the pre-crash sensor detects a frontal collision with a pedestrian, active bumpers, which are designed in a way that the contour, the position and the deformability are according to the biomechanical load of human bodies, can be deployed. In case of a collision the lower leg can thus be supported effectively. If the accident is avoided in the last moment, the deployed cross bar can be set back to the original position. This doesn’t incur any maintenance costs.

Nowadays the energy-absorbing elements on the bumpers, the so called impact-absorber, are already applied. They hold the repair costs of bagatelle damage as low as possible, for example accidents with low velocities e.g. parking accidents. They also provide a higher pedestrian protection during collision because of their flexibility.

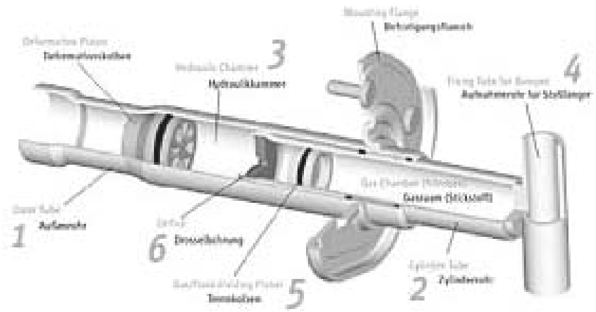


Fig. 13-10: Impact absorber from ZF Boge-Elastmetall [ZFB04]

Another development area of pre-crash components in partner protection are external airbag systems. Fig. 13-10 shows a collision protection for pedestrians and cyclists. The vehicle parts of the body shell are covered by an airbag system that is unfoldable before the collision. However until now there are only patents registrations and feasibility studies published from the manufacturers and the suppliers. The concept study Safety Concept Car (SCC) of Volvo can be taken as an example. An external airbag between engine hood and the windscreen avoids the impact of the head of the pedestrians and the cyclists on the glass. The Ford Motor company also integrated an external airbag in the Ford Explorer. These airbags, which are integrated at the windscreen and at the vehicle front, also protect the occupants during a frontal collision besides the pedestrians and cyclists.

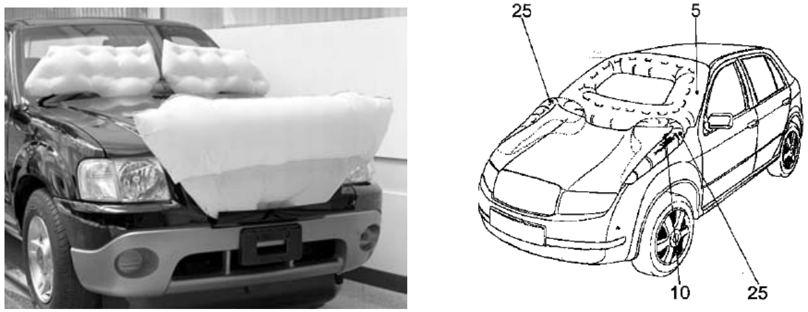


Fig. 13-11: External airbags for pedestrian protection (left: Ford Explorer, right: patent DE10014832A1)

13.2.1.4 Active crash structures

At present active bumper for pre-crash systems are in development. Fig. 13-11 shows a perspective for the possible bumpers in the upcoming pre-crash-generations. The basic idea is an extension of the vehicle frontal structure to absorb energy in case of collisions.

Fig. 13-12: Adaptive crash structures in future pre-crash-systems

At present there are only patents registrations about active crash-structures for pre-crash applications. Pre-crash airbag systems should be able to reduce the collision velocity between the vehicle and the collision object and thus the kinetic energy of the collision. Fig. 13-12 shows for example a patent registration for an external airbag system in the function of an active bumper as an example.

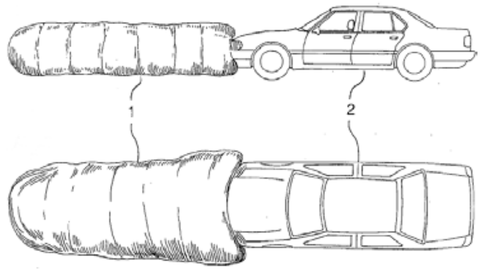


Fig. 13-13: Patent registration DE10329180A1: pre-crash-deceleration element

Another approach is the concept of changing material structures, which happens before the impact, so that the frontal vehicle structures are stiffened and adjusted to the expected collision severity (depending on the kinetic energy being absorbed and the type of the accident partner).

13.2.2 Collision mitigation

In case a critical situation occurs in the pre-crash-phase, the measures to mitigate collision consequences, which intervene in the vehicle dynamics, the so called collision mitigation, can be initiated.

Collision mitigation by braking specifies an automatic emergency brake system, which initiates autonomously a braking manoeuvre in order to avoid or to mitigate a possible crash. The brake takes place at a point of time before the crash, at which the driver is no longer able to avoid the accident.

For a standing target vehicle the distance, in which an evading manoeuvre is still possible (see Fig. 13-14), can be calculated under the assumption of a circular evading trajectory after the following equation.

The minimal distance for an evading manoeuvre results from the estimation of the radius of the evading trajectory after the equation of lateral dynamic:

$$R = \frac{v^2}{a_{lateral,max}} \qquad \text{Eq. 13-1}$$

with:

R: Radius of the evading trajectory [m]

v: own velocity [m/s]

$a_{lateral,max}$: maximal possible lateral acceleration [m/s²]

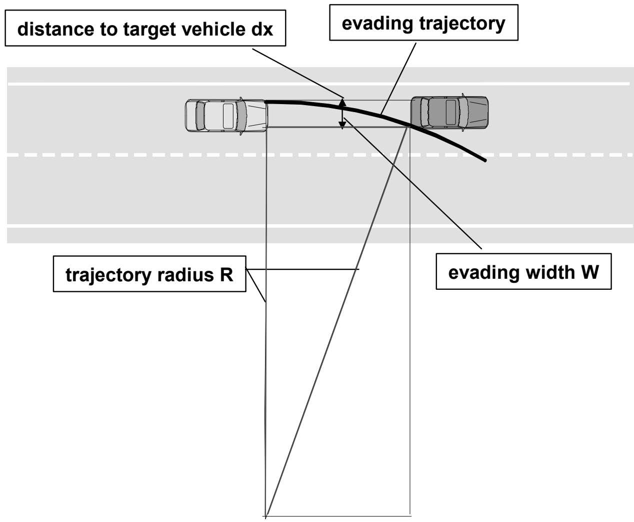


Fig. 13-14: Principle sketch of a collision avoidance manoeuvre

The Pythagoras from the triangle between the vehicle and the centre can be expressed as:

$$(R - W)^2 + dx^2 = R^2 \qquad \text{Eq. 13-2}$$
$$\Rightarrow dx = \sqrt{R^2 - (R - W)^2} = \sqrt{2R \cdot W - W^2}$$

Combining the equations Eq. 13-1 and Eq. 13-2 results the minimal distance, by which an evading manoeuvre is still possible. By a smaller longitudinal distance to the target vehicle an evading manoeuvre is not possible any more.

$$dx_{min,avoidance} = \sqrt{2\frac{v^2}{a_{lateral,max}} \cdot B - B^2} \qquad \text{Eq. 13-3}$$

As well as through an evading manoeuvre a collision can also be avoided through a braking manoeuvre. The minimal longitudinal distance, by which a braking manoeuvre is still possible results from the following cinematic.

$$dx_{min,braking} = \frac{v^2}{2a_{longitudinal,max}} \qquad \text{Eq. 13-4}$$

with:

$dx_{min,braking}$: Minimal distance, by which a braking manoeuvres to avoid

collision possible is [m]

v: own velocity [m/s]

$a_{longitudinal,max}$: Maximal possible deceleration [m/s²]

With both equations Eq. 13-3 and Eq. 13-4 the accident possibility in case of a standing vehicle can be estimated. Fig. 13-15 shows the minimal distance to avoid a collision by evading and braking depending on the own velocity. For these diagrams the following assumptions were made based on real vehicle data

- $a_{longitudinal,max}$ = 8 m/s²
- $a_{lateral,max}$ = 6 m/s²
- W = 3 m

Although higher value for the maximal lateral acceleration and the maximal deceleration are possible in reality, those values can not be directly effective directly. The assumed values are regarded as average values.

The diagram shows that with velocities lower than 56 km/h a collision can not be avoided by evading, while it can be avoided by a braking manoeuvre. In this case braking manoeuvres are more efficient for the collision avoidance. With higher velocities evasion is more promising in comparison with braking. As a result an autonomous collision avoidance system can not intervene by a high velocity until the distance is already below the minimal braking distance. That means such a system must also be able to steer autonomously. The driver's choice would be overruled by the system otherwise, in a situation, in which the driver drives up to the target vehicle in order to conduct a close lane change. If the collision avoidance system is not able to accomplish an evading manoeuvre, a collision is unavoidable. In this case the system can only introduce an emergency braking manoeuvre, in order to reduce the crash velocity and thus to mitigate the accident consequence.

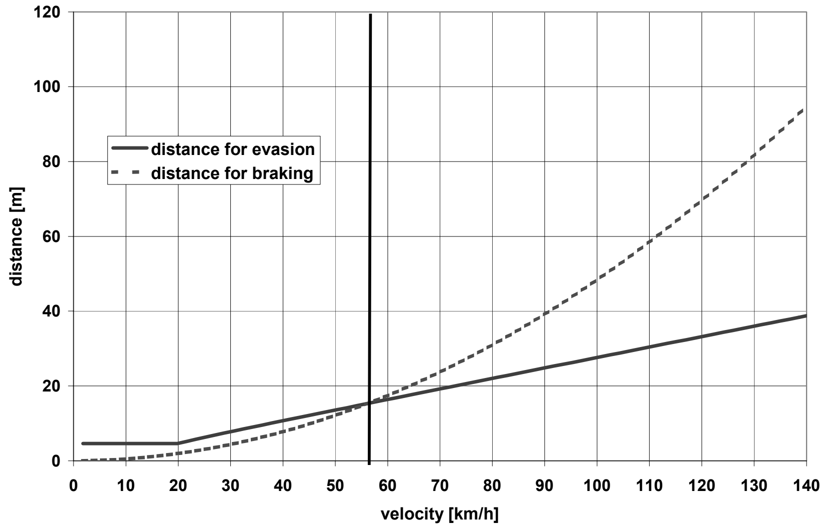


Fig. 13-15: Distances for collision avoidance through evading and braking dependent on the vehicle velocity

In the low velocity range (see Fig. 13-15, velocity lower than 56 km/h) a system, which just works in longitudinal direction, can also be introduced as a collision avoidance system. In this case the system is to be activated at the moment the driver can not avoid the collision by neither braking or steering. Therefore the driver will not be overruled by the system.

For a velocity below 20 km/h the distance at which an accident can be avoided by evading manoeuvres is constant, because the evading trajectory is limited by the turning radius of the vehicle. The turning radius is limited to 5 m in the last example.

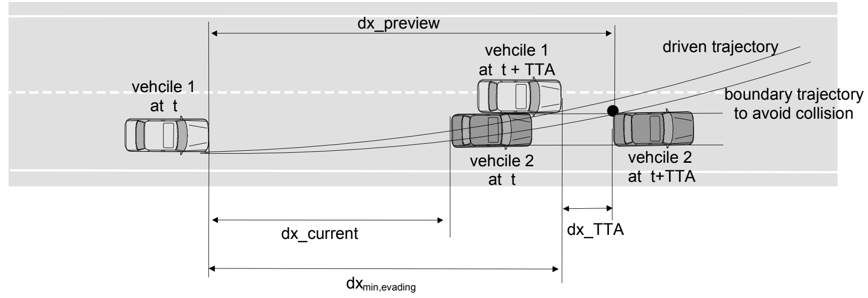


Fig. 13-16: Avoiding trajectory with a moving target vehicle

The described equations apply in case a standing vehicle is assumed as the target. Moving vehicles as targets are to be considered in the following. In this case the actual distance is not of special interest, rather the distance at the point of time, when both vehicles have a lateral offset to each other. This offset is needed to avoid the accident (see Fig. 13-16 (transparent vehicles)). The remaining time span is called the TTA (Time-to-Avoidance).

The longitudinal distance, that is needed to realize enough lateral offset for collision avoidance, depends on the velocity of the first vehicle driving, see Eq. 13-5. This distance ($dx_{min,avoidance}$) must be reached until the time TTA to avoid the crash. $dx_{min,avoidance}$ is compared with the distance $dx_{predicted,}$ which is reached at TTA. If $dx_{min,avoidence}$ is smaller than $dx_{predicted}$, then an avoiding evading manoeuvre is still possible, otherwise it is not possible.

The TTA can be calculated from the present driving state of the following vehicle:

$$dx_{min,avoidance} = v \cdot TTA + \frac{1}{2} a \cdot TTA^2 \qquad \text{Eq. 13-5}$$

with:

TTA:	Time-To-Avoidance [s]
$dx_{min,avoidance}$:	min. distance, by which an avoidance manoeuvre is possible [m]
v:	present velocity [m/s]
a:	present acceleration [m/s²]

The difference between $dx_{prädiziert}$ and $dx_{min,avoidance}$ at the point of TTA, which can be decided using the cinematic basic equations. Because the change of the state of both vehicles, the following vehicle and the target vehicle, can not be predicted, the worst possible case will be considered, in order to calculate the point of time, at which an avoiding manoeuvre is definitely impossible under any circumstances.

$$dx\_TTA = dx_{predicted} - dx_{min,avoidance} = dx_{current} + (v_{target} - v) \cdot TTA + \frac{1}{2}(a_{target,max} - a_{max}) \quad \text{Eq. 13-6}$$

with:

dx_TTA:	distance to target at time TTA [m]
$dx_{predicted}$:	estimated distance to target at time TTA, closing vehicle at present position [m]
$dx_{min,avoidance}$:	necessary distance to reach lateral offset [m]
$dx_{current}$:	present distance to target [m]
v_{target}:	present velocity of target [m/s]
v:	present velocity of closing vehicle [m/s]
$a_{target,max}$:	unfavourable acceleration of target [m/s²]
a_{max}:	unfavourable acceleration of closing vehicle [m/s²]
TTA:	Time-To-Avoidance [s]

With Eq. 13-6 can be decided, whether a collision avoidance by evasion is possible. If dx_TTA is bigger than zero, then a evading manoeuvre is possible, otherwise it is not possible.

In case of a braking manoeuvre the TTA specifies the needed time, in order to decelerate the following vehicle to a relative velocity of zero. The needed distance ($dx_{min,braking}$) for it can be calculated with Eq. 13-7.

$$dx_{min,avoidance} = v \cdot TTA + \frac{1}{2} a \cdot TTA^2 \quad \text{Eq. 13-7}$$

with:

$dx_{min,braking}$:	necessary distance to decelerate the closing vehicle down to a relative velocity of zero [m]
v:	present velocity of closing vehicle [m/s]
v_{target}:	present velocity of the target [m/s]
a_{max}:	maximal deceleration [m/s²]

With the help of the described equations a collision prediction and assessment for stationary as well as for moving targets can be realized. For the derivation of the equations a straight track is assumed. In case of curve tracks the equation for evading manoeuvre must be adapted, because the needed lateral offset can be smaller than the one on a straight track. An adjustment factor must be considered in such situations. To calculate this factor the curve radius must be known.

13.2.3 Accident-data recorder

The record of the accident data is already an important component of accident reconstruction in the aviation for a long time. The first data recorder, also called black box, were constructed by General Motors in connection with the optimisation of airbags in vehicles. In the year 1999 the ability of accident data recorder were extended, so that the velocity of the vehicle, the engine speed, the throttle position and data of the brake system could also be recorded.

In 1993 the accident data recorder 2165 of VDO-Kienzle was introduced in Germany. It records both state data e.g. of the direction indicators and the brake lights and dynamic values, which consist of longitudinal and lateral acceleration of the vehicle, its rotation around the vertical axis (measured via earth magnet sensors) as well as the wheel speed from the tachometer impulses.

State data can be gathered in normal driving operation in a total of 10 data channels. For this the accident-data recorder records the switching cycle of the connected electric consumers. In each case the switching cycle of the driving light, the driving direction indicator, the brake light and the ignition are recorded. Additionally it is possible to record the switching cycle of the parking light, the upper beam headlight, the backup light or the rear fog light as well as other electronic consumers. In a police vehicle, ambulance car or fire-brigade vehicle it is also possible to record the operation state of the blue/red light or the siren. The storage of the driving dynamical data and the state data takes place time-referenced. Different sampling rates are realized based on the different dynamical ranges and the signal forms.

- acceleration: 500 Hz
- yaw rate (rotation): 12,5 Hz
- control elements: 12,5 Hz
- pulse generator: 12,5 Hz

The recording of data during normal driving condition takes place continuously every 2 milliseconds (scanning frequency 500 Hz). Incoming data is stored for a given time interval by 100 ms in the so-called crash memory. In a second storage memory, the standard speed memory, a parallel storage takes place every 40 milliseconds (25 Hz). In this case the data remains stored for 30 seconds and is overwritten with new data again (ring storage principle). The new incoming data overwrites the “older” data in the memory storage. As soon as the accident recorder detects a collision (A trigger condition it met: a particular "vibration limit value" is reached) all recorded data will be frozen in the memory. In this case data from the post-crash-phase is recorded for another 15 seconds with a scanning rate of 25 Hz. In an accident situation detailed information about the pre-crash-phase (30 seconds/25 Hz, 100 milliseconds/500 Hz) and the post-crash-phase (15 seconds/25 Hz, 100 milliseconds 500 Hz) is stored in the accident data recorder.

In order to detect the vehicle movement in the post-crash-phase, for example during the clearing of the accident site, another 30 min of movement signals are being recorded and stored with an 2 Hz resolution. This post-crash data can provide valuable information regarding the accident sequence in case of a mass accident or in case of multiple rear-end collisions. An exact reconstruction of the accident events can be composed. A more exact evaluation of the respective question of guilt becomes possible [HAR03].

Another accident data recorder, the so-called SAFEcorder, is distributed by Perform Tech AG. The recorder collects information about all possible vehicle motions. It is equipped with a GPS and GSM module and can send data regarding the accident site and time to the next emergency station in case of an accident. The SAFEcorder can also be used for accident analysis. The use of this function and the performance of the accident recorder is the collection of data and the processing of this data [WWW04].

Fig. 13-17: Accident data recorder and recording sheet [USD04]

13.2.4 Overall systems

The increasing customer preference for safer vehicles encourages the development of pre-crash systems. Thus DaimlerChrysler took over the role of a pioneer and integrated the so-called Pre-Safe system into the S-class in the year 2003. Other manufacturers, particularly from Japan, are developing early accident recognition systems and therefore safety systems, which are integrated into the

new vehicle generations. The following examples show the function range of available pre-crash-systems today.

Pre-Safe

In the autumn of 2002 DaimlerChrysler presented a passenger protective system called Pre-Safe, which already recognizes a possible accident in advance. The system also takes preventive measures. These measures are for example very fast pretensioning of the seat-belt slack, so that drivers and front seat passengers are in the optimum seating position before a possible collision. Another example are the airbags, which can deploy at the optimal time after the impact. This measure is only activated in case the belt is tightened and the occupant detection system recognized a passenger on the seat. At the same time Pre-Safe brings the passenger seat of the rear passengers into a favourable position and closes the sun roof automatically (see Fig. 13-18) The driver's seat is not adjusted, in order not to divert the driver from the stressful driving conditions. Thereby the components of the system are reversible. If the accident is prevented in the last moment, preventive belt lifting decreases automatically and the passengers can reset the seats and sun roof into its previous positions. Pre-Safe is immediately working again thereafter [PAS02].

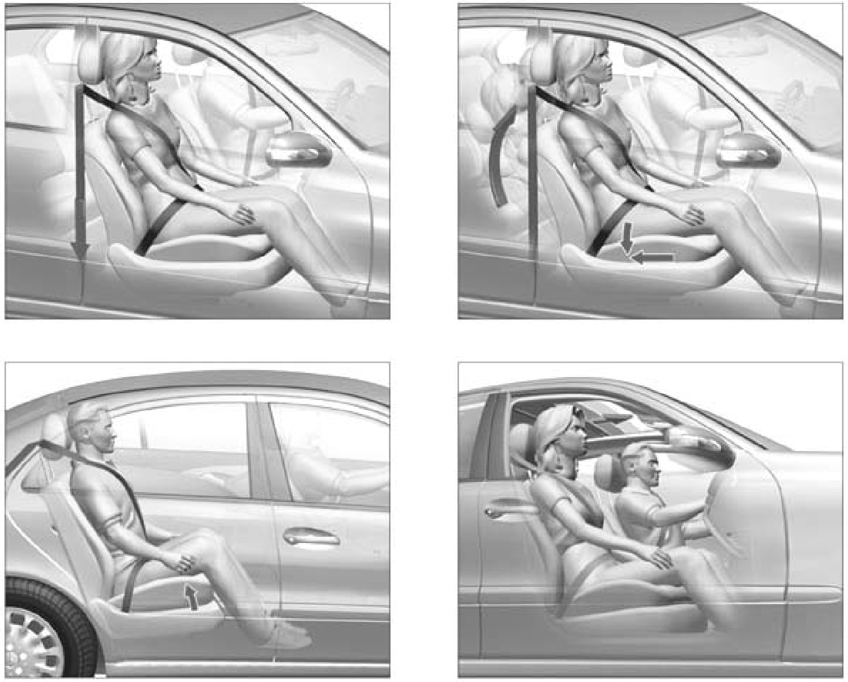


Fig. 13-18: Passenger protection system Pre-Safe [WWW01]

Pre-Safe uses the time before the impact to change from the comfort into the safety mode. Therefore reversible electric driven systems (e.g. electrical belt pretensioner) are necessary (shown in Fig. 13-19). However the conventional, pyrotechnic systems are only activated during the crash. For this active security measures the necessary sensor technology of the passive safety systems is used.

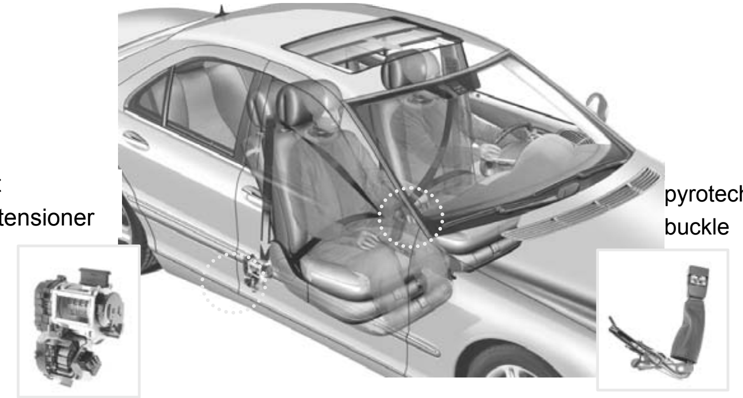


Fig. 13-19: Belt pretensioner of the Pre-Safe-system

For the preventive accident recognition Pre-Safe uses sensors of the electronic stability program ESP and the brake assistant. Another activation criteria for Pre-Safe is the operating speed of the brake pedal [PAS02]. Pre-Safe detects crash situations only indirect without independent pre-crash-sensor technology. Since only reversible systems are used, no subsequent measures are necessary in the case of a false alarm.

In the future a further developed Pre-Safe system can have additional features. Possible are out of position corrections for the seat belt and the airbag, the preventive movement of energy absorbing cushion (e.g. for a reversible knee protection) or the preventive-adaptive adjustment of child seats. Data about the driver and front seat passenger can be coded into individual vehicle keys, so that the safety system is informed about the driving person. Relevant data can be individual parameters, like weight, size, age and sex of the person, who should be protected. Thereupon for example volume of the airbag, belt pretensioner and belt force are adjusted. The absorption level of the steering column and other safety systems can be adapted. The transmission of accident-specific data is conceivable after the accident to the rescue management (post crash) [PAS04b].

As long-term vision measures regarding the whole vehicle are possible, like for example preventive height adaptation to the increase of the impact compatibility with a frontally colliding accident opponent.

Bosch pre-crash system

In the centre of the pre-crash research activities of Bosch is the demand-responsive activation of intelligent airbag systems, dependent on accident weight and process and on the passenger presence. In addition, the pre-crash system considers other support systems, e.g. reversible belt pretensioner.

The pre-crash sensing of Bosch is divided into three different function stages:

- **Preset** (pre-crash setting of algorithm thresholds),
- **Prefire** (pre-crash firing of reversible restraints) and
- **Preact** (pre-crash engagement of active safety devices).

In the first stage (**Preset**) radar detectors supply additional information like the relative velocity to the obstacle and the expected impact time. This information is included into the deployment decision by the system. On the actual release of the restraint system the pre-crash-system decides on the basis of acceleration sensors, since the radar detectors cannot supply information about mass and condition of the colliding obstacle. With the Preset function the point of time for the deployment of the second step of the airbag release can be optimised for example. Beyond that the additional information prevents a not desired airbag release in minor accidents. Altogether the Preset function improves the recognition of crash weight and the type of accident.

In the second stage (**Prefire**) restraint systems can be demand-responsive released on the basis of pre-crash information before the impact. Since no information about the mass of the obstacle is known before the crash, it requires the development of new restriction means, for example reversible belt pretensioner, which function reversible.

The third stage (**Preact**) has the aim of reducing crash severity up to the avoidance of the accident by an active interference of the system. This can be conducted by an automatically introduced emergency braking for example. This stage within the pre-crash evolution is the one with the most demanding aims. For it's realization Bosch works on image processing technology and on long range radar as well as on the fusion of the described subsystems. The conversion of this vision requires a new system architecture and new safety strategies [ZEC01].

13.3 Post-crash systems

The post-crash phase begins with the end of the in-crash phase. Therefore the use of systems in the post-crash phase follows the pre-crash systems by means of the time flow (see Fig. 13-1). Post-crash contains the end-of-collision procedure of the vehicles as well as the following rescue management.

If an accident took place, a manual emergency call must be accomplished in general. At present there are the following possibilities available:

- emergency call box,
- telephone,
- vehicle manufacturer based emergency call systems
- and witnesses and/or other participants.

In case an accident occurs under exclusion of witnesses and/or post-crash systems, the passengers are left to their own resources. If the passengers are in no condition to place an emergency call due to serious injuries, valuable time can pass until rescue measures are provided. In Fig. 13-20the number of arising deaths over time are presented. The number of deaths is related to 1000 deaths in each case. It becomes evident that death occurs with 60 % of the accident victims in the first two hour after the injury. Over 80 % of the victim die in the first four hours after the accident took place. The figure shows great action needed in the sense of fast rescue management in order to reduce the number of deaths in traffic.

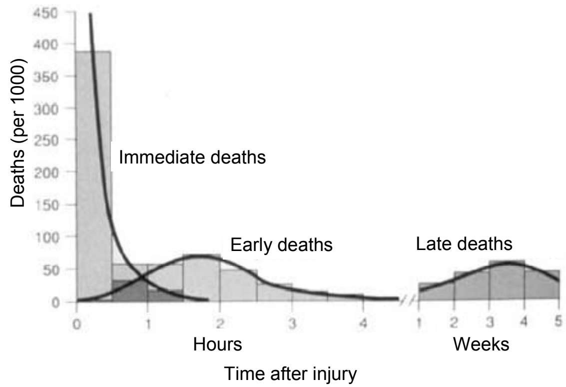


Fig. 13-20: Time curve of deaths after the accident [WAN01]

Vehicle manufacturer provide a broad range of solutions for emergency systems with the purpose to manage the post-crash phase. These systems sent emergency calls to the manufacturer's control-centre in case of an accident. The driver is connected to a call centre via a GSM connection. If the driver is in no condition to answer the call-centre the police and rescue unit is alarmed immediately. The position of the vehicle can be determined by an installed GPS system in the vehicle. In some cases the emergency call is placed manually as soon as the airbag or other crash sensors are activated.

The disadvantage of those systems are the different architectures of each manufacturer's system. Each single manufacturer provides its own technical solution and therefore no common solution is available. Furthermore those systems do not allow roaming into different European countries. The quality of information processing of the different manufacturer is dependent on the different standards in various European countries.

The post-crash systems being developed in the present try to reduce post-accident injuries and costs by providing an optimal rescue chain regarding the time and an the rescue management. Fig. 13-21 shows the concept of a modern post-crash rescue system.

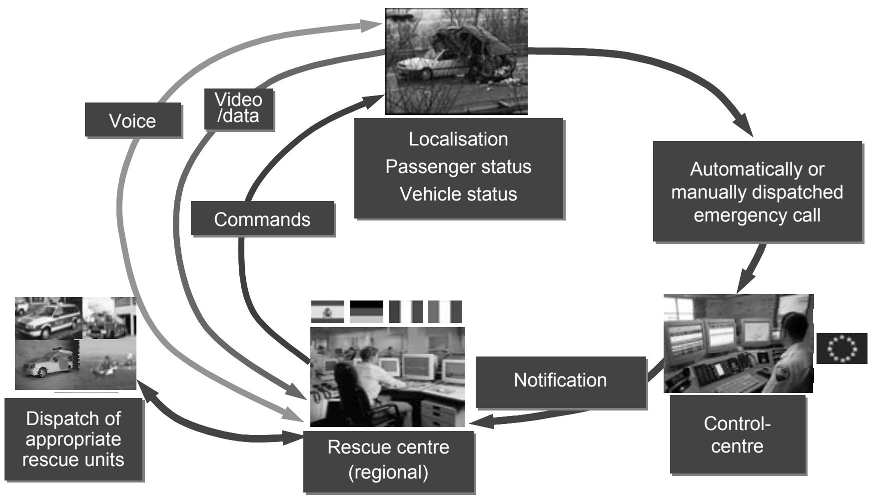


Fig. 13-21: Post-crash-system concept [DEU03]

The concept is based on a direct cooperation between the following three components:

- the **communication system**, based on GSM/GPRS-technology and a back-up satellite channel via COSPAS/SARSAT
- the **control centre**, which forwards the incoming emergency calls to the appropriate rescue unit
- **vehicle-on-board-systems** for automatic accident detection

The communication between the on-board system and the control-centre as well as the communication between the control-centre and the optimal placed rescue units has the be reliable and time critical. The communication paths are visualised by arrows in the figure. The control-centre receives the emergency call independent of the region. From here the information is transmitted to the local rescue centre. The communication with the driver or the vehicle takes place from the local rescue centre as well.

Tasks of the control centre

The approach for a situation adapted rescue management of the control-centre in case of an accident is organised as follows:

1. information collecting
   the control-centre receives automatic/manual information with the help of the on-board-systems
2. validation of accident position and time
3. information of rescue team and police on site
4. securing accident site
   closedown of highways is possible in case of a multiple collision
5. monitor information flow
   the control-centre passes information about accident to other traffic participants e.g. by radio stations
6. information exchange between control-centre and local rescue team

7. inform driver of accident vehicle about progress the automatic rescue system the degree of injuries and the number of involved persons as well as the type of accident and all additional information have to be transmitted. The degree of detail is dependent on the sensor system.

Requirements of the on-board-system

The requirements of the automatic data acquisition of the on-board system for automatic accident detection is rather complicated. The following listing shows the relevant points for a first analysis of the accident [DIC02]:

- number of occupants and passenger location before/after impact
- seat occupation
- seat belt usage
- passenger movement before/after the accident
- sex and age class
- parameters with predictive power for injury analysis
  - vehicle/crash dynamics
  - vehicle's speed when accident happens
  - airbag deployment
  - energy impact on passenger body parts
  - detection of crash impulse impact location
  - roll-over angle
  - driving dynamic parameters (3-D-movements)
- biomedical parameters
  - respiration rate
  - blood pressure
  - oxygen saturation
  - heart Rate
- passenger related seat conditions
  - seat belt used
  - position of deployed Airbag
- weather conditions (rain, fog, ice on the road,…)
- additional parameters to be transferred for accident reconstruction
  - motor-Vehicle Classification
  - automobile Classification by Size
  - automobile Classification by Weight

In order to transmit the collected data to the control-centre appropriate hardware components are necessary. Today data recording devices, which can record only single parts of the necessary relevant information, are already available in the market (see chapter 13.2.3).

The APU (AIDER-Processing-Unit) shown in Fig. 13-22 is one of the first systems developed for the special use in vehicle post-crash situations. The requirements of the components compromise the following details:

The build-in powerful computer unit must be able to execute the following system tasks [WEI03a]:

- memory: hard disk and flash memory
- hardware interface for other on-board-components
- GPS receiver / Communication antennas for
  GPS, GPRS, GSM, SARSAT/COSPAS
- biomedical processing board (which interface a dedicated bio-medical sensor)
- power supply (inclusive backup battery)
- DLU (Data Link Unit) for cellular radio connection

Fig. 13-22: APU (AIDER-Processing-Unit) [WEI03a]

Furthermore interfaces for vehicle sensors, image processing systems as well as bio-medical sensors have to be integrated into the APU. Communication antennas for GPS, GPRS, GSM and SARSAT/COSPAS are available. The human-man interface is realised with the help of a microphone, loud speakers, buzzers and buttons.

The system has to provide a GSM connection to a service provider and transmit all necessary data. The device has to survive the actual collision without damage.

Securing of an accident site

In the future vehicle-to-vehicle communication can be used in order to secure an accident site.

Accidents, especially on the autobahn, lead in most cases to mass collisions. The reason is the high density of vehicles and the high vehicle velocity. A necessary emergency brake is executed to late in case the driver is tiered or not concentrated. The accident site can be overseen, if the accident takes place in a curve or at an exit junction. An early warning of the driver can lead to the adoption of an appropriate velocity and therefore can help to minimize this type of mass collision. The transmission of the relevant information is realised by vehicle-to-vehicle communication. In case of an accident the system detects the deployment of the airbag and starts to transmit the information to the following vehicles. It is possible to transmit not just the information about the accident, but the position relative to the closing vehicles as well. The system has to determine if the accident happened on the own driving lane or for example on the next intersection. Therefore GPS-systems in the vehicles are necessary.

Fig. 13-23 shows in three steps the course of events for the securing of the accident site using vehicle-to-vehicle communication. At the time of the collision the first vehicle sends out an emergency signal. The driver of the vehicle D can therefore brake in time and avoid another collision. Vehicle D now himself sends out a message and the following vehicles reduce their velocity.

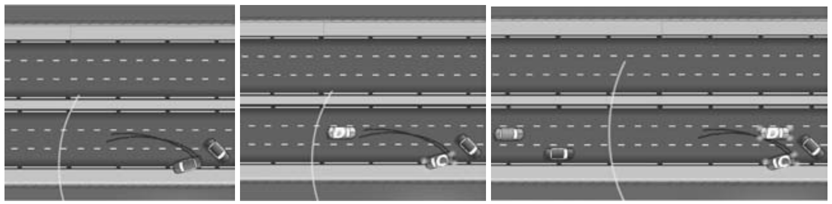


Fig. 13-23: Securing of an accident site using vehicle-to-vehicle communication [IVH03]

14 Requirements on system integrity

14.1 Development of vehicle systems

The development of automobiles shows clearly the trend of rapid increasing tendency to implement electronic systems into vehicles besides further development of mechanical components.

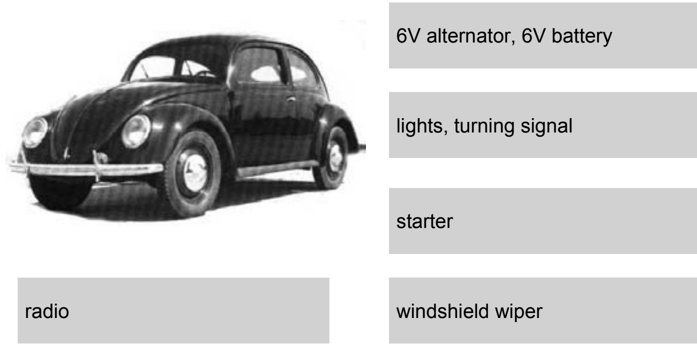


Fig. 14-1 Typical equipment of a VW Käfer in the sixties

The electrical systems of the VW Käfer (Fig. 14-1) provided only basic driving functions of the vehicle. Fig. 14-2 shows the example of the VW Phaeton, which includes 36 electronic controllers, which are connected through 3 different bus-systems, to provide the implemented functions. The three different bus-systems divide the particular functions in the three areas: power train, comfort and infotainment. For example, the CAN-bus, as seen in the picture, connects 14 electronic power train controllers. Some of the comfort and infotainment systems also use information from the power train CAN-bus, so that so called gateways are needed to crosslink the three bus systems. The number of functions that are thereby realised using the controllers of the power train CAN is a multiple of the number of these controllers. Besides the sheer number of functions, the fact, that these functions are interferencing themselves, clearly increases the systems complexity. For instance, the traction slip control is implemented in the brake controller but influences the output torque of the engine. The electronic stability program ESP is also implemented in the brake controller but strongly influences the damping controller, too. Overall the car uses an electronic system with lots of interconnected and interferencing functions and a correspondingly high complexity that strongly influences the development of modern passenger cars.

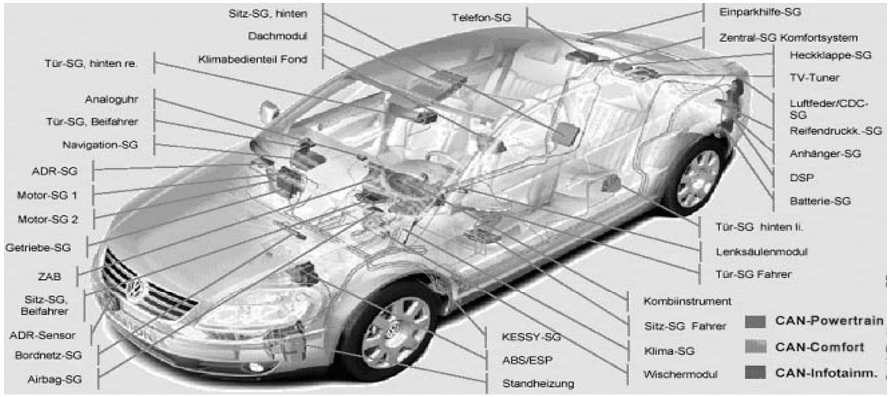


Fig. 14-2: CAN-connected components of the VW Phaeton

One of the most significant characteristics of such vehicle structures is their system architecture, which provides the possibility to systemize and compare all vehicle components and therefore will be introduced in the following section.

14.2 System architecture

A very useful way to investigate the above mentioned vehicle systems is to analyse their system architectures. The meaning of the system architecture is interpreted in various ways. Most of them focus on one certain aspect of system architecture, for example the networking of the systems is analysed only by watching the used bus systems.

To get a common understanding in the mentioned context, the following attempt of a definition is made:

The systemarchitektur defines the existance, the number, the networking and the arrangement of the used components.

Components are the used sensors and actuators, the parts of the signal and power distribution as well as the single subcomponents of the signal processing in hard- and software.

This definition is illustrated in Fig. 14-3. The essential components are the actuators, the sensors and the signal processing. The signal processing should be

differnciated further by the hardware, the way of software implementation and the functionalities that are realized using the signal proscessin component.

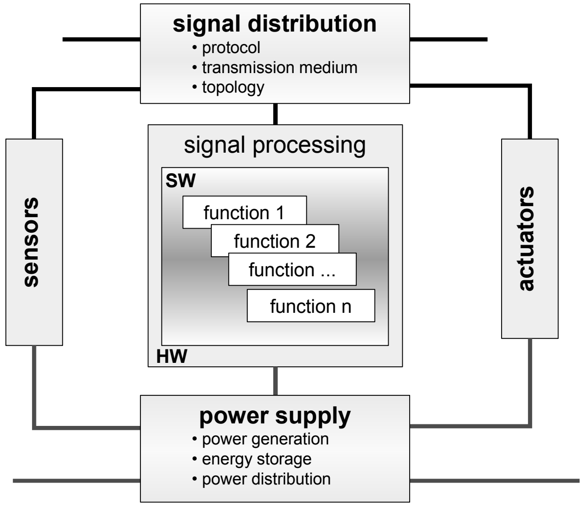


Fig. 14-3: Schematic build up of a system architecture

The hardware must be further differentiated by the number of used control units. The control units themselves must be categorized by the number and kind of used controllers, the signal conditioning, the set-up of the power amplifiers and the used bus drivers.

For the software it is important to focus on the basic software layers first, which reach from the hardware interface up to the software-functions interface. Then the single functionalities, which are established in the signal computing component, must be investigated for vehicle observer, driving-state detection, coordinator and control functions.

The aims of improvement mentioned in Fig. 14-4 are valid for all components of the system architecture. Beneath the aims of reducing the environmental pollution and the running costs, the aim of increasing the comfort, the driver information and the safety takes a major place.

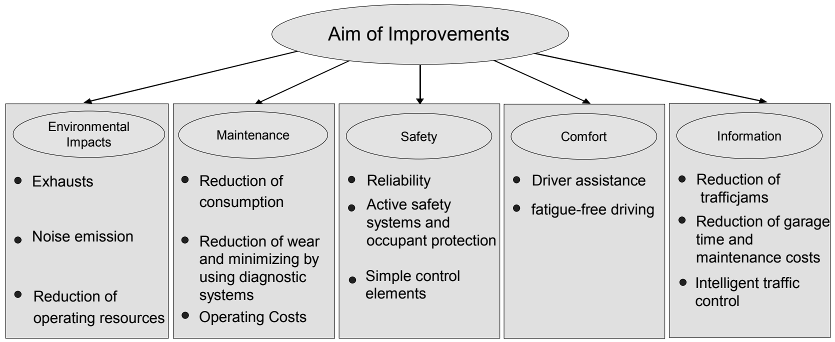


Fig. 14-4: Aims of improvement in the development of vehicle systems

Here not only the establishing of systems of active and passive safety are meant, but as well the provision of reliability and functional safety for the complete system. This is called system integrity.

14.3 System Integrity

Relating to modern vehicle systems the term "integrity" is often used. The Oxford-Dictionary describes this word as following:

> <u>Integrity:</u> 1 quality of being honest and morally upright: He's a man of integrity; he won't break his promise. ○ personal, commercial, intellectual, etc integrity.
>
> 2 condition of being whole or undivided: respect, preserve, threaten, etc a nation's territorial integrity.

Transferred to vehicle-development, this description means that a vehicle system shall continue to work properly and dependable even in the case components are malfunctioning.

There have to be mechanisms in the system, that give the possibility to detect and to compensate failures of single components. This is a main requirement especially for safety relevant systems, but also for all basic functions of the vehicle, in order to create more dependability.

Therefore one aim for the development of systems with increased requirements shall be, that the whole system remains in an active also when one ore more failures occur.

aim:

- the system has to remain active in case of failures: "fail operational" for at least one failure, not only „fail save" and not only „fail silent"

The solution is to generate dependability and safety, and therewith system integrity, by designing a failure tolerant system. This is not only valid for the single components but also for the whole system architecture.

method of solution:

- dependability and safety, and therewith system integrity, are mainly determined by the failure tolerance of the system!

In practical development various well-known and standardized methods are used to evaluate the requirements on the system integrity. These include:

- Dependability Analysis
- Event-Tree-Analysis (ETA) and Fault-Tree-Analysis (FTA); DIN 25424, 25448
- Failure Mode and Effects Analysis (FMEA)
- Hazard Analysis (HA)
- Classification of risks

With the help of this methods it is possible to evaluate for each function the adequate level of integrity and the required methodto reach this level already during the early development process.

In doing so it can be seen, that either over sizing of components or the creation of redundancy are the most reliable methods of assuring system integrity. These methods can be used for all components of the system architecture. Nevertheless every method only makes sense as long as the requirements on the system integrity of the considered (sub-)system demands this method. It would not be reasonable to equip a navigation system with a redundant power supply for example.

14.4 System integrity by redundancy

Whereas the over sizing of components is a very simple, but not always economic method of integrity-improvement, the design of redundant system architectures provides a broad spectrum of possibilities.

14.4.1 Hardware redundancy

The most obvious type of redundancy is the hardware – or physical – redundancy. Thereby at least one nearly equivalent component is added to the concerned component.

A further distinction is drawn between static and dynamic redundancy. For instance a yaw rate sensor can be installed twice, which is a typical case of static redundancy, where both components are typically used simultaneously.

In dynamic redundant systems the parallel component is only activated demand-responsive. An example is the power supply of a safety-relevant braking system, where an additional energy-storage device is only activated, when the main-power supply fails.

Regarding to sensor-signals and the possibilities to detect malfunctions during the processing of this signals, the hardware redundancy is the method with the most dynamic signal plausibilization.

14.4.2 Model-based (analytic) redundancy

Alternatively to the physical redundancy, sensor signals can be processed in a redundant way by implementation of model-based or analytic redundancies. Here not the information of a second sensor is used, but the information of different sensors are compared with the help of analytic knowledge about the relations between the single sensor-signals. A typical example is the plausibilization of yaw-rate-sensor signals by comparing them to the signals of steering-angle and vehicle speed corresponding to a single-track model of the vehicle. Caused to the necessary calculations, the dynamics of signal plausibilization are lower than in a hardware-redundant system.

14.4.3 Redundant controll unit architectures

Especially in the layout of electronic controll units, are hiding additional possibilities of redundancy. For instance contemporary controll units use multiple parallel micro-processors in order to achieve a higher level of integrity.

In doing so, a typical strategy can be to generate an identical redundancy by using identical hardware components, identical algorithms and identical code generators (compilers). This method bears the risk of duplicating failures while generating the system-duplicate.

A more clever way is to use at first different processors. This prevents processor-related failures from remaining undetected and furthermore provides the possibility to design a more economic redundancy with a slightly decreased performance. The usage of different code-generation tools (which is required, when using different processors) also increases the integrity of systems with identical processors, because eventual logical failures in the compiler software are not transferred to the redundant system.

The usage of different algorithms or even different development-teams can also prevent logical failures in redundant systems and algorithms.

14.4.4 Information redundancy

At the level of signal-distribution, information redundancy is achieved by processing additional information, e.g. in form of parity bits, checksums and error-detecting or error-correcting codes. With the help of calculation formulas, that are executed at the sending component and the receiving component respectively, the correct transmission of information can be secured.

14.4.5 Temporal redundancy

The method of temporal redundancy uses remaining computing time to rerun calculations and to compare the calculation results. Therewith transient failures, i.e. failures that only occur for a short time (e.g. by electro-magnetic influences), can be detected.

14.5 System integrity through the plausibilization of sensor data

The system integrity recurres as constitutive factor, that clearly determines the architecture of a system. In this context system integrity means, that the system is made dependable and safe by a failure-tolerant design.

The first step towards a failure tolerant system is to detect the failures. This is possible through the plausibilization of sensor data. If a failure is successfully detected, the control algorithm can choose an appropriate emergency strategy based on of the severity of the failure and the safety relevance of the affected system.

Fig. 14-5 shows a typical triple-stage concept for the plausibilization of sensor data in the related simulation environment:

- Single-signal plausibilization (block 1)
- Redundancy-based plausibilization (block 2)
- Model-based plausibilzation (block 3)

During one cycle of the palusibilization chain the plausibility-ratings of the particular stages are added up. In addition this concept possesses a feed-back loop (block 4), which can be parameterised.

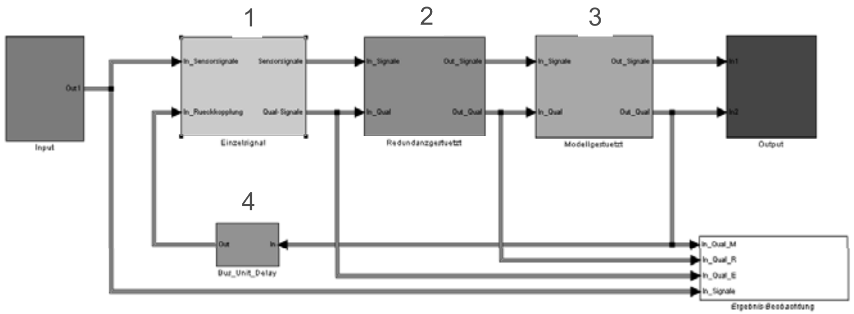


Fig. 14-5: Triple stage concept of the sensor data plausibilization

The surrounding, not yet described blocks serve the input of real measuring data in the simulation environment and the display of signals.

The plausibilization of single signals monitors every single signal and reduces (kompromits) the corresponding plausibility-ratings if the signal exceeds or falls below critical values or if the gradient of the signal becomes too high. For some signals a minimal signal noise can also be used as plausibility criteria.

The redundancy-based plausibilization compares the signals of redundant sensors whereas the model-based plausibilization compares different signals that are associated with each other in a model of the real system.

A closer look to the particular plausibilization methods shows that none of them provides an optimal result in the detection of failures when it is used exclusively.

The plausibilization of single signals typically not detects failures until they are very ample. The simple redundancy-based plausibilization (double sensor) cannot differentiate which one of the sensors fails.

Likewise, the model-based plausibilization cannot detect, which of the used signals is the incorrect one.

Only a reasonable combination of physical and model-based redundancies provides, supported by a feed-back, a highly dynamic and precise detection of failures with a maximum failure tolerance.

The main requirement for a successful plausibilization is always, that the used signals are held ready by the sensor environment. Besides it makes sense to situate the plausibilization-structures in a section of the system, that can access all sensor signals in the vehicle.

14.6 Examples

The various possibilities of creating system integrity through redundancy shall be described in the following on the basis of some examples.

14.6.1 Electronic Accelerator Pedal (E-Gas)

The electronic accelerator pedal (E-Gas) has been introduced onto the market as one of the first x-by-wire systems. The original mechanical connection between the accelerator and the throttle per Bowden-transmission has been replaced by an electric connection.

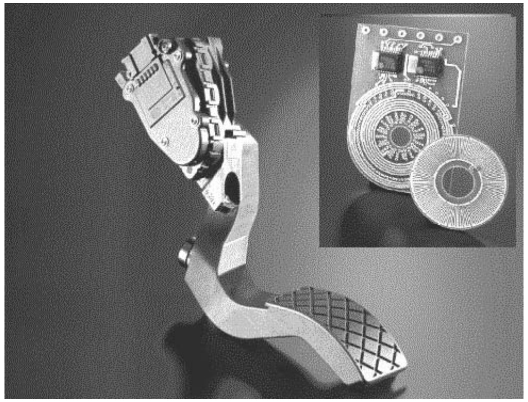


Fig. 14-6: Electronic accelerator pedal, source: Hella

As well as the required electronic throttle actuator, the electronic accelerator pedal has to satisfy the requirements on the system integrity. Fig. 14-6 shows the accelerator pedal, that possesses a contact-free, inductive pedal-position sensor, that triply detects the pedal position. Thereby the connected electronic controller can safely detect on the basis of the three signals, when the accelerator sends a wrong signal and which one of the signals is the wrong one.

14.6.2 Brake system

Another interesting example is the electromechanical brake. Because the brake system is one of the most safety relevant vehicle systems, the requirements on the system integrity are notably high. In present hydraulic systems as ABS or ESP, the control algorithm can be completely deactivated in case of failures with a simultaneous warning for the driver. The mechanical basic function of the brake remains. In order to secure the system integrity, two hydraulic circles are realized, each feeding two diagonal opposed brakes of the vehicle (mechanical redundancy).

An electro-mechanic brake (EMB) also possesses a mechanical fallback level. As the braking power of this fallback level is clearly under the power of the working EMB, every failure state is extremely undesirable. Therefore the system integrity is much higher than for a classical brake system.

The application of the electromechanical brake is forecasted for upcoming vehicles in the future. These brake-by-wire system will have high demands on system

integrity. Caused by the lack of a mechanical fallback level, the system will not be deactivated even in case multiple failures occur. The future systems will not only work “fail-silent” bur “fail-operational”.

To achieve this high level of system integrity various arrangements are designed. Fig. 14-7 shows the redundancies that are applied into the system. Analog to the layout of a hydraulic steering system, two independent circles are realized, that each connect two diagonal opposed wheels. Every one of this circles uses an own EMB-bus, an own EMB-power supply and an own line for direct signals (e.g. rotational wheel speeds), so that redundancy is provided for every component. Besides one central redundant-designed ECU, every wheel uses an own brake-ECU that can serve as an electronic fallback level.

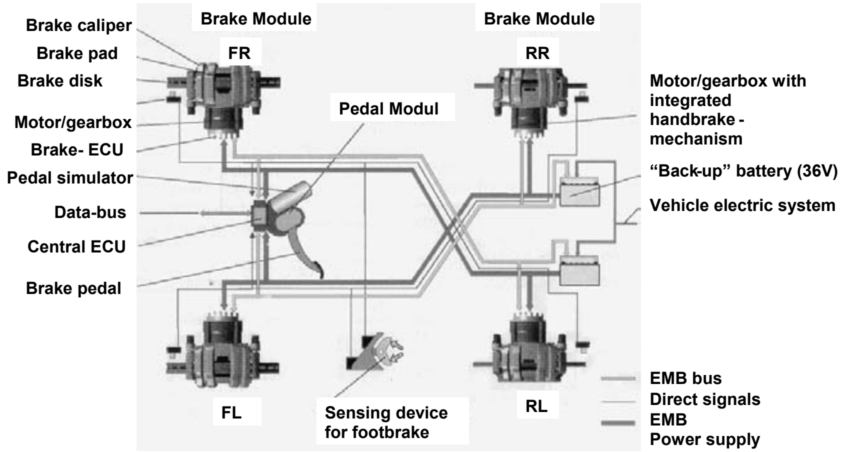


Fig. 14-7: Layout of an electromechanical brake, source: Continental

At last the power supply of the particular circles is buffered by own batteries, so that the function of the brake is secured even when the vehicle electric system fails. Altogether a very high level of system integrity is achieved here by using this various redundancies.

14.6.3 Steering system

Another very safety relevant system is the steering system. The recent trend shows, that especially in the area of smaller vehicles electrical power-steering systems (EPS) achieve acceptance contrary to un-assisted steering systems or to hydraulic power-steering systems. Because false steering interventions can lead to critical situations very fast, the requirements on the system integrity of EPS-systems are accordingly high. Fig. 14-8 shows the components of an electrical power steering system. The electronic controller is designed with an internal redundancy. In contemporary systems the torque-sensor is also integrated in a redundant way. Using the plausiblization of signals, the motor speed, the motor current and the steering angle can also be verified against each other, depending on the motor concept.

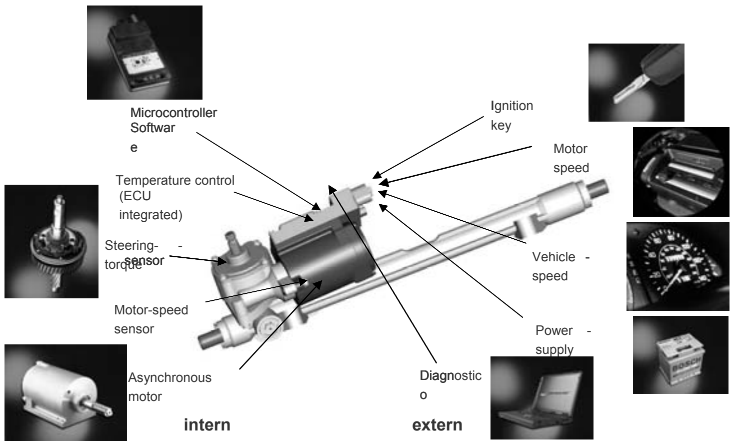


Fig. 14-8: Components of an electrical power steering system, source: ZF

Analog to the electromechanical brake the steer-by-wire system makes the highest demands on system integrity. As seen in Fig. 14-9, all actuators and sensors are applied double (simple redundancy). There are two steering-wheel actuators, two steering-wheel-angle sensors and two steering-torque sensors. That layout makes sure, that the control and monitoring of the steering wheel remains secure even when one component completely fails.

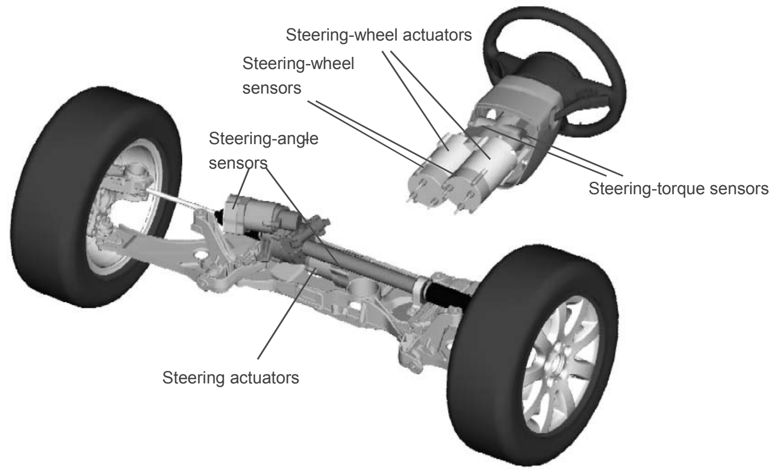


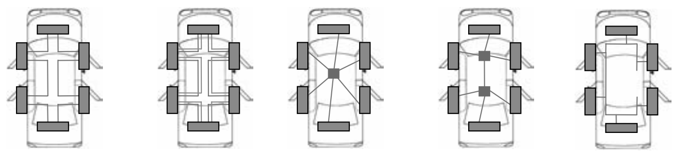
Fig. 14-9: Design of a steer-by-wire system

The same level of redundancy can be found at the outboard steering system at the front axle. Two actuators with respectively own steering angle sensors control the steering gearbox. The steering torque of both actuators is measured using the motor current, so that this signal is available as a redundant signal, too.

As a last example the different possible layouts of signal distribution and the thereby achievable levels of system integrity will be explained below.

14.6.4 Signal distribution

Again the comparison of the different bus-topologies in Fig. 14-10 shows, that the highest system integrity can be achieved through redundancy.



	Ring	Double-Ring	akt. Star	akt. multiple star	Bus
Failure tolerance					
S/E-comp. failure	nearly breakdown	no interruption	only subarea fails	only subarea fails	only component fails
Failure of a lead	nearly breakdown	no interruption	only subarea fails	inly subarea fails	complete breakdown
Failure at central unit	-	-	complete breakdown	one star point fails	-
Cabling complexity	little	high	medium (increases with the number of connected components)	little (increases with the number of connected components)	little
Extensibility	very good	very good	limited (number of ports)	limited (number of ports)	very good
Miscellaneous	o serial data transport from one component to the other o point-to-point connection	- doubled number of sender- and receiver-components	o central unit	+ optimised cabling - two central units	+ simple adding of new components

Fig. 14-10: Influence of system topology on system integrity in signal-distribution systems

On the other hand the higher costs and complexity of such redundant system have to be regarded, so that it is sometimes suggestive (dependent on the system requirements) to find a compromise between the maximal required system integrity and the restricted system costs.

14.6.4.1 Summary and outlook

It has been explained, that redundancy is the most effective possibility of generating system integrity. Unfortunately it is also the most cost-intensive possibility. Nevertheless it is often possible to replace identical redundancy by analytical redundancy through an intelligent design of system architecture in order to save costs. In the majority of cases this cost-saving is unfortunately accompanied by a loss of dynamic and by a diminished remaining functionality in the case of failures, that has to be accepted.

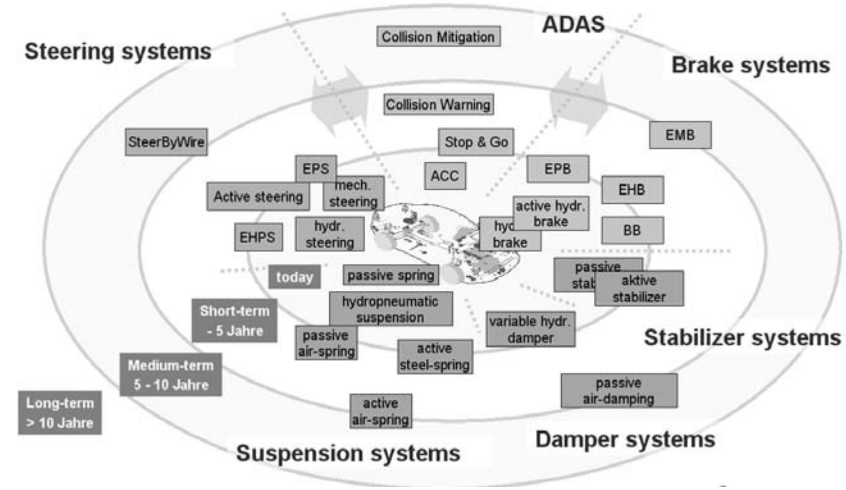


Fig. 14-11: Contemporary and upcoming drive train- and driver-assistant systems

The evolution of vehicle-chassis systems and driver-assistant systems as shown in Fig. 14-11 reveals a significant trend towards more safety relevant vehicle interactions. X-by-wire systems but also driver-assistant systems for the prevention of collisions, that intervene automatically, make highest demands to system integrity. The automotive engineers of the future will have to meet these new challenges in vehicle-system development.

15 Index of Formulae and Indices

a	acceleration
a_y	lateral acceleration
B	avoiding width
c	concentration, speed of light
$c_{\alpha v}$ / $c_{\alpha h}$	cornering behaviour
c_W	drag coefficient
D, D_0	diffusion coefficient
dx	distance to target vehicle
E	activation energy
e	mass coefficient
e_i	addition error in system
f_R	rolling-resistance coefficient
F_Z	wheel load/
g	gravitational acceleration
h	enthalpy
ΔH	solvent enthalpy
l	length
l_v / l_h	centre of gravity of the axes
m	mass
$\dot{m}$	mass flow
M_B	braking torque
m_F	vehicle mass
$m_{vehicle}$	overall vehicle mass

m_{zu}	load
P	permeation coefficient
P	power
P_a	acceleration power
P_{Bed}	demand power
P_L	power requirement to overcome drag coefficient
P_{Roll}	power requirement to overcome rolling resistance
pi	pseudo distance to the four satellites
□p	deviation of distance due to Clock Error
$\dot{Q}_0$	cooling power
R	common gas constant
R	trajectory radius
R_{dyn}	dynamic wheel radius
Re	Reynolds number
S, S_0	soluble coefficient
T	temperature
t	time
Δt	error between clocks (Clock Error)
v	velocity
v_{char}	characteristic velocity
x	diffusion direction coordinate
x_p	x-coordinate to certain place
y_p	y- coordinate to certain place
z_p	z- coordinate to certain place

$\dot{\beta}$	float angle speed
ρL	air density
η_V	compressor efficiency
ε_{KM}	power number
λ	tire slip
μ	friction coefficient
Θ_{red}	reduced inertia torque
φ_{wheel}	wheel angle
$\dot{\varphi}_{wheel}$	angular speed of wheel
$\ddot{\varphi}_{wheel}$	angular wheel acceleration
$\dot{\psi}_{desired}$	desired vehicle speed
$\dot{\psi}_{vehicle}$	vehicle yaw speed
ν	cinematic viscosity
ω_{wheel}	speed

16 Literature

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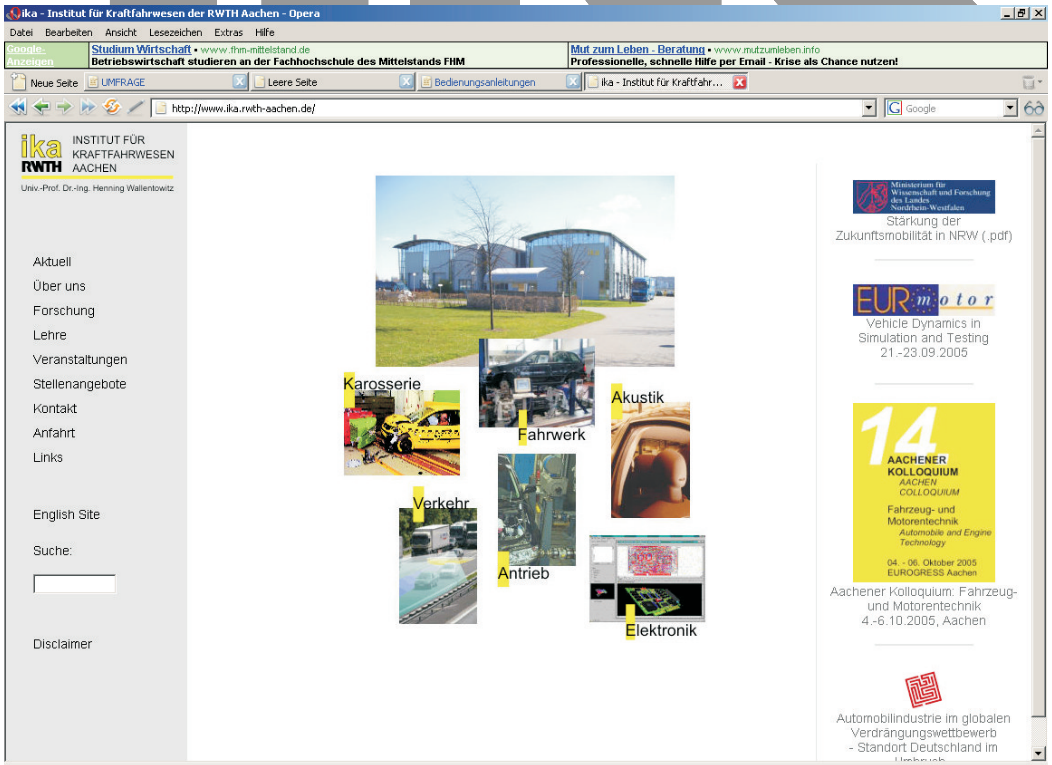

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