PREREQUISITES TO IMPROVE TRAFFIC SAFETY

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Abstract
The paper proposes a paradigm shift on the major cause of road vehicle collisions. It is shown through currently available interpretation of given statistical data that the widespread view of speed being the major cause of accidents has to be questioned. Driving is described as a process, the complexity of which varies with the driving conditions. In traffic, a situation with many individuals interacting, conflicts result from the individual trajectories intersecting in time and space. Inherent in the normal driving process is the resolution of these occurring traffic conflicts, regardless of where the fault lies. Accidents are initiated in complex situations where a given conflict is not being resolved by counteraction of the parties involved. These deficiencies or “driving errors” can be caused by deficiencies in the cyclic “Vehicle Control Process” (VCP) i.e. the sequence of perception, decision/evaluation, and execution. It is exactly here where speed comes in to play a role. Proper driving is thus the permanent match of a sufficient Vehicle Control Process to an appropriate speed, or, in other words the VCP has to “master” the speed at any given time. Hazardous situations are regularly mismatches of these two. In terms of safety “excessive speed “ is always the result of a deficient Vehicle Control Process. This makes road safety dependent not from absolute speeds at a given location, but from the relative match of speed and the driving situation. So the advantageous target is not a general “lower the speed” but cater for the appropriate match and/or make up for match deficiencies. Recent research indicates that the predominant deficiency resides in the perceptional area. It is this understanding of the driving process and the accident generating factors that constitute the basis of the BMW Driver Assistance concept, in order to enhance traffic safety successfully and efficiently.

Interdependences between Mean Speed and Fatalities
Information accumulated over the last quarter of the previous century now seriously force us to reconsider the paradigm in the accepted cause of traffic collisions and thus perforce in the most effective means of preventing them. When one looks at only the physics "Speed Kills" is a truism. However, as a theory to guide our actions aimed at preventing collisions it has proven to be less than helpful, since it is misleading. Moreover, looking at the MFR (Motorway Fatality Rate i.e. Fatalities per Billion km, (Fig.1 – [1]) in Germany one can see that the fatality risk on motorways has in general decreased dramatically from the early seventies towards the turn of the century. Although there are small "spikes" to be seen e.g. in 1983 and 1990 (German reunification) the trend line clearly leads down.

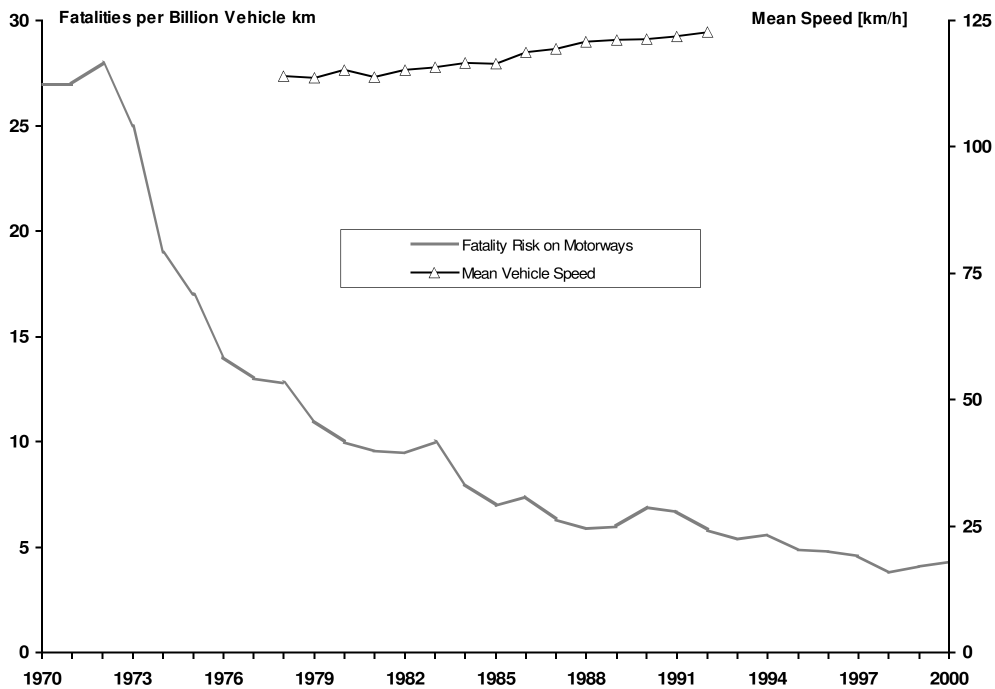

Fig. 1: Fatality Risk and Mean Speed

Speed measurements taken by the BASt (Bundesanstalt für Straßenwesen) at 18 different locations during this period however show an opposite trend line. Mean speed of vehicles (including trucks and two wheelers) rose by approximately 0.9 km/h per year during 1981 through 1990. The mean speed of "free driving" (i.e. more than five seconds distance between two vehicles on the same lane) passenger cars even rose by 1.2 km/h in the same time period (Fig 1 [2]).

Speed is one out of many, but not the Driving Factor of the Fatality Rate
Obviously the trend lines of mean speed and fatality rate do not correspond but are, in fact, diverging. This means that speed cannot be – put aside its dominance regarding accident consequences – the major factor in accident genesis. Consequently General Speed Limits (GSLs) on motorways are widely irrelevant to traffic safety. Even without making country comparisons one can see this non-correlation within the following countries (Fig. 2 [3]):

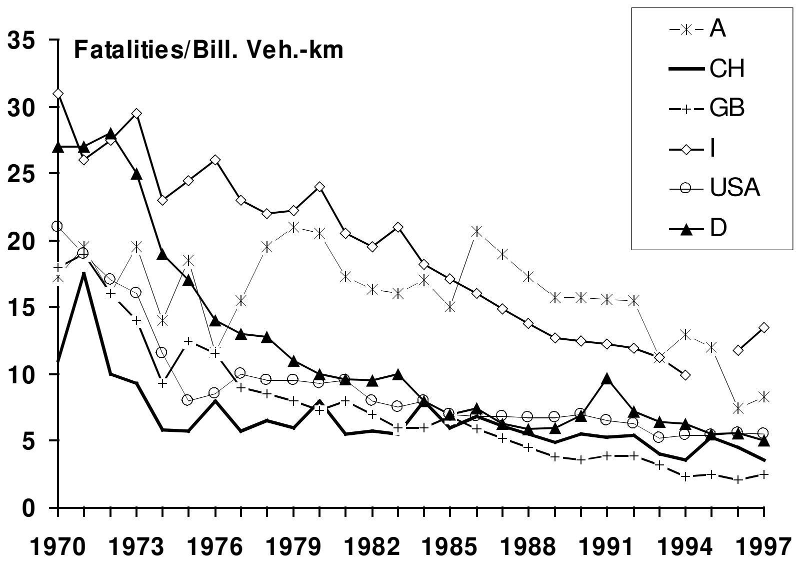

Fig. 2: Fatality Risks in Different European Countries and the USA

Switzerland has, though consistently near the 74/75 levels, several “spikes” in the MFR that are well above that level. The Austrian MFR is for most of the last 25 years, well above the 1974 level.
Great Britain imposed a GSL in the late sixties, but saw no “improvement” until the recession in 1974.
Italy imposed a GSL in the mid seventies but the trend line shows spikes in the early eighties and mid nineties.
Furthermore one should note that all the European countries made the very large change from no limit to a GSL ranging from 100 to 130kph. The USA imposed a much smaller change of about 16kph (most states from 65 down to a federal 55mph) and yet its trend line is indistinguishable in general shape and timing from all the others.

The above so far deals with various attempts to find a reduced GSL in decreasing fatality rate trend lines. But what can be found in the context of increasing speed limits? We return to the USA where the federal authorities raised the limit from 55 to 65 mph in 1987. In the mid nineties a second step of liberalization took place and states were again permitted to set their own limits. Over the next couple of years some states raised the GSL to 70 or 75mph while some retained 65 or even 55mph. After numerous studies, over several years, the only conclusion possible is that there is no correlation between the fatality rate (per VMT) and the imposed limit. Some of the earlier reports were able to report increases in the number of fatalities. However, since these reports neglected changes in the volume of traffic (e.g. [4] and [5]), but only reported fatalities per year, their findings cannot be interpreted in terms of fatality risks and thus are widely meaningless regarding traffic safety.

This scientific view on “collisions per traffic volume” is expressed in the study by Lave and Elias in 1994 that reviews various studies on US highway fatalities[6]. Incorporating a broader perspective they mentioned that, “most of these studies looked at the *number* of fatalities … but we should be looking at *rates*, i.e. fatalities per vehicle mile traveled (VMT).” (italics in original) Lave and Elias then went on to show that the transfer of traffic from, “… other, more dangerous, roads …” to the now faster (65mph) expressways has, “… reduced statewide fatality rates by 3.4% to 5.1%, holding constant the effects of long-term trend, driving exposure, seat belt laws, and economic factors.”

In Libertiny´s report two years later [7] the information can be found that the Insurance Institute for Highway Safety’s often quoted claim of 24% higher fatality figures due to the speed limit increase on the Interstate system is to be considered as a lower fatality rate due to the 40% higher traffic volumes reported by the U.S. Department of Transportation in January, 1994. (NB: This is not inconsistent with the Lave & Elias study above since their 3-5% calculation was compiled after correcting for the positive effect of passive safety measures.)

Understanding the Road Traffic System is a Precondition for Safety Improvements
Having thus shown that GSLs and their enforcement have never been effective measures on motorways we now need a “new paradigm” to guide our efforts towards enhancing traffic safety.

In order to identify the real road safety threats we have to take a holistic approach i.e. understand road traffic and the Vehicle Control Process (VCP) as a whole. Road traffic is a free accessible and self-organizing system in contrast to the completely scheduled and controlled rail and air traffic. In this "chaotic" system many individual VCPs are operating simultaneously. Each one of these VCPs represents an individual system comprising the elements **driver**, **vehicle** and **driving environment**. The road traffic system can be seen as "stochastic", since from the view of the individual driver the behavior of other participants is undetermined, and has thus got to be continuously monitored and, where possible, anticipated. The elements of the road traffic system themselves consist of subsystems or components, all of which include several elements that have an influence on the performance of the total system (Fig. 3).

The system hierarchy of Fig. 3 describes a static structure of the road traffic system. Obviously, the safety relevant factors are changing constantly according to the evolving traffic situation along the chosen route. The task of driving thus consists of recurrent **Vehicle Control Processes** (according to [8]) comprising the following sequential actions:

- Perception of visible or audible signals, i.e. seeking and retrieving the relevant information
- Evaluation of the evolving situation on the basis of **experience/training** and decision on the appropriate action
- Execution of the chosen action

These VCPs can be distinguished in regard to their "range" in terms of time and/or distance by the following three action-levels (according to Donges [9])

- Navigation level
- Guidance level
- Stabilization level

Navigation accounts for orientation. It is done fully consciously and appears in multi-minute or longer intervals (e.g. on long motorway travels) and is thus long time/distance ranged.

Guidance accounts for the visible range in front of the car. Conscious decisions lead e.g. to turning maneuvers or change of lanes. Keeping appropriate distance is done rather subconsciously. This action level occurs in multi- second or longer intervals depending on the traffic situation and is thus medium time/distance ranged.

The **Stabilization** level is a permanent one and comprises all lane-keeping actions. It is at least a very short time and/or short distance ranged process, however predominantly a real time process.

The fact that a high percentile of the population in every developed country holds a driver´s license may give us the wrong impression of driving being a trivial task. The comparatively very trivial task of human "walking" has been successfully automated with a robot only a few years ago. The robot is able to walk up and down stairs and move about in a home, i.e. not deeply structured, environment. This example may show that driving is - as the static model of the road traffic influencing factors and the driving process shows - a rather complex task. The range of misperceptions and evaluation errors or mistakes in the execution of the action is really vast. This is why some experts claim that in more than 90% of accidents a "driving error" is the cause.

Failure Probabilities

Basically, a failure of the system as a whole can be expected if one of the subsystems (driver, vehicle or driving environment) produces a failure that is not resolved by another component. In case of the vehicle it can be stated that technical failures leading to an accident are very rare provided the vehicle is maintained properly. In regard of the driving environment it can be said that the road and the road environment are components, which are not active and thus do not change in the real time VCP. This does not account for the traffic data and the weather conditions. These two areas are subject to permanent and sometimes unforeseeable changes and therefore represent a major safety risk. Considering the Information-Technology-principle "Garbage in, garbage out" in the context of the Vehicle Control Process consisting of **perception, evaluation/ decision** and **execution** it is obvious that the results of the VCP is driven predominantly by perception.

- Driver
    - Intentions
    - Personal Disposition
        - Temporary
            - Mood
            - Actual State of Health
            - Fitness
                - Tiredness
                - Pharmaceutical Drugs (incl. alcohol)
            - Performance reducing Comfort Deficiencies
        - Permanent
            - Physical and/or sensory Deficiencies
            - Neural Reaction Time
    - Experience
- Vehicle
    - Equipment
        - Compatibility of technical options to drivers needs
        - Electronic Driver Assistance Functions
    - State of Vehicle Maintenance
- Driving Environment
    - Road
        - Road surface
            - Profile
            - Surface damages (lane grooves, pot holes)
            - Friction
        - Road Passage
            - Width of lane
            - Visible range
            - Traffic guidance
            - Road marks and signs
            - Inclinations and declinations
            - Bends and Radiuses
            - Junctions, Exits and Crossings
    - Road environment
        - Road side equipment (furnishing)
        - Obstacles
    - Traffic data
        - Speed and dynamic speed changes
        - Traffic density
        - Other Users (Pedestrians)
        - Incidents (Third parties inappropriate behavior)
    - Weather conditions
        - Overall visibility (Fog, Spray, Dust/Smoke)
        - Light Intensity, Contrast, Reflection
        - Precipitation (Rain, Snow)
        - Winds

Fig. 3: Hierarchy model of the Road Traffic System
(not necessarily complete)

It has to be stressed that a driving error does not inevitably lead to an accident. Traffic at a given location and a given time consists of the driving processes at the time and given location that mutually influence one another. It is inherent in the traffic system that one must attempt to resolve driving errors of other participants. In contrast to aviation, “near misses” in road traffic are not reported and no statistics exists, although any driver with average experience could tell of situations where he or she prevented an accident by active counteraction. Instead of “accident causes” the more striking expression is “critical boundary conditions”. In this context speed plays a contributive, but not a major role. This is confirmed by statistical data [1], which show that 34 per cent of serious accidents in Germany were attributed to inappropriate speed. Twelve per cent of these included a speed limit infringement or, in other words, only four percent of all serious accidents. Clearly, the task is not enforcing the legal speed, but help drivers to identify the appropriate speed. The critical boundary conditions lead to a model where the accident is an outcome of an unresolved or non-avoided traffic conflict [10]. The below graphic (Fig. 4) shows a generic failure tree model for the initiation of accidents in road traffic. The structure shown has to be seen as the minimum precondition for the accident genesis. A real traffic situation with many “contributing” participants may have a much more complex failure tree structure.

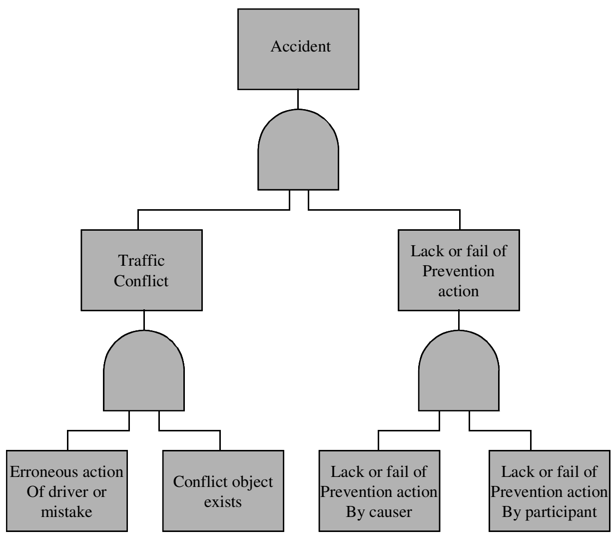

Fig. 4: Generic Failure Tree Model for the Initiation of Road Traffic Accidents [10]

Possible Human Perceptual Deficiencies

For correct perception information has to be **accessible**, it must be **correct** and **sufficient** and it has to be provisioned in a **timely fashion**. But even if the information is accessible it is not guaranteed that it is perceived, as the phenomenon of the driver who claims to have “not seen the motor-cycle” is widely known. This seemingly paradox is explained by the process of perception which comprises the optical depict of the object on the retina and its mental identification to be a motor cycle. Optical perception is by far the most important perceptual technique. It accounts for more than 90 per cent of the gathered information. The ability for optical perception can of course be seriously compromised by various factors. Put aside the pure physical problems, (insufficient light intensity, dazzling reflections etc) there are two major factors that account for perceptual deterioration. It is the complexity of the situation to be perceived and of course the “quality” of the perceptual process.

In terms of Physiology a full VCP process constitutes the widely known reaction time. Decisive for the duration of this process is mainly the perception and decision-time, which is dependent on the complexity of the situation and can vary significantly (Fig.5). In this perceptual process two kinds of **attentiveness** compete. The **selective attentiveness** accounts for correct recognition of relevant information i.e. it filters it out. The **shared attentiveness** accounts for parallel or simultaneous processing of various information be they visible and/or audible. It is obvious that a complex situation with a variety of different information needs more time for computation than a comparatively trivial one.

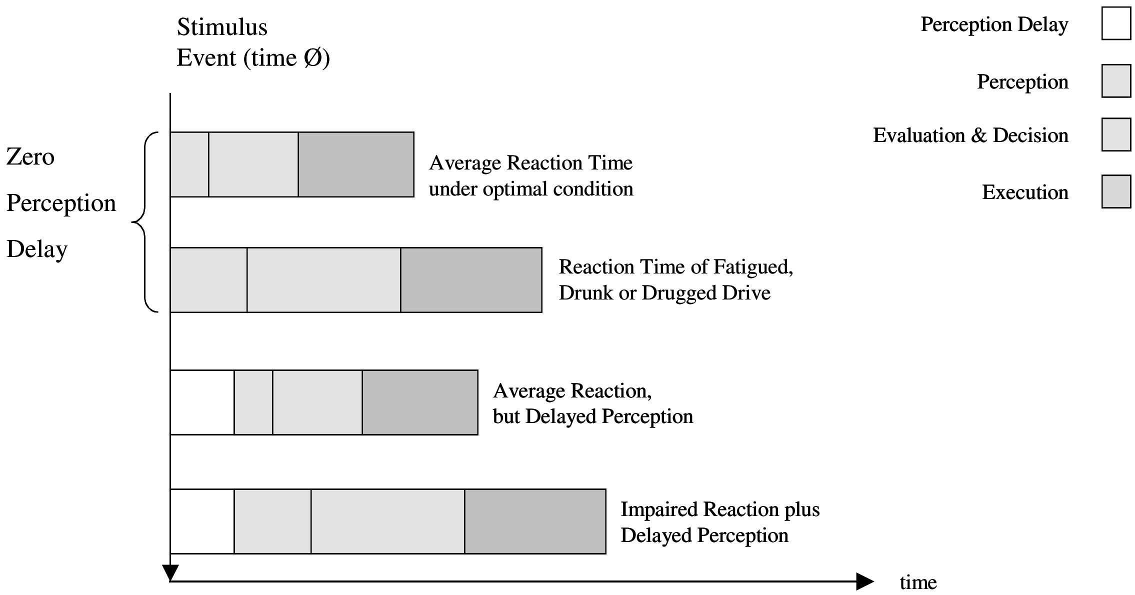

Fig. 5: Duration of Vehicle Control Processes

It has to be considered that the vehicle moves along with the given speed during this prolonged time and thus a dangerous situation may result. However, the complexity driven prolongation of perception is not the sole problem. Delayed perception initiation or prolonged perception time can just as well be caused by a compromised perception system. Compromised by drugs, tiredness, alcohol and last but very prominently, because it is an every day problem, **mental distraction**. According to A. Gullon´s research [11] eight police officers in seven different countries unanimously (and anonymously) held mental distraction to be the decisive generic factor for road accidents when questioned what in their opinion the major cause was, put aside the tick boxes of official reports.

Insufficient mastering of the VCP is the real problem

Undoubtedly mental distraction lowers the overall attentiveness of the driver in a way that at least perception initiation is delayed, perception time prolonged or, worst case, crucial information is missed and not being picked up at all. In a case like this the time left to react may be too little to sufficiently master the VCP. It is obvious that this problem, where the driver´s mind is as the French say "dans la lune", is not bound to a special speed or situation. Clearly, this problem can occur at any speed at any time. So general speed limits on motorways are not the satisfactory answer to it. On the contrary, GSLs tend to lead people to believe that whatever is allowed must likewise be safe.

Defining possible solutions

The general target is to avoid the occurrence of driving errors that cannot be corrected by the driver or any other traffic participant. Above all, the solution to be found, regardless in which area, has to make driving more comfortable and easier, otherwise it would not be accepted. On the other hand, over-simplifying will not help to solve the problem at all. As Einstein pointed out "make it as simple as possible, but not simpler". According to the proverb "every chain is only as strong as its weakest link" the weakest link of the road traffic system is the driver, although equipped with the most outstanding mental and physical features. Within the VCP it has been shown before that the predominant deficiency is to be found in the field of information perception. With information four attributes were defined to be crucial. Information has to be **accessible**, **correct**, **sufficient** and provided in a **timely fashion**. Up to now it was the task and responsibility of the driver to actively pick up the information needed, through continuous monitoring of information supplied by the vehicle´s gauges and of the traffic environment outside the vehicle. A paradigm shift from actively seeking and retrieving information to being supplied with timely information can improve perception significantly. Warning lights or buzzers for the cooling water temperature are "classic" examples of this philosophy of "information supply". The new concept is to supplement the road traffic elements with modern means of Information Technology. Thus driver assistance systems link the driver to the vehicle, guidance and information systems link the driving environment to the driver and lastly the monitoring of traffic links the road environment to the vehicle (Fig. 6)

Fig. 6: The general assistance concept

A question of philosophy: take over or assist?

There is a wide range of possible solutions for Driver Assistance Systems to be seen: from simple visible or audible information, through haptic signaling down to the extreme situation where the machine completely takes over. The question of whether or not the machine should take over is answered by the suitability of machines to efficiently fulfill a given task in comparison to human capabilities. The question of the differences between man and machine arises. **Humans** are powerful in associative parallel and contextual thinking, they think and act failure tolerant, fuzzy logical and synergetic and lastly have the ability to filter relevant items and fill in missing links (Fig. 7).

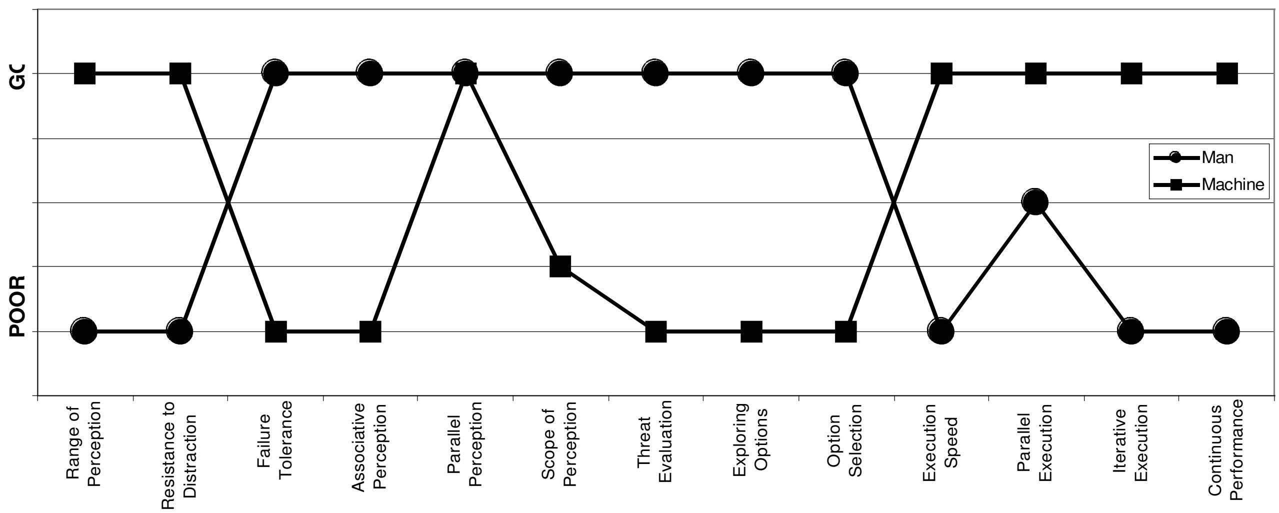

Fig. 7: Powers and Weaknesses of Humans and Machines

Their weakness is to be notoriously prone to disturbance by outer stimuli, they are slow and non-precise with iterative action and not very suitable for overloading and permanent performance. **Machines** are fast and precise with iterative action, suitable for permanent performance and thus predestined for iterative tasks. Their weakness comprises the lack of associative, intuitive and synergetic acting and the restriction to act on pre-set strict rules. So the often-quoted question “man or machine” is somehow absurd. Man and machine ideally complement one another.

It has been shown before that any executed action during the VCP can be assigned to one of the three levels Navigation Guidance or Stabilization, with the latter as a real time process, guidance as a mid term process and navigation as a long term process. This distinction represents at the same time a recommendation for the employment of machines. Stabilization processes operate in real time and therefore are predestined for machines. Widely known examples are anti locking brake systems that take over when man has already failed to properly adjust brake force. Then the electronic stability processors assess a possible destabilization of the vehicle and counteract immediately. On the other hand are guidance and even more navigation “future bound” functions. Between two processes of guidance or navigation a lot can happen the machine just does not “know” because it lacks the appropriate perception and recognition features. In these cases man with his unique perceptual and mental abilities is the best choice to handle these parts of the processes (Fig. 8)

		V C P		
		Perception	**Evaluation/ Decision**	**Execution**
A C T I O N L E V E L S	**Navigation**	**Plan the route** Give route recommendations, announce incidents on the route	**Decide on route** Compute alternative routes, suggest deviations	**Decide on route and stops**
	Guidance	**Perceive general driving Environment** Monitor environment details, temperatures, distances, friction, monitor lane keeping	**Decide on turns, Decide on lane changes etc.** Compute safe distances and lane keeping conditions	**Execute turns and lane changes etc.** Actuate accelerator pedal, steering etc.
	Stabilization	**Subcontiously perceive lane keeping information** Monitor destabilisation factors	**Subcontiously decide on action** Compute countermeasures against destabilisation	**Execute action** Execute countermeasures against destabilisation

Bold print = Man ; Normal print = Machine

Fig. 8. Task Assignment for Man and Machine

A Consistent Assistance Concept

The prevalent philosophy of an assistance concept should be to keep the driver fully in the control loop (VCP). This is for several reasons. From an ergonomic viewpoint the question of manual takeover in case of system malfunction or complexity overload still raises questions. Put aside the system malfunction, the situation driven complexity overload will very likely take the driver by surprise. Naturally, the better the system´s complexity handling abilities are, the scarcer the take-over situations will be. In other words, it will be the highly complex situations that cannot be handled by the machine that then will surprise the driver.

Similar exception handling is known from the operation of power plants or highly automated commercial aircrafts. However, in these fields the operators are "hand-selected" and have to undergo special trainings. Lastly but decisively, only a responsible driver who literally is "driver in the loop" can be legally held liable in case of errors and their consequences.

The conclusions out of these considerations are for the vehicle manufacturers (Fig.9):

- Supply all safety related information to the driver that cannot be detected with his senses e.g. external temperature, friction etc.
- Enhance the drivers vision, supply safety related information that is beyond the drivers vision (Extended Floating Car Data).
- Supply timely the prioritized data/information (avoid an information overload)
- Give the driver feedback on active system components, preferably haptic (active accelerator pedal) or visible (flashing light for active Anti locking brake system).

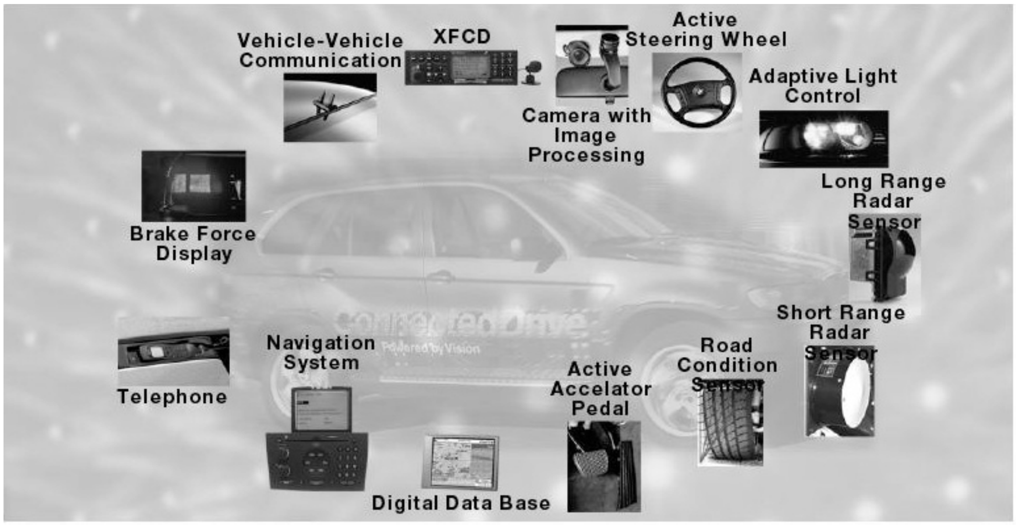

Fig. 9: Detection of Driving Environment

The systems of the above graphic significantly help the driver to manage the VCP. The general objective is to assist the driver that he or she can operate the VCP with "average reaction time under optimal conditions" (Fig. 10).
This asks for avoidance of perceptual delays and for reducing the duration of the VCP to a possible minimum.
Delays are avoided by incorporating short and long-range radar that continuously detect the distance to the preceding vehicle and the relative speed. If the driven speed does not match the distance, a haptic signal is generated through the accelerator pedal. The camera in co-operation with the active steering wheel works likewise. When the car is about to leave it´s lane a counteractive torque in the steering wheel will signal the driver that it is time to react. The adaptive light control is navigation driven. Before entering corners the headlights will turn appropriately, better light the road side and thus facilitate an earlyer perception of whatever obstacle or hazard. Early information is provided on incidents via extended floating car data (XFCD). Critical road conditions are detected through friction monitoring and the driver thus timely warned.

The perceptual and decision phase within the VCP get shortened by navigation that assists the driver to manage the complexity of parallel processing: retrieving direction signs i.e. navigate, retrieving traffic signs i.e. prioritize, and last but not least continuously monitor the traffic flow. A similar effect can be seen with the systems that help to control the stabilization phase like anti locking brake systems, dynamic skid control or cornering brake control. Since these systems avoid destabilization situations, the duration of the stabilization phase is minimized (Fig. 10).

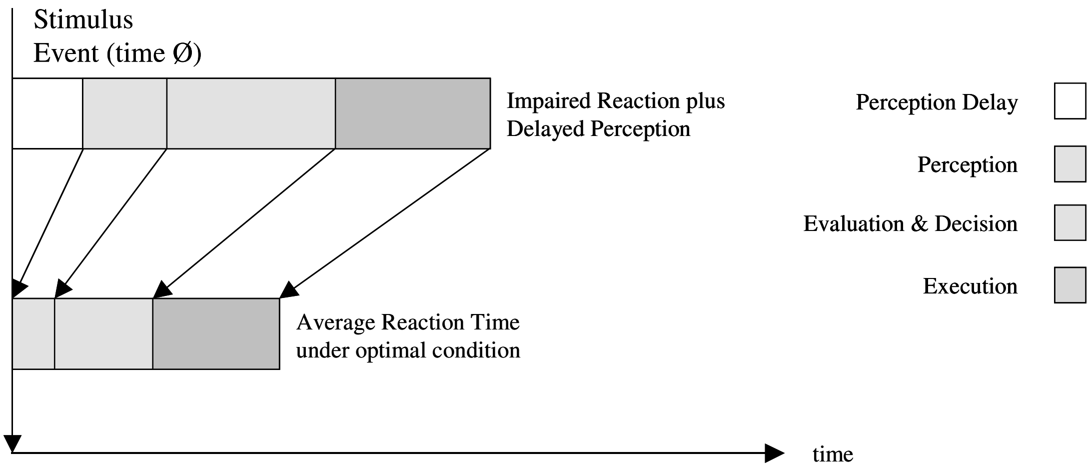

Fig. 10: Influence on the Initiation of Perception and Duration of Perception/Decision in the VCP

Conclusions

Accident research so far concentrated on accident consequences and has led to significant passive safety improvements in the past. However, the field of passive safety is to be seen as largely exploited. In terms of enhancing road safety the improvement of the traffic system as a whole gets increasingly important. Major potentials are still to be seen in the field of active safety, albeit a lot has been done up to now. Here Driver Assistance Systems will play a decisive role.

However, the actual target set by the European Commission to half fatalities by 2010 on the basis of 1998 figures [12] raises questions. A reduction of this magnitude asks for matching safety concepts. Generally speaking, there is lacking knowledge regarding accident generic factors for the computation of these concepts. In detail we face the following situation:

- The car manufacturers, until now the forerunners of passive safety have ongoing and will have future co-operation in projects to gather data on real time traffic and incidents data in order to improve active safety by provisioning real time information on local hazards. The same accounts for co-operations in the field of Driver Assistance Systems.
- Instead of a holistic approach, there is still too much concentration in the public safety discussion on few but relatively non-decisive factors, like speed and general speed limits (GSL).
- The **GSL** philosophy should be exchanged by another approach: **SAVE**, i.e. **S**ituation **A**dapted **Ve**locities, the only philosophy that meets human intentions and behavior and thus can be expected to really **SAVE** lives.
- Too little is known about the safety influential impact of infrastructure characteristics.
- Too little knowledge exists on the interdependence between information deficiencies and thereby induced driving errors and possible accidents.
- Accident statistics throughout Europe are inconsistent regarding structural depth and definitions. Inconsistent accident reporting methodologies severely compromise the monitoring of the prevalent traffic safety data. This may be detrimental to follow up the above mentioned challenging goal of reducing traffic fatalities throughout Europe.

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