1 Human Capacity for Vehicle Guidance

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Abstract

Human information processing systems, as well as the individual driver characteristics interacting reciprocally with them, are particularly significant for the task of vehicle guidance. This chapter will describe these connections between driver, vehicle and environment using a simple system model. The driver's intake, processing and output of information will be delineated. The relevant driver characteristics, capacities and skills for vehicle guidance will be described. Based on this understanding, requirements for vehicle guidance with regards to the driver will be systematised by considering subtasks and evaluated with respect to the limits of human capacity.

Vehicle guidance is a predominantly informational activity in which work content and information are converted into reactions. Normally, the driver performs the action of steering while continually processing information.

Accordingly, the most significant factors associated with vehicle guidance are the systems of information processing and the individual driver characteristics which interacts reciprocally with them.

In order to describe the connections between driver, vehicle and environment, a simple system model will be employed (cf. [1]). It consists of two elements: driver and vehicle. The input variable of vehicle guidance, which is also influenced by environmental factors, impacts both of these elements. Above and beyond this, disruptive variables such as distractions caused by passengers may arise. This system's output variable can be described by the system functions of mobility, safety and comfort.

1.1 Human Information Processing

In order to describe human information processing there are a variety of models which specify general intake, which transforms a signal entering a receptor (stimulus) into a cognitive representation and a human reaction (response). Some of the most well-known models in the field of engineering include the sequential and resource models. Sequential models allege that the transformation from stimulus to response occurs in a strictly sequential manner, meaning that the next step can only be performed once the previous one is completed. Resource models are based on the assumption that the capacity available for various activities is limited and must be shared between all simultaneously performed tasks. The theory of multiple resources extends this view; according to this theory, the degree of interference between two tasks depends on whether they demand the same resources [2]. In this model, simultaneous processing of visual, spatial image information (e.g. navigation displays) and auditory, verbal information (telephone calls, news on the radio) would be free from interference, since they use different sensory channels and different regions of the working memory. However, experimental studies have shown that this freedom from interference is not absolute.

Human information processing can be explained through a combined sequential and resource model (see Fig. 1.1). This is based on the following processing steps: information intake (perception), information processing in the narrower sense (cognition) and information output (motor function) [3]. Additionally, it must be remembered that the available capacity of resources is limited.

The efficiency of these three levels of the information processing system is influenced by available processing resources and requires the application of attention. This leads to targeted selection of information which is intended to be the content of conscious processing. The constant oversupply of information exceeds human processing capacity, so that it is impossible for a human being to consciously perceive everything which reaches the level of the sensory receptors.

Human beings can distribute their entire attention to varying degrees among the three levels of the information processing system in order to select relevant sources of information and further process this information. For each operational task it is possible to learn an efficient distribution of attention, while in extreme cases a poor distribution of attention can cause human error.

On a theoretical level, varying forms of attention can be divided into the dimensions of selectivity and intensity. Selective use of attention describes the fact that human beings must decide between different competing sources of information. Within this divided attention, a human being must simultaneously perceive various stimuli, while a shift in attention means ignoring one stimulus in order to subsequently engage with another. Intensity of attention concerns the level of activation; relevant factors here include reduced vigilance (low proportion of relevant stimuli) and sustained attention (high proportion of relevant stimuli).

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Fig. 1.1 Driver-Vehicle-Environment System Model (cf. [1])

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1.1.1 Information intake

Information intake includes all processes relating to the discovery and recognition of information. The procedure of internally representing the environment will be designated as perception. This internal image of the environment is influenced by the situation in which a person finds themself and the experiences at their disposal. Information intake occurs with the sensory organs. A human being can take in a variety of simultaneously transmitted information through all sensory channels in parallel; however, simultaneously processing a variety of information can diminish performance. The specific performance range of the sensory organs influences the quantity and quality of information absorbed, and thus every subsequent step of information processing. During driving a vehicle, visual, acoustic, tactile and vestibular perception are of the highest significance. The sensory memory register (also called ultra-short term memory) is also classified under information intake. The sensory memory register exclusively stores physically-coded information. Visual information is stored in the iconic memory register and acoustic information in the echoic register for a period of between 0.2 s and 1.5 s respectively [3].

During the intake of visual information, the eye has the following three basic tasks: adaptation (adjusting the eye's sensitivity to the current light density), accommodation (alignment to varying visual distances) and fixation (directing the eyes onto the visual object so that both optical axes converge). The eye aids colour and object recognition as well as the perception of motion, spatial depth and size.

The ear fulfils three basic functions during the intake of auditory information: adaptation (increasing the auditory threshold necessary for distinguishing the hearing process), auditory pattern recognition (necessary for language and noise identification) and acoustic spatial orientation, which is accomplished by binaural (two-ear) hearing.

Tactile information intake involves the haptic or kinaesthetic perception channel. The tactile perception system enables recognition of distortions to the skin. Receptors (lamellar corpuscles and Meissner's cutaneous receptors) impart sensations of pressure, touch and vibration in and beneath the skin. The kinaesthetic perception system recognizes the stretching of muscles and the movement of joints. Various types of receptors located on the muscle spindles, joint regions and tendons enable the perception of body movements and the relative positions of parts of the body with respect to one another.

Spatial orientation is accomplished in human beings by the vestibular perception system. The vestibular apparatus, located in the inner ear, functions as a receptor. This apparatus also has the task of relaying information about maintaining balance and triggering positional reflexes for normal head and eye posture. During vehicle guidance, the vestibular sensory channel contributes to the perception of speed and acceleration of the vehicle.

Most of the information relevant to driving an automobile is taken in visually (usually around 80–90 % [4]). The basis for a driver's correct choice of action is an optimally complete internal representation of the relevant transport space. It is also important for the driver to take in information relevant to vehicle guidance from a great distance, leaving sufficient time to react to this information. This can only be guaranteed by the eye, since the eye is the only far-reaching human receptor system which can be focused selectively [5].

During tasks encompassing human behaviour in traffic, information intake is strongly dominated by the limits of eye movement. The area from which a driver can take in visual information is determined by the driver's visual field and range of vision while looking forward or turning around. Depending on the object's mapping location on the retina, there is a differentiation between foveal and peripheral vision: with foveal vision, the object is mapped onto the central depression of the retina (fovea); in this region, only objects within an aperture angle of 2° can be seen distinctly. The further the image is from the fovea, the less distinct it will appear. In the peripheral field of vision, movements and changes of brightness can be perceived. In the literature, various views can be found on the role of foveal and peripheral vision and their contribution to information intake during driving. For example, [5] assert that foveal information intake during driving plays a significant role under heavy stress, that is, under a high density of information and therefore high demands on information processing.

The size of the usable field of vision varies between good and bad drivers. While good drivers possess a usable field of vision of 9–10°, bad drivers can only manage 6–7° [6]. The usable field of vision is defined as a variable spatial expansion around the fovea which determines the region within which a person can identify the information necessary for performing a particular defined task.

The quality of a person's visual information intake is influenced by the type of signals and the frequency of their occurrence. Thus [7] distinguishes between critical, neutral and non-critical signals, as well as critical and non-critical additional signals. With respect to the frequency of information occurrence, the studies of several authors ([7] gives an overview) have shown that observational performance improves under an increased occurrence of signals requiring reaction over a unit of time. This rule applies up to an optimal signal frequency of approximately 120 to 300 signals per hour. If this signal frequency is significantly exceeded, the observer enters a situation of excessive demand, with the result that more and more signals remain unanswered. In their "Theory of Pathway Inhibition", [8] assert that similar stimuli interfere with one another, and therefore heterogeneous stimuli result in better attention performance.

1.1.2 Information processing

Signals from the environment (e.g. road conditions, other vehicles, weather and visual conditions) and the vehicle (e.g. displays, input devices and vehicle dynamics) are taken in by human receptors, adapted and then further processed at the level of information processing in the narrower sense (cognition). Here a decision is made about whether information should lead to an action (active case) or is merely endured (passive case). This decision is principally influenced by the driver's individual characteristics. The range of choices and actions can be explained by three levels of behaviour which build upon another, which [9] explains as skill-based, rule-based and knowledge-based (see ▶ Sect. 2.1). The behaviour level on which information processing occurs depends on the type of the task to be performed as well as the driver's individual characteristics, in particular the driver's experience with the demands.

Memory plays a central role in the cognitive processing of information. With the help of memory, sensory impressions are compared with learned and stored structures of thought and judgment. According to the classic three-level storage model, memory consists of the sensory register (ultra-short term memory), short-term memory and long-term memory. Information is actively processed in short and long-term memory. In a continuous process, stored information is summoned from long and short-term memory and compared with those characteristic traits absorbed by the senses.

A driver's risk of accident is influenced by individual tolerance and inaccurate perceptions of traffic risks. One significant aspect of the decision procedure within information processing is the fact the selected action promises the greatest utility under varying external circumstances with regard to associated risk. The concept of risk is defined in various ways. Often it is interpreted as the probability that an undesirable outcome will occur. Thus, for example, [10] define risk as the relation between variables which describe the negative consequences of outcomes and variables which characterize the probability of those conditions arising under which the consequences represent a possibility. This view, however, does not include consciousness of risk. [11] sees risk as a multidimensional characterization of a negative expectation resulting from a probabilistic decision process.

Countless models have been developed to explain drivers' risk perception. Among the most well-known are the "zero risk" model [12] and the "risk homoeostasis" model [13]. According to the zero risk model, humans behave such that their subjective risk amounts to zero; this model is based on the individual motivations influencing driving behaviour and adaptation to risks perceived in road traffic. The theory of risk homoeostasis asserts that, upon reduction of objective risk (e.g. through technical measures), humans alter their behaviour so far in the direction of "more dangerous" that their subjective appraisal of risk takes on the same distance to their personally accepted risk as before the introduction of the measure [13].

The model of subjective and objective safety contrasts subjectively experienced safety with those forms of safety which are physically measurable [14]. The threat-avoidance model [15] proceeds from the assumption that a driver's behaviour when perceiving a potentially dangerous event is primarily selected by weighing the utility and cost of all the alternatives.

The chief components of risk perception, according to [10], are information about potential dangers in the traffic environment and information about the capability of the driver-vehicle system, each of which mitigate the potential danger of an accident.

1.1.3 Information output

On the third level of the information processing system, decisions reached at the level of information processing in the narrow sense are transformed into actions. For driving, these actions encompass motor movements of the hand-arm system as well as the foot-leg system. The physical stress of a physiologically performed task is low compared with the stress associated with information intake and processing and is further reduced by technical support systems in the vehicle (e.g. power steering).

1.2 Driver characteristics and the limits of human performance capacity

Human performance is generally characterised by work output and the demands on the individual carrying out the task. Both work output and demands are subject to inter- and intra-individual variation: not all individuals fulfil the same task equally well, but even individuals can demonstrate performance variability if performance of the same task is measured at different points in time. This variability can be attributed to individual human characteristics and thus also to varying performance conditions. The following section will delineate the relevant human performance conditions for vehicle guidance and their impact on driving performance and safety. To this end, a systematic differentiation between characteristics, capacities and skills will be carried out.

Properties

Properties will be defined as intra-individual influence variables which are predominantly independent with regards to time (or which only change over very large periods of time). The most relevant traits for driving are often identified as gender, age and personality traits.

While some studies have identified gender-specific differences in driving behaviour, other studies were unable to confirm differences with respect to risk behaviour or speed. Nevertheless, differences in perception of the risk of an accident have been determined between men and women: men estimate their driving capabilities better than women, though women tend to underestimate their capacity while men tend to overestimate theirs. Furthermore, male drivers judge certain behaviours to be less dangerous and less likely to result in an accident than female drivers.

The human capacity to orient oneself with the senses, process information received and carry out motor actions alters with age, during which human organs undergo changes. Increasing functional deficits can be at least partially compensated for by the fact that older drivers generally have more driving experience. There are various approaches to defining the term "older". Often calendar or chronological age is used as an orientation point, according to which people are considered older after their 60th or 65th year of life, even though the functional changes associated with the aging process are subject to significant inter-individual variations.

Various personality traits can also influence a driver's behaviour. Thus, correlations have been identified between a driver's risk tolerance and their driving speed and use of traction. Drivers who are emotionally unstable, impulsive and incapable of teamwork have a higher accident risk than people who are adaptable and emotionally stable. Furthermore, selectiveness, perception style and reaction time are identified as individual traits which act as indicators of accident involvement.

Capacities

Capacities are defined as accessible, intra-individual, time-dependent short or long-term changes; they affect the physiological function of organs, or the so-called basic human functions.

A driver's actions are influenced by those mental capacities defined as intelligence, particularly on a knowledge-based level. The concept of intelligence is debated in the literature. According to a broad definition, intelligence is understood to be the hierarchically structured entirety of those general mental abilities which determine the level and quality of a person's thought process. With the help of these abilities, the characteristics significant to action within a problem situation can be recognized in context, allowing for alteration of perceived objectives according to the situation.

However, human cognitive and sensomotoric abilities such as reaction capacity also indirectly influence driving through the impact of these traits on information processing.

With increasing age, the ability of receptors diminishes, which leads to overall limitation in information intake.

Parts of the eye change with age due to a loss of tissue fluid. The resulting effects on visual capacity are summarized in Tab. 1.1.

Progressive limitation of the visual field during aging aggravates motion perception issues while driving, since the motion of relevant objects is first observable in the peripheral field of vision.

Changes in hearing during aging include reduction in auditory amplitude, particularly at higher frequencies. Difficulties in discriminating the frequency and intensity of tones, as well as in recognizing complex noises such as language under difficult perceptive conditions (e.g. background noise, distortion) and partially impeded directional hearing are further changes.

As age increases there is also a loss in sensitivity of tactile perception.

The sense of equilibrium is best formed in 20 to 30-year-olds and decreases strongly after the 40th year of life, reducing by half in the ages between 60 and 70.

Sensory storage works less efficiently as age increases. Acoustic signals demonstrate a higher speed of decay in echoic storage, while visual signals remain longer in iconic storage. During the preparation of information relevant to driving, this leads to acoustic information only being available for processing for a temporally shortened span, while visual stimuli can only be received to a limited extent due to blocking of the iconic storage register.

Among the individual areas of attention, older people exhibit reduced performance, which in their additive effect result in an overall decrease in attention capacity. Consequently, older drivers must decide on their actions based on a relatively smaller pool of environmental information than younger drivers, since they do not have access to all potentially important information.

Overall it has been demonstrated that older drivers can encounter difficulties, above all in complex and novel situations which require fast action. Additional impediments occur in the form of limitations to information intake, which result in partially delayed sensorial preparation of relevant information, leaving less time for older drivers to process information relevant to driving and act accordingly.

Tab. 1.1 Changes to the visual system which occur with age (↑ Increase; ↓ Decrease)

Impact		**Cause and Influence Variables**	
↓	Range of accommodation	↓	Fluid in tissue
↓	Static visual acuity		Lighting conditions
↓	Dynamic visual acuity	↓	Speed of accommodation
		↑	Dullness of sensory cells
↑	Sensitivity to bright light	↑	Functional disruptions in the retina
		↑	Adaptation time
↓	Contrast sensitivity		
↑	Necessary light density	↑	Deterioration of cornea, lens and vitreous body
↑	Limitation of the visual field		

Skills

Skills are understood as human working functions which are determined by basic human functions and the concrete formal state of the task and work environment. In the context of driving, driving experience, driving style (classified by vehicle dynamic parameters chosen by the driver) and driver type (classified by observed driving behaviour) are particularly significant. Driving experience can have varying effects on the risk of accidents. With increased driving experience, driving skills are improved, along with recognition and judgment of risks. Improvement in driving skills can be attributed to the fact that the number of varying driving situations experienced grows with an increase in distance driven, thus enabling the formation of routine actions. While vehicle control becomes better with increased driving experience, experience in other areas leads to the formation of errors and bad habits, for example not looking in the mirror, braking late and tailgating. When it comes to skills which reflect their control over the vehicle, beginners have been shown to perform more poorly than experienced drivers. This is evident in late acceleration, poor and inconsistent steering motions and slow gear shifting. Inexperienced drivers make more steering motions than experienced drivers. Inexperienced drivers' eye behaviour is often described as less efficient, since they fixate too frequently on points in close proximity. Thus young, inexperienced drivers recognize distant accident risks relatively poorly compared to experienced drivers; however, there is no difference between the two groups when it comes to recognizing nearby dangers. With increasing experience drivers learn to recognize dangerous objects and events based on certain parts of the traffic system. This also corresponds with the fact that visual fixation and search patterns differ between inexperienced and experienced drivers. Various rates of speed are demonstrated when driving around curves depending on driving experience. Experienced drivers drive faster into curves and slow down more within the curve than inexperienced drivers.

Driving style is influenced both by driving experience and the personality of the driver. Various driving styles have been identified. These can be used to describe drivers of commercial vehicles as "weak and lax", "jerky and abrupt" or "swift and lively". Drivers of passenger vehicles are identified by parameters for speed, longitudinal acceleration and distance to the car in front as "slower and more comfort-conscious", "average, with high safety consciousness" and "fast and sporty". On the basis of behaviour observation, similar driver types were found, which were described as "inattentive average driver", "less habitual, indecisive driver", "sporty, ambitious driver" and "risk-seeking, aggressive driver".

1.3 Demands on vehicle operators in the driver-vehicle-environment system

The demands on the driver result from the task of vehicle guidance, which is jointly determined by environmental factors. Here, the complexity of the situation which the driver must manage is paramount. This results from the characteristics of the route and the dynamic behaviour of other road users. How the driver manages these challenges depends on both the driver's individual characteristics and the driver support offered by the vehicle (advanced driver assistance systems). Depending on the volume and duration of stress, bottlenecks occur in the driver's information processing system, which can lead to deviation from so-called "normal behaviour" all the way to critical traffic situations and even accidents, based on the continuum of traffic behaviour as outlined by [14]. In order to identify these bottlenecks, the following section will compile the subtasks involved in vehicle guidance, and the demands resulting from these tasks.

Subtasks involved in vehicle guidance

Approaches to describing the task of vehicle guidance by means of subtasks exist at various levels of detail; some were derived for special explanatory purposes or singular aspects of vehicle guidance. In the following section, only two frequently mentioned classifications will be presented.

An arrangement of driver tasks according to their significance to fulfilling the purpose of a journey has been suggested by [16]. Primary activities consist of those activities which are absolutely necessary for the completion of the journey, such as steering and pressing on the accelerator, and which are predominantly determined by the course of the road, other road users and environmental conditions. Secondary activities are characterized by an output of information to the environment (e.g. honking the horn or using the indicators) as well as reactions to the current situation, such as turning on the windscreen wipers or turning on headlights. Tertiary actions are not directly connected with the actual operation of the vehicle, but rather serve to increase the comfort of a journey (e.g. controlling ventilation and air conditioning or operating the radio).

The 3-level model proposed by [17] (see ▶ Sect. 2.2) describes a hierarchy of primary driver tasks at the highest level using the following activities: navigation (choosing the route for a journey), guidance (determining target lane and target speed) and stabilisation (adjusting vehicle movements to the designated driving variables).

This hierarchy also reflects the temporal margin available for the execution of a particular task, along with the tolerance for error. While a delayed decision or error at the navigation level generally does not lead to a critical situation, thoroughly critical driving situations or even accidents can arise at the stabilisation level.

Requirements for vehicle guidance

Generally the requirements involved in an activity stem from the tasks to be performed. With regard to task non-specific, situational operating conditions, stressors arise which can be described objectively. Among these situational factors, the duration and temporal composition of these requirements and influences from the operational environment are significant.

In order to investigate the requirements for operational tasks, various procedures of activity analysis have been developed. In order to analyse the requirements for driving, [18] created a version of the “Fragebogen zur Arbeitsanalyse” (work analysis questionnaire, FAA, [19]), modified for road transport. This modified version takes into account information processing and vehicle control, while the former is further subdivided into information sources, sensory and perception processes, acts of judgement and thought and decision processes. A total of 32 operational elements were defined for information processing and 7 operational elements for vehicle manipulation.

On the basis of the FAA modified by [18] and with the help of the section on the cognitive performance of the “Tätigkeitsbewertungssystem” (activity evaluation system, TBS, [20]), the requirements associated with vehicle guidance can be derived.

In the list of requirements presented below, the domain of information sources, sensory and perception processes encompasses acts of orientation to the environment. Additionally, perceived circumstances are registered and processed as signals. Signals are stimuli which are identified and differentiated, which have a particular meaning for the activity of operation when appearing in a particular manifestation and which mark a specific action as necessary. Evaluation is rendered by the deduction of diagnoses about circumstances used to find appropriate measures. To this end, stimuli are set apart and compared and signal manifestations are combined. Requirements on thought and decision-making can consist of diagnostic efforts which encompass the investigation of possible variants or prognostic efforts which assist the selection of functional variants. Vehicle control takes place in the context of processing efforts.

I Information sources, sensory and perception processes

- Visual displays in the vehicle
    - instruments (e.g. speedometer), positioning of input devices (e.g. heated rear window), information from on-board computer (e.g. exterior temperature)
- Acoustic information
    - speech output from the navigation system, sirens on emergency and rescue vehicles
- Secondary acoustic information
    - radio, conversations with passengers or on the telephone
- Other road users
    - vehicles, pedestrians
- Characteristics of the route
    - transversal and longitudinal course of the route, junctions, road width, number of lanes
- Traffic signs
    - speed limits, right of way and direction signs
- Condition of the road surface, weather and visual conditions
    - moisture, dirt, snow, black ice; light in the eyes, rain or snowfall, fog

E Evaluation

- Longitudinal distances from or between other road users or objects
    - from the vehicle in front, between two vehicles in adjacent lanes, from pedestrians, cyclists and obstacles in the same lane.
- Horizontal distances from or between other road users or objects
    - vehicles at the "same point" as vehicles by the side of the road
- Speed of the driver's vehicle and other vehicles or road users
- Anticipation of critical traffic situations
    - Sudden vehicle merging, disregard of right of way by others, a child running into the street

D Decision making and thought processes

- Selecting suitable actions for navigating the vehicle
  - deciding which route to choose, which direction to take at intersections
- Selecting suitable actions for vehicle guidance
  - deciding what speed to drive at and what distance to maintain from other cars, passing manoeuvres, choosing a lane and a lateral position therein

V Vehicle manipulation

- Controlling the vehicle's longitudinal motion in order to stabilise the vehicle
  - accelerating, braking, shifting gears
- Controlling the vehicle's horizontal motion in order to stabilise the vehicle
  - steering
- Controlling further functions
  - lights, windscreen wipers, radio

1.4 Evaluating the requirements for driving with respect to human performance capacity

In conclusion, the demand areas delineated above will be evaluated with respect to human performance capacity in order to demonstrate meaningful areas for technical driver support.

Information sources, sensory and perception processes

Perception of those information sources relevant to fulfilling the task of vehicle guidance is of the utmost importance for the driver. With the help of this information, the driver creates an internal image of the current state of the vehicle and its environment which serves as a basis for the driver's decisions and actions.

From this, the following requirement can be concluded: namely, that relevant situation-dependent information about the vehicle and its environment must also be perceivable by the driver. This impacts information newly accrued for the driver through the use of driver assistance systems and the need for systems which attempt to compensate for the driver's information deficits from the environment.

The process of human perception is limited by perception thresholds and the necessary application of attention. Perception thresholds vary from individual to individual, so for example age is a significant influencing factor, and they are also dependent on the environment. Since driving occurs in radically differing environments, it is important to ensure that information presented in the vehicle falls above the perception threshold and that relevant information from the environment, in case it cannot be perceived under certain conditions, is supported by technology (e.g. night vision systems which mark relevant information such as pedestrians). During driving, visual, acoustic and tactile information play a particularly large role and must be configured according to their environment. Light conditions can vary between full brightness or strong glare all the way to full darkness. Differences in acoustic environment can be equally great. There are vehicle situations without background noise or exterior sounds entering the vehicle, all the way up to conversations or loud music in the vehicle. Tactile information within the vehicle must also be adapted to possible vibrations transmitted by the vehicle or road. Particularly when configuring visual information within the vehicle, it is important to note that human beings can only sharply distinguish objects when they are mapped on the fovea up to an aperture angle of 2° . Hence it is necessary for the driver's vision to navigate far from the vehicle's external environment in order to take in complex information within the vehicle. This goes beyond simply coded signals, leading the driver to be visually distracted from the actual task of vehicle guidance.

Whether the driver perceives relevant information or not depends largely on whether the driver pays attention to the information. This application of attention is strongly influenced by the overall driver-vehicle-environment. Here the amount and type of mutually competing information from the vehicle and its environment, the mental and/or emotional preoccupation of the driver with concerns irrelevant to driving as well as the driver's personal experience all play a role. In general it has been shown that drivers perform better in paying attention to nearer objects and that changes in application of attention occur more quickly and efficiently from "far to near" than the reverse.

Acts of judgement

Acts of judgement are required in order for the driver to evaluate distances, speeds and potential critical situations.

Since judging absolute distances is difficult for humans, the driver uses various information as variables for judging longitudinal distance. Perspective speed, which is calculated by the size of the vehicle in front as well as the difference in speed and absolute distance to that vehicle, sends the driver a message about how quickly the distance to the vehicle in front is changing. Similarly, the time to collision (TTC), which takes into account absolute distance to the vehicle in front as well as difference in speed, is often identified as a relevant judgement variable for the driver. It can be assumed that TTC determines a driver's actions [21].

The human threshold for perceiving motion while driving under ideal visual conditions lies between 3 and $10 \cdot 10^{-4}$ rad/s. However, length of observation also influences the threshold for perceiving distances and differences in speed from vehicles in front [22]. With a decreasing difference in speed and decreasing length of observation, the distance from which a difference in speed can be registered also decreases. In general, it has been shown that drivers tend to leave a larger safety margin than necessary at lower speeds, while they fall short of this at higher speeds.

Acoustic information can also contribute to judging distance from other vehicles; however, subjective evaluation errors can result, for example overestimating the distance of a very quiet truck or underestimating the distance of a very loud passenger car.

Anticipation of critical situations is influenced by the driver's experience with a given potential critical situation. Depending on which situations a driver has already experienced and committed to long-term memory, the driver will classify a critical situation as such based on the situation's distinguishing characteristics and react accordingly.

Decision-making and thought processes

While fulfilling the tasks of navigation and guidance, the driver must choose an action appropriate to a given situation on the basis of decision-making and thought processes. Under the condition that humans are given sufficient time to make a necessary decision based on an external traffic situation, humans will choose more successfully than technological systems. This can be attributed to the fact that a driver has access to a more complete representation of the driving environment, although this will be less precise in particular aspects, and that with increased driving performance a driver can call on more and more experiences with identical and similar situations.

Driver reaction times lie at around 0.7 s in expected situations (e.g. approaching a vehicle), at around 1.25 s in unexpected but typical situations (e.g. braking of the car in front) and up to 1.5 s in surprising situations [23]. The more critical a situation is, the faster the driver reacts. Slowness and human reaction time vary depending on driving situations and attention. Drivers react faster in heavy traffic and choose smaller distances.

Vehicle manipulation

Manipulating a vehicle in order to fulfil primary and secondary driving tasks normally does not present a problem for the driver. Control of longitudinal and horizontal movements occurs on a skill-based level for the driver, which means they are automatic processes that scarcely require any attention. This allows a driver to react quickly and flexibly to situational changes. The case is similar with secondary activities as long as they occur frequently and are accordingly well-practiced by the driver.

However, it is possible for the driver to meet excessive demand on the level of tertiary driving tasks, particularly if those functions are only seldom used, if complex control menu structures must be navigated or if the driver is confronted with infrequently occurring warning signals.

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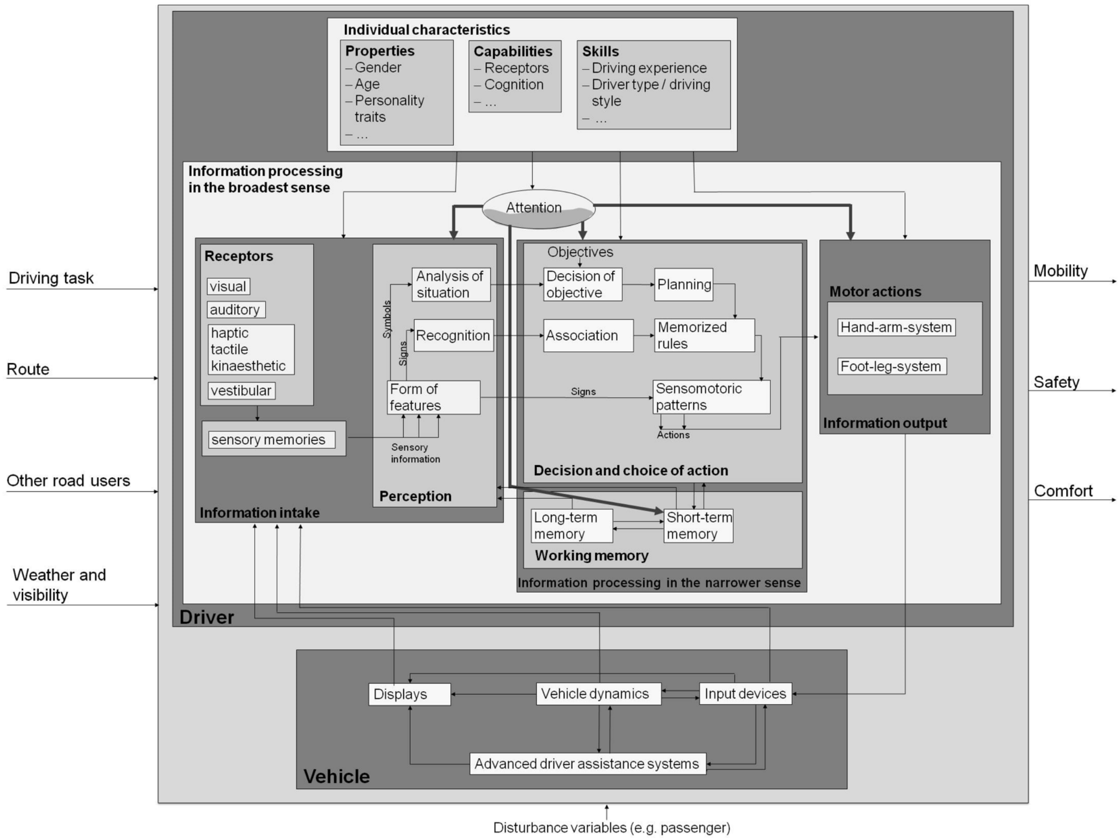

Fig. 1