Ergonomics of cockpits in cars

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It is essential that designers of motor-vehicle cockpits see the driver as part of the driver-vehicle-environment system. This article starts by systematizing the factors influencing the driver-vehicle-environment system and then goes on to examine features like design of signals, controls and driver assistance systems. The section entitled “Anthropometrics in the vehicle cockpit” (LANDAU) deals with the question of anthropometrics in cockpit design.

1 The driver-vehicle-environment system

In the following section a simple model is constructed to define the associations between driver, vehicle and environment and to identify the demands that the task of driving the vehicle imposes on the driver.

The model illustrated in Fig. 1.1 consists of the two elements - driver and vehicle. The driving task factor exerts an effect on these two elements and is itself also influenced by environmental factors. Disturbance variables, e.g. passengers, can also exert an effect. The initial features of this system can be defined against the criteria of mobility, safety and comfort. This model only takes into account those factors relevant to the aspects being examined here.

The driver as an element in the system

Driving a motor vehicle is a task involving primarily informatory activities and the job content is to use information to trigger reactions. The driver performs a control activity involving continuous processing of information (ROHMERT 1983).

Consequently, the processing of information and the factors interacting with this, which can vary according to the personal characteristics of the driver, are of crucial importance for the driving task.

A model combining stages and resources is used here to examine the information processing. The processing stages are information perception, actual information processing in the sense of cognition and information transmission in the sense of action. Allowance is also made for the fact that the available resources are limited.

The information processing model illustrated here is a classic form reflecting a purely static view of the situation. There are, of course, completely different approaches to model design based on recent psychological action theory and on physiology, but these were not used in this case because a static model is perfectly adequate to illustrate associations arising in the driver-vehicle-environment system.

Information reception

Information reception is an integral part of all processes relating to discovery and recognition of information. It is mediated by a person's sensory organs and its quality and quantity, and consequently all the subsequent processing steps, are determined by the performance range of those sensory organs.

The greater part of the traffic-relevant information received whilst driving is visual. In order to enable the driver to take the correct decisions on action required from him, the view of the relevant traffic environment available from the driving seat must be as complete as possible. When a vehicle is traveling at high speed, it is extremely important that the driver receives the information relevant to the driving task over a considerable distance, so that he will have adequate time to adjust the movements of the vehicle accordingly and with sufficient precision. This demonstrates the importance of the driver's visual system in performance of the driving task, because the eye is man's only natural long-range receptor system.

The physical limits of eye movements have a predominant effect on information reception in tasks involving human behavior in road traffic. The extent of the area from which the driver can receive information visually is determined by his range and field of vision and by his ability to enlarge these by eye, head and body movements.

Actual information processing

Signals from the environment (e.g. road status, traffic status, weather conditions and visibility) and from the vehicle (e.g. displays, controls and vehicle dynamics) are registered by human receptors, sorted and then actually processed by cognition. It is here that the driver decides whether a piece of information necessitates as action on his part (active case) or whether it can be tolerated without any action being taken (passive case). This decision will be heavily dependent on the individual driver's characteristics. Actual information processing includes the stages of perception and decision (selection of a specific action). These stages can be explained by the three complementary types of behavioral levels defined by RASMUSSEN (1983) - skill-based, rule-based and knowledge-based. The behavioral level on which the information processing takes place will depend on the nature of the task at hand and the characteristics of the individual driver and, in particular, on his past experience with similar demands.

Information transmission

The third stage is the performance of the actions decided during the actual information processing. In the case of vehicle driving, these actions include motor responses of the hand-arm system and the foot-leg system.

Individual characteristics

Human performance is generally characterized by the results of the work performed and the strains resulting in the individual performing the work (BOKRANZ & LANDAU 1991). There are inter- and intra-individual deviations not only in the work results but also in the resulting strains. Each individual person does not perform a specific task equally well, but the performance of a single individual can also vary widely when measured at different points in time. These variances are attributable to individual personal characteristics and, consequently, to differences in performance conditions.

The vehicle as an element in the system

Ergonomic analysis of the vehicle as an element in the system focuses on the driver-vehicle interfaces. These include the controls, the vehicle's dynamics and the signals. These interfaces can be modified by installation of driver assistance systems.

2 Controls

The following list itemizes the key design requirements for controls in general and vehicle controls in particular.

- The number of controls should be kept as low as possible in order to facilitate performance of the desired function and prevent errors.
- The design of the driving seat must minimize effort required to operate controls in order to prevent premature fatigue and bodily injury.
- In order to be classified as safe, a control must be quick to operate correctly and the operation must cause a minimum of visual, motorial and cognitive distraction. Controls must also be self-explanatory and reliable and not require long training periods.
- Vehicles controls must be designed and installed in a way that guarantees safe performance of the driving task and does not impose an excessively high or low demand on the driver.
- The aim of a control’s ergonomic design is to ensure a high level of fulfillment of the control/work task whilst exerting a balanced level of stress on the person performing it.

The flow plan shown in Fig. 2.1 (KIRCHNER & BAUM 1986) shows a systematic procedure for the design of controls.

Designers should always remember that the number of controls should be as many as necessary, but as few as possible.

Table 2.1 lists standard guidelines for dimensions, regulating distances and angles, and actuation resistance of selected controls.

3 Signals

Most of the systems for communicating variable information in a motor vehicle are in the form of visual displays. This is far from optimal, as most (80-90%) of the information relating to traffic status is also perceived visually. Designers should therefore verify whether it would be possible to diminish the load on the visual faculty by devising other means of communicating information in the vehicle cockpit. These could, for example, be acoustic, tactile or kinesthetic (haptic).

Visual displays can be either digital or analog. The pros and cons of these two forms are listed in Table 3.1.

The quality of a person's visual reception of information depends on the nature of the signal and the frequency of its appearance. For example, SCHMIDTKE (1993) makes a distinction between critical, neutral and non-critical signals and non-critical and critical supplementary signals. Several investigations have shown that awareness of a signal demanding a reaction improves in direct proportion to its frequency per given time unit. This rule generally applies up to an optimal frequency of between 120 and 300 signals per hour. Frequencies significantly exceeding this figure will overtax the subject with the result that more and more signals will fail to elicit a response. In their Theory of Pathway Inhibition, GALINSKY et al. (1990) assume that similar stimuli inhibit each other and that heterogeneous stimuli attain higher awareness levels.

In cases where acoustic communication of information is used, care must be taken to ensure that the driver accepts the signals and is not disturbed by them. This means that the driver must perceive the type of signal (tone, voice) as pleasant, and also that acoustic signals must not occur too frequently. Acoustic signals are very suitable in time-critical cases such as warnings.

Haptic signals have the advantage that they can assist the driver in performing the action expected as a result of the information. For example, a haptic gas pedal can indicate the speed at which the driver should travel.

Signals of all kinds must be designed so that they lie above the driver's sensory perception threshold.

Signal design should follow the sequence set out in Fig. 3.1.

4 Driver assistance systems

The basic aim of assistance systems is to help prevent driver errors, give warnings and provide support in performance of driving tasks.

Past development of driver assistance systems has tended to go in two directions:

Firstly, systems capable of enhancing driver competence by providing additional information. Secondly, systems relieving the driver by automatically performing parts of the driving task. In order to improve and supplement the supply of information, they use a broad spectrum of statements, tips, observations and instructions up to the point of actually intervening in the driving of the vehicle and automating vehicle control procedures.

Novel display forms may be used to provide supplementary information. These may give rise to safety problems, for example:

- by requiring longer fixation of the eyes on the instrument panel and thereby distracting the driver's attention from the road.
- by displaying complex information at an intelligence level to which the driver has difficulty in adjusting, once again distracting his attention and impairing his performance.

This broad definition of the term "driver assistance systems" includes both information systems (e.g. navigation systems) and support systems (e.g. distance control systems).

It has been discovered that, whilst driver assistance systems reduce the stresses emanating from the driving task, they can also create new stresses by requiring performance of new tasks, for example, programming the navigation system.

One ergonomic requirement for control concepts is that they must meet usability criteria, i.e. the criteria guaranteeing the highest possible level of usability (JORDAN 1998).

One of the main benefits expected from an intelligent driver assistance system is that it will relieve the driver of routine tasks. It must meet the criteria of compatibility, conformity to user expectations and consistency. It must be compatible with the driver's resources and must not cause overload of information. It must, above all, provide the driver with clear feedback, be sophisticated enough to perform the required tasks and give help where needed, while always expressing itself clearly and remaining controllable by the driver. It must be easy to learn and not error-prone. Obviously, these usability criteria have areas of intersection.

A further fundamental design requirement for driver assistance systems is the incorporation of anthropometric and information technology elements, plus data obtained from ergonomic research.

Allowance must also be made for a number of other requirements which may seem of subsidiary importance to the designer of the system itself but are often far from subsidiary for the car manufacturers affected by them, for example, space restrictions in the cockpit, fashion trends, globalization of the market (e.g. internationally understandable codes) and the omnipresent need to cut costs by rationalizing manufacturing processes.

An expert rating assessing the usability criteria from safety, performance (or reduced strain) and convenience aspects yielded the picture shown in Fig. 4.1.

Six experienced users of driver assistance systems (inc. navigation, cruise control and voice-controlled telephone) rated the systems' perceived contribution to safety, strain reduction and convenience on an ordinal scale from 1 to 5. Then the arithmetic mean of these ratings was determined. All three axes are related to the whole man-machine interface rather than to the driver alone. In this case, a one-dimensional definition of comfort was used for the sake of simplicity.

The diagram demonstrates very clearly that all the usability criteria lie in the upper quadrants. This indicates that the respondents were expecting significant contributions to safety, strain reduction and convenience from the relevant criteria, especially from those aiming at optimization of consistency, driver resources, feedback and low error rate which received high safety ratings. The criteria "relief from routine tasks", "driver resources" and "help where needed" were perceived as capable of improving driver performance and reducing driver strain. Relief from routine received a very high convenience rating.

Having discussed usability criteria, we will now go on to look at driver resources.

Driver resources

Demand profiles for various levels of driver assistance will be used to examine the criterion "driver resources". The requirements placed on visual, auditory, tactile and kinesthetic functions during *information reception* were rated by an expert (Fig. 4.2: Rating by the author on a three-stage ordinal scale). Driving without an assistance system places high demands on the eyes and only low demands on the auditory, tactile and kinesthetic functions.

In cases where an information system is installed, the need for auditory perception increases because voice information is provided. As the driver is also required to input data through a switch or a key on the steering wheel, the demands on tactile functions also increase.

It can be assumed that installation of a support system will aim to reduce the need for visual information perception to a certain extent. Whilst normal tactile and auditory requirements will remain essentially unchanged, new kinesthetic requirements will be added, e.g. the driver's awareness of the assistance system in the steering function whilst the car is moving. In the best case, automation of the driving function leads to a reduction in the full spectrum of demands imposed on the driver. It would, however, be over-optimistic to expect a reduction in visual requirements because, in the final analysis, the driver will always have to perform supervisory tasks.

When formulating the demand profile for *information processing* (Fig. 4.3), a distinction has been drawn between man-related and computer-related requirements. This shows that installation of a support system brings a complete shift in requirements, mainly by automating the driving process. For example, system requirements increase with the level of support, whereas driver requirements have to be differentiated. While driver assistance systems slightly reduce knowledge and concentration requirements, they tend to increase intelligence requirements.

The same applies to the *actions* required of the driver, where there are once again major shifts in demands placed on the relevant physical systems (Fig. 4.4).

The demands imposed on different sensory pathways, such as visual and auditory perception, can naturally overlap. This poses the question as to how this superimposition of demands affects information reception and processing and subsequent motor actions.

Different types of stress can either be additive, neutral, i.e. devoid of mutual effect, or even compensatory. Ergonomic research on this point is still at a very early stage.

If we regard man as a single-channel information processing system, possessing limited and constant maximum capacity but needing to process multiple items of information presented to him simultaneously, it would seem logical to expect an additive effect. However, there are several objections to this additive hypothesis. For example, no allowance is made for possible reduction in the effects of stress type and duration when various sensory pathways are involved. Could this more or less neutralize them or could they even cancel each other out?

In the 1980's WICKENS (1984) investigated the question of stress superimposition in multiple tasks performed in parallel. Fig. 4.5 depicts a qualitative resources model for the simplest case of a person performing two tasks.

Those of the driver's resources which may possibly come under strain from the use of a navigation system of the future are marked in Fig. 4.5. The route proposed by the system is registered visually by the driver and processed to a geographically coded form in his mind's eye. If the system calculates that the driver will be late for his appointment, it automatically dials the phone number of the person with whom the appointment has been made so that the driver can apologize and agree a revised time.

The model distinguishes between the methods of perception, in this case visual and auditory, the processing codes, spatial or verbal, and the three processing stages – information reception, information processing and action. The right side of the diagram shows whether the reaction is manual or speech-producing. Wickens (1984) comes to the conclusion that parallel multiple tasks belonging to different cells of this cube can present themselves simultaneously without causing any undue problems. This conclusion is based on the assumption that the different types of task are processed by the separate halves of the cerebrum which are relatively independent of each other.

These findings are still fairly vague. The question is what changes will have to be incorporated into the resources model if other sensory pathways and other processing codes are added in?

Introducing user adaptability is a first approach to the development of a resource-oriented driver assistance system. The assistance system simply determines the driver's requirements, so that a detailed analysis of data processing of the driver is not necessary.

One way of changing the functionality of the assistance system directly or indirectly would be to let the driver himself specify his requirements. Another option would be for the system to analyze his actions and adjust the requirements accordingly. The driver would not need to make any changes himself.

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Figures and tables

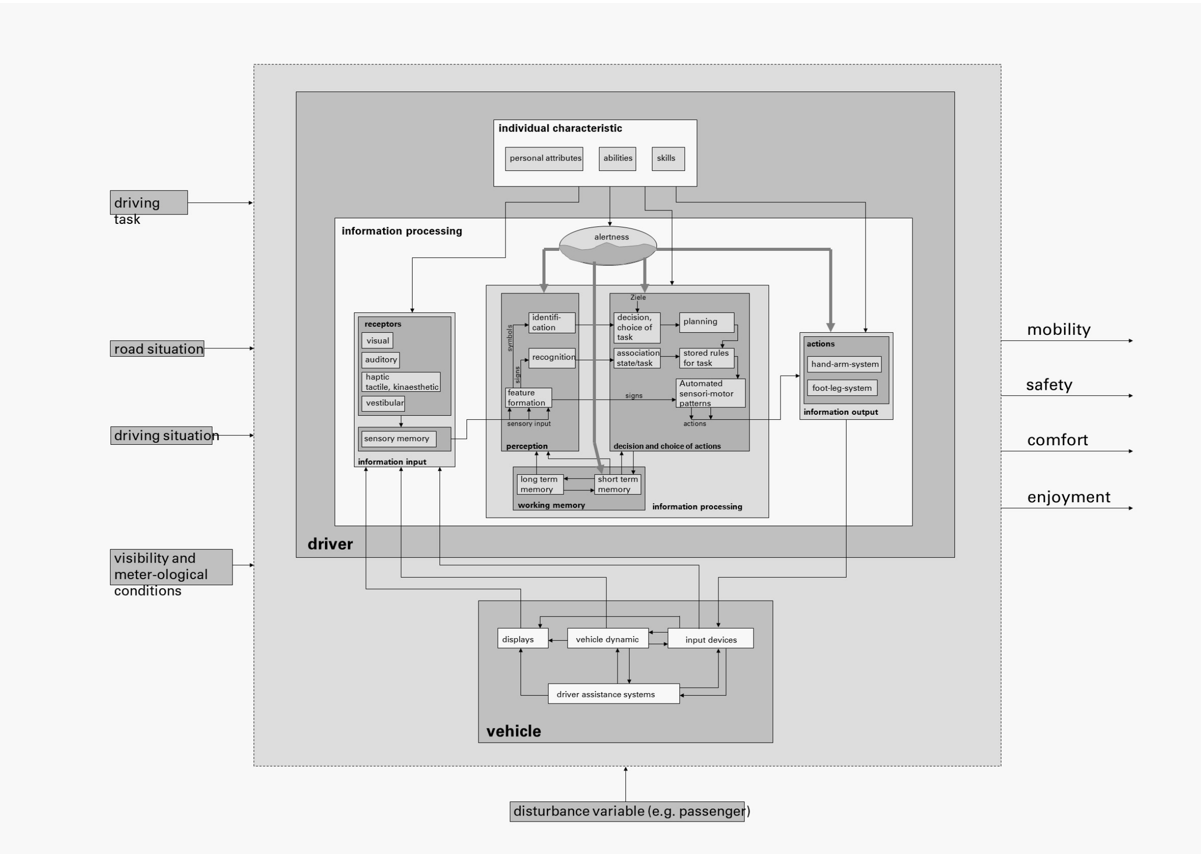


Fig. 1.1: system model driver-vehicle-environment

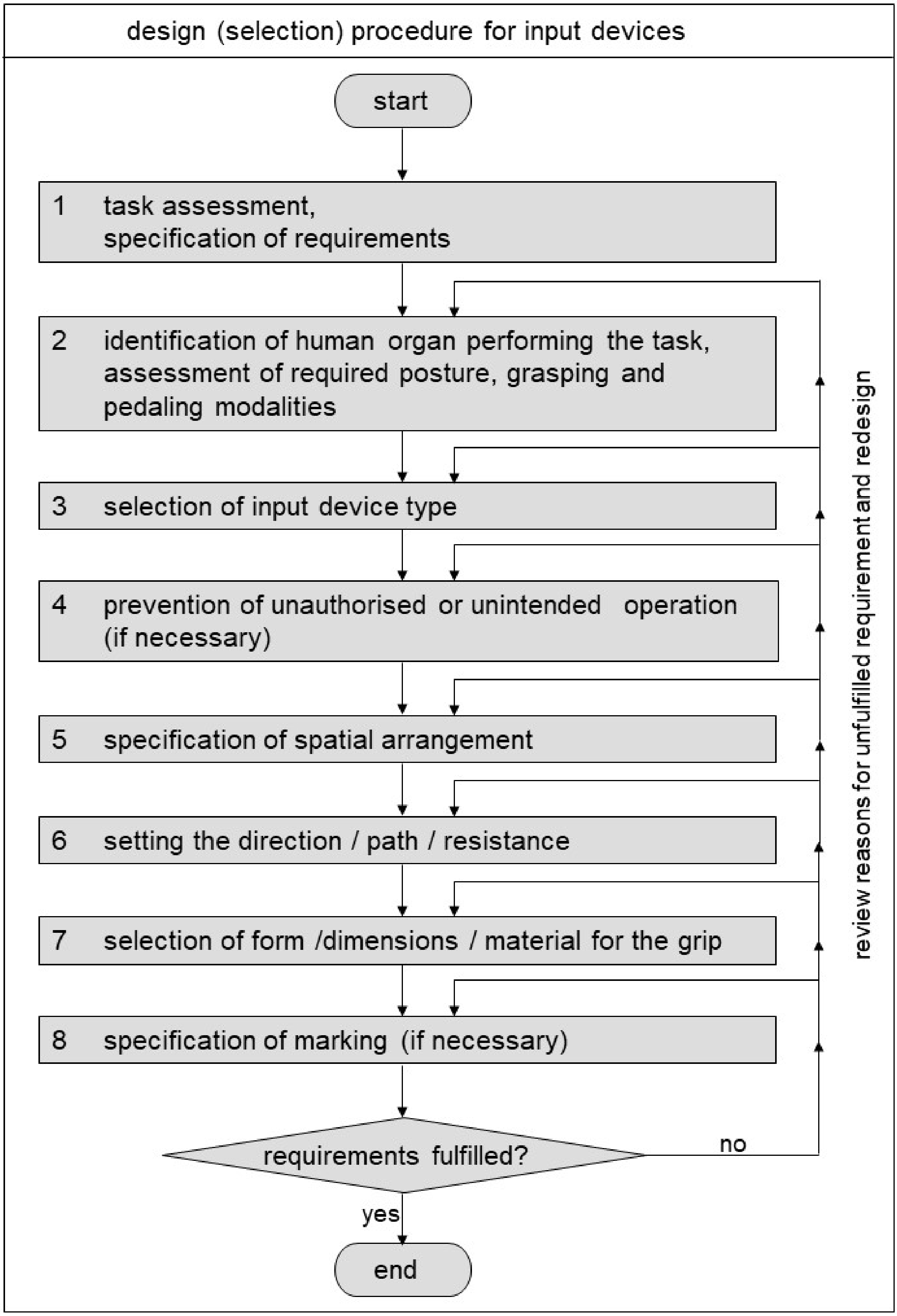
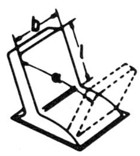
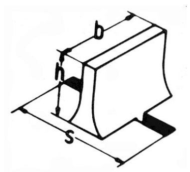
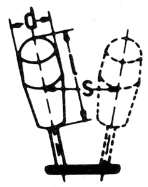
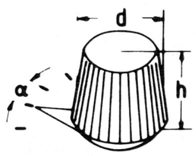
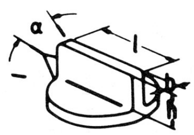
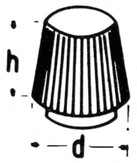
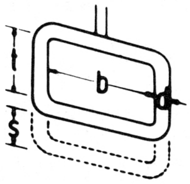
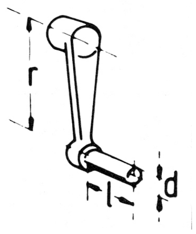
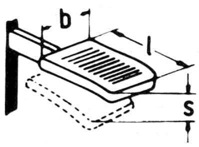
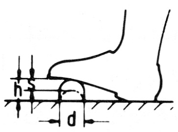


Fig. 2.1: Procedure for design of controls (from KIRCHNER & BAUM 1986)

Control type	Actuation	Dimensions [mm]	Regulating distance s / angle α	Actuation force / moment
 Push button/key	Finger Hand	d ≥ 10 d ≥ 40	min. 3 mm / max. 10 mm min. 6 mm / max. 15 mm	min. 1 N / max. 8 N min. 4 N / max. 16 N
 Rocker switch/key	Finger	l ≥ 15 b ≥ 6	min. 3 mm / max. 10 mm	min. 2 N / max. 8 N
 Tumbler or toggle switch	Finger	l ≥ 10 b ≥ 3	2-point switch [total actuation angle] min. 40° / max. 120° 3-point switch [angle per point] min. 30° / max. 60°	min. 2 N / max. 10 N
 Slide knob	Finger Hand	h ≥ 6 b ≥ 6 h ≥ 75 b ≥ 20	min. 5 mm / max. 100 mm min. 10 mm / max. 400 mm	min. 2 N / max. 20 N min. 20 N / max. 60 N
 Lever	Finger Hand	d ≥ 5 l ≥ 15 d ≥ 15 l ≥ 90	min. 20 mm / max. 100 mm min. 50 mm / max. 400 mm	min. 2 N / max. 10 N min. 10 N / max. 150 N
 Rotary switch	2 fingers 3 or more fingers	d ≥ 10 h ≥ 12 d ≥ 20 h ≥ 12	Actuation with visual control min. 15° / max. 45° Actuation without visual control min. 30° / max. 45°	min. 0,02 Nm / max. 0,1 Nm min. 0,04 Nm / max. 0,7 Nm
 Pointer knob	Finger	l ≥ 20 b ≥ 5 h ≥ 12	Actuation with visual control min. 15° / max. 45° Actuation without visual control min. 30° / max. 45°	for l ≤ 25 min. 0,1 Nm / max. 0,3 Nm for l > 25 min. 0,3 Nm / max. 0,7 Nm

 Rotary knob	2 fingers 3 or more fingers	d ≥ 10 h ≥ 12 d ≥ 20 h ≥ 12	unlimited	min. 0,02 Nm / max. 0,1 Nm min. 0,04 Nm / max. 0,7 Nm
 Push-pull knob	Finger	l ≥ 12 d_1 ≥ 10 d_2 ≥ 15	min. 5 mm / max. 100 mm	min. 5 N / max. 20 N
 Pull grip	Hand	b ≥ 90 t ≥ 35 d ≥ 10	min. 10 mm / max. 400 mm	min. 20 N / max. 100 N
 Crank handle	Hand	d ≥ 15 l ≥ 90 r ≥ 50	unlimited	Peripheral force min. 6 N / max. 80 N
 Pedal	Foot Leg	l ≥ 50 b ≥ 75	min. 20 mm / max. 70 mm min. 50 mm / max. 150 mm	min. 30 N / max. 100 N min. 50 N / max. 200 N
 Foot-operated knob	Foot	d ≥ 15 h ≥ 30	min. 12 mm / max. 30 mm	Foot resting on control min. 100 N / max. 150 N Foot resting at side of control min. 5 N / max. 50 N

Tab. 2.1: Dimensions, regulating distances and angles and actuation resistance of selected controls (from RÜHMANN 1993)

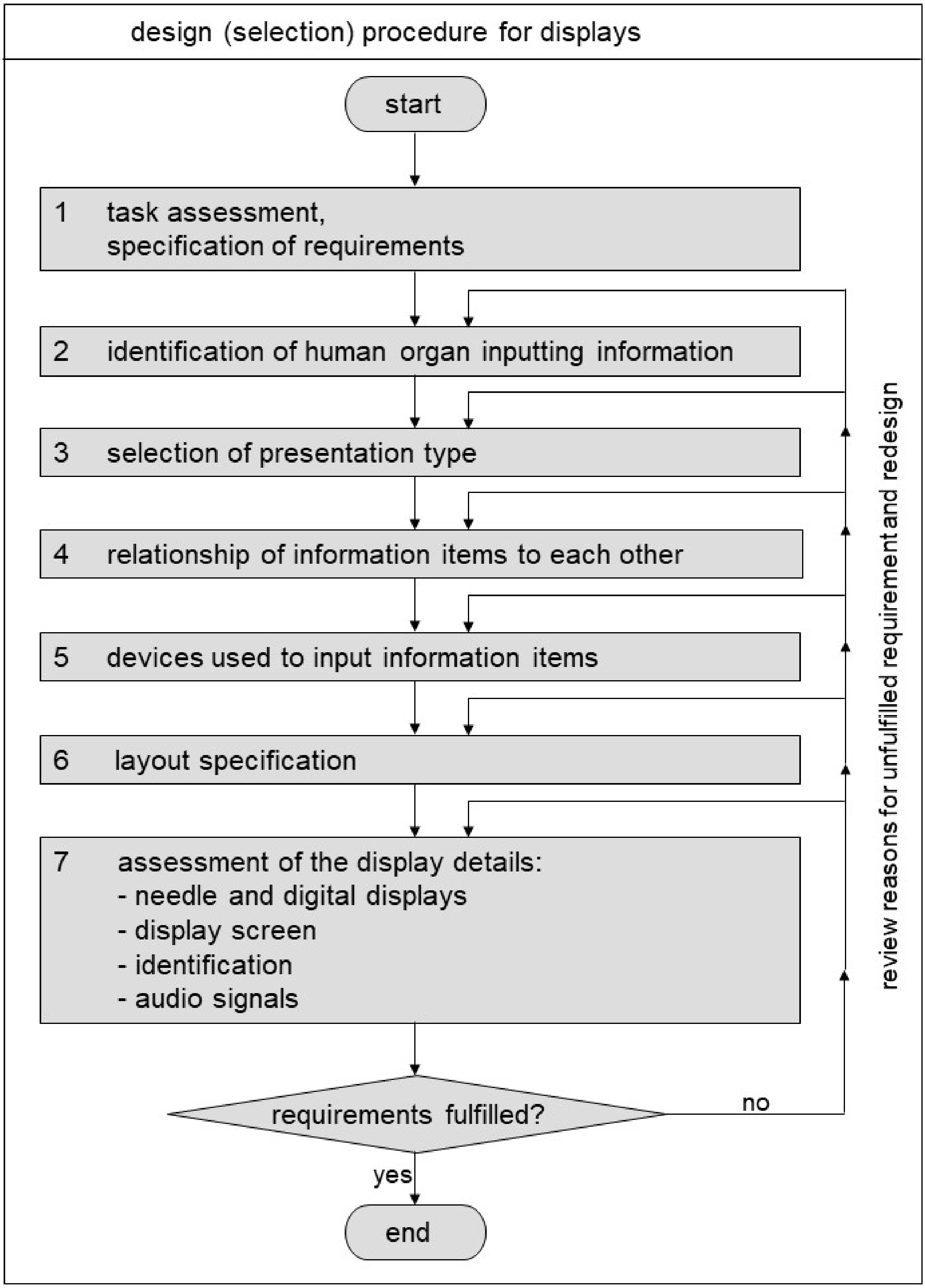


Fig. 3.1: design (selection) procedure for displays (from KIRCHNER & BAUM 1986)

Type of use	**Digital display**	**Analog display** **(moving needle)**
Quantitative readings	Good Minimal reading time and error rate for numerical values	Moderately suitable
Qualitative readings	Not recommended. Figures must be read off. Difficult to register changes in position	Good Needle position readily visible. Unnecessary to read off scale values. Changes in position registered quickly.
Setting of figures	Good Numerical setting very precise. Relationship of setting to movements of operating unit less direct than with movable needle. Difficult to read when settings have to be input quickly.	Good Clear relationship between needle movement and operating unit. Movement of needle facilitates monitoring. Settings can be input quickly.
Regulation	Not recommended No setting changes for monitoring. Relationship to actual movements of operating unit difficult to determine. Difficult to read when changes occur quickly.	Good Needle setting easy to monitor and regulate. Easy to determine relationship to movements of operating unit.

Tab. 3.1: Use of analog and digital displays

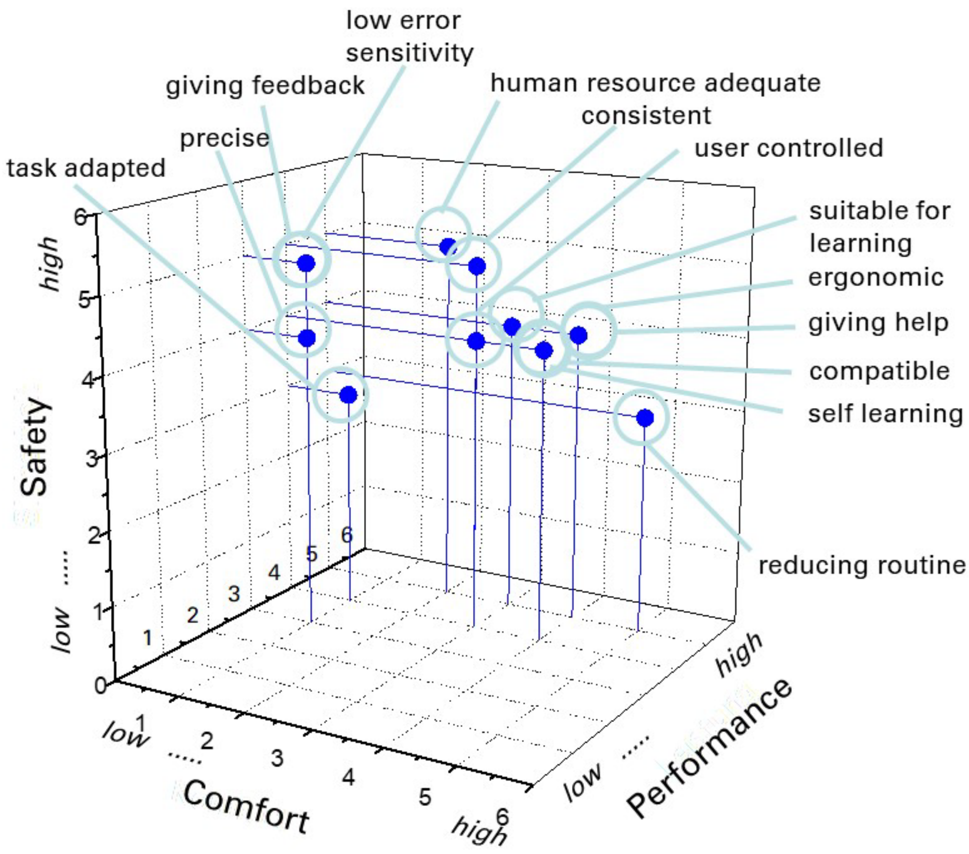


Fig. 4.1: Expert rating of usability criteria in terms of safety, performance (strain reduction) and comfort (n=6)

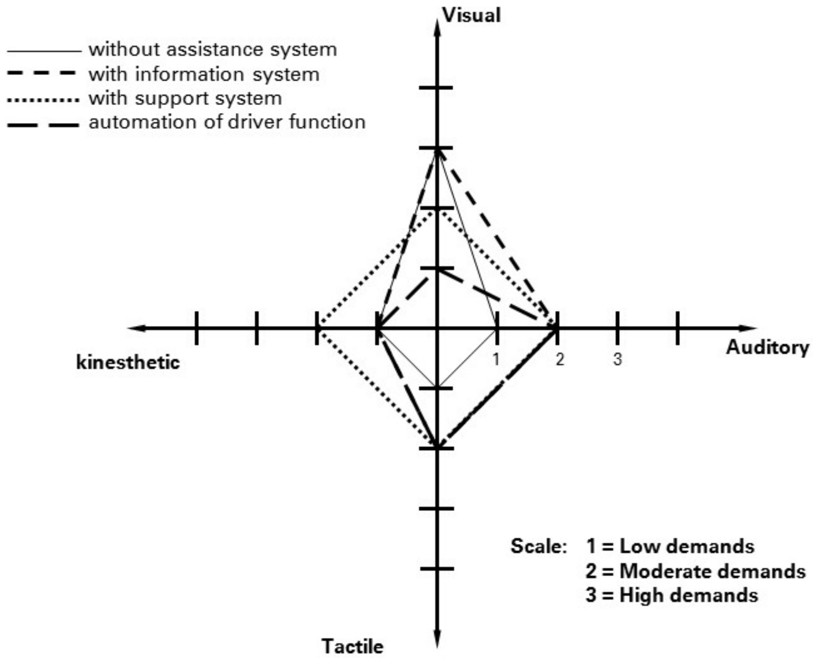


Fig. 4.2: Demand profile for information reception at varying stages of driver assistance (author's own rating)

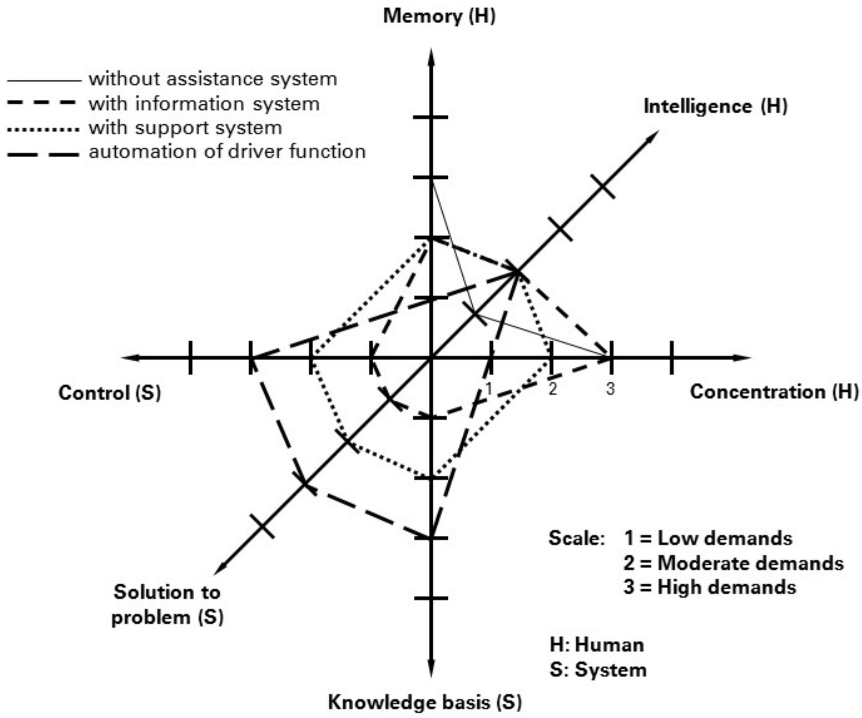


Fig. 4.3: Information processing requirement profile for various levels of driver assistance (levels chosen by author)

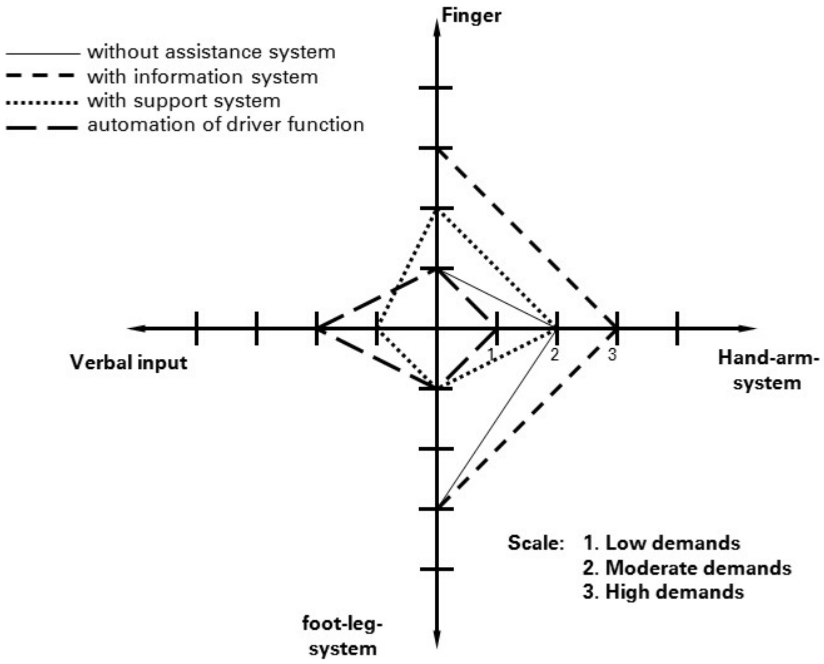


Fig. 4.4: Driver action requirement profile for various levels of driver assistance (levels chosen by author)

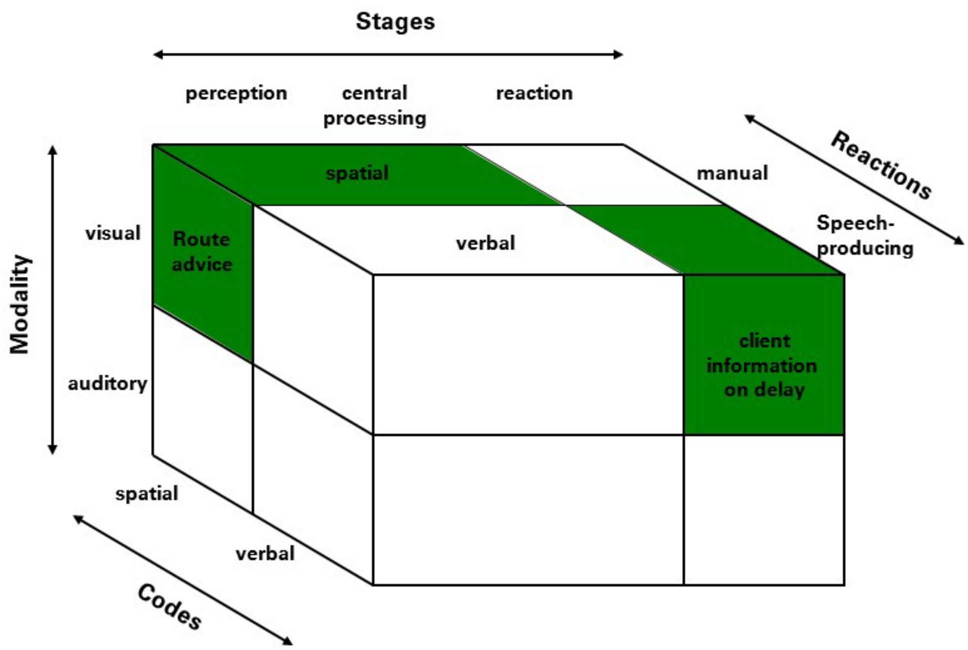


Fig. 4.5: WICKENS (1984) multiple resources model. The author has marked possible strains on the driver's resources from use of a navigation system of the future