Chapter 2
Teaching and Training with Simulators

2.1 Drivers, Vehicles and Errors

Traffic systems are very different human/machine systems for monitoring and controlling very different information and deployment processes. The ergonomic view of this type of complex system is user-oriented and starts out with tasks and activities. The classic understanding of motor vehicle operation sees it as a constant or discrete closed-loop system involving the driver, the vehicle, the environment, and sees traffic as moving objects by mechanical means in order to cover spatial distances. The task of driving itself has been broken down into subtasks and given a hierarchical structure (Rößger et al., 1962; Käppler & Bernotat, 1985; Johannsen, 1990), see Fig. 2.1.

On the navigation level, a roadway is selected from the traffic network. On the road guidance or handling level, the lead dimensions of course and speed are adjusted with respect to the current traffic situation, taking into account the traffic rules (e.g. overtaking maneuvers). Stabilization means operating the vehicle on the street itself even in the presence of disruptions (e.g. crosswinds) and monitoring course and speed. Differences between intended and actual variables are minimized. A driver will perceive relevant information, plan any minimization at the cognition level and act. Rasmussen (1983) drew attention to differences between the task and its actual implementation. He dealt with actual activities and disassembled them into:

- Skill-based action
- Rule-based action
- Knowledge-based action.

Skill-based action takes place without deliberate attention. It is not possible to say what information it is based on. Some examples are simple driving operations such as changing gear. In the case of rule-based action, a situation is diagnosed by recognizing a combination of symptoms. Every situation is tied together with if-then-else rules and certain actions are associated. Some examples are the application of traffic rules, overtaking or critical driving situations. Knowledge-based action

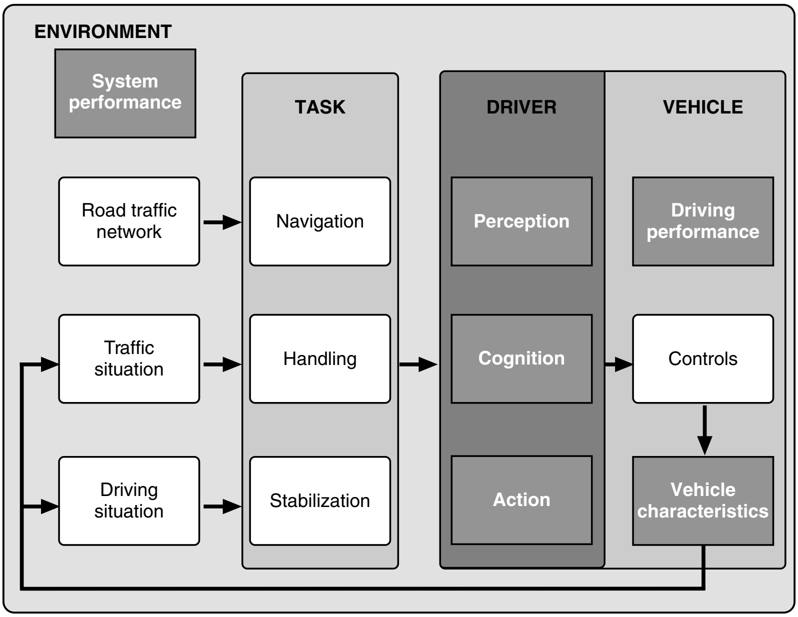

Fig. 2.1 Closed-Loop System of Driver, Vehicle, Environment (Käppler, 1993c)

includes the deliberate formulation of goals plus the design, analysis and choice of action plans. One example is searching for a route in an unfamiliar area.

The overlaps between the tasks in Fig. 2.1 and these action levels are fluent. Each subtask (navigation, road guidance and stabilization) can be processed at a skill-based, rule-based or knowledge-based level. For example, an unskilled driver masters the stabilization of the vehicle with deliberate attention, i.e. knowledge-based, if he is inexperienced or if vehicle handling characteristics are problematic. However, even this representation is not yet complete. Looking at all motoring activities shows that drivers, like other operators, actually do much more than conventional models suppose. They collect and judge a lot of information about different planning levels in order to plan and implement transports. This may be classified as follows:

- Determination: "What is the situation like?"
- Assessment and decision: "What does this mean and should I act?"
- Planning action: "How shall I act?"
- Carrying out the action: "I act."
- Checking: "Was I successful?"

Alongside technical problems which are of no further interest here, a range of disruptions can occur, such as:

- incomplete information for any assessment
- large number of steps, apparently of equal merit

- consequences of actions which can hardly be evaluated
- little practice in current conditions.

Nonetheless, even in more difficult circumstances, the driver retains the responsibility. He carries out the assessment and makes decisions, even in case of breakdowns, technological faults or accidents. As it is understood, he always has to:

- act appropriately fast, and
- act safely and with fault-tolerance.

What does this mean in terms of road safety? Beyond simply operating the vehicle, driving in traffic also means solving tasks in constantly changing situations. The behavior of a road user must take reality into account and incorporate the driver's experience. Traffic regulations set down standards for behavior. They provide limits and an orientation. A driver's behavior in traffic takes place in a physical and social environment, which affects it. It is characterized by constant confrontations with situations requiring the driver to find possible, multi-dimensional solutions. Dynamic interactions take place between his convictions, attitude and his actual behavior. The concept of traffic safety therefore does not just discuss traffic as moving objects by mechanical means, in order to cover spatial distances, but as a form of social behavior.

Some additional remarks. Duncan et al. (1991) showed, for example, that there are hardly any significant correlations between accident rates and driving skills. Summala (1989) showed that truck drivers' high qualifications or traffic experts' knowledge were not reflected in their driving more slowly. Studies such as Aschenbrenner et al. (1976), Edwards et al. (1977), Olsen (1973), Seydel & Beetz (1978), Tränkle et al. (1988), or Utzelmann (1985) and Müller (1994) showed that serious problems with driving skills only occur with certain groups of drivers, such as novice drivers or older road users with reduced ability. It becomes clear that behavior, attitude and motivation have consequences on driving knowledge and skills (e.g. Biehl, 1976; Käppler & Voß, 1988; Käppler, 1991, 1993a, b, c, and 1997a). The link between general attitude and actual behavior in concrete situations is not clear. However, it seems clear that attitude does not necessarily cause certain behaviors, but allows us to predict them.

Traffic is a social and sociological problem and a form of human behavior, as well as a complex product of basic cultural conditions, institutional rules, situation-related circumstances and personality-specific factors (Büschgens, 1993).

Behavior means any physical activity, which, unlike psychological processes, can be objectively observed by third parties. This also includes processes of experiencing, thought and wants (Dorsch, 1987/1991).

Attitude is an individual's tendency or predisposition to evaluate an object in a certain way; it is characterized by consistency of reaction (Katz & Stotland, 1959; Lindgren, 1973; Herrmann et al., 1977).

Motivational variables explain why a person acts in a specific way and with a specific intensity under certain circumstances. As well as stimulus variables, they are important behavioral determinants (Dorsch, 1987/1991). So far, so good, but people do not do everything according to plan. For example, the isolation of the drivers in their vehicles is held responsible for decreased danger perception or lack of patience. Falling back upon earlier stages of development, known as regression (Dorsch, 1987/1991), is encouraged by the fact that car drivers, unlike pilots on scheduled flights, have markedly greater freedom to make choices and act, for example in choosing their speed. This means there is more space for the variables of attitude, motivation and behavior. Yet the driver still retains the responsibility and is, after all, expected to act quickly and safely without making any errors.

Motivation means assumptions about the number of reasons for acting; these assumptions activate, control and maintain behavior despite obstacles (Wittig, 1994).

This is where the concept of human error comes in. It not only addresses the concrete action in the actual situation, but discovers mistakes and their causes in detailed investigations. The concept treats errors as (unwelcome) outputs of human/machine systems and a natural product of human behavior. According to Senders & Moray (1991), actions become errors when their results are assessed. Under certain conditions, the same behavior generates positive results, under others apparently negative ones. For example, driving faster means arriving earlier. In reduced visibility or rain, however, the same driving style increases the probability of accident and, perhaps even more importantly, the seriousness of the accident. This is not wanted: in this case, we speak of speeding. Yet in both cases, the driver determines the situation, judges it, makes a plan, carries it out and checks the outcome, just with different results.

After all, at the start we leave it up to the driver to decide what speed is appropriate, and trust that he will choose a speed correctly and reliably, so that there are no unwanted consequences. Ultimately, our traffic system is in fact based on trusting that people's actions are generally reliable, safe and error-free – and yet accidents still occur. Recent attempts question this view and refer to in-depth accident analyses which, over and over again, show behavior-conditioned errors and faulty ascertaining, judging and incorrect action as the main causes of accidents. The question arises of why even experienced professional truck drivers speed and fail to keep their distance, ignoring others' right of way and priority, i.e. take risks. Spontaneously, one thought that comes to mind is that these types of inappropriate behavior are mainly caused by personality factors. Nevertheless, analyses have showed only slight interactions between the variables of personality and error.

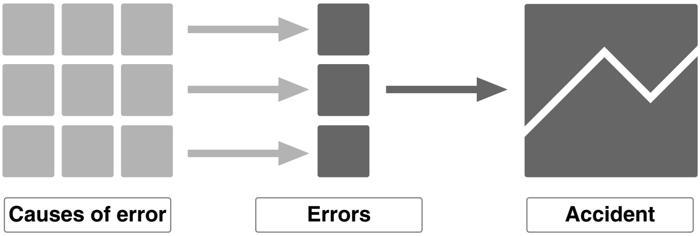

Fig. 2.2 Three-level model of accident evolvement (Käppler et al., 2008)

The problem of human error came into the focus of several international projects during the nineties, see Reason (1990) and Senders & Moray (1991). The author himself is a member of several international working groups dealing with new methods of in-depth accident and incident analysis based on human error. As one result the Safety Management System (SMS) ARIADNE was developed and realized (Käppler, 2004, 2005, 2006, 2007; Käppler & Dalinger, 2005; Käppler et al., 2008). It may help to get more insight into the aims of driver education and training. The underlying three-level model is shown in Fig. 2.2. Several causal factors (on the left) result in three errors (in the middle) that create an accident (on the right).

In Fig. 2.3, these errors are grouped into the three driver activity related categories shown in Fig. 2.1:

- *Errors of perception* are a lack of ability to generate an adequate, consistent image of social and physical environmental characteristics.
- *Errors of cognition* are the formulation of faulty plans based on adequate perception of relevant information. These plans do not follow the requirements of the task or the situation.
- *Errors of action* are the incorrect execution of a correct action plan, mixing up gears or automatically applying similar, common routines.

These errors, in turn, are a consequence of causal factors already present in any working environment and technology as latent risks. In Fig. 2.4, causal factors are grouped into eight subcategories.

Errors of perception Errors of cognition Errors of action

Fig. 2.3 Error categories (Käppler et al., 2008)

Fig. 2.4 Causal factor categories (Käppler et al., 2008)

- *Working Organization* causal factors are defects in the purposeful order, regulation and integration of tasks and activities in social systems, e.g. laws, rules or working means.
- *Communication* causal factors are defects in verbal and nonverbal processes of information exchange.
- *Personnel & Qualification* causal factors are the inadequate selection, allocation and qualification of the knowledge and abilities which enable the activity to be carried out.
- *Quality Management* causal factors are defects in the running examination of the quality and state of the work results, e.g. with norms, instructions, manuals.
- *Attitude* causal factors are interferences by workers due to an inclination to value subjects and objects in a certain consistent way, e.g. as a result of craving for recognition.
- *Physiology* causal factors are interferences by workers due to life processes such as growth or illness.
- *Behavior* causal factors are observable interferences caused by workers' actions and decision-making. This includes processes of experience which are conscious to varying degrees.
- *Environment* causal factors are environmental characteristics which increase risk and can be described on the basis of physical data.

Over the past years, more than 2,000 accidents and incidents in road, sea, train and air traffic and the handling of explosives have been analyzed with ARIADNE. The comparison of accident rates has showed the frequencies and types of human errors to be quite consistent in different technical environments. Only minor changes were required to transfer the SMS application from motorbike accidents to explosives handling (Käppler et al., 2008).

Consequently, experts today assume that a large number of accidents and incidents are caused by inadequate human behavior and human error. The official accident statistics show that human error is the cause of more than two thirds of road accidents with personal injuries in Germany, see Table 2.1. And it is no surprise that

Table 2.1 Driver-related causes of accidents with personal injuries in 1996 (Statistisches Bundesamt; Federal Statistical Office, 2007)

Causes of accident	Absolute frequency	Relative frequency (%)
Vehicle operators involved, in total	596,982	100
Erroneous behavior by vehicle operators, in total	403,886	67,7
Caused by alcohol	19,405	3,3
Incorrect road use	29,495	4,9
Speeding	64,742	10,8
Distance errors	47,104	7,9
Overtaking errors	16,120	2,7
Right of way, priority errors	59,700	10,0
Erroneous turning	33,150	5,6
Erroneous behavior towards pedestrians	17,791	3,8
Other error caused by vehicle operator	116,379	19,5

almost 20 percent of these driver errors cannot even be explained in detail. This is why the reliability, performance and operation of people, organizations and technology have become a major goal of traffic safety.

Whenever human beings act, supervise, steer, control, or make decisions, they affect reliability and safety of the entire system, and any training approach should be based on knowledge about problems and errors of drivers during this process. One additional remark. Table 2.1 hardly deals with behavior, psychological, social or cognitive processes and human errors and is of minor help in the discovery of accident and error causes, because the classification system it is based upon is aimed at settling questions of liability in a legal sense.

During this work, the question arose of whether human reliability can be corrected systematically by means of training measures, and which errors can be treated with which measures. Thanks to advanced technology, today's High-tech simulators may come with impressive quality and realism. They use current driver's cabs, motion systems which copy the real movements of vehicles to a great extent, and visual systems which generate out-of-window views according to the actions of the driver. The control elements react realistically, noise simulation is deceptively real and the behavior of simulated road users in the virtual driving world also seems closer to reality than one might expect.

Simulators like these mean that there are now training opportunities which were previously inconceivable: it is hardly surprising that training concepts aimed at improving safety and human reliability are currently en vogue, and plan to shift about 50 percent of practical training for the truck driver's license from real roads to simulators, or supplement safety training programs with driving simulators, or streetcar and road driver courses with rail and driving simulators.

Many driving schools and other commercial suppliers or training centers offer special simulator-based training programs for driver education and professional drivers, to practice economic and safe driving manners and increase reliability. But which are the basic issues and models behind driving simulation?

2.2 Developing a Model

Depending on how much practice he has had, a driver's actions depend on operative and normative concepts which are represented as flexible internal models by the information-processing human being. In the case of practiced sensorimotor tasks, people work multivariately, synchronizing their movements with these models. As they gain experience, the models become automatic to differing degrees. For systematic training, there are various measures which can be carried out, with different steps, to act and make decisions more effectively, faster and safer: See the following diagram according to Godthelp (1992).

The *training cube* shown in Fig. 2.5, for example, shows the three dimensions:

- Task: navigation, handling, stabilization
- Activity: perception, decision, action
- Automation: knowledge-based, rule-based, skills-based.

The training modules, of which there are a total of 27, include *driving around curves* or *hill starts*. The training concept it is based on assumes that behavior gradually becomes more reliable as it moves from knowledge-based, to rule-based, to skills-based.

Hacker (1986) namely believed that targeted action requires temporally stable, *invariant* representations of:

- Aims
- The program of action
- And the conditions of implementation.

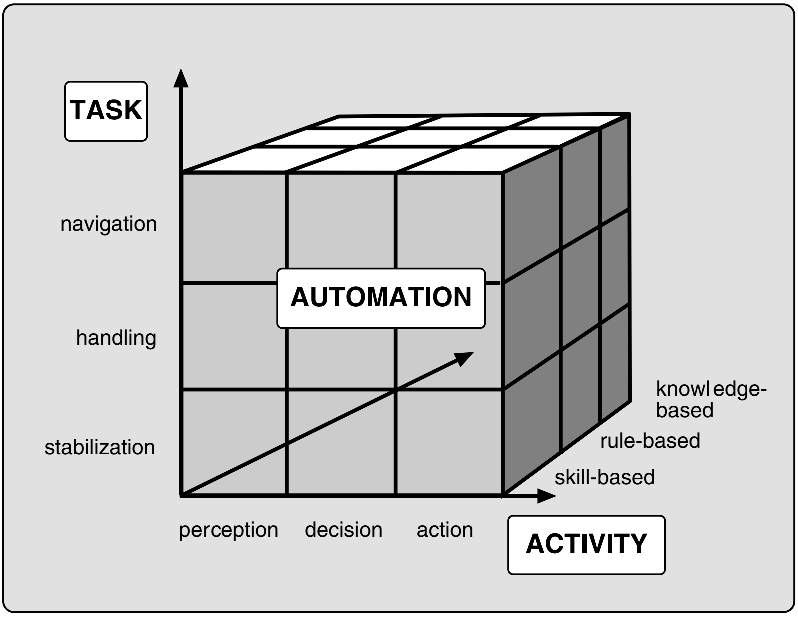

Fig. 2.5 Tasks, activities and automation when driving a car (Godthelp, 1992)

Accordingly, a targeted action can be regulated in the form of:

- Reacting to events
- Anticipatory expectation
- Bringing events about.

Anticipatory expectation means practicing activities which are organized in advance, so that the driver can carry out fast movements precisely. Operative representation systems (ORs) of these invariable process segments are constructed for regulation. The shift is made to anticipation.

These operative representations determine reliability and performance. They must develop, at the latest, in the phase of preparation for action, and must remain intact at least until the action is completed, so that the current status can constantly be compared with the target status in a feedback process. ORs are relatively permanent internal models; they are memory representations which guide actions, with both predictive and explanatory functions. Their operative qualities distinguish them from normative representations. For example, they depend upon the type and speed of information processing and motivation, and a system's navigability or error tolerance.

Here, education and training play a major role. If the ORs are not complex enough, activities are based on time-consuming, error-prone, mentally demanding comparisons with external specifications. This is one cause of unreliable actions, delayed interventions, searching for or trying out actions, or of errors altogether.

ORs depend upon the demands placed on a person, and represent facts selectively, sometimes distorting them, the scale of this representation depending on their concrete importance. They make generalizations, concentrate on prototypes and only represent classes of characteristics. They are effort-related, leading to strategies for fulfilling requirements with the lowest possible effort. They are encoded in such a way that minimal effort is required to recode between practical execution and the stored model, and correspond with the requirements of the response organization, not only with the information input or the code which is convenient to maintain. For this reason, despite differing information inputs with similar responses, increasingly similar representations develop. The aim is to lessen the load by minimizing cognitive transformation operations (Hacker, 1986).

ORs depict *targets* as the result of anticipations judged in terms of their results; they depict the *conditions for implementation* which result, for example, from knowledge of how vehicles function, of environmental problems or the probability of accidents and defects. The *program of action* depicts transformations from the current status to the target status as hypothetical measures to take, with their possible results, and the relationships between the current and the target status, such as the moment to take action and what action can be taken.

Depending on how well an OR is learned, a considerable proportion of information retrieval and processing is no longer required (Poulton, 1971). The ideal result of the training course is to shift from perception- to memory-based regulation. This is characterized by time-saving, reliability and a reduction in errors and stress. Orientation is improved when preparing to act, as ORs allow hypotheses to be made about a state of affairs, enabling more efficient search strategies and the selection of information sources which better fit the purpose. ORs have the following characteristics:

- They depict facts to match the degree of their importance. They are selective and distorted.
- They are of a generalizing, schematic nature and represent classes of characteristics.
- They depend upon demand and lead to strategies which enable requirements to be fulfilled with little effort.
- They are encoded in such a way that minimal effort is required to recode between practical execution and the stored model.
- They form hypotheses, predictions and expectations.

Hacker sees the development of operative representations as a multi-stage process which includes a redefinition of the tasks and targets. For example, tasks which require precise numerical values to be derived according to rules are transformed into allocation tasks. Often, representations are encoded more than once. There can simultaneously be both concrete semantic and sensory representations, and different encoding procedures. In the case of everyday tasks, there are signs that more general representations are preferred, and simpler procedures preferred to more detailed ones (Rasmussen & Jensen, 1974).

According to Leontiev (1973), to the subject, mental models must appear as a reality which he can be guided by and interact with. Improving the ORs offers opportunities for improving safety, performance and reliability. For example, the task of driving does not only require steps to be taken, but also previous perception and assessment of the situation, planning, checking and repeats as necessary. The modern view of these multiple tasks, activities and conditions aims at improving *performance* and *reliability* and reducing *errors* or *the consequences of error*.

The activities of *perception* and *analysis*, *planning* and *deciding*, followed by *actions*, the *errors* made during these actions and the *stress* which occurs, are considered the main topics of interest in improving safety and reliability by means of modern teaching and training methods.

2.3 Training Course Design

According to Hacker (1986), learning processes determine the representations which develop, not only in terms of their content, but also in terms of their form. One thing which affects their coding is the way information is presented – the teaching matter and methods must be harmonized with one another. Teaching concepts must be designed to encourage the formation of adequate ORs. This requires a knowledge of the ideal ORs to be taught.

Even carrying out a plan we have made ourselves, behaving reliably according to a specification, is no easy task, as we know from our own mistakes in everyday life. The task of encouraging other people to behave safely is considerably more complex and complicated still. Of course, steps taken to change the environment and traffic neutralize known dangerous situations and make it easier for people to behave appropriately in difficult circumstances. These steps start off with ways of adapting technology and surroundings, i.e. with the vehicles and the traffic environment.

Our approach focuses on the active subjects and is centered around errors and causes of error (Käppler et al., 2008). The aim is to help prevent dangerous situations arising in the first place due to individual actions, and to encourage and consolidate appropriate behavior in dangerous situations.

Teaching means the acquisition of basic skills, abilities and knowledge by means of targeted measures, with the aim of fulfilling minimum aptitude requirements.

Training builds upon successful teaching and education and aims to sustain and extend existing skills.

The mere fact of raising people's consciousness of issues and topics related to safe driving is doubtless a first step in supporting safe behavior. However, more effective approaches require more than this kind of general verbal conveying of information and making appeals. They use people's interest in gaining new experiences and repeatedly put them in learning situations. Thus, people are given the opportunity to make mistakes. They experience the consequences of their decisions and actions, and gain experience interactively. They learn that it depends upon them whether or not they get into dangerous driving situations.

Of course, anthropocentric teaching and training systems of this kind do not usually constrict people to fixed sequences of actions, e.g. technological constraints. They define teaching aims and criteria to judge success. They offer alternative ways of carrying out tasks by means of variable task segments with room for decision-making and action.

They are rooted in task- and performance-based analyses of technological and organizational subsystems. Long-term learning results require people to experience real traffic. Theoretical and practical training courses are combined in such a way that there is no longer the conventional divide between cognitive, affective or evaluative, psychomotor components: in real traffic these components interact, too.

Using these model predictions and metatargets, teaching and training systems formulate hypotheses about subtargets which are set in an overall concept. Different media, vehicles, simulators and audiovisual systems are used to teach different subject matter. Every teaching device is allotted a clear function and an ideal position in the overall framework of the course.

For this reason, simulator instruction alone cannot, of course, guarantee that all teaching targets will be met, but needs to be just one part of a training system, which it is integrated into as advantageously as possible. Training systems of this kind can only be put together with precise knowledge of which types of error occur, where, how and why. A specific training measure thus needs a differentiated analysis of existing weaknesses which is as individual as possible. Figure 2.6 shows a schematized depiction of the design of the training program and its development (Patrick, 1992). It is based on knowledge of the trainee, the training targets and the available training methodology.

Of course, courses in driving, or for drivers, cannot actually correct organizational errors or those made by superiors or managers. The subject of interest here is the causes of errors of action and cognition.

The author's investigations into human error show that 60 percent are cognitive, 30 percent errors of action and only 10 percent errors of perception, across different kinds of technological backgrounds (Käppler et al., 2008). As modern safety cultures assume that errors are purely natural products of human behavior, training targets are also not centered around directly avoiding errors by setting up bans, etc. Instead, modern training courses concentrate on the causes of these errors and work on correcting them. For example, Käppler et al. (2008) showed that approx. 45 percent of errors are caused by mistaken *behavior*, 20 percent by lacking *personnel and qualifications* and 15 percent by flawed *quality management*.

The remaining 20 percent are distributed among flawed *attitude*, *work organization*, *communication*, *physiology* or *environmental conditions* and are still of little

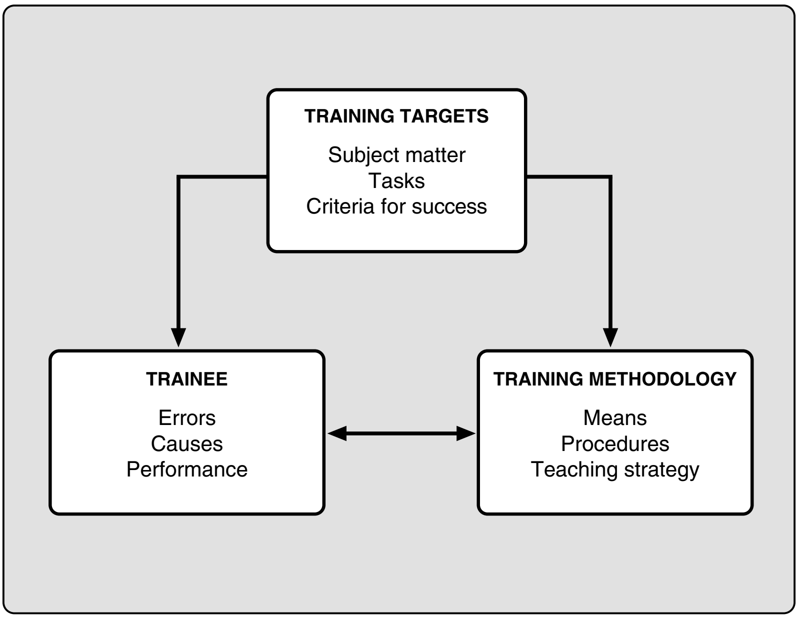

Fig. 2.6 Schematic depiction of training course design (according to Patrick, 1992)

interest as corrective targets for costly driving qualification courses, as are the fields of *quality management* and *personnel and qualifications*.

On the other hand, an analysis of incorrect *behavior* shows that it is mainly due to *deficient knowledge*. One example: Motorcyclists have the highest mortality rate, in the field of transport and elsewhere. However, almost three quarters of these accidents are not caused by their own errors, but by other road users. Motorcyclists are not aware that they are often overlooked and that their speed is misjudged (Käppler, 2002, 2005).

This analysis points to other correctable aspects, possible training targets and training methods. Long-term traits displayed by drivers include aspects of their personality or education which cannot be influenced by short training courses. In this case, the driver's current state is of interest, e.g. his motivation or previous knowledge.

Knowledge of the driving task or possible accident situations are therefore not a sufficient basis for successful training. Before the training course takes place, information is required not only of qualifications and errors, but also of the trainee's emotional state, skills, self-assessment, previous experience or social situation. Questionnaires and surveys need to be carried out. Biehl & Brown (1986), Brown et al. (1987) and Duncan et al. (1991) believe that the value of conventional driver training is overestimated, partly due to the lack of this kind of information. This is where the training concept described comes in. The practical examples of application in Chaps. 3 and 4 contain information with respect to this.

2.3.1 Aims and Subject Matter of Training Courses

The following training task categories (Käppler & Voß, 1988) show teaching and training topics in conventional literature:

- Controlled weather effects, driving in fog, at night
- Stress situations, time pressure, emergency procedures
- Driving tactics, self-control, evasion, overtaking, driving behind others, advanced driving
- Judging distance to vehicle in front, other distances, speed and time
- Orientation, navigation, searching, observing, eye movements, eye fixation.

These are general topics with varying degrees of practicality which hardly justify the use of expensive training media. This is not the case, however, with operative representations which, because they are used only rarely, are not sufficiently developed, or are forgotten again after they have been learned. To make drivers more reliable, the point will therefore be to correct areas which are stressful, complicated, sensitive, forgotten or unknown. This can be done by speeding up the time scale for the development of ORs and driving experience, using model if-then-else rules, and for the storage of ways of acting. At the heart of this are

Table 2.2 Requirements, contexts and training targets

Requirement	Context	Training target
Rare	Never occurs in everyday driving, experienced rarely or only in part	Refresh, cement and ingrain understanding
Sensitive	Errors of action have considerable consequences	Motivate to strictly adhere to rules Encourage to pay close attention
Complicated	Complex technological context	Compensate for problems with understanding by building up familiarity and experience
	Fundamental understanding hard to achieve	Ingrain simple coping strategies
Stressful	Increased psychological pressure Flood of information Time pressure	Ingrain simple coping strategies

cognitive processes such as awareness, perception, memory, recognition, imagination, thought, conjecture, expectation, planning, problem-solving and decision-making (Dorsch, 1987/1991).

Table 2.2 shows this kind of rare, sensitive, complicated and stressful situation as requirements for the training program, explains the context in which they occur and lists the training targets.

2.3.2 Training Concept

Conventional training courses work from the assumption that people will act safely if they have firm knowledge of the function, context and logic of the system in question. Based on comprehensive knowledge of certain requirements, specific combinations of situations considered crucial for safety are emphasized and specifically drilled. However, there are not enough ways of finding situations of this kind, and very little is known about them. Using simple methods, it is possible to find and describe common combinations which are crucial and occur often in everyday life, but this is precisely why drivers are already familiar with them. Special training in how to deal with these combinations thus seem fairly pointless or even counterproductive, particularly for experienced trainees. Furthermore, experienced drivers generally already have the knowledge they need. It is also unclear:

- How long the behavior taught lasts
- Which intervals there should be between repeating the courses to effectively stop them being forgotten.

Moreover, typical traffic situations involve such a large number of combined elements crucial to safety that specific training seems impossible in the time available. This brings up the question of how to add to conventional training concepts. One argument in particular speaks in favor of this: Most cases of damage take place in

Table 2.3 Schematic diagram of the training program

Step	Situation	Contents	Training target
1	Stressful	Psychological pressure	Drill simple coping strategies
	Complicated	Flood of information	Compensate for problems with understanding by building up familiarity and experience
	Sensitive	Time pressure	
		Complex technological context	Motivate drivers to strictly adhere to rules
		Fundamental understanding difficult	Encourage them to pay close attention
		Errors of action have considerable consequences	Self-control
2	Anticipation	Extent to which driver's behavior is anticipatory	Analyzing prospective events and adapting actions
3	Rare	Never or rarely experienced in everyday life, or only partly	Refresh, cement and ingrain understanding
4	Inappropriate	Driving style inappropriate to topography, traffic, resources	Experience, reflect on conditions behind situation; learning measures to take

relatively low-stress, generally uncomplicated and perfectly common situations. It is this fact, after all, which always makes people wonder how the accident could ever have happened. Everything points to the fact that the concepts do not cover the entire range of potential conditions for errors to occur, and that there are not enough approaches to stop people making errors due to psychological factors; errors which happen as a result of the situation as a whole.

The training program concept presented here is shown in Table 2.3. The first step consists of an artificial, virtual reenactment of crucial safety situations. During this process, a combination is utilized which has been tried and tested in aviation and shipping: creating fixation by repeatedly placing obstacles in the driver's way. Trainees are tricked into making errors, which they do not realize at first, and they then only experience the consequences, but not how it came about. Following this, the conditions in which the accident occurred and the combination of circumstances are reflected on and discussed, and ways of resisting anger and frustration are demonstrated and practiced.

In step two, the idea is to make tangible the extent to which the driver's behavior is anticipatory, turning it into a focus for closer examination. Here, the starting-point is the consideration that safe actions and behavior necessarily have to consider as wide-ranging an analysis of the situation as possible, looking far into the future.

In step three, situations are drilled which are rarely experienced, or which are known only by word of mouth, and which involve large potential risks, e.g. tractor trailer brake failure when driving downhill, see above. In step four, situations are practiced which require the driving style to be specially adapted to the topography or the traffic, e.g. in order to save fuel.

Finally, one point must be brought up which is often neglected: evaluating the training course itself. This requires a comparative analysis of accident and damage frequency in trained and untrained groups of drivers. In the form of a kind of transfer test, the effectiveness of all scenarios in the simulator must be tested, and individual scenarios fine-tuned. A scenario in which nearly all drivers manage to deal with brake failure, for example, without any problem, can no more be considered a success than can obstacles set in their path to no effect.

The fine-tuning, including that of the situational circumstances, requires means of testing which can capture and analyze data of this kind. The type of events and their integration in a context of higher-order tasks and targets are of great importance. Importance is attached to ruling out the isolated observation of "good" features, e.g. oriented toward technological feasibility, or arbitrary combinations of tasks and events: see the practical applications in the following chapters.

> Simulation requires the conception of a *training system* which covers the vehicle, simulator and other means and systems and is based on a detailed, systematic analysis of aims and requirements (Roscoe, Jensen & Gawron, 1980).

2.3.3 Description and Analysis of Activity

So what is actually drilled? At the heart of practical training courses are tasks which pursue the above-mentioned targets and are typical of processes in real life. They are found by analyzing tasks and activities, aims and boundary conditions, as well as technological and organizational elements. This results in creating tasks and setting down training methods and media. These are based on classification schemata or taxonomies of certain aspects of an activity. There is a long tradition of developing this kind of taxonomy for a large range of different activities and applications. The main aspect of selecting a certain taxonomy is the practical application of its results. The steps toward developing training units are:

- Describing the task and activity
- Analyzing the task and activity
- Identifying problem zones and critical incidents.

Often, descriptions of the task already exist and can be analyzed. Here, it must be taken into consideration that the actual implementation of the task is highly likely to differ from the description of how it should be carried out, and indeed generally does. Thus, in the first working step, it is important for the activity to be described. This has the advantage of describing the activity which was actually carried out. The descriptions of the task or activity are then analyzed, using information (already implicitly contained in the description) about the contents, processes, means of assessment, measurements, boundary conditions etc.

An understandably brief overview of task analysis processes can be found in Patrick (1992). Below is a short depiction of a well-established process by Kirwan & Ainsworth (1993): task decomposition. As an example of application, an approach by Goettl (1993) is described for systemizing the development of sensorimotor skills in a flight simulator. Basic skills are identified using the reverse transfer technique. Basically, this means decomposing complex flight tasks into simple subtasks (task decomposition, Gopher et al., 1989). The theory behind this sees expertise, like Hacker's ORs, as an organized pattern of reaction strategies which are implemented flexibly. Task decomposition combines elements of skills theory with attention theory and is based on similar structures and elements between simple subtasks which follow one another.

Let us continue with Goettl's example, where a flight task is learned by starting off simply flying straight ahead at increasing speed. Building upon this, the loop learning situation follows, first in two and then three special dimensions, also at increasing speed and with decreasing radii. The complex situation which follow consist of a low-altitude flight through a landscape of buildings with a high degree of vertical structuring. The special feature of Goettl's procedure (1993) is that similar elements are identified, using performance criteria, by means of correlations between the complex low-altitude flight and the individual prototype situations.

The aim is to speed up learning by transfer from simple situations at the start to subsequent situations which increase in difficulty. Extra time is taken when it takes longer to learn complex task structures than to combine simple tasks which were previously separated. Papers have been published on task decomposition since the end of the '80s. There are no known applications in driving simulation, but they can be derived in analogy to aviation. For more in-depth information, see papers on work analysis processes and situation definition (e.g. Küting, 1986; Fastenmeier, 1988a; Jensch et al., 1978; Schagen et al., 1987; Utzelmann, 1985; Frieling & Hoyos, 1978).

Descriptions are not available, or even possible, for all tasks, let alone the activities. One example is critical driving situations and accidents. Here, it helps to centre on the skills required to process tasks safely. The tasks themselves are analyzed; the necessary skills and means of assessment are defined. Using this information, specific training courses are composed. This process initially appears simpler than it is to carry out. The main problem is ascertaining which skills are actually necessary to process a task safely – a job for experts.

Guilford's (1977) corresponding structure-of-intellect model shows clearly that even a classification of cognitive skills is already bewilderingly interlinked. During ten years of research Guilford himself extended the number of factors to be taken into account from the original 120 (Guilford, 1967) to 150 (Guilford, 1977), see Fig. 2.7. The statistic rotation system of the main component analysis can be criticized, as the choice of factors is based on subjective decisions. Thus, Guilford's model can be seen as a rich source of hypotheses on the nature of intellectual activities and can contribute to theoretical understanding.

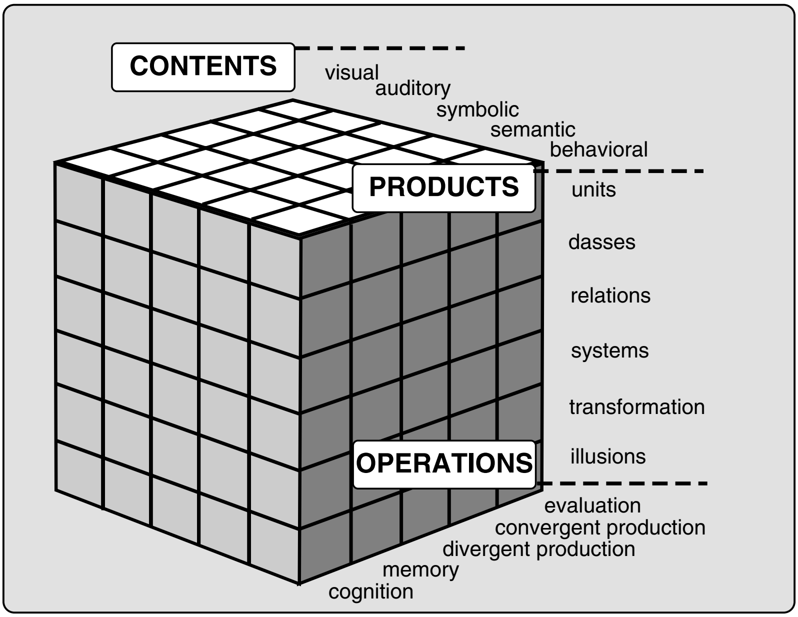

Fig. 2.7 Structure-of-intellect model (according to Guilford, 1977)

2.3.4 Evaluation and Effectiveness

Duncan et al. (1991) proved that without effective structured feedback, gaining experience does not necessarily lead to the driving experience desired. One central argument for using simulators is that driver-specific interactive data can be acquired and evaluated, to provide feedback on and assess driving and operating quality. The poor cost-effectiveness ratio of the simulator compared with a vehicle makes it more or less obligatory to use this data, which, in reality, cannot be captured as extensively, in such detail, and above all in such a well-regulated and standardized manner.

During training, this data can be used to demonstrate very specifically which behavior by drivers is good or needs improving. Driving style can be determined using suitable assessment methods. There are already some performance criteria, or at least some experience has been gained in experiment, related to the evaluation of driving quality, but most criteria still need to be elaborated. This is particularly true of safe driving. However, as well as appropriate parameters, it also depends on the quality of the combinations of situations used, and the task itself. For this reason, appropriate parameters need to be determined not only to evaluate the driver's behavior, but also to assess the effectiveness of the training situations themselves.

The procedure is as follows. While the training program is being tried out, after the first data has been gathered on good and poorer drivers, e.g. in terms of fuel consumption, relevant parameters must be separated from irrelevant ones by a statistical comparison of these extreme groups. These values are used to assess combinations of situations. Those combinations are selected which produce greater increases in learning than the others. The influence of specific personality variables can also be checked, such as age, driving experience or the type of vehicle used every day.

During the evaluation process, data from good or poorer drivers are made into performance criteria. These must be reliable, simple to understand and easy to interpret. The prerequisites are knowing about and having a clear vision of learning targets, tasks, values to be achieved and the resulting interventions and training measures. Hence, "artificial values" which are complicated to calculate and almost impossible to interpret are given a wide berth.

2.4 Training Media

The subject matter of the course produces technological and operational specifications for teaching and training media. All-round orientation, looking to the rear or increasing fixation distance to improve safe following distances can all be practiced using appropriate audiovisual methods, independently of the driving process. Basic skills training in part-task trainers integrated into full-mission situations was already suggested by Gubser & Spörli (1970), as it clearly has advantages in terms of acceptance. By contrast, demonstrating the influence of alcohol on driving ability, while popular, is problematic, as demonstration without real consequences can result in false conclusions. Table 2.4 shows the media available within the context of driver instruction and training.

Table 2.4 Teaching and training media, tasks and examples

Medium	Type of task	Example of task
Vehicle	Practical driving exercises	Realistic
Full-task simulator	highly dynamic, emergency events	Brake failure Evasive maneuver
Normal driving simulator	Quasi-stationary normal trip	Motorway, secondary road
Procedural simulator	Simplified procedures in trip as a whole	Navigation through a city
Part-task trainer	Isolated tasks	Hill start Stopping
Computer-assisted instruction/training, (CAI, CAT)	Learning tasks, rules, procedures for action	Introduction to simulator or task
Tutorial systems	Introduction	Introduction to software
Audiovisual	Lessons	Theoretical lessons
Paper and pencil	Test	Examination

2.4.1 Simulators

This manual is about the use of simulators as modern training media to improve reliability. Why simulators? As early as 1929, Edwin A. Link introduced his Pilot Maker, a blue airplane cabin on a moving platform. He developed the Total Training System, which, apart from flying instruction in the simulator, involved only two hours of flight in an airplane, and guaranteed people would learn to fly for US$ 85. In the first year alone, 100 pupils left the Link Flying School as trained pilots. In 1934, Link managed to sell six trainers to the US Army Air Corps – and the simulator industry had been founded. In the Second World War, more than 500,000 Allied soldiers were trained in more than 10,000 blue boxes. Modern pilot training can hardly be envisaged without flight simulators. Lufthansa, for example, carries out more than 90 percent of commercial pilots' practical training on the ground.

At the end of the 1950s, industrial societies had visions of infinitely plannable, feasible and controllable technical and social progress; they had optimistic expectations of what was technologically possible (Geißler, 1992). Even experts believed that road traffic safety could be improved by means of driving simulators. Thirty years after Link, in 1960, the University of California in Los Angeles introduced the first interactive driving simulator. It was for scientific research and consisted of a movable seat in a driver's cab, a projected picture and simulated force feedback (Hulbert & Wojcik, 1960).

Over the 1960s, '70s and '80s, many different driving simulators were developed for totally different scientific and training purposes. At the start of the 1990s there were already 50 verifiable driving simulators of differing construction around the world (Käppler & Alexander, 1995). Altogether, however, the improvements and success achieved by driving simulators remained well behind expectations. According to Evans (1991), despite considerable investment – Daimler Benz actually put 26 million DM into one single driving simulator at the start of the '80s – there is no discernible contribution of scientific interest causally linked to the use of driving simulators.

Simulation is the simplified replication of any system or process by means of another system or another process, and experimenting with this model.

This view is still widely shared today, with only few exceptions. Not only the scientific community, but also industry and investors, are asking for the reasons why – and there are many reasons. Simulator-assisted training is a thoroughly interdisciplinary specialist field. When combining such different fields as informatics, psychology, educational science, or electrical and mechanical engineering, difficulties occur, and not only due to the different nature of these fields, the ways in which they overlap or attempts to keep them separate. Depending on how you see it, simulation is a science, a technology or an application. Semantic problems also play a role, and it is possible that communication problems contributed quite considerably to the difficulties. For this reason, first let us answer the question: What is simulation?

2.4.2 Definitions

The Latin *simulare* means to imitate or to copy, but also to pretend, to play a part and to feign (Petsching, 1967; Meyers, 1987). Simulation is therefore *playing a part, pretense, sham*; the Latin plural means *the art of deception*. (Dorsch, 1987/1991) adds to the definition, calling it a simplified representation of a slice of reality, and points out that the models used can be of a physical, technological or abstract nature.

This is the case with numerical simulation. It is the recreation of systems by means of mathematical equations on digital computers. The computer programs it is based on take the form of theoretical models and allow combinations of variables and possible solutions to be played out. The aim is to understand these processes and the factors which influence them better, for example in testing scientific theories or in planning mechanical or administrative systems. In reproducing tasks whose accomplishment by human beings would be described as an act of intelligence, computer simulation has broad overlaps and similarities with artificial intelligence, see Lotens et al. (2005), e.g.

When the time taken by the processes depicted remains unaltered when reproduced on the computer system, this is called a real-time system. In this case, the computer simulation is subject to quantifiable schedule requirements designed to synchronize events. Real-time systems can be found, for example, in automation and control engineering, or in informatics. The use of the term "real-time system" occasionally appears generous. For example, the financial services provider Vereinigte Wirtschaftsdienste (United Economic Services) calls its information system on current stock exchange prices a real-time system because the prices are transmitted constantly during the trading session. Hewlett Packard calls its PostScript process for calculating edge correction in laser printers a real-time algorithm as it blocks printing until these calculations have been carried out.

Account management systems in banks and airline dispatch systems are also described as real-time systems. Here, the customer himself chooses when to use his account and synchronizes the process, and only has to wait a short time. The timing is flexible.

In contrast, the timing of true real-time systems is inflexible, involving precisely fixed times. In production processes, for example, individual goods are conveyed on belts and taken to further processing steps by robots. By the time a workpiece arrives on the conveyor belt, the robot must be ready to pick it up. This synchronization is ensured by means of runtime control or buffering. Control mechanisms in nuclear power plants work in a similar way. They measure the reactor temperature with a repeat rate of 10 Hz and, if the maximum temperature is exceeded, set off the shutdown mechanism within 50 ms. If the shutdown did not occur exactly on time, and the cooling system experienced total failure, emergency shutdown could no longer be guaranteed.

With these true real-time systems, falling behind schedule produces expenses which are not incurred when the schedule is followed. As a result, *staying on time* is an operational target which can be achieved by keeping to deadlines rather than by other synchronization measures. For computers, these deadlines are the start and finish times: the earliest point a computation can start or the time it must finish by. Schedule requirements are generally focused on keeping to target finish times.

To separate driving simulations from these true real-time systems, the term real-time simulation is used in the literature. Real-time simulations are used for demonstration, experiment or training purposes, such as pilot training (Dorsch, 1987/1991; Meyers, 1987). Sonntag (1989) describes them as a special kind of cognitive training and investigation process. Real-time simulation does not apply to the simplified depiction of processes which can be objectively determined by others. It is used if, when practicing tasks in real life:

- Falling behind schedule or making mistakes leads to system failure
- Practice is seldom possible
- The task cannot be reproduced due to the dangerousness of events in real life
- The task cannot be reproduced due to the structure and complexity of situations.

> *Real-time simulation* means a human/machine system which uses one or more media to depict information. This information can be in the form of optical, acoustic, haptic or vestibular processes, which can be represented by means of film, a computer screen or a servo motor and springs. One characteristic of real-time simulation is direct interaction by one or several people with this information for the purpose of information processing. Its aim is to create a simple reproduction of a system or process, or slice of reality, using another system or process, and to use this to stimulate subjective representations of the environment, so that people have the illusion of fulfilling real tasks.

In this way, the range of applications for simulations corresponds to the training targets for increasing reliability, described above. This is why real-time simulation is so widespread in airplane operation. To train pilots, the environment is recreated, so that pilots are subjected to less danger, even in critical situations (Frieling & Sonntag, 1987; Drosdol & Panik, 1985; Flexman & Stark, 1987). Now it becomes clear what a simulator really is, in the original meaning of the word: a person, an *imitator*, or, in the words of Socrates, a *master of the art of deception* (Petsching, 1967).

In our application, it is about replicating movement from place to place: the task of transportation is not carried out at all. The simulator imitates conditions so realistically that drivers experience the unbroken illusion of dealing with tasks. The main features of simulators, therefore, come from requirements determined by the ways people take in and process information. Investigations by Springer et al. (1993), for example, showed the significance of visual, tactile and proprioceptive information. Constantly providing this information, on time, continuously and without delays, is one important operating target for simulators, as unless the flow of information is constant, the perception of moving through space is disturbed.

One example: A driver turns the steering wheel when entering a curve. If the representation of the out-of-window view, showing the motion of the computer-simulated vehicle, turns with a delay, e.g. because the computer calculates too slowly, then the steering degree cannot be adjusted on time.

> *A simulato*r is a device which enables people to operate vehicles with no real movement, but in realistic conditions.

A virtual vehicle of this type can hardly be kept on the virtual road at high speeds. Practicing the task of *entering the curve* is only possible if special skills are learned for using the simulator which, in the original situation, would be unnecessary or even a hindrance – such as prematurely setting an exaggerated steering angle in anticipation of a curve.

Teaching and training are pointless or counterproductive, however, if learning processes from the first, simulated test situation cannot be transferred to carrying out the second, real test. This transfer effect can have a positive influence on processing a task, or, under certain circumstances, even have a negative influence. This is known in the literature as positive and negative transfer (Latin *transferre,* "*bear across,*" Dorsch, 1987/1991).

As a result of current advances in computer technology, more and more new techniques are being created for virtual representations of the environment, e.g. the use of input and output media such as data gloves, or graphic representations using helmet-mounted displays or virtual-reality goggles. In view of this, the question arises of which requirements real-time simulation has to satisfy in order to comply with teaching or training tasks with maximum possible transfer. The answer to this question goes beyond technological requirements for simulators as regards simply staying within schedule when delivering information. In fact, the operating aims of simulation are subject to a range of other requirements, whose common aim is to enable the best possible transfer from the test situation to real life.

2.4.3 Developing a Model, Transfer and Validity

Transfer answers the question of the extent to which dealing with one task makes processing further tasks easier. If totally new activities are required, transfer does not usually occur. Müller (1911) discovered early on that the transfer of learned skills from the learning situation to application does not take place generally, but is restricted to similar learning matter and learning methods. Bartlett (1947) investigated transfer between identical classes of specific learning situation and stimuli. He found that one condition for positive transfer is that the learning situation must be harder than the transfer situation. However, Nissen & Bullemer (1987) and Braun et al. (1993) showed that complex processes are learned faster when the stress is reduced. A differentiation must therefore be made between learning conditions.

According to Thorndike & Gates (1930) transfer occurs between situations containing identical elements. Thus, practicing adding up should have a positive influence on learning to multiply, in that multiplication is seen as combined adding, and the latter recognized as an identical element of the former. It has, however, been pointed out that the search for identical elements could be never-ending, as identical subcomponents must be found which are increasingly harder to grasp. Thorndike is thus not able to determine the exact nature of identicalness and to explain to what extent conclusions can be drawn or generalizations made about the task as a whole, based on the learned element (Pavlov, 2006).

In view of the difficulties and doubts involved in hierarchical decomposition, even of simple tasks, into clearly defined subcomponents, the assumption about identical subcomponents seems dubious. Bergius (1964) therefore dealt with structural conditions for transfer and was of the belief that transfer is most likely when *insights* are gained into circumstances and procedures. At the end of the 1980s, transfer was still seen as the central problem of all training applications, even of real-time simulation, e.g. by Hale & Singer (1989). They believed simulation had to deliver benefits which were known and plannable in advance (Blaauw, 1982; Häcker, 1972; Roscoe & Williges, 1980; Käppler, 1997a). Otherwise, they believed, experimental investigations, et cetera, would be pointless, or teaching and training even dangerous. Transfer was considered the aim of simulation.

Transfer occurs when a task set is new, but the way to deal with it requires similar activities to the original situation. Transfer is strongest between very similar situations and becomes weaker as the similarity lessens.

Validity deals with statements on the soundness of tests, in the sense of how precisely one criterion can be measured (Dorsch, 1987/1991) and shows the degree of precision with which a test actually measures that trait or behavior it is intended or claims to measure.

This is demonstrated by Fig. 2.8, below, which shows that transfer in simulation is not an insignificant process. From everyday life, we know that there can be little correlation even between what is known as the *objective event* (circle on left) and our *subjective view* of it (circle on right). Pirandello (1999) came up with a good phrase for this: "It is so, if it seems so to you." If we construct this, our subjective view, mathematically, as a formal incident or event model, e.g. of how the accident occurred (circle at top), in our example the model validity only covers conditions in the upper triangle of the ellipse, somewhat shaped like a Rotary engine rotor.

A mechanical simulation of the event (circle at bottom) is then added to our example and the mathematical model is extended, making it a driving simulation. The conditions of the investigation are varied dynamically and the drivers are trained and studied. This example shows clearly that the validity of the simulation results

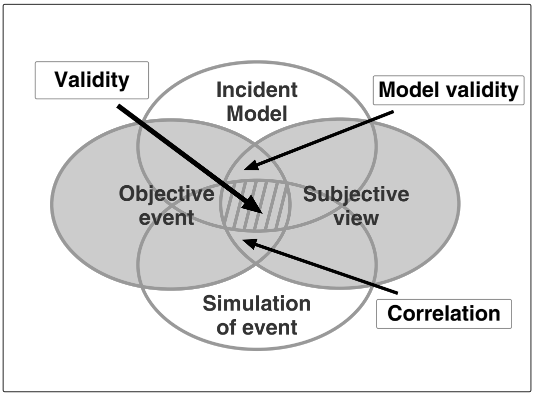

Fig. 2.8 Model development and validation

is guaranteed when none of the conditions, views or simulations reach beyond the boundary of the "lens" in the centre of the picture.

Minsky (1988) shed light on this in a good, ironic example, see Fig. 2.9. He explained as follows: Model M_1 is a model of object A for observer B_1 to the extent that he can use M_1 to answer questions which interest him about A. On the other hand, for observer B_2, model M_2 is a model of object A to the extent that he can use M_2 to answer questions which interest him about object A.

With this knowledge, Binninger (2000) formulated his succinct, and also slightly ironic, "Laws of Simulation," which speak for themselves:

- DON'T believe your model is reality
- DON'T extrapolate beyond the region of fit
- DON'T distort reality to fit the model
- DON'T retain a discredited model
- DON'T fall in love with your model.

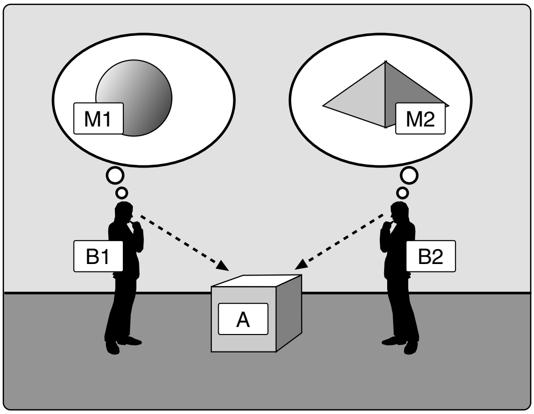

Fig. 2.9 Model development according to Minsky (1988)

Thus, the logical procedure with simulation can be summed up as follows:

- The *aim* of the simulation needs to be set down in a technological, scientific hypothesis.
- *Models* must be developed and evaluated, or selected, as an abstraction of reality.
- *Simulators* must be developed or selected as a means of carrying out training courses or lessons.
- *Boundary conditions* must be set for the simulation.
- *Boundaries* must be set for the validity of the results.
- The *validity* of the results must be proved.

What is therefore needed?

- A well thought-out concept
- Representative subject matter for the investigation and the training course
- An experimental environment for training.

This set of tasks and difficulties is accompanied by linguistic ambiguities. Patrick (1992) complained, for example that *fidelity* should be the theme of every discussion on simulators. The term *fidelity* comes from information theory and means the property of diagnostic tests to provide very precise measurements which are not, however, very wide-ranging. The term can hardly be applied to the transfer of learning processes. Patrick (1992) does not go into these questions at all.

Steininger (1995) admired the precision and faithful reproduction of almost perfect training devices: Using digital simulation, he said, it has been possible to improve the fidelity of the simulators so greatly that almost total simulation has become possible, rendering earlier questions of transfer of training superfluous. The author is not able to share this optimistic attitude. Even if simulators are perfect, this still says nothing about whether or not their use makes sense, about the correspondence between training targets and the overall context, the representativeness of training tasks or the validity of evaluations, etc. It is precisely the high technological perfection of the training media which tends to obscure discussion of these questions, and the corresponding answers (Mehl & Käppler, 1998a). Thus, simulation, in particular, needs to ask itself the question of how valid the training results are for the intended purpose. According to the Standards for Educational and Psychological Testing (AERA, APA, NCME, 1985), three types of validity can be distinguished (Anastasi, 1990):

- Construct validity
- Content validity
- Criterion-related validity.

The aim of *construct validity* is to provide a theoretical explanation for results; it is achieved by using logically structured concepts for teaching and training. It is comprehensive, as it focuses on explaining the causes behind circumstances.

The aim of *construct validity* is to provide a theoretical explanation for test results. It deals with attempts to explain the meaning of a measurement by means of the theoretical background. It is achieved by using logically structured concepts, e.g. for teaching and training. It is comprehensive, as it focuses on the formulation of hypotheses, i.e. explaining the causes of circumstances.

Content validity is related to the test contents. It occurs when the test tasks already contain the trait to be measured. This special case is described as logical validity. The content validity of the simulation implies that the test situation and subject matter are representative of real situations, and that registered measurement values are actually performance criteria, e.g. of learning outcomes.

Criterion-related validity is the quantifiable or empiric validity. It is related to statistical relationships between test values and criterion values, which are placed in relation to one another.

The *content validity* includes the face validity. This relates to what a situation seems to depict, at face value. In itself, face validity cannot replace objective validity. High face validity does not improve the content validity of the simulation. Its advantage is that it improves the acceptance, motivation and cooperation of the people involved.

This leaves *criterion-related predictive validity*. The time the test value and criterion value are ascertained means that it makes sense to differentiate between concurrent validity and predictive validity. During the training course, the test values should predict future criterion values. Thus, transferability predictions result in a quantification of the predictive validity of results. Strictly speaking, validity requires the test creator to inform the trainee in advance of the required test results. Indeed, determining the predictive validity for every specific learning situation is problematic, if simulators are specifically designed to be used in rare, dangerous and highly complex training units. Precisely for this reason, comparative data, e.g. for critical driving situations, cannot be produced at all – and these slices of reality are precisely what the simulation changes, making them common and harmless, with no consequences if errors are made.

However, if this is the main characteristic of the simulation, the requirement for validity becomes extraneous. The content validity of these slices of reality is not possible at all, as they have been changed into central characteristics, and are, for instance, harmless. The question arises of the extent to which results of this type can be validated at all.

But if simulator training is integrated logically and sensibly in an *overall system*, *construct validity* can be assumed. There is *content validity when educational situations are representative* of real situations, and when measured values are actually *performance criteria* for learning outcomes. Face validity guarantees the test subjects' acceptance, motivation and cooperation.

One approach to *criterion-related predictive validity* is comparing assessments of driving quality in the driving simulator with corresponding assessments in the real-life situation. To do so, a representative sample of the driving task, situation, vehicle and drivers must be investigated, and these estimated values collected and compared with those from the corresponding real situation. In this way, criterion-related validity can be quantified, although with subjective estimated values.

Of course, correlations between performance criteria in the simulator and the vehicle can also be calculated and checked for their significance. This is probably also the reason for Steininger's (1995) optimism. Hollnagel (1981) even took the view that criterion-related validity is not necessary at all, if there is enough construct and content validity. In this case, he believed, training results could be transferred qualitatively to the real situation.

2.4.4 Driving Simulators: Setup and Requirements

Figure 2.10 is an attempt at distinguishing between different simulation processes. It shows the *variability* of a development or investigation tool and the quality of the results it aims at, labeled the *degree of realism* (note: not the validity). Although its *variability* is higher, a *constructive simulation* with a sketch or numerical simulation provides only little reality. The whole system, as well as the operators and tasks, are

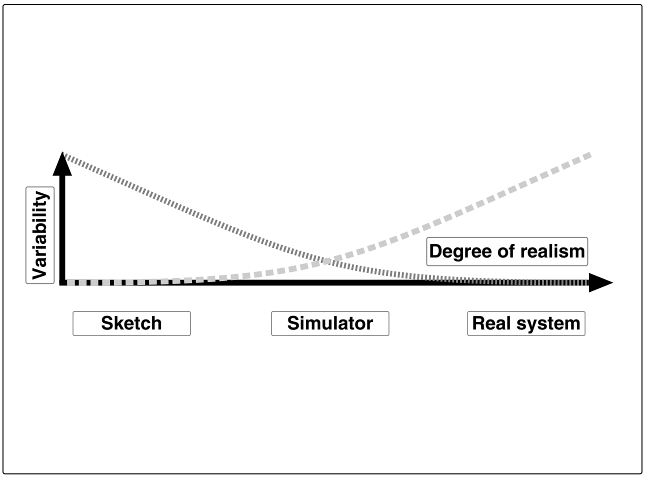

Fig. 2.10 Structure of simulation processes

all simulated. In the center, *virtual simulation* includes driving simulators. Here, the operator is real, and the vehicle and task still simulated. In the so called *live simulation*, the system and operators are real, while the task may still be simulated, as before. Due to actual simulator design and requirements, either with high variability or high realism or a good mix of both, simulators may be put almost anywhere in the middle of that Figure.

Which characteristics place a driving simulator where? Figure 2.11 shows the schematic layout of a driving simulator. It consists of a driver's cab, known as a mock-up, often original vehicle or replicated bodywork or parts of bodywork, and other simulator element, controls and simulation of force feedback:

- Mock-up
- Vehicle model
- Traffic model
- Road model
- Visual model
- Sound model
- Motion model
- Force feedback model
- Display model
- Data recording model
- Data evaluation model
- Replay model
- Training model
- Courseware.

The mock-up contains all the relevant controls and displays. The driver's operation of the controls is registered electrically and transferred to computers. In the

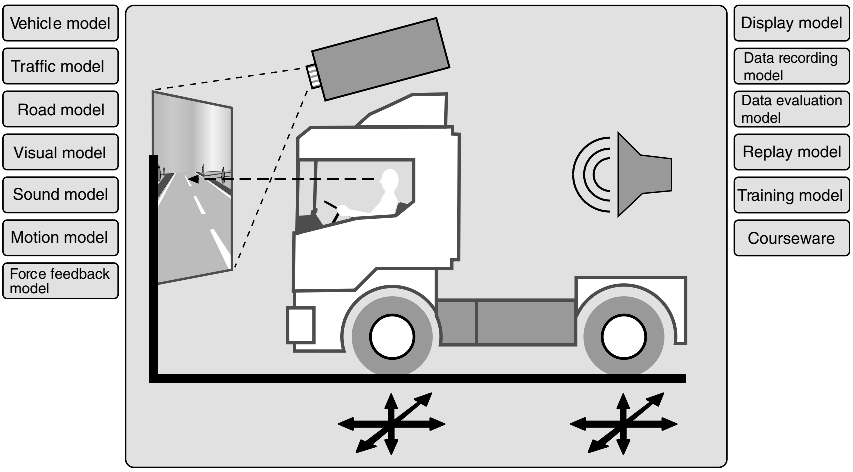

Fig. 2.11 Schematic layout of a driving simulator

digital computers, programs are installed for simulating the vehicle dynamics. From the gas and brake pedal input parameters, and the position of the gear lever, for example, they calculate the driving speed.

The output variables for the vehicle dynamics are used to control programs for the out-of-window view. It creates an out-of-window view from the driver's perspective on the screen of a graphics system or using a projector, depending on the vehicle's position and turning angle in the data base. Furthermore, other information is displayed, such as the speed on the speedometer. Other simulator elements replicate engine, tire and wind sounds, as well as the force feedback, such as the steering momentum. Motion or acceleration simulation recreates the vehicle's movements across the terrain: for example, the mock-up is moved using complicated equipment. The main input parameters for this simulator element are the vehicle movements calculated in the dynamics model. Another simulator element recreates the steering momentum, depending on the steering angle, the lateral acceleration and the speed.

A driving simulator must fulfill certain minimum requirements to serve as a useful training medium for the target training purpose. The quality of the simulated vehicle dynamics, with the movement and out-of-window view, have a decisive influence in conveying the effect of a road trip. There are vehicle models which provide a close approximation of driving characteristics in many ways. However, as regards their programming technology, they are extremely elaborate, and running them in real time on a process computer is problematic. An out-of-window view with a lot of detailed information is desirable from the point of view of the driver, but processing the necessary volume of data in real time can only be carried out at great expense. Over the years spent dealing with simulators, expert knowledge has led to a wide range of technological requirements for them. They mainly revolve around creating the illusion that the test subject is carrying out a driving task in the real world. If stimulus-response patterns in stimulators are similar in quality to those in the real world, they can be perceived and integrated in this way, and processed to produce decisions.

Representing the information on time and without delay is one of the most important operating targets for simulators, as unless there is a continuous flow of information, the perception of moving through space is disturbed. Overviews of out-of-window view specifications, now outdated, can be found in surveys of the literature by Padmos & Milders (1992), Haug (1990) or Korteling (1991). A group of specialists from the US National Research Council (Käppler et al., 1992) compiled specifications for driving simulators and 54 driving tasks. The German Federal Highway Research Institute (BASt) had a report written up on simulators' suitability for training and testing drivers (von Bressensdorf et al., 1995), with a summary of the most important technological characteristics; this is still fairly up-to-date.

Altogether it can be seen that technological requirements for driving simulators are very demanding, due to the high angle-of-view speeds, high-frequency system dynamics and the driver having a lot of freedom. In general, a specification is only valid in the context of the task it is derived from, meaning that there is no one single specification for *the* driving simulator. There now follows a short discussion on the main characteristics from von Bressensdorf et al. (1995) and Käppler & Alexander

(1995). Interested readers can find out about technological requirements here and note that these are still essentially dictated and limited by technological development opportunities – and development is ongoing: ideas which open up new opportunities one day are dismissed again the next.

2.4.4.1 Out-of-Window View

Requirements in terms of the out-of-window view dictate, among other things, that visual information must be provided smoothly, without delay and in real time. Their quality can be seen from the following characteristics:

- View to front and back; visibility
- Horizontal and vertical resolution; luminance
- Information content
- Segmenting and levels of detail
- Frame rate and transport delays
- Textures and anti-aliasing.

For traffic tasks, 180-degree horizontal angles of view were once considered sufficient (Padmos & Milders, 1992; Käppler et al., 1992); today this is already far too little. The visual range, especially in city traffic surroundings, must extend to below 1 m (3 ft), so that it is possible to drive close up to traffic lights, for example; in many cases, this is not possible. The maximum visual range is limited by the computing capacity and the resolution of the display systems.

The human eye has a minimum resolution of 3 arc minutes. Thus, modern monitors' raster technology require 15 lines per degree; to identify traffic signs, 60 lines per degree are necessary (Padmos & Milders, 1992), but can hardly be achieved. The literature describes luminance of $20\,\mathrm{cd/m^2}$ as sufficient, but these values are minimum requirements at best.

Segmentation cuts a data base into adjoining sections so that the entire course of the road ahead does not have to be calculated from the terrain in the data base, but only for the section in the visual range in front of or behind the driver. This can lead to pop-up effects during fast driving, when large segments of street pop into view at once, as well as *levels of detail*. The latter means the degree of detail in displaying objects which are integrated dynamically, depending on how far the observer can see.

The impression of moving along is created by presenting individual images in fast succession. From a frame rate of about 30 images per second, human observers start to perceive it as smooth movement. In general, *higher frame rates* are needed, in the interests of high image quality and faster vehicle reactions, and to avoid visual elements popping up into the peripheral field of vision. This is just as important a requirement as that for smooth-running repeat rates, to avoid misleading motion information from images which are sometimes smooth, sometimes jerky. *Transport delays* (the delay between the driver's input, e.g. with the steering wheel, and the display of the corresponding out-of-window view) should preferably be below 60 ms in the interests of smooth systems dynamics, but this can hardly be achieved.

2.4.4.2 Motion, Display, Controls and Sound

Specifications for the layout of technological systems to replicate acceleration, motion or vibrations concern distances, angles, acceleration, transport delays and the corresponding cut-off frequencies, and none have been validated. Thus – unfortunately – it remains up to the individual simulator designer's expertise to make a good choice, or determine one by trial and error. There is still reason to believe that here, especially, the cost/benefit ratio is very unfavorable.

Replicating force feedback and sounds ensures that the vehicle can be controlled realistically, and that only short training sessions are required to get used to it. Here, once more, the manufacturer and designer are mainly left to rely on trial and error due to lacking or poor specifications.

2.4.4.3 Vehicle Dynamics

In simulators, for reasons of capacity, the number of vehicle parameters available for variations is considerably lower than in real vehicles. Tire characteristics are often linearized and models simplified. This does not have any negative consequences as long as the simulations are limited to their expected uses. In the case of the *one track model*, a linear model with three degrees of freedom, for example, the wheels on one axle are seen as one imaginary single wheel. This model can yaw and move in a longitudinal and lateral direction, but it cannot properly roll, pitch or make vertical movements (oscillations). Thus, linearized models may only be used for small drift angles; the maximum permissible lateral acceleration is then considered to be 0.3 g. Dynamic behavior in the borderline area ought not to be practiced with simulators of this kind . . .

Complex four-wheel models, on the other hand, can replicate all degrees of freedom. Here, ultimately, the number of parameters specifies the range of variations and the precision of a replication of vehicle dynamics. For this reason, there are often immense differences in quality, and the parameters – unfortunately – are often not even validated, but adjusted according to taste. The problems then start when training with experienced drivers . . .

2.4.4.4 User Support

One very important requirement is that the simulator and courseware are user-oriented and simple to use. This relates to simple-to-use ways (even for people other than computer scientists) of selecting and adjusting:

- Vehicles, trailers and loads
- Environmental conditions
- Traffic conditions
- Events and what they feature
- Levels of difficulty
- Measurement values.

The composition of tasks, routes and events must be user-friendly and provide assistants for navigating through the scenarios. Sufficient information must be available during the simulator training session. For the evaluation, it must be possible to select performance criteria and illustrate and process them quickly and simply after a trip. The usage examples in the following chapters show that this is all in development.

2.4.5 Typology of Driving Simulators

Another important point has also not been dealt with. When can a driving simulator be called by this name, and what characteristics must it then possess? Can any driving simulator be used for any teaching or training? Of course, one driving simulator is not like the next. There is a whole range of different constructions with different qualities and purposes. This subchapter proposes a conceivable means of categorizing the technology and how it is used; see Fig. 2.12, including examples.

The classification proposes six different categories and is based on known needs in terms of human perception when driving, i.e. mainly the depiction of movement and the out-of-window view, above all. It must not be forgotten that this is an attempt at a technological classification of simulator construction, which does not say anything at this point about how they are used on driver training courses. Corresponding

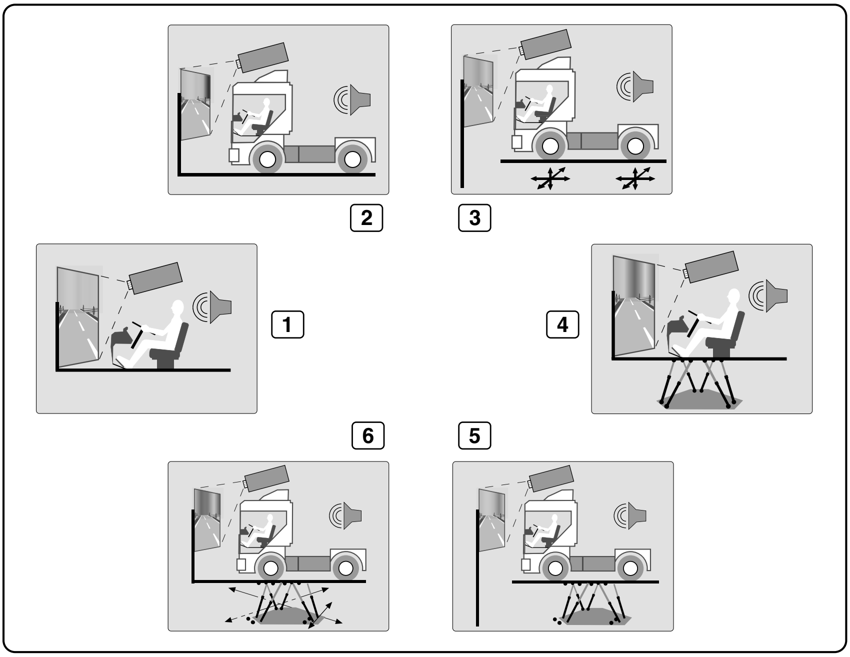

Fig. 2.12 Technological typology of driving simulators in six categories

requirements, rules and guidelines need to be developed when firm information is available on teaching and training outcomes. The current state of knowledge is not yet sufficient for this.

2.4.5.1 Constructions with no Degree of Freedom

We start off on the overview in Fig. 2.12 at 9 o'clock, with the most simply constructed static fixed-base driving simulators with no degree of freedom. Both mock-ups, number 1, and reconstructed or modified bodywork, number 2. Below, Fig. 2.13 shows the schematic representation of number 1, a static driving simulator with a mock-up cab and primary controls, with zero degrees of freedom (dF = 0).

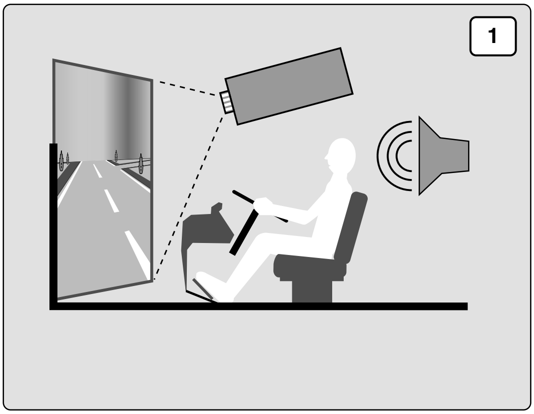

Fig. 2.13 Schematic representation of a static driving simulator with a mock-up cab and primary controls (dF = 0)

These simple driving simulators are characterized by:

- Optical representation of dashboard and surroundings
- Acoustic representation of surroundings
- Haptic feedback from controls.

As they lack any form of movement, and, especially, as they are similar to toys, driving simulators of this type are not well suited to serious training courses. These types are mainly in use for demonstrations or simple part task research or training applications One example which has been put into practice is the police pursuit trainer in Fig. 2.14, the product of cooperation between Time Warner and Atari Games Corporation AGC at the Technical University of Berlin.

Figure 2.15 shows the schematic representation of number 2, the same version with a modified vehicle instead of the mock-up cab. The advantage of this is the face validity with realistic vehicle shape for the field of view, and the sounds. Here, again, the disadvantage is the lack of any movement for the driver.

As an example in practice, once again, Fig. 2.16 shows the IVI Driving simulator of the Fraunhofer Institute for Transportation and Infrastructure Systems in

Fig. 2.14 Time Warner's AGC SV500LE static simulator at the Technical University of Berlin with mock-up cab, primary controls and out-of-window view on 5 screens (dF = 0)

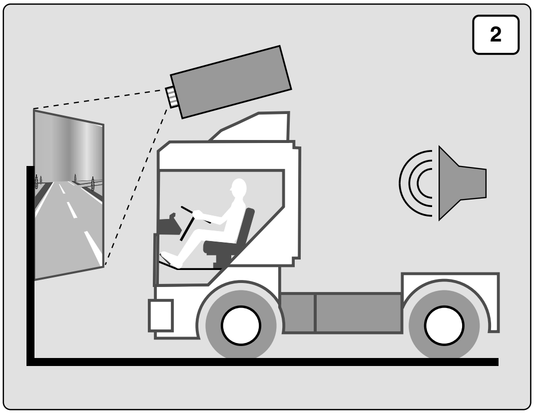

Fig. 2.15 Schematic representation of a static driving simulator with modified vehicle bodywork and primary controls (dF = 0)

Fig. 2.16 IVI Driving simulator of the Fraunhofer Institute for Transportation and Infrastructure Systems in Dresden

Dresden; a close to series vehicle without motion and extended outside view. It is used for research into driver assistance systems, e.g.

2.4.5.2 Constructions with up to Three Degrees of Freedom

This construction can be extended, for example by adding simple movement with information on the shape of the road surface. The advantage of this is feedback on road cues in a vertical direction, and the haptic information. Such simulators may be equipped with pneumatic pistons, with affiliated coil springs and shock absorbers located in each of the vehicle cab's wheel wells. This system simulates the normal vibrations experienced while driving and can provide minimal car cab pitch.

The top version of these constructions adds other movements apart from road surface cues and has three degrees of freedom at most. One special feature is that the vertical vibration is imitated in a translatory manner, but the longitudinal and lateral acceleration generally by means of rotation around the roll and pitch axes, using changes in angle. Of course, this cannot be described as longitudinal or lateral acceleration: It is simulated roll and pitch. Figure 2.17 shows the schematic representation of number 3. This construction is commonly found in different forms, as it offers the advantage of suggesting movement so that the driver perceives the driving environment as more realistic, but without excessive expense.

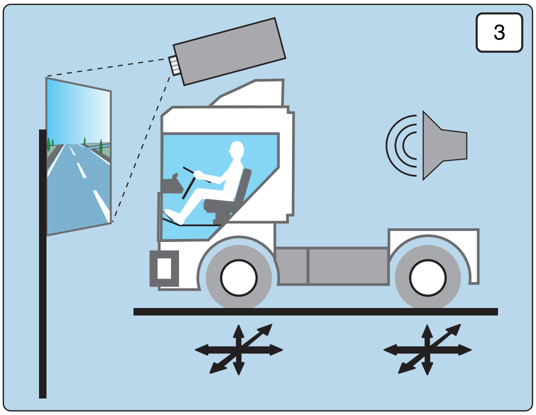

Fig. 2.17 Schematic representation of a dynamic driving simulator with information on the shape of the road surface and the longitudinal and lateral acceleration (dF = 3)

One early example which was put into practice in 1976 is the driving simulator at the Forschungsgesellschaft für Angewandte Naturwissenschaften (FGAN – Research Establishment for Applied Science) in Germany, which uses two cylinders in the back of the cab to replicate roll and pitch angle, superimposing vibrations, see Fig. 2.18.

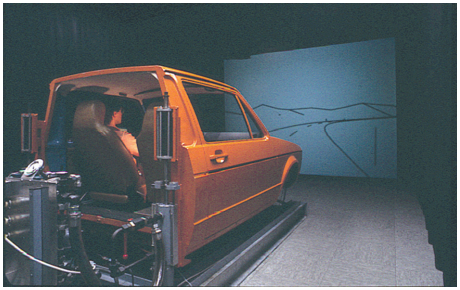

Fig. 2.18 FGAN driving simulator with hydraulic roll and pitch movement cues, as well as vibration (dF = 2+)

2.4.5.3 Constructions with More than Three Degrees of Freedom

What was once a static driving simulator with a mock-up cab and primary controls is placed, along with a moving screen, on an electrically or hydraulically operated system (generally a hexapod), thus turning it into a dynamic simulator with six degrees of freedom (dF = 6). All three translations and the three rotations are, of course, limited, see number 4 Fig. 2.19.

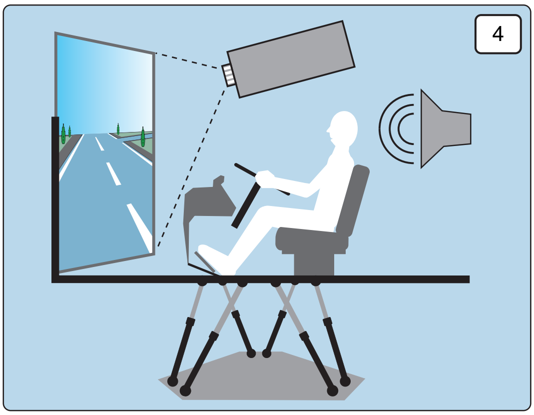

Fig. 2.19 Schematic representation of a dynamic moving screen driving simulator with a mock-up and vestibular information (dF = 6)

One advantage of this construction is that vestibular perception is cued quickly; one disadvantage is the limited angle and path, as described above. Nonetheless, this design is very well suited for studying particularly dynamic driving tasks (partly due to its relatively low weight), if less so for regular teaching or training because of limited face validity. Below, Fig. 2.20 shows the University of Saragossa's SYMUSYS as a rigorously well-constructed non-hexapod example. This innovative simulator

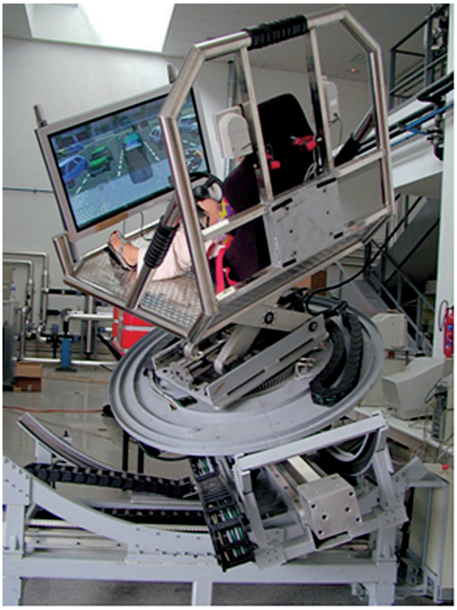

Fig. 2.20 SIMUSYS driving simulator from the University of Saragossa with movement (dF = 4)

with spherical platform and 4 degrees of freedom is used for entertainment and research applications with extreme driving situations.

The next construction locks the out-of-window view in place as a fixed screen and uses modified bodywork close to the original. This markedly improves the face validity and sound simulation. The field of view is more realistic and also suited to perception of objects behind the driver. This offers the advantage of the vehicle being in a better position relative to the surrounding traffic, or the driver knowing the position better, depending on the quality of visibility and movement; see number 5 in Fig. 2.21.

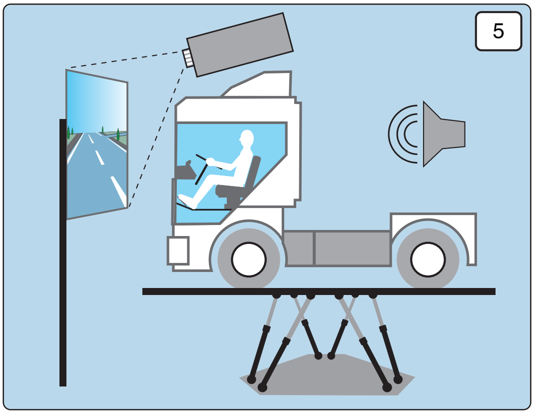

Fig. 2.21 Schematic representation of a dynamic driving simulator with near-original bodywork, a fixed screen (dF = 6)

There are plenty practical examples for research and training applications; one which is well-known and relatively new is the truck simulator at the University of Munich for studying traffic safety with an electric motion system at operating height in Fig. 2.22.

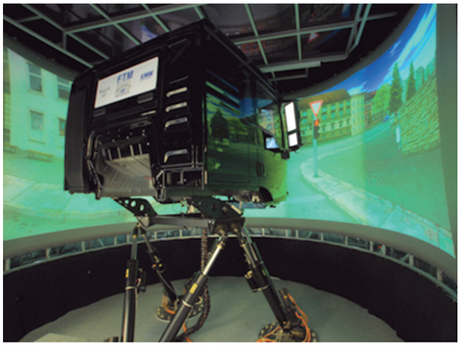

Fig. 2.22 Truck simulator with hydraulic movement and fixed screen, chair of automotive technology at the Technische Universität München (Technical University Munich, dF = 6)

Here, too, there are improvements. If the hexapod is placed on a platform which can be driven back and forth or sideways and the out-of-window view is also integrated on the platform, the current final stage of driving simulator development is reached, see number 6 in Fig. 2.23. This construction is known as the 6+ degree of freedom version. The moving screen and movements caused by the vehicle suspension relative to the platform create quite a realistic impression of driving. A rail system below moves the cab and the hexapod, e.g. and allows for extended acceleration duration times.

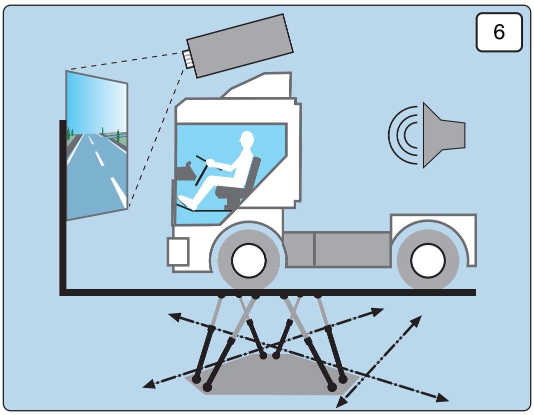

Fig. 2.23 Schematic representation of a dynamic driving simulator with near-original bodywork and close-to-reality vestibular information (dF = 6+)

There are few practical examples at the upper end of the scale. One example in practice is the VTI driving simulator in Sweden, partly including a car mock-up shown in Fig. 2.24. This non-hexapod rail system allows for either lateral or - if the upper part including cab is revolved by 90 degrees–for longitudinal movements and is used in research applications.

Fig. 2.24 VTI driving simulator in Sweden with hydraulic movement and a moving screen (dF = 6+)

Figure 2.25 shows Daimler's research simulator in Berlin. This is a hexapod placed on a rail system. Again, it allows for either lateral or – if the dome is revolved by 90 degrees – for longitudinal movements and is used in dynamic research applications. Longitudinal movements have not yet been realized.

As well as this attempt at structuring, there are a range of other possible taxonomies for driving simulators. For example, some interesting versions with four degrees of freedom have not been mentioned at all, so as not to complicate the facts further. Of course, this categorization is technology-driven, yet it is also anthropocentric, as it is based on known needs in terms of perceptions of movement and out-of-window view, from the driver's point of view.

This overview should, however, suffice simply to illuminate the fact that not all driving simulators are alike. Also, unlike vehicles, for example, it is not at all clear which device is best suited for which use. When buying a car, a sports-loving driver would hardly consider a minivan. Categorizations of vehicle construction types are familiar to everyone as "model ranges" and are clearly defined, even though their numbers are tending to increase. When buying a driving simulator it would not be as easy to put it into a category.

For a driving school or training company, high-end constructions can certainly be ruled out due to their construction costs alone. Some low-cost constructions are also poorly suited to practical driver training, as they cannot replicate aspects of driving which are fundamental, especially for teaching and training purposes, and their face validity is closer to that of simulator games. However, falling prices, new processes and higher-performing technology do not make it any less necessary to clarify the variety of requirements and technological solutions using "driving simulators." It is

Fig. 2.25 Daimler's driving simulator with extensive movement and a moving screen (dF = 6+)

left up to discussion if the driving simulator number 5 shown in Fig. 2.21 may be located at the anchor in the middle of Fig. 2.10, the point of intersection of both gradients.

Anyway, this technologically driven taxonomy remains a daring attempt because the training requirements have not even been discussed yet but should play the key role. Nevertheless taxonomies to this effect are certainly possible, bearing in mind the current state of knowledge. It seems worthwhile and necessary for the driving simulation community to identify and create these wide-scope definitions.

2.4.6 Advantages and Limits of Simulators

This technologically based identification of simulator constructions leads directly to considerations of the advantages and limits of driving simulation. The general advantages of simulators have been described already early in the literature (e.g. Frieling & Sonntag, 1987; Kelley, 1969; Hoskovec, 1972; Pain et al., 1973; Pelz & Krupkat, 1974; Frieling & Sonntag, 1987; von Bressensdorf et al., 1995). It is agreed that simulators may deliver:

- Systemization: systematic learning strands and possibility of repeating, standardizing and automating the sequence of events and tasks; singling out subtasks
- Documentation: documenting the learning and driving process with on-line error recognition and processing, measuring learning progress
- Objectivization: objective checking of training process and success using parameters
- Localization: creating any situation at any place, at any time; rare occurrences
- Adaptation: adaptive learning to save time and individual variability of levels of difficulty, complexity
- Replay: "save" function and repeating a trip for later evaluation and reflection on behavior displayed during a debriefing, see Briefings and Replays
- Safety: safe learning under all conditions, critical sequences can be carried out as often as required and subject matter which cannot be practiced in reality due to danger, e.g. tire burn.

Experience in aviation and ship simulation has shown, nonetheless, that there is still insufficient knowledge today about evaluation criteria for automated training evaluations and interactive training control. However, one aim of using training simulation is computer-controlled adaptation of task difficulty based on an evaluation of driving quality, meaning that a training session is shortened when the training target is achieved early. Based on the current status of our knowledge, this aim can only be achieved by means of sufficient test phases.

The limits. Often, safety in simulators is only shown from its good side. However, the almost complete safety of simulators is also the main limitation of experiencing realistic driving (Biehl, 1976; Fastenmeier, 1988b; Käppler & Voß, 1988; Käppler, 1991; Käppler et al., 1992; Käppler 1993a, b, 1994a, b, 1997a). As there are no real risks in taking a decision, and no real burden of responsibility, there is no danger and the driver's actions have no consequences. The outcome is that these aspects of real-life situations cannot be reproduced.

It has been pointed out that compared with pilots on scheduled flights, for example, car drivers enjoy markedly more scope for their decisions and actions. Thus, their motivation and behavior have clear effects, and presuming a priori that people will act realistically in simulators is untenable with no further evidence (Biehl, 1976; Fastenmeier, 1988b; Käppler & Voß, 1988). Risk-free decisions and a lack of consequences can encourage an inflated view of one's own skills and an uncritical feeling of safety. This can result in undesirable transfer, or no transfer at all, as well as uncertainty with regard to changes of attitude and behavior. It is also unlikely that misdirected attitudes and driving motivation (aggression, enjoying risk) will be unlearnt.

For processes to become automatic, there must be an unbroken illusion of realistic experience. This can be disrupted if the driver experiences physical or mental discomfort, or simulator sickness. Reports of this kind have accompanied driving simulation from the very start. Findings by Förstberg (2000), e.g. showed for real vehicles use that such sickness was reported at least once by about 10 percent of train users, 9 percent of airplane passengers, 28 percent of bus riders and even 36 percent of passengers in cars. Thus, in about 10–20 percent of the driving population symptoms similar to simulator sickness even appear outside simulators: this can only really be described as simulator sickness when it occurs in higher percentages in simulators.

On the other hand, simulator sickness can be the result of discontinuities within one kind of information or between different kinds of information, i.e. not caused by technology. An investigation in flight simulators showed that simulator sickness occurs far more rarely when the visual display is improved, without the motion simulation being changed (Kennedy et al., 1993).

Experience suggests that the same is true of driving simulators. However, corresponding technological specifications are not available for many tasks, and it is left to the skill of the developer in question to find the best solution from his or her point of view. Therefore, it is difficult to produce full-task simulators which not only provide an unbroken illusion of real experience, but also guarantee realistically risky decisions and actions with consequences. This means that the use of simulators is drawn toward a preference for cognitive subject matter and rare topics, and areas which can hardly be practiced in a vehicle at all, or can only be practiced insufficiently, for operational, political or environmental reasons.

One difference compared with conventional driving school training is a result of social isolation in simulators and the effects on the learning situation itself. On one hand, the out-of-window display can only be properly perspectively adjusted to the driver's point of view. From the passenger's point of view, for example, distances and hidden objects seem wrong. Thus, driving instructors, as passengers, are more likely to suffer simulator sickness. An out-of-window view which was also correct for the driving instructor, for example, would be possible with virtual reality technology, but it would also be expensive, hardly acceptable for reasons of face validity and comfort, and would further restrict interaction (Käppler, 1993a, b, c). Thus, typical learning situations in driving simulators will still be unaccompanied trips without the usual interaction with driving instructors or passengers, i.e. without the conventional teacher-pupil relationship.

On the other hand, the lack of other road users creates disadvantages in terms of social learning. Topics related to collective behavior require interaction with other road users. In simulators, they are usually replicated by formal models of human behavior. However, the range and variation of the corresponding algorithms are still limited, meaning that only a few situations, such as overtaking maneuvers or following the vehicle in front, are reproduced. There are often no interactive cyclists or pedestrians. Moreover, it soon becomes easy to see through the simulated road users' limited range of reactions. Here, artificial intelligence methods and neural networks will only be able to create satisfactory results in the medium term.

In the short term, multi-simulator networks offer educational opportunities of this kind by recreating social contexts realistically. Drivers interact with road users in other simulator cabs. In this case, what is problematic are learning situations where beginners interact with beginners.

With an awareness of their advantages, boundary conditions and disadvantages, driving simulators have been, and are still, increasingly employed in teaching and training. In the following chapters, a range of project reports are followed by two illustrative examples:

- Fundamental reflections on the structure of integrated driving lessons with simulators and vehicles
- Specific professional driver training courses carried out in training centers.

The end of an era . . .

Safety to a . . . legislator is being able to almost demolish a concrete block. This block-busting mentality does not take in the finer points of a car which enable it to avoid hitting concrete blocks in the first place, given a driver of minimum ability. – Harvey (1985)

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