

Deze pagina en de verzendlijst en het RDPformulier uit de WP template halen!!!!

TNO-report
TM-00-C044

Title
Opportunities for technology supported driver training

authors
K. van den Bosch and J.E. Korteling

TNO Technische Menskunde

Kampweg 5
Postbus 23
3769 ZG Soesterberg

Telefoon 0346 35 62 11
Fax 0346 35 39 77

date
November 22, 2000

Opdrachtgever : ..

Alle rechten voorbehouden.
Niets uit deze uitgave mag worden
vermenigvuldigd en/of openbaar gemaakt
door middel van druk, fotokopie, microfilm
of op welke andere wijze dan ook, zonder
voorafgaande toestemming van TNO.

Aantal pagina's : 29 (incl. bijlagen,
excl. distributielijst)

Indien dit rapport in opdracht werd
uitgebracht, wordt voor de rechten en
verplichtingen van opdrachtgever en
opdrachtnemer verwezen naar de
Algemene Voorwaarden voor onderzoeks-
opdrachten aan TNO, dan wel de
betreffende terzake tussen partijen
gesloten overeenkomst.
Het ter inzage geven van het TNO-rapport
aan direct belanghebbenden is toegestaan.

© 2000 TNO

CONTENTS	Page
SUMMARY	3
SAMENVATTING	4
1 BACKGROUND	5
2 INTRODUCTION	5
3 CURRENT DRIVER TRAINING PROGRAMS	6
3.1 Current theoretical training	6
3.1.1 Philosophy of instruction	7
3.1.2 Selection of content	7
3.1.3 Presentation of content	7
3.2 Current practical training	8
4 APPLICATION OF ADVANCED TRAINING INSTRUMENTS	9
4.1 Training with flight simulators	9
4.2 Opportunities for CBI in traffic theory	10
4.3 Opportunities for driver training simulators	12
4.3.1 Tasks to be trained on a driving simulator	12
4.3.2 Simulation technology	14
4.3.3 PC-based driving simulator	15
4.4 Validation of driving simulators	16
4.5 Current driver training simulators	17
5 DIDACTIC MODEL FOR A TECHNOLOGY-SUPPORTED DRIVER EDUCATION PROGRAM	21
5.1 Objective	21
5.2 Global functional specifications of CBI	21
5.3 Global functional specifications of a cost-effective driver training simulator	22
6 DISCUSSION	26
REFERENCES	28

Opportunities for technology supported driver training

K. van den Bosch and J.E. Korteling

SUMMARY

Purpose. Driver education programs in the Netherlands focus on practical lessons on the vehicle, under supervision of the instructor. An important drawback is that the driving instructor has limited control over the learning environment. Opportunities for instruction depend on incidental events taking place in actual traffic. Advanced training instruments, like Computer Based Instruction (CBI) and simulators may be used to structure the learning situations according to an optimal sequence and frequency. However, despite rapidly improving simulation technology, a full mission simulator, enabling the training of all driving tasks, is not yet possible. The “*Adviesdienst Verkeer & Vervoer*” (AVV) of the Ministry of Transportation in the Netherlands, in cooperation with Volpe National Transportation System Center in the United States, investigates the possibilities of utilizing advanced learning aids for driver training purposes. Under contract of AVV, TNO Human Factors has prepared a paper discussing the opportunities of CBI and simulators for driver training, and the technological and educational requirements to realize their potential.

Methods. In the past two decades, TNO Human Factors has acquired extensive knowledge and expertise on using advanced learning aids for driver training. This knowledge base was used as departure point. A small-scale literature review served to include actual developments in the paper.

Results. Developments in technology have opened new possibilities for driver training. CBI may be used to prepare student drivers to handling certain traffic situations that, for practical or safety reasons, can not be addressed in the practical lessons. Emphasis should be given to cues for recognizing and identifying potential risk and to teaching adequate maneuvers to prevent or reduce such risk.

The advantage of simulators is that traffic situations and driving conditions can be modeled as desired. This makes it possible to tailor the training course to a trainee’s individual training needs. The driving performance of the students can be assessed automatically, accurately, and objectively, and the results can be fed back instantaneously to the trainee. Furthermore, students can be safely confronted with unexpected behavior of other traffic participants, and can practice emergency procedures (e.g. tire-burst).

Conclusions. There is evidence that driving simulators can be successfully used for training certain parts of the driving task. However, for successful application a series of questions still need to be answered. These are technological questions (how do I create, against acceptable costs, a simulated task environment that enables student drivers to acquire task critical skills accurately and rapidly?), as well as training questions (e.g. which task do I select for simulator-based training, which procedures do I use for performance assessment and feedback?).

Kansen voor een technologie-ondersteunde rijopleiding

K. van den Bosch en J.E. Korteling

SAMENVATTING

Vraagstelling. Bij rijopleidingen in Nederland ligt het accent op lessen in het voertuig, onder leiding van een instructeur. Een belangrijke beperking van deze onderwijsvorm is dat de rij-instructeur voor het aanbieden van leersituaties afhankelijk van wat er zich toevallig in het verkeer voordoet. Leersituaties kunnen in principe door de inzet van Computer Ondersteund Onderwijs (COO) en rijsimulatoren, systematisch, en in een optimale volgorde en frequentie worden aangeboden. Echter, ondanks snelle technologische ontwikkelingen is een full mission rijsimulator, waarmee alle rijtaken kunnen worden geoefend, nog niet mogelijk.

De Adviesdienst Verkeer & Vervoer van het Ministerie van Rijkswaterstaat onderzoekt, in samenwerking met Volpe National Transportation System Center in de Verenigde Staten, naar de toepassingsmogelijkheden van simulatoren voor rijopleidingen. Ter voorbereiding van een symposium daarover is, in opdracht van AVV, door TNO-TM een discussie-paper opgesteld waarin de mogelijkheden van COO en simulatoren voor training van rijvaardigheden zijn nagegaan, en wat de technische en onderwijskundige eisen zijn om die mogelijkheden te kunnen realiseren.

Werkwijze. TNO-TM heeft in de laatste 15 jaar uitgebreide kennis en expertise vergaard over de mogelijkheden van geavanceerde leermiddelen voor rijopleidingen. Bij het schrijven van het discussie-paper is deze expertise als uitgangspunt gebruikt, aangevuld met een beperkt literatuuronderzoek om actuele ontwikkelingen in het discussie-paper te kunnen verwerken.

Resultaten. De ontwikkelingen in de simulatortechnologie hebben nieuwe mogelijkheden ontsloten voor de rijopleidingen. COO kan gebruikt worden om de student voor te bereiden op verkeerssituaties die, vanuit praktische of veiligheidsoverwegingen, niet aan de orde kunnen komen in de praktijklessen. De nadruk moet liggen op het leren onderkennen van signalen die op (het ontstaan van) een gevaarlijke situatie wijzen, en hoe in zulke omstandigheden gehandeld moet worden.

Trainingssimulatoren hebben als voordeel dat verkeerssituaties en rijomstandigheden naar wens kunnen worden gemodelleerd. Daardoor kan het onderwijstraject optimaal en efficiënt op de individuele instructiebehoefte worden afgestemd. De rijprestaties van leerlingen kunnen automatisch, nauwkeurig en objectief worden gemeten en deze informatie kan worden teruggekoppeld naar de leerling. Verder kan de leerling naar wens en zonder gevaar worden geconfronteerd met onverwacht gedrag van medeweggebruikers, en behoort ook het oefenen van noodprocedures (bv. klapband) tot de mogelijkheden.

Conclusies. Er zijn goede aanwijzingen dat simulatoren met succes kunnen worden ingezet voor het leren van een aantal onderdelen van de rijtaak. Voor de toepassing van rijsimulatoren op ruime schaal in de praktijk moeten echter nog veel vragen worden beantwoord. Dat zijn vragen op technologisch gebied (hoe creëer ik tegen aanvaardbare kosten een gesimuleerde taakomgeving die leerling-chauffeurs in staat stelt om taakkritische vaardigheden snel en goed te leren?), maar ook vragen op onderwijskundig terrein (o.a. welke taken selecteer ik voor training in een simulator, welke procedures gebruik ik voor prestatiemeting en terugkoppeling?).

1 BACKGROUND

Within the framework of the memorandum of understanding between the Transport Research Center of the Dutch Ministry of Transport and Volpe National Transportation Systems Center of the U.S. Department of Transportation, a series of research projects have been defined that may affect traffic safety in a positive manner. One of them concerns the opportunities of modern instruction technology to improve drivers' knowledge, skills, and behavior. Under contract of the Transport Research Center, TNO Human Factors has produced an overview of advanced training aids, like Computer Based Instruction (CBI) and training simulators. In addition, a didactical model has been developed for utilizing such aids in driver training programs. The present report is produced for the workshop "Human Factors & Safety Research", held on 13–15 November 2000, at the Volpe National Transportation Systems Center, in Boston, USA.

2 INTRODUCTION

"Learning to drive can only be achieved in practice". This statement is true for contemporary driver education in the Netherlands because prevailing courses tend to consist exclusively of practical lessons on the vehicle, under supervision of the instructor. Some driving schools offer their students collective instruction in traffic theory, but most of them just hand over a textbook for self-study. Hence, no coordination between theoretical and practical training exists. Students regularly lack the knowledge and skills required handling traffic situations, forcing instructors to interrupt the lesson for teaching on the spot (e.g. explaining the meaning of a traffic sign, a particular rule). This is clearly a waste of precious training time.

An advantage of in-vehicle training in real traffic is that the transfer to the operational task is relatively easy because driving skills are trained in a representative context. However, this form of training has its limitations as well (Van den Bosch & Riemersma, 2000). A first drawback is that the training strategy remains implicit: learning objectives, instruction method and evaluation are concentrated in the brain of one person. Secondly, the driving instructor has limited control over the learning environment. The selection of road configurations (e.g. intersections, crossings, etc.) for training is limited to what is available in the vicinity, and the events taking place (e.g. approaching traffic, presence of pedestrians) can, of course, not be manipulated. It is therefore impossible to structure the learning situations according to an optimal sequence and frequency. A third limitation is that practice in recognizing and handling dangerous traffic situations is not possible, due to practical and ethical considerations.

The aforementioned limitations of learning to drive in a real-life setting can, in principle, be overcome partly or entirely by the use of advanced training instruments, like Computer Based Instruction (CBI) and simulators. CBI may be used to prepare students effectively and efficiently for their practical training, making sure that the required knowledge and skills are mastered adequately and in time. Compared with lessons on the vehicle, training simulators offer a series of advantages. Traffic situations and driving conditions can be modeled as desired. The driving performance of the students can be assessed automatically, accurately, and objectively, and the

results can be fed back instantaneously to the trainee. This makes it possible to tailor the training course to a trainee's individual training needs. The structure of training can be enhanced by practicing the components of the driving task piecemeal, in a well-chosen sequence and in gradually increasing levels of complexity. Furthermore, students can be safely confronted with unexpected behavior of other traffic participants, and can practice emergency procedures (e.g. tire-burst).

Simulators can contribute to driver training. Although simulation technology is rapidly improving, a full mission simulator, enabling the training of all driving tasks, is not yet possible. There is evidence, however, that driving simulators can be successfully used for training certain parts of the driving task (Korteling & Van Randwijk, 1991; Korteling, Kappé & Van den Bosch, 2000). The present paper gives an overview of opportunities of employing advanced training instruments, i.e. CBI and training simulators, for driver education. The focus will be on training simulators.

In order to investigate how advanced training instruments may be used to replace vehicle-based training, or how they may be used to train skills that currently can not be trained, it is necessary to examine the strengths and weaknesses of current driver training programs. This issue is addressed in chapter 2. Chapters 3 and 4 address the opportunities of CBI and simulator for the training of driving skills, and the technological and educational demands for realizing these opportunities. It is concluded that advanced learning technologies provide ample opportunities for improving current driver training programs, but successful application in practice requires a series of questions to be solved. These are presented in chapter 5.

3 CURRENT DRIVER TRAINING PROGRAMS

Articles 62 and 70 of the regulations for driver licensing define the statutory demands that trainee-drivers must meet. These demands are operationalized in a document specifying the various driving procedures. This may be used to formulate the mission of driver education as follows:

“Teaching prerequisite theoretical knowledge and skills for safe, alert and environment-minded participation to traffic. Furthermore, the program should prepare the student driver to handling certain traffic situations that may occur in reality, but that cannot, for practical or safety reasons, be addressed in practical lessons. Important is the recognition of potential risk and to teaching adequate maneuvers to prevent or reduce such risk.” (after Van Bosch, Van Berlo & Riemersma (1994))

Achieving this mission is hampered by limitations in the design and delivery of theoretical and practical training of current driver training programs. These limitations will be discussed below.

3.1 Current theoretical training

The large(r) driving schools in The Netherlands offer their students a course in traffic theory. Students of the small(er) schools have to rely on self-study using textbooks. A major drawback

of current instruction in traffic theory is its limited transfer to practical driving performance. Three possible causes for this situation are: the philosophy of instruction, the selection of content, and the presentation of content.

3.1.1 Philosophy of instruction

Statutory traffic rules have a juridical rather than an educational function. Because the regulations are nevertheless used as leading principle, instruction is rather formal and abstract. However, if the goal of driver education is to prepare student drivers for participation in actual traffic, more needs to be done than teaching the formal regulations. After all, correct, smooth, and safe driving is for an important part determined by implicit knowledge that is not recorded in formal rules, like e.g. seeking eye contact when approaching intersections, adjusting following distance in accordance with road-, weather-, and sight conditions. Knowledge of such implicit rules, and understanding why their application improves the circulation and safety of traffic, should also be part of theoretical training. Instead, current methods of instruction focus on learning definitions, rules, and the meaning of signs. For example, students learn to identify the sign indicating the entrance of a residential area (fact), learn that a cyclist belongs to the category of “drivers” (definition), and learn that on crossings in residential areas all drivers approaching from the right have right of way (rule). Because this information is of a formal nature, it is doubtful whether trainees will be able to integrate the knowledge elements successfully, and translate it to a concrete situation at the right moment.

3.1.2 Selection of content

In current theoretical training, statutory rules are almost by definition selected as learning content, although its relevance for actual practice may be questionable. This leads to the situation that irrelevant factual information (e.g. the maximum length of a towing cable) is explicitly addressed in the program, whereas knowledge that is very relevant to driving (e.g. adapting driving style to the road conditions) receives little or no attention. Sometimes too much effort is spent on teaching knowledge that everybody already possesses (e.g. the meaning of traffic lights), or time is spent on teaching rules that are already dictated by the situations to which they apply (e.g. “it is illegal to turn around on motor ways”). Addressing these rules in valuable instruction time is clearly a waste of time. Another issue is that all formal knowledge is part of the curriculum, irrespective their frequency of occurrence in everyday practice (e.g. limits on dimensions of transport). In such cases, it needs to be considered whether including such information in a curriculum for initial training is contributing to driver competency.

3.1.3 Presentation of content

An other criticism concerns the fact that the situations selected for instruction and testing often provide contexts that do not fit in with most problems encountered in reality (see e.g. Figure 1).

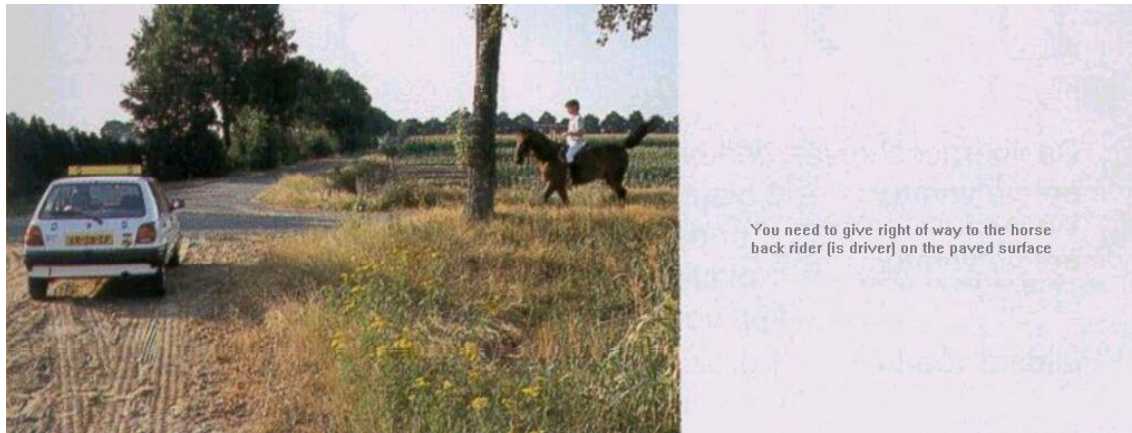


Fig. 1 Instruction in a right-of-way rule using a photo of an exceptional situation.

The large amount of such examples in the methods suggests that it is considered more important to verify whether the student masters his knowledge of abstract definitions and rules, than that he demonstrates to be able to handle complex, but real-life traffic problems in a correct manner. Another point is that visuals are often very schematic. Well known are helicopter-view diagrams of three or four-way crossings with conflicts between all kinds of road users (see e.g. Figure 2).

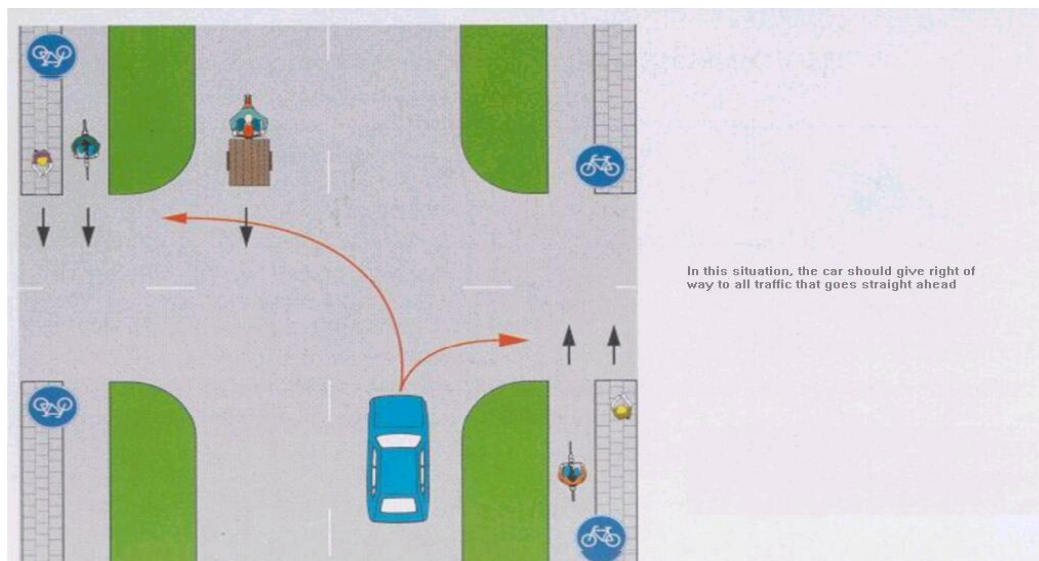


Fig. 2 Instruction in right-of-way rules using a diagram.

This format allows rules of way to be explained in a compact and orderly fashion. Experience suggests that this seems to be an effective procedure because students learn to solve such problems rather quickly. The problem is however, that students fail to apply this knowledge in real situations because they do not recognize the correspondence between instructional and actual context.

3.2 Current practical training

Practical driver training consists of lessons on the vehicle, under supervision of an instructor. The training usually starts with simple vehicle control exercises in secluded areas and quiet

public roads. At this stage of training, the focus is on the interaction between student-driver and his vehicle. The objective is to acquire skill in performing procedures (e.g. starting, driving off, changing gears), and to further develop and integrate perceptual-motor skills where new tasks have to be integrated with earlier learned skills (driving backwards, taking a curve backwards, accelerating, decelerating). Once a sufficient level of skill in vehicle control is acquired, practice in actual traffic starts. The interaction between student-driver and other traffic becomes the focus of training. Adequate and smooth application of traffic rules is the main objective. Another important goal is learning to handle unusual situations (e.g. short access roads) or complex traffic situations (e.g. merging areas). The tasks to be learned require cognitive-perceptual skills (like recognizing (potentially) dangerous situations), and cognitive skills (deciding how to minimize or eliminate the emerging danger).

An advantage of in-vehicle training in real traffic is that the transfer to the operational task is relatively easy because driving skills are trained in a representative context. However, this form of training has its limitations as well (Van den Bosch & Riemersma, 2000). A first drawback is that the learning strategy remains implicit: learning objectives, instruction method and evaluation are concentrated in the brain of one person. Secondly, the driving instructor has limited control over the learning environment. In an ideal training program, skills are initially trained in standard and simple environments. As skill progress, special and exceptional situations can be included in training with gradually increasing levels of complexity. However, this is not possible in real traffic. The selection of road configurations (e.g. intersections, crossings, etc.) for training is limited to what is available in the vicinity. The instructor can direct his trainees to selected locations, but he has, of course, no control over the events taking place (e.g. approaching traffic, presence of pedestrians). Furthermore, riding from one location to the next is costly in terms of training time and may require driving skills that are, didactically speaking, not appropriate. It is therefore impossible to structure the learning situations according to an optimal sequence and frequency. A third limitation is that practice in recognizing and handling dangerous traffic situations is not possible, due to practical and ethical considerations. The teaching of how to respond to emergency situations is therefore, by necessity, limited to theoretical training.

4 APPLICATION OF ADVANCED TRAINING INSTRUMENTS

Limitations of current vehicle-based driver training in actual traffic may be overcome by advanced learning aids, but its successful application requires good consideration of the possibilities, but also of the limitations. First the use of flight simulators for pilot training is addressed, followed by a discussion on the potential of CBI and simulators for driver training, respectively.

4.1 Training with flight simulators

Simulators are used for the training of pilots already since a long time. Even in the second World War, simple simulator systems were used for the training of RAF-pilots (Rolfe, 1998). In the

following decades, flight simulators improved thanks to developments in psychology and technology. The research accumulated a large database of knowledge on human factors, instruction- and training psychology, and simulation technology. For instance, the study of cues required for the perception of depth, object motion and self-motion has obtained an impetus through needs of flight simulator designers. Also, the technical development of sophisticated digital image systems, mechanical motion cueing systems and control loading systems was much accelerated through the needs of flight simulation.

Van Rooij (1997) distinguishes the following applications of flight simulators:

- *Initial training*: basic training and certification
- *Conversion training*: the acquisition and transfer of skills from one type of aircraft to the next
- *Refresher training*: maintaining performance standards and relearning partly lost skills
- *Mission training*: acquiring or sharpening skills for a specific mission (in particular for military pilots).

The common finding in the literature is that the use of simulators combined with aircraft training consistently produced improvements in training for jets compared to aircraft training only (Hays, Jacobs, Prince & Salas, 1992). Because successful flight simulators may bring substantial savings on pilot training costs in return, even expensive simulator systems are cost-effective. This explains why, in general, there is general a large budget available to produce high-fidelity simulators, with advanced motion- and image systems. There are, however, studies suggesting that the profits of these extra investments are limited. Adding motion cues, for instance, adds little to nothing to training effectiveness (Hayes et al., 1992), and training with low-detail scenes produce better transfer than training with moderate-detail scenes (Lintern, Taylor, Koonce, Kaiser & Morrison, 1997; Roscoe, 1991).

Although the use of simulation technology for flight training has given an important impulse to simulation based training in general, findings in this domain can not be transferred directly to driver training applications. For example, learning procedures is much more important in flying than it is in driving. Another difference is the role of motion information. For flying, motion cueing is important for landing only. For driving, motion information is much more salient. Perhaps the most important difference is the required visual representation of the environment. Low-detail images will suffice for flying. Driving, instead, requires high-quality images. Due to the close proximity of static and dynamic objects, vehicle movements have a large impact on the visual information representing the task environment. Quickly adapting the visual image to the actual situation demands a much more sophisticated technology than is required for flying.

4.2 Opportunities for CBI in traffic theory

Prevailing methods of instruction in traffic theory used in the Netherlands focus on preparing the student for the theoretical exam, not to prepare them for actual driving in every day traffic. The major drawbacks are discussed in §2.1.

The impact of theoretical instruction on actual task behavior can improve significantly if the material to be learned is presented in the context of traffic situations that are functionally similar

to the ones students are likely to encounter in real life. Students should therefore be taught how to identify a certain road as belonging to a particular road category, to identify common and more complex traffic situations, and how to behave when in such situations. Such an approach, rather than teaching general rules and principles, will more likely bring about transfer from theory to practice.

Computer Based Instruction (CBI) may make it possible to realize that goal. One of the advantages of CBI is that it is more flexible than traditional classroom instruction. Students can work with the program at self selected moments and individual differentiation in difficulty level and speed is possible. Because students can more easily be made active, this type of instruction is often effective and highly motivating. New sophisticated multimedia technology has expanded the potential of CBI programs to create realistic interactive learning environments. Until recently, static pictures were about the technological limit. Now it is possible to combine a variety of media, like printed text, spoken comment, sound, static and moving pictures (digital video), animations, in one multimedia application. If the student has, to some extent, control over the (instruction) program (e.g. starting a video clip, requesting spoken feedback, zooming in on a detail of a picture, etcetera), this is called an interactive multimedia program. An important question is whether this new technology not only looks better, but also improves instructional effectiveness. Earlier research has yielded ample evidence that the efficacy of training courses can indeed be increased by advanced learning aids, provided that the application of the technology is grounded in a consistent theory of learning and a sound framework of instruction (Baggett, 1988; Fletcher, 1989; Smith, 1987).

The goal of CBI in traffic theory in the context of the entire driver education program is to teach the relevant theoretical knowledge and skills required to participate correctly in actual traffic. In particular, the program should prepare the student driver to handling certain traffic situations that, for practical or safety reasons, cannot be addressed in the practical lessons. Emphasis should be given to cues for recognizing and identifying potential risk and to teaching adequate maneuvers to prevent or reduce such risk. There is evidence that novice drivers in particular have difficulty with detecting possible danger, interpreting risk-indicating events, en deciding how to solve complex situations (Hull, 1991; Regan, Triggs & Wallace, 1999). In the United States and in Australia, CBI programs have been developed focusing on precisely these skills (Regan et al., 1999). Students are asked to observe traffic scenes displayed on digital video. At a certain point in time, the situation “freezes”, and the student is asked to click on elements in the scene requiring the attention of the driver. The program subsequently provides feedback. Programs such as these are an important step to interactive training of skills that, until recently, could not be trained in this manner. However, the effectiveness of programs could be enhanced by reducing the amount of cueing. The scenarios are presented in such a fashion that it is immediately clear to the student that a dangerous situation is imminent, and often even what kind of problem is about to occur. Due to the cueing, the problem automatically draws the attention of the students, whereas focussing on possible danger is precisely the critical skill (Hull, 1991). A possibility to train this critical skill is not to let the program freeze the scenario, but to let the student do this. Insight in the nature of complex traffic problems could be improved by showing situations not only from the perspective of the “own” driver, but also from the

perspective of other traffic participants (drivers approaching the scene from other directions, bikers, pedestrians, playing children, etc).

It has been argued that students can make the link between theoretical knowledge and practice more easily if the information is presented in real-life like contexts (Lave, 1988; Suchman, 1987). Perhaps the most salient characteristic of real-life traffic is that it is dynamic. CBI technology makes it possible to represent the dynamic aspect of traffic situations through digitized video. Video is suited to demonstrate the characteristics and function of different road categories, to show (potential) problems and conflicts in traffic situations, to show the outcomes of different reactions to a certain problematic situation, and to show the antecedents that produced the problematic situation in the first place. Running video is, however, not required for all learning objectives. More static aspects of traffic can be addressed with photos very well. Because digitized photos can be manipulated relatively easy, they offer more opportunities than conventional slides. An example for instruction in road classification may illustrate this point: appropriate or inappropriate features of a road category can be added or deleted at will, thus allowing for effective highlighting of essential characteristics. Defining (invisible) active areas in the picture permits the program to respond to requests for information (e.g. by mouse clicking).

4.3 Opportunities for driver training simulators

The exploitation costs of providing vehicle-based training are low. Full mission simulators (covering the full driver-training program) are very expensive, and are therefore not suitable for providing cost-effective training. Fortunately, the training of many driving tasks does not require full mission simulators, but can instead be achieved using a much simpler device. It is the challenge to identify which driving tasks are potentially suitable for training on a driving simulator, and to specify the functional and technical requirements for successful training delivery.

In order to specify a cost-effective simulator, one must have a good understanding of the driver training program (i.e. what are the various components of the driving task, what are the critical skills required to perform the driving tasks successfully, what are the requirements to be able to learn these skills?). In addition, knowledge of the current and near-future possibilities of simulation technology is required to appraise its potential for driver training applications. Combining these sources of information is necessary to develop a cost-effective driver training simulator, achieving an optimal balance between the factors *costs* (of the simulator system itself plus costs of training delivery), and *functionality* (savings because some subtasks need no longer be trained by conventional means in actual traffic).

4.3.1 Tasks to be trained on a driving simulator

Two main components of the driving task may be distinguished: *vehicle control* and *traffic participation*. Vehicle control involves primarily perceptual motor skills (like steering, braking, driving in reverse, keeping course) often combined with procedural skills (like in starting,

shifting gear, overtaking). Traffic participation involves mainly cognitive skills (identifying traffic situations, assessing which rule(s) apply, recognizing whether situations are potentially dangerous, deciding whether a certain maneuver is appropriate, acknowledging the impact of road-, weather, and sight conditions and applying this knowledge in actual driving behavior, and so on).

Vehicle control

The objective is that the trainee learns how the vehicle behaves, how much force should be applied to the interface instruments (e.g. braking pedal), how these forces transfer to the vehicle, and how the behavior of the vehicle returns forces upon the interfacing instrument. The following tasks can be distinguished:

- Starting, pulling up, stopping
- Control of the accelerator pedal, braking
- Special operations
- Changing gears
- Steering on straight roads and in wide bends
- Steering in sharp bends and at crossroads

Traffic participation

Adequate traffic participation requires the accurate and timely application of traffic rules. In addition, accurate and fast recognition of traffic situations demanding a safe response of the driver is also needed. For example, estimating gaps in the traffic stream while negotiating intersections, evaluating whether overtaking is safe, and so on. Acquiring these skills require training in assessing the spatial and temporal characteristics of the vehicle in relation to the environment and other objects.

Each driving task should be learned in its representative context (e.g. overtaking on a motorway is very different from overtaking on a country road, each requiring specific cues and responses). Therefore, driving tasks can be grouped according to the road categories to which they apply. Van den Bosch (1995) distinguishes the following road categories:

Table I Road categories (from Van den Bosch, 1995).

Road categories
Non-right of way roads within buildup areas: 50 km/h
Right of way roads within buildup areas: 50 km/h
Non-right of way roads within buildup areas: 30 km/h
Non-right of way roads outside buildup areas: 80 km/h
Right of way roads outside buildup areas: 80 km/h
Highway: 100 km/h
Motorway: 120 km/h

For each road category, the associated tasks can be identified. For example, when driving on a motor way, a driver needs to be able ‘to turn onto an approach road and join the traffic’, ‘to drive and follow’, ‘to overtake’, and ‘to exit’. Analyzing these tasks produces a specification of the prerequisite knowledge and skills, criteria for adequate task performance and a list of possible task conditions and complications. Correctly driving onto a motorway, for instance, requires the driver to recognize the approach road and the motorway (both on its formal characteristics such as the sign, and on informal characteristics, like the presence of a dual carriageway and a hard

Such analyses are necessary to specify simulator requirements. For example, the simulated visual environment should contain the cues for recognizing the type of road; the simulator should be equipped for practicing and testing the associated driving procedures; it should be possible to arrange traffic situations.

4.3.2 Simulation technology

The various components of a full mission driving simulator, and their interconnections, are depicted in Figure 3.

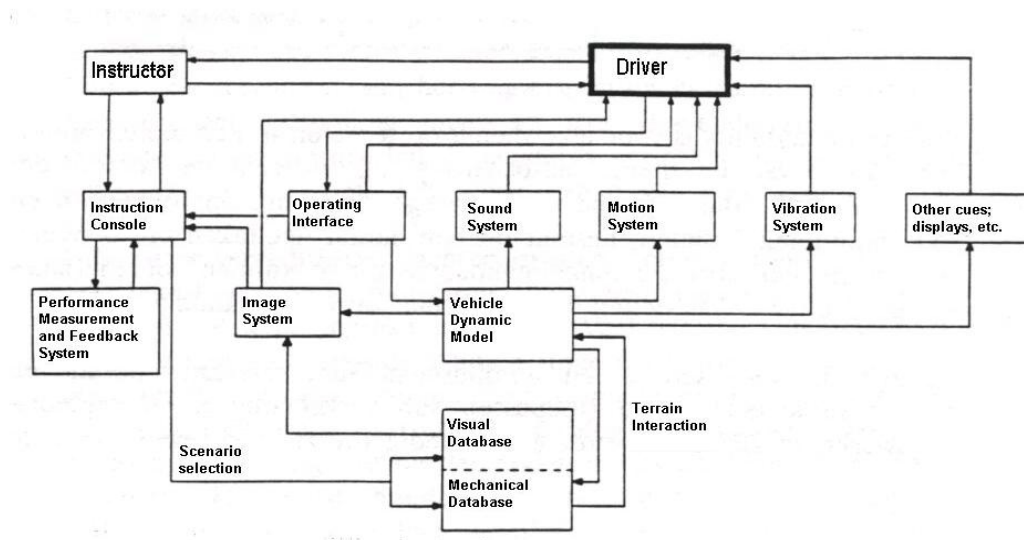


Fig. 3 Schematic display of a full mission driving simulator (from Korteling & Van Randwijk, 1991).

The rapid developments in technology enable more and more opportunities for simulation-based training. However, the costs of a full mission driving simulator are still too high for cost-effective application. The motion system and the visual system are especially strong cost drivers.

For some driving tasks, the vehicle's motion provides important cues to the driver. For example, smoothly steering a car through sharp bends requires information about lateral acceleration. When braking, the driver uses longitudinal acceleration to adjust his force on the braking pedal. However, generating valid motion cues in a simulator requires an advanced motion system, and is therefore a costly affair. This mature technology is on a very slowly growing market segment and no major cost reductions are expected in the near future. Fortunately, the majority of driving tasks can be successfully trained without motion altogether, or by using a simple seat shaker to generate movement onset cues (initiation of braking or acceleration). This implies that using a simple motion cueing facility substantially improves the cost/functionality ratio, when compared to a system equipped with a high-end motion system (Korteling, Kappé & Van den Bosch, 2000). It remains a point of investigation to what degree of fidelity motion cueing is required.

Another costly component of a driver training simulator is the image generation system. The majority of driving tasks demands substantial and detailed visual information (e.g. approaching and negotiating intersections or lane changing on a motorway). Displaying multi-channel wide Field Of View (FOV) images with sufficient resolution requires an expensive image generator system. Fortunately, a closer look at the training requirements reveals that for most of the driving tasks a high resolution image over the entire field of view is not necessary. High resolution images are needed for the area upon which the driver focuses. To reduce the costs of the image system, it is possible to use a cheaper system for the generation of peripheral images. In order to achieve this, a sensor attached to the driver's head sends the direction of view to the image system. This system uses the information to display the area of interest in high visual resolution; the peripheral displays are generated by the channels providing lower quality images. This technique is called Head Slaved Display (HSD). Research comparing HSD technology with an all channels high-quality image system, shows that with HSD substantial saving can be achieved on costs, while maintaining full functionality (Kappé, 1997; Korteling et al., 2000).

4.3.3 PC-based driving simulator

The Department of Transportation in the United States issued a feasibility study into the opportunities of *low-cost* technology for novice driver training (Decina, Gish, Staplin & Kirchner, 1996; Decina, 1998). Low cost was defined as the price of an average PC configuration. In a workshop, 7 experts in the field of instruction technology were asked to identify which training elements can be successfully trained using low-cost simulation applications. The following elements were considered appropriate:

Table II Elements suitable for PC-based driver training (Decina, 1998).

Training element	Clarification
Hazard Perception	The ability to make appropriate speed, lane, and braking responses in anticipation of potential hazard or changing demands
Visual scanning behavior	Driver response requiring combinations of eye, head, neck, and upper torso movements to foveae acquire information
Visual performance	Combination of useful field of view, central, and peripheral training elements
Knowledge-based training	Rule-of-the-road concepts, hazard avoidance and vehicle control techniques

The elements that were considered not suitable were: processing of visual peripheral information, performance degradation factors (fatigue, alcohol), speed and headway selection. The motivation is that perceiving peripheral objects require a wide horizontal field of view, and that perception of speed and depth demands a high resolution display with a high update rate. A common PC cannot meet these requirements. We agree with that opinion. It is, however, unclear to us why the argument is not used to reject the elements of Table II as well. Detection of, and responding to, imminent danger (as defined by Decina, 1998) is based upon the perception of subtle (movement) cues that can not be presented with sufficient level of fidelity in a PC-based environment. Similarly, processing visual-foveal information requires no head-, neck-, or torso movements, and visual-peripheral information cannot be presented using a single-monitor configuration. Finally, a PC-based learning tool may be used to train various traffic rules, but is certainly not appropriate for practicing vehicle control skills (see above).

In our view, Decina et al. (1996) are too optimistic about the opportunities of PC-based technology for novice driver training. Especially the restrictions on image size and image quality limit the functionality of PC-based configurations. Our view on the technological requirements needed to deliver effective and efficient driver training is presented in §5.3.

4.4 Validation of driving simulators

An important clue for a training simulator's value is the effectiveness and efficiency with which the learning objectives are achieved. The ultimate criteria for evaluation are, however, the transfer of training (Reder & Klatzky, 1994), and the retention of acquired knowledge and skills (Van den Bosch & Verstegen, 1996). Empirical research into the question whether simulator training helps students to perform better on the actual task (compared with no training, or alternative forms of training), or are faster in achieving the criterion level, are called validation studies. Such studies are rarely conducted (Korteling & Sluimer, 1999). An important reason is that they require ample time and money, especially for extensive training programs. A practical problem is that the transfer of training can not always be determined. It is evidently not possible to deliberately expose students to dangerous traffic situations in order to establish whether training has helped them to respond more adequately compared to students that did not receive this type of training.

The substantial implications of proper validation often discourages organizations to conduct adequate studies. to nevertheless obtain a measure of a training simulator's value, alternative but disputable methods are frequently used (Rolfe & Caro, 1982). A well-known method is to collect user judgments. This approach is contestable because issues that do not relate effectiveness of training influence student judgments. Learning, for instance, often demands revising habits and opinions. Students may prefer not to invest in the efforts to do so, and this may affect their judgments. This is not to deny, of course, that consulting student opinions is wise to design or improve instruction and training, but as a measure of quality it is not sufficient. A second alternative method is to infer training quality from the simulator's physical fidelity. Experts tend to appraise simulators with a high-fidelity interface higher than simulators with a more symbolic task interface. Full fidelity is, however, seldom required for training (see also §4.3).

A third alternative method is to infer training quality from the simulator's intensity of use. This is also a dubious measure. The procurement and exploitation of a training simulator often involves high costs, and this may encourage organizations to use the system as often as possible. The measure is, in itself, unrelated to the quality of training.

Driving simulators are suitable for facilitating the transfer of theory to practice, to prepare students for specific practical lessons (e.g. approaching, and driving on, intersections; merging onto a motorway) through systematic and intensive simulator drills, and to teach how to recognize and solve dangerous traffic situations. For simulators to be of value, they need to be tuned to theoretical and vehicle-based lessons. They are not (yet) suitable as stand-alone training tool. This implies that for a fair evaluation of the effects of simulator-based driver training

lessons, validation “in the field” is necessary, in which simulator training is integrated in the driver education program.

TNO Human Factors is currently conducting such a study for the driving school of the Royal Netherlands Army. A low-cost driver training simulator (see Figure 4) is used to train approaching, and driving on, intersections and roundabouts (Sluimer & Van den Bosch, in preparation).



Fig. 4 TNO Low-cost driving simulator.

In the beginning of the training program, students received a few lessons in vehicle control and theoretical lessons to acquire the task-prerequisite knowledge. On the four following days, students received simulator training (total of 4 hours), and practical lessons on the vehicle (total of 12 hours). The simulator lessons consisted of systematic and extensive practice in the aforementioned driving tasks; the vehicle-based lessons were given as usual. Students in the control group received practical lessons on the vehicle only (total of 16 hours). On the day after completion of simulator training, all students drove a pre-specified route in actual traffic under supervision of a driving examiner. The route included ample situations requiring the trained driving tasks. The examiners assessed driving performance on a number of criteria. Results of the study are expected at the end of 2000.

It is important to realize that adequate validation is not restricted to the simulator system. A meaningful evaluation requires inclusion of all factors of the system's intended use, like the training scenarios, the coordination with other parts of the training program, the entry level of the trainee group, etcetera. The better these factors can be represented in a validation study, the more meaningful the outcomes of the study are for the expected training value. For driver training, such studies are lacking. The need for more adequate validation research is, however, recognized (Decina, 1998).

4.5 Current driver training simulators

There are currently a number of driver training simulators commercially available (see www.inrets.fr/ur/sara/Pg_simus_e.html for an extensive overview). They cover a wide spectrum of simulators, varying from high-end truck driving simulators to low-cost virtual reality systems

using Helmet Mounted Displays (HMDs). Most simulators use computer generated images, but there are still systems using video on disk. The available simulator systems are reviewed below.

A driver-training simulator consists of the system itself (technology) and the training program with accompanying instructional facilities. Training programs are sometimes provided by the manufacturers, in other instances the users have to develop lessons themselves. The following driving simulators have been found in the literature and on the Internet.

Truck driving simulators:

Oerlicon Contraves:	ADAMS
STN-Atlas	ADS
Thomson:	TRUST/Tracs
Dornier/DASA	
Digitran:	SafeDrive truck
DNS Group:	Heavy truck simulator
FAAC Group:	DTS Driver Training System
Faros	F500

Passenger car simulators

Digitran:	DTS Driver Training Simulator
STISIM:	Drive
FAAC Group	DTS
Hyperion	Novice Driver Trainer
Faros	Various simulators
Autosim	Car Driving Simulator

Virtual reality systems

CGSD Corporation	Virtual Reality Driving Simulator (passenger car)
Imago Systems Inc	Virtual reality system (passenger car)

Videodisk systems

Doron precision	passenger car / truck / bus
Simutech	passenger car / truck / bus
Simulatorsystems	passenger car

The ADAMS truck simulator of Oerlicon Contraves is a high-end simulator (0.5 m\$), equipped with an advanced image system, a Steyr cabin, powersteer and a seat-shaker, but without a moving base. They have a comprehensive traffic model (obtained from Iowa University) with scenario editing facilities. The simulator is in use by the Swiss army (7 purchased, 35 ordered). A large part of the training program (~20 hrs) is covered by the training simulator.

The TRUST truck simulator of *Thomson* has a Renault cabin equipped with a moving base, however it has a simpler image system. The traffic model is developed in cooperation with Renault. A tool for developing simulator driving lessons is available. The system is in use by the Vakopleiding Transport en Logistiek (VT&L) in the Netherlands, AFT-Iftim (France) and Stora Holm (Sweden). VT&L figures to use the simulator for providing 10 of the 20 driving lessons. These involve vehicle control skills, like maneuvering, steering and gear shifting. The system is probably not flexible enough for efficient provision of training traffic participation skills because

the scenario tool operates by “position triggers” (If I am at this location, then a car is approaching from the right). If a trainee drives faster or more slowly than planned, the event will come too early, or too late.

STN-Atlas and *Dornier/DASA* have, in cooperation, developed a truck simulator for the German army (see http://www.bwb.org/Vorhaben/AAFR/frames/fahrsim_i.htm). Prototypes of the simulator are currently submitted to field tests. The German army orders 200 systems of the winning simulator. The call for tender pays considerable attention for didactic facilities of the simulator and the intended integration of the simulator with CBI and practical lessons.

Digitran, *FAAC* and *I-sim* are American companies, each offering various different types of simulators (passenger cars, trucks, bus, police, and emergency vehicles). They concentrate on the American market. The driving simulator of *Digitran* (DTS simulator) is simple and has limited training potential. It is particularly suitable for operational skills, steering and anticipating dangerous situations. *FAAC* has sold quite a number of simulators already (e.g. police and government organizations). The simulator comes with lessons, also for the European market. *I-sim* has sold training simulators to the US police. However, their internet-site provides too little information to tell more about their products.

DNS has developed a heavy vehicle simulator, suitable for the training of drivers of vehicle used in the mining industry.

FAROS is a French simulator manufacturer (passenger cars, trucks). Their systems have a simple mock-up and a monitor image system, powered by PCs. They provide four hours of driver training lessons. The objective of these lessons is to teach the main risks of car driving. The manufacturer supplies driving lessons. It is not known whether or not a scenario-editor is included.

Stisim has a series of PC-based low-cost driver training simulators, with one- or more image channels, either presented on monitors or on HMDs. It is equipped with a simple traffic model and a scenario editor for developing (relatively simple) traffic situations.

Hyperion has two driving simulators in its line of products: a low-cost system (Novice Driver Trainer) for training purposes, and a high-end system (Vection Research Simulator) for research purposes. They come with an excellent scenario-editor for designing road configurations and for defining traffic situations. Their web-site shows an artist impression only, suggesting that the system is not yet commercially available. The same can be said for the driving simulator of *Autosim*. Apart from a drawing on their WWW-page, no information is available.

CGSD Corporation developed a PC-based driving simulator utilizing a head-up display (HUD). It has a simple mock-up and a steering wheel equipped with contrasting material for good visibility through the HUD. Little attention has been paid to the training aspects.

The driving simulator of *Imago Systems Inc.* also utilizes HMD. The simulator is equipped with rudimentary tools for modeling the training environment, creating traffic scenarios and for registering trainee performance.

In our opinion, the performance of commercially available HMDs are not yet good enough for use in driver training simulators. Due to limitations in the field of view, resolution and delays in image display when the driver turns his head, it is not easy to control the vehicle, let alone provide effective training.

Simulators of *Doron Precision Inc.*, *Simutech* and *Simulatorsystems* use video as images. The route is fixed in advance, thus allowing limited interactivity (sometimes the driver may choose among a series of alternatives). Vehicle speed can be selected, although the image presentation speed is calibrated for one particular speed only. If the trainees drives faster, pedestrians suddenly become heel-and-toe walkers; if the trainee stops the car, pedestrians become statues. The advantage of video is that very realistic and complex environments can be displayed, although in a low-resolution (512×512 pixels or lower). These types of simulators are particularly suitable for training the recognition of potentially dangerous traffic situations. The content of the lessons is fixed; only the sequence and accompanying comment can be changed. The video fragments show country-specific road configurations and traffic situations, that can not be simply be transferred to other countries. For using such a system in the Netherlands requires the shooting of new video material, which is a costly affair in terms of time, effort, and money.

General comments

Very few training simulators are equipped with robust training programs and instructional facilities. Only high-end truck driving simulators (ADAMS, TRUST, ADS, and the Dornier/DASA system) are really prepared for training delivery. The other systems are less suited for training because of lacking support facilities (instruction, performance assessment, and feedback). There are only a few simulators offering detailed driving lessons. However, they are not directly suited for the Dutch market (unfamiliar traffic signs and situations, interface and instruction/feedback in foreign language).

The conclusion is that there are currently no simulators on the market that can be applied directly for driver training purposes in the Netherlands. It is believed however, that the developments will opens good opportunities in the near future.

References:

CGSD Corporation	http://www.cgsd.com/DrivingSimulator/index.html
Digitran SafeDrive	http://digitranhq.com/safe.html
Digitran	http://digitranhq.com/dts.html
DNS group	http://www.dnsgroup.com.au/trucksim.htm
Doron	http://www.doronprecision.com/dorondriver.htm
FAAC group	http://www.faac.com/Driving_Simulators.htm
FAROS	http://www.faros.com/eauto.html
Hyperion	http://www.hyperiontech.com/
I-sim	http://www.i-sim.com/
Imago Systems inc.	http://www.drivr.com
Reiner Foerst GmbH	http://www.drfoerst.de/e_page.htm
Simutech	http://www.simutech.de
Stisim	http://www.systemstech.com/stidrs1.htm
TRACS/TRUST	http://www.tts.thomson-csf.com/activities/roaddrivframe.htm
	http://transport.storaholm.educ.goteborg.se/info
	http://www.aft-iftim.asso.fr/m2bis/apprent.htm

5 DIDACTIC MODEL FOR A TECHNOLOGY-SUPPORTED DRIVER EDUCATION PROGRAM

A decision to utilize a simulator for driver training has implications for the entire training program. The use of the learning aid should be integrated in the learning trajectory, which also includes theoretical and vehicle-based training lessons. In current driver training programs, there often exists a gap between theory and practice: trainees master the required knowledge but receive too little systematic practice for consolidating that knowledge. Precisely this problem may be alleviated, or even overcome, by the use of CBI and simulators. With multimedia supported CBI, theoretical lessons can be set in an interactive, and context-rich environment. Simulators are especially suitable for practicing knowledge and skills systematically, and in a functional-realistic learning environment. It is important, however, that the employment of the different training forms is adequately tuned, with respect to content as well as timing. This chapter addresses the functional and educational requirements of CBI and simulators for realizing their potential for driver training.

5.1 Objective

Developments in technology have opened new possibilities for driver training. Knowledge and skills that could not, or hardly, be addressed can now be explicitly and systematically trained. It is expected that these developments broaden the ambitions of driver training schools. Holding on to the objective to teach students the traffic rules only would be a missed chance. The following definition of a driver training's objective may be more appropriate:

“Teaching theoretical knowledge and practical skills for adequate, smooth, and safe participation to traffic. Furthermore, the program should prepare the student driver to handling certain traffic situations that, for practical or safety reasons, can not be addressed in the practical lessons. Emphasis should be given to cues for recognizing and identifying potential risk and to teaching adequate maneuvers to prevent or reduce such risk.” (Van den Bosch, 1995)

Achieving this goal requires a good coordination between theoretical and practical lessons. These parts are, however, not very well integrated in current driver training programs. This hampers the transfer from theory to practice. In the driver training program proposed here, the goal of theoretical training is to teach the prerequisite knowledge for performing the driving task (like facts concepts, statutory rules, codes). The goal of practical lessons is to apply the acquired knowledge in representative situations. Ideally, each practical lesson should be preceded by a (computer-based) lesson in traffic theory. This would foster the acquisition and consolidation of knowledge and skills.

5.2 Global functional specifications of CBI

CBI can replace self-study or classroom instruction fully, or partly. De utilization of computers can enhance efficacy and efficiency of instruction, for instance by interactive and individualized training, automatic performance assessment and immediate feedback, illustrative education using interactive video, photo's, animations, sound, etceteras. To effectively utilize CBI's potential, it is necessary to take principles of learning and instruction psychology into account

when designing instruction. Van den Bosch and Van Berlo (Van Berlo & Van den Bosch, 1995; Van den Bosch, Van Berlo & Riemersma, 1994) present an overview of these principles and suggest an instructional design.

Principles of learning psychology: recent development in cognitive psychology emphasize that task performance is to a large extent regulated by cues of the specific context in which the behavior takes place (Brown, Collins & Duguid, 1989; Lave, 1988; Resnick, 1987). The implication of this perspective for instruction is that the process of knowledge acquisition should be guided by presenting information in a variety of realistic settings. This enables students to associate and use the relevant knowledge with the implicit and explicit correlates and restrictions of the context in which the knowledge eventually needs to be applied.

Principles of instruction psychology: instruction psychology distinguish between “discovery learning” and “directive learning” (e.g. De Klerk, 1979). Traffic signs and rules are, in a sense, arbitrary agreements (there is no intrinsic logic behind the rule “traffic form the right has right of way”). For learning this type of knowledge, directive instruction is appropriate. For objectives calling upon understanding a traffic situation, discovery learning is likely to be the optimal strategy.

Due to internal dependencies between objectives in the learning content (you have to know the rules first before you can practice their application in practice), a prestructured learning trajectory is the most appropriate. By demanding proven mastery of a module before the trainee is allowed to proceed with the next, the instructor is able to maintaining good control of learning progress.

Instructional design: The principles of learning and instruction are realized in task-oriented training, structured according to the different road categories (see §4.3.1). Representative and functional-realistic learning environments can be created using multimedia technology. The learning content is divided into different modules. Frequent testing allows the monitoring of learning progress, and to determine, for each trainee, the best approach for proceeding the program.

5.3 Global functional specifications of a cost-effective driver training simulator

It is not possible to specify *the* cost-effective driver training simulator. The optimal choice is always a function of many variables, like the number and types of trainees, the nature of the driver training program, the possible use of other (advanced) training devices, etc. The specifications below are thus very global and are intended only to provide the reader with an idea of the kind of training system that is supposed to be maximally cost-effective.

Cost-effective driver training simulators concentrate primarily on efficient and effective learning of simple vehicle-control skills, the application of traffic rules and the training of traffic insight. These tasks allow an optimal trade-off between simulator training costs and the obtainable reduction of the costs of in-vehicle driver-training. Driving simulators are not yet suitable for

practicing advanced vehicle control skills (e.g. fast curves, skidding, emergency braking, trailer driving). Below, we will outline and discuss the specifications of the constituent components of a cost-effective driver training simulator.

The *mock-up* of the simulator should contain all controls and interfaces that are normally present in a vehicle. Force feedback on brake pedal and steering wheel should be simulated, but an exact match between simulator and the real vehicle is not necessary. The degree of fidelity of the control force loading needs still to be determined. Since the simulator is intended for practicing simple maneuvers only, a relatively simple vehicle model is sufficient (without wheel-slip etc.).

The *image presentation system* of the simulator should couple a large instantaneous FOV ($180^\circ \times 40^\circ$ or more) to a high resolution (25 pixels/degree), presented at a refresh-rate of 60Hz. The for traffic participation relevant objects (e.g. traffic signs, traffic lights) must be visible and recognizable from a distance of at least a few hundred meters in front. The resolution of rear-view images may be lower.

Estimating the distance and speed of objects, and especially the time to reach objects, are important skills. To effectively train these skills in a simulated environment, it is important that the optic expansion of objects is fluent and accurate. This means that the frame rate must be sufficient, that the resolution must be high enough, and that the size of objects, as a function of distance and angle, must be accurate. These demands generally require an expensive image system. But there are solutions to meet these demands while reducing the costs of the system. One solution is to present images with a high level of detail in the viewing direction, surrounded by peripheral images with a low level of detail (HSD, see above). The level of detail may be decreased in terms of objects in the database, polygons, textures and resolution. A related elegant solution is to decrease the level of detail to the periphery in a similar way as is currently done in the depth-direction for present simulators.

The visual system needs at least 3 channels (monitors or projectors). Monitors are substantially cheaper than projectors, but have disadvantages, such as edges between the channels and a short line of sight.

The *image generating system* should generate monocular images with a high update-rate (at least 30 Hz) at a fixed frequency. Maintaining a fixed frequency requires a provision to prevent overloading of the image generator, for instance by reducing the number and the level of detail of distant objects. The image generator should render a large number of textured polygons in a large number of colors.

Finally, the degree of fidelity of mirror information that is required for effective training needs further investigation.

The *database* should accommodate training in vehicle control skills as well as traffic participation skills. For the training of vehicle control skills, the database should contain a static road layout with all usual kinds of curvatures needed for the training of steering and speed control during curve negotiation. The mechanical database needs to represent the effects of driver actions and of the environment (e.g. friction of road surface) on the vehicle's behavior. In addition, the visual database needs sufficient detail to evaluate the road's features (e.g. curves),

and the mechanical database should provide sufficient information about the vehicle's behavior, so that the trainee can learn to adjust his driving speed to the road and environmental conditions (curve radiation).

For the training of traffic participation, the database should contain representative examples of all types of roads (e.g. country roads, urban roads, motorways, etc). Practicing the accurate and timely application of traffic rules requires the presence of other (simulated) traffic. Other traffic should behave realistically. Furthermore, it should be able to manipulate their behavior on demand, so that the instructor is capable of designing the intended situation for practicing the target skill (e.g. arranging that traffic is present in the outer lane of the motor way when the task of the trainee is to merge).

Whether or not a *moving base* is required remains to be evaluated for the precise training objectives for which the simulator is used. A moving base can provide useful intrinsic feedback when braking. But it should be realized that accurate simulation of all vehicle movements can never be achieved by a moving base. In fact, one can not even get close to the g-forces that are exerted on a normal vehicle. Moreover, if it is decided to include a moving base in the simulator configuration (e.g. to train advanced vehicle control skills), this implies that a sophisticated vehicle model and terrain database are also needed. This increases demands on the computing power of the host computer. Using a motion system may also introduce other negative aspects. Any movements generated by the motion system should be exactly accompanied (in size and timing) with visual movements on the display. If this match fails, the simulator is very likely to elicit motion sickness.

As a compromise, it is suggested that a simple motion system may be worth the investment. A simple system consists of a 6 Degrees Of Freedom (DOF) for the mock-up only, not for the displays. Including a motion system is likely to be cost-effective for training when relatively expensive vehicles are involved (heavy transport vehicles, reconnaissance vehicles, tracked vehicles), or when the simulator is used for dedicated training purposes, like safety training or driving in special circumstances.

As an alternative to a motion system, a vibration system may be used. A vibration system masks the absence of mechanical movement. It is recommended to present vibration information related to the frequency and amplitude of motor vibrations, through the seat (and possibly through control apparatus). Other sources of vibration (surface of the road, gearbox) do not necessarily have to be present.

Driver training simulators should be equipped with a high quality *sound system*. Especially for vehicle control, auditive cues are important. For example, the engine's rotations per minute noise are an important cue for the training of gear switching.

Fortunately, the required sounds can be generated relatively simple and cheap. Sounds of the following sources are needed: wind and wheels, engine, cabin resonance, changing gears. These sounds should be recognizable as for source, direction, and character. Care must be taken that the simulated sounds are correctly related to the source for intensity, pitch, and timbre. Evidently, sounds should be synchronized with image and mechanical motion. If relevant, the

system should present special sounds when starting the engine, or when driving against obstacles (sound of crashing).

It is important to make a distinction between a driving simulator and a driver training simulator. A driving simulator is a simplified representation of an interactive system; a driver training simulator is especially intended to teach people how to drive. This requires *Instructional facilities*, mostly concentrated at the Instructor Operation Station (IOS). The most important facilities are scenario design and control, performance assessment, and guidance and feedback.

Scenario design and control: When procuring a training simulator, many organizations concentrate on fidelity aspects, and fail to appreciate the importance of scenario design and control. But even a high-fidelity simulator is of no avail if proper training scenarios are lacking. Scenarios must be constructed in such a fashion that trainees practice the target skills in prototypical and novel situations. This requires from training developers to resolve many questions like: “how many learning objectives should I address in a training scenario?”; “How do I specify or select events that call upon the skills of interest?”; “How do I ensure that intended events actually take place in the training scenario?”; “how do I accomplish the connection between learning goal, event, performance measure, and feedback?”. This requires an advanced scenario authoring tool, equipped with instructional and domain-specific support. Furthermore, the instructor should be able to monitor the scenario while it is running, and to manipulate the course of events for purposes of guidance and feedback.

Performance assessment: The quality of a trainee’s driving behavior in a simulator can sometimes be captured automatically by the system, sometimes it needs to be evaluated ‘manually’ by a domain specialist (i.e. the instructor). Automatic performance measurement is particularly appropriate when there is a close relationship between stimuli and response (causally, and in time), like for instance, steering a car through a bend. A steering error immediately results in a deviation of the car’s optimal course. Thus, measures referring to course deviations (e.g. RMS of lateral position) are appropriate for evaluating steering competence. Measures that are collected automatically by the system should be well-defined and, particularly, appropriate for the skill of interest. Some aspects of driving behavior can not be assessed automatically, however. For example, an overtaking maneuver on a motorway starts with looking in side- and rearview mirrors. Attaching a sensor to the trainee’s head may be sufficient to determine his general viewing direction, but this technology is not sensitive enough to assess whether or not the trainee has actually used his mirrors. The instructor should therefore have the facilities to observe the trainee while he is performing the task.

Guidance and feedback: One reason that simulators provide powerful learning environments is their ability to present immediate and clearly defined performance feedback to the trainee, to present augmented cues, and to adapt the training trajectory to the individual trainee’s skill acquisition progress. Most of the guidance and feedback provided by instructors during training sessions is in the form of verbal communications. In addition to this, it should be possible to (pre-)set particular performance alerts. *Performance alerts* are visual or auditory signals presented to the trainee or the instructor when performance tolerances have been exceeded, e.g.,

crossing a line. Their purpose is to enhance monitoring abilities of both the trainee and the instructor (Sticha, Singer, Blacksten, Morrison & Cross, 1990). It can be followed by an automatically generated coaching message suggesting the trainee to take corrective actions, e.g. “drive more closely to the right side of the road”. The coaching message can replace the alert signal or can be added to it.

6 DISCUSSION

In the past century, traffic has grown intensely. In 1991, almost 100 years ago, Carl Benz made the following statement:

“The global market for automobiles is limited because there are going to be no more than one million people capable of being trained as chauffeurs.” (cited in Evans, 1991, p.100)

In The Netherlands, there are 7 million cars, 1 million driving exams are administered annually, and the roads are congested with long traffic jams every day. The ever-increasing busyness requires drivers to be capable of handling complex situations accurately and smoothly. It is the task of the driver schools to prepare people adequately. A program focussed on the theoretical and practical training of traffic rules is no longer sufficient; considerable attention needs to be paid to traffic insight, attitudes, and motivation (Vlakveld, 2000). Driver training programs currently consist exclusively of vehicle-based training on public roads. The heavy traffic more and more restricts the opportunities, efficiency, and flexibility of traditional training. For instance, it is getting more difficult to find quiet roads, and valuable training time is wasted due to traffic jams and congestion.

The technological developments may increase the potential of theoretical and practical lessons. CBI and simulators may enhance the quality of driver training, provided that the possibilities, but also the limitations, are taken into account in the application of the learning aids. This is addressed in the present report.

It can be concluded that there are promising developments in the application of computers and simulators for driver training. However, for successful application a series of questions still need to be answered. These are technological questions (how do I create, against acceptable costs, a simulated task environment that enables student drivers to acquire task critical skills accurately and rapidly?), as well as training questions (e.g. which task do I select for simulator-based training, which procedures do I use for performance assessment and feedback?). Below is a list of the important issues:

- When an organization decides to purchase a simulator, lots of effort, time and money is spent on the development of the system. Once the system is ready, it is introduced in the operational training, without paying attention to the issue of its validity (does the system do for which it was developed?). The functional and less-functional features of a simulator can only be revealed by a validation study, thus opening the way for improvement. There exist a number of methods for performing validation research (Rolfe & Caro, 1992; Korteling & Sluimer, 1999), varying in size and costs. The need for proper validation research of new and existing driver training simulators can not be over-emphasized.

- HSD is a promising technique for reducing the costs of image generation without major sacrifices on functionality (see §§4.3.2 and 5.3). There are different possibilities for making concessions to the quality of peripheral images (level-of-detail switching, reduction number of polygons, larger textures). Research is needed to determine the optimal method(s).
- In the procurement phase, organizations often concentrate on the system's fidelity. But even a high-fidelity simulator is of no avail if proper training scenarios are lacking. Methods for developing, delivering and evaluating training scenarios have thus far been a severely neglected area of research. Research into this important issue is needed.
- Effective simulator-based training requires adequate facilities enabling the instructor to monitor the learning process of each individual trainee, and thus to be able to adjust the training trajectory to the individual's actual training needs. Until now, determining the instruction facilities has received little attention. More knowledge is needed about scenario-management, automatic performance assessment and feedback, and cue augmentation.
- Current driving simulators tend to have a small database. However, for training a large database is needed. Knowledge and skills are inextricably a product of the activity and situations in which they are acquired. The specific characteristics of the situation and the performance recast the knowledge in a new and more fully specified form with each new occasion of use. The implication is that for obtaining good transfer the program should consist of a large and varying set of realistic settings. This enables students to associate and use the relevant knowledge with the implicit and explicit correlates and restrictions of the context in which the knowledge eventually needs to be applied. There is a high need for tools that support the creation of databases with large numbers of varying realistic traffic representations.
- Interaction with other traffic is the most salient aspect of driving. In current driver training simulators, only the behavior of other cars is modeled. Cyclists and pedestrians are usually absent, probably due to the difficulty of capturing their behavior in generic mathematical models. That is, however, a serious limitation from a training point of view. Anticipating and responding to the behavior of this group of road users are important training objectives of driver training programs. Adequate models of these road users would significantly enlarge the possibilities of driver training simulators.
- In the past decade, there have been great developments in the PC-gaming industry. A lot of these games involve car driving (usually in the form of racing matches). The image quality of these games is often astonishing. Large investments in research and development are possible thanks to the high market. It may be that collaborating with large manufacturer of games (e.g. Microsoft) can lead to the technological breakthrough necessary for developing high-quality driver training simulators.
- The regular occurrence of simulator sickness is an objection why organizations refrain from further interest in utilizing simulators for driver training. Research how to prevent, or reduce, simulator sickness, may significantly increase the confidence in the technology.

REFERENCES

- Baggett, P. (1988). The role of practice in videodisc-based procedural instructions. *IEEE Transactions on Systems, Man, and Cybernetics*, 18(4), 487-496.
- Berlo, M.P.W. van & Bosch, K. van den (1995). *Een didactisch model for computer-ondersteund onderwijs in verkeerstheorie* [A didactical model for computer-based instruction in traffic theory] (Report TNO-TM 1995 A-75). Soesterberg, The Netherlands: TNO Human Factors Research Institute.
- Bosch, K. van den (1995). Computer Based Instruction in traffic theory. *Proceedings of International Training Equipment Conference and Exhibition*, The Hague, The Netherlands, April 25-27 (pp. 483-490). Willshire, UK: ITEC Ltd.
- Bosch, K. van den, Berlo, M.P.W. van & Riemersma, J.B.J. (1994). *Leerpsychologische en onderwijskundige uitgangspunten voor Computer Ondersteund Onderwijs in verkeerstheorie* [Psychological and educational principles for Computer Based Instruction in traffic theory] (Report TNO-TM 1994 A-49). Soesterberg, The Netherlands: TNO Human Factors Research Institute.
- Bosch, K. van den & Riemersma, J.B.J. (2000). Praktijktraining met simulaties. In P.W.J. Schramade & J.G.L. Thijssen (Eds.), *Handboek Effectief Opleiden* Vol. 23, Chap. 7.4-6 (pp. 107-132). The Hague, The Netherlands: Elsevier.
- Bosch, K. van den & Verstegen, D.M.L. (1996). *Effects of task and training design on skill retention: a literature review* (Report TM-96-C056). Soesterberg, The Netherlands: TNO Human Factors Research Institute.
- Brown, J.S., Collins, A. & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 32-42.
- Decina, L.E. (1998). Training novice drivers using simulation and other electronic devices. *The Chronicle of ADTSEA*, 45 (1).
- Decina, L.E., Gish, K.W., Staplin, L. & Kirchner, A.H. (1996). *Feasibility of new simulation technology to training novice drivers* (Report DOT HS 000 000). Washington, DC: National Highway Traffic Safety Administration.
- Evans, L. (1991). *Traffic Safety and the Driver*. New York: van Nostrand Reinhold.
- Fletcher, J. D. (1989). The effectiveness and cost of interactive videodisc instruction. *Machine-Mediated Learning*, 3, 361-385.
- Hays, R.T., Jacobs, J.W., Prince, C. & Salas, E. (1992). Flight simulator training effectiveness: a meta-analysis. *Military Psychology*, 4 (2), 63-74.
- Hull, M. (1991). Mandatory hazard perception testing as a means of reducing casualty crashes amongst novice drivers. *Proceedings of the Conference on the Strategic Highway Research Program and Traffic Safety on Two Continents*. Held at: Gothenburg, Sweden.
- Kappé, B. (1997). *Visual information in virtual environments*. Unpublished doctoral dissertation, Rijksuniversiteit, Utrecht, The Netherlands.
- Klerk, L.F.W. de (1979). *Inleiding in de Onderwijspsychologie*. Deventer: Van Loghum Slaterus.
- Korteling, J.E., Kappé, B. & Bosch, K. van den (2000). *Low-cost simulators 3c: the configuration of an optimal low-cost driver training simulator* (Report TM-00-A024). Soesterberg, The Netherlands: TNO Human Factors.
- Korteling, J.E. & Randwijk, M.J. van (1991). *Simulatoren en verkeersoefenterreinen in de militaire rijopleiding: literatuurstudie en advies* [Simulators and training grounds for military driver training; literature survey and advice] (Report IZF 1991 A-11). Soesterberg, The Netherlands: TNO Institute for Perception.
- Korteling, J.E. & Sluimer, R.R. (1999). *A critical review of validation methods for man-in-the-loop simulators* (Report TM-99-A023). Soesterberg, The Netherlands: TNO Human Factors Research Institute.
- Lave, J. (1988). *Cognition in practice*. Boston, MA: Cambridge University Press.

- Lintern, G., Taylor, H.L., Koonce, J.M., Kaiser, R.H. & Morrison, G.A. (1997). Transfer and quasi-transfer effects of scene detail and visual augmentation in landing training. *International Journal of Aviation Psychology*, 7 (2), 149-169.
- Reder, L.M. & Klatzky, R. (1994). Transfer: Training for Performance. In D.E. Druckman & R.A. Bjork (Eds.), *Learning, Remembering, Believing* (pp. 25-56). Washington, DC: National Academy Press.
- Regan, M.A., Triggs, T.J. & Wallace, P.R. (1999). Design of a cognitive skills trainer for novice car drivers. *Proceedings Fourth International SimTecT Conference*. Held at: Melbourne, Australia. SimTecT.
- Resnick, L.B. (1987). Learning in schools and out. *Educational Researcher*, 13-20.
- Rolfe, J.M. (1998). Flights of fancy and the legacy of Zeuxis and the grapes. After-dinner speech held at the *MASTER symposium*. Held at: Soesterberg, The Netherlands: TNO Human Factors Research Institute.
- Rolfe, J.M. & Caro, P.W. (1982). Determining the training effectiveness of flight simulators: some basic issues and practical developments. *Applied Ergonomics*, 13 (4), 243-250.
- Rooij, J.C.G.M. van (1997). *Onderwijskundige richtlijnen ten behoeve van specificatie van simulator-eisen* [Didactic guidelines for the specification of simulator requirements] (Report TM-97-A077). Soesterberg, The Netherlands: TNO Human Factors Research Institute.
- Roscoe, S.N. (1991). Simulator qualification: just as phony as it can be. *International Journal of Aviation Psychology*, 1 (4), 335-339.
- Sluimer, R.R. & Bosch, K. van den (in preparation). *Transfer of training of a low cost driving simulator*. Soesterberg, The Netherlands: TNO Human Factors.
- Smith, E.E. (1987). Interactive video: an examination of use and effectiveness. *Journal of Instructional Development*, 10 (2), 2-10.
- Sticha, P.J., Singer, M.J., Blacksten, H.R., Morrison, J. E. & Cross, K.D. (1990). *Research and Methods for Simulation Design State of the Art* (AD-A230 076, Technical Report 914). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.
- Suchman, L.A. (1987). *Plans and situated actions: the problem of human-machine interaction*. Cambridge, MA: Cambridge University Press.
- Vlakveld, W.P. (2000). *Leerdoelen voor het rijbewijs B*. Rotterdam, The Netherlands: Adviesdienst Verkeer en Vervoer, Ministerie van Verkeer en Waterstaat.

Soesterberg, November 22, 2000

Dr. K. van den Bosch
(First author, Project leader)