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title

Low-cost simulators 3b: Minimal functional requirements for a driver training simulator

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Het EUCLID programma stimuleert de ontwikkeling en de kosten-effectieve productie van systemen die voorzien in de toekomstige Europese militaire behoeften. Eén van de Research Technologie Projecten (RTPs) binnen EUCLID is RTP 11.8, getiteld: Low-cost Simulators. Low-cost simulators worden gedefinieerd als een nieuwe klasse van trainers die, door gebruik van commercieel beschikbare en opkomende technologieën, hogere baten-kosten ratio's opleveren dan full-fidelity simulatoren. Het research project wordt uitgevoerd in opdracht van de ministeries van defensie van vijf landen, nl. België, Frankrijk, Duitsland, Griekenland en Nederland. Het project wordt ELSTAR genoemd, wat een acroniem is voor: European Low-cost Technology for the Armed forces. Dit rapport bevat het verslag van een deel van de TNO bijdrage in werkpakket 3 ('Simulator requirements').

In werkpakket 1 (Analysis of military training) van het ELSTAR project werden vier trainingsgebieden geselecteerd voor verder onderzoek naar de mogelijkheden voor toepassing van low-cost simulatoren, i.e. rijvaardigheidstraining, UAV crew training, training van het gebruik van infrarood en image intensifier apparatuur en missie management training. Deze selectie was gebaseerd op de ELSTAR taxonomie-scores, de resultaten van de taak- en cost-utility analyses, en expert oordelen over generieke waarde en de complementariteit van de kennis die verworven zal worden.

Eén van de uitgangspunten van de ELSTAR benadering voor het ontwikkelen van low-cost simulatoren is het identificeren van de kritische taakelementen die eenvoudig (goedkoop) en met een hoge mate van natuurgetrouwheid kunnen worden nagebootst en die een hoge leerwaarde hebben. Daarom wordt in werkpakket 3 van het project een uitgebreid onderzoek verricht naar de taak- en trainingseisen en de trainingsinvesteringen van de geselecteerde trainingsgebieden. Dit moet gedetailleerde specificaties voor de bijbehorende trainers opleveren. Het eerste deel van werkpakket 3b betrof een taakanalyse die nodig is voor het kunnen opstellen van de specificaties voor low-cost wielvoertuig simulatoren (Van Winsum & Korteling, 1998).

Het huidige rapport betreft de functionele specificaties voor een simulator om bepaalde onderdelen van de rijtaak te kunnen trainen. Voor elk van de 17 'elementaire rijtaken' die in de taakanalyse zijn geïdentificeerd worden functionele specificaties opgesteld. Aangezien in de literatuur niet alle basis gegevens voor deze specificaties beschikbaar zijn worden hierbij soms vuistregels toegepast en aannames gedaan. Doordat de gegevens, vuistregels, aannames en formules duidelijk staan beschreven is het mogelijk om nieuwe gegevens later alsnog in te voeren. De resultaten geven een zo nauwkeurig mogelijke schatting van de functionele eisen die aan een simulator moeten worden gesteld om een bepaalde elementaire rijtaak te kunnen trainen. Gecombineerd met een analyse van de trainingsinvesteringen per elementaire rijtaak kan deze kennis in een later stadium worden gebruikt om op vrij eenvoudige wijze de kosten en de besparingen te onderzoeken van verschillende mogelijke simulator-configuraties. Dit zal in de volgende fases van WP3 gebeuren. Uiteindelijk kan hiermee een low-cost rijsimulator worden ontwikkeld waarop een groot gedeelte van de rijopleiding kan worden getraind, met een minimale investering in hardware.

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Low-cost simulators 3b: Specification of functional requirements for driver training simulators

B. Kappé and J.E. Korteling

SUMMARY

To investigate the possibilities for application of low-cost simulators within military training courses, the research project called *ELSTAR* (European Low-cost Simulation Technology for the Armed forces) is carried out under contract of the Ministries of Defence of the five participating countries of Research Technology Project (RTP) 11.8, viz. Belgium, France, Germany, Greece, and The Netherlands. In the first workpackage (Analysis of military training), four training areas were selected for further research, i.e. driver training, UAV crew training, infrared and image intensifier operation training, and mission management training. This selection was based on expert-scores on the *ELSTAR* taxonomy, the results of global task-, training-, and cost-utility analysis, and expert judgements on the generic value and complementarity of the knowledge that would be acquired.

One of the basic premises of the *ELSTAR* approach for developing low-cost training systems is to identify and select those critical task elements that can be simulated at low cost with high fidelity and training value. Therefore, in workpackage 3 (Simulator requirements) of the *ELSTAR* project, an elaborate investigation of the task- and training requirements and the functional specifications of the selected training system. In *ELSTAR* Wp 3b, 17 so-called 'elementary driving tasks' have been identified (Van Winsum & Korteling, 1998). Elementary driving tasks are defined such that they are relatively independent of each other. This relative independency allows the construction of (complex) higher-order subtasks just by combining these elementary tasks.

The present report describes the derivation of the functional simulator requirements to train each elementary driving task. This is done for six most relevant functional simulator specifications, i.e. display resolution, field of view, complexity of the environment, etc. For each elementary driving task the line of thought and the data leading to the definition of a functional specification is described. Since not all relevant data is available in the literature, this process inherently involves the use of 'rules of thumb' and 'educated guesses'. Since the process is transparent, new relevant data can be introduced readily at the appropriate elementary driving tasks The result of the process is a matrix of elementary driving tasks and functional specifications that allows an elementary driving task to be related to specific simulator specifications.

By relating these functional specifications to hardware components, it becomes possible to easily explore the costs of various simulator configurations. Combined with an analysis of the

cost of conventional training, cost effective low-cost driving simulators concepts may be developed. The present report describes the minimal functional requirements (costs) per elementary driving task, whereas the relationship between elementary driving tasks at one hand and training needs and -investments (savings) at the other, and the development of one or several low-cost simulator concepts for driver training will be subsequently reported.

Low-cost simulatoren 3b: Minimale functionele eisen voor rijsimulatoren

B. Kappé en J.E. Korteling

SAMENVATTING

Het EUCLID programma stimuleert de ontwikkeling en de kosten-effectieve productie van systemen die voorzien in de toekomstige Europese militaire behoeften. Eén van de Research Technologie Projecten (RTPs) binnen EUCLID is RTP 11.8, getiteld: Low-cost Simulators. Low-cost simulators worden gedefinieerd als een nieuwe klasse van trainers die, door gebruik van commercieel beschikbare en opkomende technologieën, hogere baten-kosten ratio's opleveren dan full-fidelity simulatoren. Het research project wordt uitgevoerd in opdracht van de ministeries van defensie van vijf landen, nl. België, Frankrijk, Duitsland, Griekenland en Nederland. Het project wordt *ELSTAR* genoemd, wat een acroniem is voor: *European Low-cost Technology for the Armed forces*. Dit rapport bevat het verslag van een deel van de TNO bijdrage in werkpakket 3 ('Simulator requirements').
In werkpakket 1 (Analysis of military training) van het *ELSTAR* project werden vier trainingsgebieden geselecteerd voor verder onderzoek naar de mogelijkheden voor toepassing van low-cost simulatoren, i.e. rijvaardigheidstraining, UAV crew training, training van het gebruik van infrarood en image intensifier apparatuur en missie management training. Deze selectie was gebaseerd op de *ELSTAR* taxonomie-scores, de resultaten van de taak- en cost-utility analyses, en expert oordelen over generieke waarde en de complementariteit van de kennis die verworven zal worden.
Eén van de uitgangspunten van de *ELSTAR* benadering voor het ontwikkelen van low-cost simulatoren is het identificeren van de kritische taakelementen die eenvoudig (goedkoop) en met een hoge mate van natuurgetrouwheid kunnen worden nagebootst en die een hoge leerwaarde hebben. Daarom wordt in werkpakket 3 van het project een uitgebreid onderzoek verricht naar de taak- en trainingseisen en de trainingsinvesteringen van de geselecteerde trainingsgebieden. Dit moet gedetailleerde specificaties voor de bijbehorende trainers opleveren. Werkpakket 3b betrof een taakanalyse die nodig is voor het kunnen opstellen van de specificaties voor low-cost wielvoertuig simulatoren (Van Winsum & Korteling, 1998).
Het huidige rapport betreft de functionele specificaties voor een simulator om bepaalde onderdelen van de rijtaak te kunnen trainen. Voor elk van de 17 zogenaamde 'elementaire rijtaken' die in de taak analyse zijn geïdentificeerd worden functionele specificaties opgesteld. Aangezien in de literatuur niet alle gegevens beschikbaar zijn om deze specificaties te genereren worden hierbij soms vuistregels toegepast en aannames gedaan. Doordat de gegevens, vuistregels, aannames en formules duidelijk staan beschreven is het mogelijk om nieuwe gegevens later alsnog in te voeren. De resultaten geven een zo nauwkeurig mogelijke

schatting van de functionele eisen die aan een simulator moeten worden gesteld om een bepaalde elementaire rijtaak te kunnen trainen. Gecombineerd met een analyse van de trainingsinvesteringen per elementaire rijtaak kan deze kennis in een later stadium worden gebruikt om op vrij eenvoudige wijze de kosten en de besparingen te onderzoeken van verschillende mogelijke simulator-configuraties. Dit zal in de volgende fases van WP3 gebeuren zodat een optimale low-cost simulator configuratie kan worden samengesteld.

1 INTRODUCTION

1.1 Background

This report concerns a part of a research project that has been carried out in the context of the *EUCLID RTP 11.8* programme entitled: *Low-cost Simulators*. Before we will describe the work of the present research project we will first give a general description of this EUCLID project and the research projects it encompasses.
The EUCLID program focusses on the European development and production of cost-effective systems that can fulfill future military needs. Research Technology Project (RTP) 11.8, concerns the specification and development of low-cost simulators. Low-cost simulators are defined as a new family of training devices that, through the use of commercially available and emerging technologies, provide superior benefit-to-cost ratios when compared to full fidelity simulators. The present research project is called ***ELSTAR***, an Acronym for: ***European Low-cost Simulation Technology for the ARmed forces***. It is carried out under contract of the Ministries of Defence of the five participating countries of RTP 11.8 (Belgium, France, Germany, Greece, The Netherlands).

The *ELSTAR* approach for developing low-cost training simulators is to identify and select those critical task elements that can be easily simulated with high fidelity and training value. The approach involves three steps: 1) selection of military task domains that are suitable for cost-effective simulator training 2) aggregation of (sub)tasks and critical cues that can be easily simulated with high-fidelity in combination with the elimination of the (sub)tasks that are difficult to simulate, and 3) careful integration of simulator training into the curriculum, taking into account the opportunities and limitations of low-cost training simulators.

As a first step, military task domains were selected that may be conceived as the most promising for application of simulation technology and for the generation of relevant knowledge (by relating to the most prominent questions), see Korteling, Van den Bosch, and Van Emmerik (1997). For this purpose a military task taxonomy, called the *ELSTAR* taxonomy of military tasks, was constructed, consisting of about 100 task domains. With this taxonomy, judgements from training- and simulator experts were obtained on each task domain and on 15 different criteria which reflected prospects for low-cost simulation and generation of relevant knowledge.
On the basis of the expert-judgements, many domains were considered very appropriate for further investigation. In order to narrow the potential number of subjects, a concise set of 9 military training areas was defined that represented the selected task domains. These are the short descriptions of these training areas (Korteling, Van den Bosch & Van Emmerik, 1997; Korteling et al., 1997):
1 Wheeled vehicle control (Driving)
2 Air platform navigation (APN or Navigation)
3 Image intensifier and thermic infrared equipment (II/IR)
4 Manoeuvring unmanned platforms (UAV)

5 Within visual-range, guided, fire-and-forget, single-unit operated weapon systems (Stinger)
6 Within visual-range, guided, fire-and-forget, coordinated weapon systems (FAC)
7 Beyond visual-range, non-guided, fire-and-forget, single-unit weapon systems (M109)
8 Fault diagnostics and maintenance of complex composite systems (Maintenance)
9 Mission planning and implementation (Mission management).

On these training areas, more detailed data were acquired with respect to task- and cost-utility information (Helsdingen, Korteling & Van den Bosch, 1998). Subsequently, these data were analysed in the global training- and cost-utility analyses of workpackage 1c (Van den Bosch, Korteling & Van Winsum, 1997; Van den Bosch et al., 1997). The training analyses identified and described the *critical* knowledge and skills to be trained and the critical cues and task elements (with regard to training and to simulation) of the most representative subtasks of each selected training area. The cost-utility analysis compared training utility and cost reduction potentials which provided indications with respect to selection of further research candidates. These analyses were used to verify whether, and to what degree, the selected task domains are indeed interesting for low-cost simulator development and application. These data were also used for the final part of workpackage 1, that is: the selection of 4 training areas for further research. This selection method involved all relevant information available and attained so far. This included the consideration of the scores on the military task taxonomy (WP1.a), the field inventory (WP1.b), the training- and the cost-utility analyses (WP1.c), and expert judgements (WP1.d). In this final phase of workpackage 1 also global functional descriptions of generic training simulators that could be developed for training programmes were provided. These simulators will be the focus of further research, which ultimately (after 4 subsequent workpackages) aims at a handbook comprising methods and guidelines for low-cost simulator development, acquisition, and its application.
In workpackage 3 of the *ELSTAR* project, an elaborate investigation of the task- and training requirements of the selected training areas, must render more detailed descriptions of the selected training systems. For that purpose, the information collected in workpackage 3, will be combined with the results from workpackage 2 (analysis of low-cost technology).
A low-cost, or cost-effective, driving simulator achieves optimal balance between the factors *costs* (of the simulator system and training delivery), and *functionality* (savings because some driving tasks do not have to be trained conventionally). Workpackage 3 consists of three work elements that are described in three subsequent TNO reports (Van Winsum & Korteling, 1998; Van den Bosch 1998, the present report and a subsequent report that will finalize this part of the project). Van Winsum and Korteling (1998) have analysed the driving task into 17 so-called 'Elementary Driving Tasks' (EDT's):

EDT	Name
1	Choosing speed in accordance with legal speed limits
2	Adapting speed and steer to (possible) lateral control disturbances
3	Adapting speed to possible longitudinal control disturbances
4	Voluntary stopping and parking
5	Managing following vehicles
6	Managing overtaking vehicles
7	Lane change/merging
8	Car following
9	Obstacle avoidance for slowly driving or stationary objects in the same lane
10	Passing
11	Obstacle avoidance with an oncoming vehicle
12	Overtaking
13	Approaching an intersection
14	Negotiating an intersection
15	Handling right-of-way violations by other traffic participants
16	Perception of and responding to the proximal environment
17	Perception of and responding to vehicle attitude

The EDTs cover the entire driving task and whilst having a minimal overlap. Each EDT includes a general description of the task and of the circumstances in which the EDT is executed. In addition, the relevant inputs (objects, object-positions and -distances) and outputs (required behaviour) are specified. Furthermore, the rules to which drivers must adhere, the perceptual-motor, cognitive, and procedural operations that are involved are specified. Finally, each EDT description includes an overview of the critical environmental- and task-variables (see Van Winsum & Korteling, 1998).

1.2 The present report

The present report concerns another important step-in the development of a low-cost driving simulator with an optimal ratio of functionality and costs, i.e. the minimal functional simulator specifications that are required for training each EDT. Functional specifications are defined here as simulator characteristics on an intermediate level, e.g. the display resolution that is required (in pixels/deg) without specifying how this resolution should be attained. Since the functional specifications may vary significantly for different Elementary Driving Tasks (EDTs), a set of functional specifications is elaborated for each EDT. When these functional specifications are related to investments in hardware components, the cost of the hardware that is required to train an EDT in the simulator can be calculated. The present report, however, only concerns the functional specifications required for an EDT. The cost of hardware, and the calculation of save-cost factors is part of *ELSTAR* WP3c.

The development of functional specifications is based on a.o. the input variables that are specified for each EDT, such as the position and distance of the traffic participants, the moment that a manouevre is initiated, the road layout, traffic signs, etc. These are specified in the task analysis of Van Winsum and Korteling (1998). When necessary, assumptions are made on the physical parameters that are relevant in an EDT. For instance when passing, the distances and velocities of the traffic participants are defined for 'standard' passing manoeuvres. Since the physical parameters vary for different road category's, the functional specs vary accordingly. Therefore, when applicable, each EDT is assigned a set of functional specs for four different road categories (30, 50, 80 and 120 km/h).
There are many different simulator characteristics for which functional specifications can be defined (Dimitriadis et al., 1997, 1998; Dimitriadis & Helsdingen, 1997). In a literature review on quality criteria for simulator images, Padmos and Milders (1992) have identified several functional specifications that are generally met by the currently available simulator systems (e.g. luminance, contrast-ratio, colour-palette, etc.), whereas others were found not to be relevant in driving simulation (e.g. moving textures, light points, etc.). On the basis of this literature study, and in coordination with our simulator experts, the most relevant and significant cost-drivers in low-cost simulator systems were identified:

- resolution
- field of view (horizontal, vertical)
- complexity of the environment
- the number of moving objects
- atmospherical effects
- presence of mirrors
- active components (active steer, moving base)
- sound system.

For each of the 17 EDTs, we have described these 8 functional specifications in detail. In the definition of these functional specifications, knowledge about human information processing is combined with the design rules for Dutch roads. Since the *ELSTAR* project concerns military applications, when relevant, the specifications are based on the characteristics of terrain vehicles (e.g. landrover-like 4-wheel drive vehicles). Not all necessary environmental elements are mentioned, only the most typical ones, i.e. the signs at an intersection, but not the road markings, refuges, etc. etc. For a more complete list of environmental elements per EDT, the reader is referred to the critical conditions as presented by (Van Winsum & Korteling, 1998).

2 METHOD

2.1 General

Deriving functional simulator specifications is a daunting task. While some functional specifications maybe derived from literature data, others can not be accounted for. In these cases, they can only be determined using a 'rule of thumb' or an educated guess. Also, the exact nature of the traffic situation that will be encountered in an EDT is not always known. Due to the interactive nature of driving simulation, some drivers may show different driving behaviour than others. For instance, the time taken to complete an overtaking manoeuvre may vary, and the resolution that is required for accurate perception of oncoming traffic varies accordingly. This requires that boundary conditions have to be set to the manoeuvres in an EDT. Just like the definition of functional specifications, the definition of boundary conditions requires the use of rules of thumb and common sense assumptions. It therefore seems inherent that when deriving functional specs, some assumptions have to be made, and there will always be some uncertainty about the result. Never the less, as long the deduction process is transparent and best-effort assumptions are made, functional specifications can be derived.

2.2 Example

As an example, we will elaborate on the development of the set of two sets of functional specifications related to EDT 1: *Choosing speed in accordance with legal limits*.
To our knowledge, there is no data available in the literature that indicates the *resolution* that is required for the perception of speed. However, since legal speed is generally indicated by a sign and the reading of signs in cars is very critical, the resolution in this EDT was based on the legibility of speedsigns. Reading a sign requires some time. A commonly used formula to calculate this time interval is:

$$t\ (s) = \frac{n}{3} + 2$$

where n is the number of items that has to be interpreted (Odescalchi, Rutley & Christie, 1962). Assuming that N is two or 3, the numbers on the sign should be legible 3 s before it is reached. Since speed varies for different road categories (i.e., 30, 50, 80 and 120 km/h) the distance at which a sign should be legible differs with road category (see Table I). The size of the numbers on a speed sign, however, also varies with road category: 0.13 m at 30 km/h roads up to 0.33 m at 120 km/h roads). The angular size of a number on a sign can be calculated using the size and the legibility distance. Since a number should be presented b at least 5 pixels in order to be legible (i.e. the smallest visible detail is about 1/5 of its size, Alferdinck, 1990; CIE, 1988), the required resolution can be calculated.
Likewise, the required *field of view* can be calculated. Assuming that the driver should be able to read a sign until it is 0.5 s before it is passed, the distance to the sign can be calculated for

each road category. The position of a sign varies for different road categories. Within the built-up area, signs are higher, smaller and positioned at a shorter lateral distance than outside the built-up area (Beijers, 1982). Using these data, the required horizontal field of view can be calculated. Assuming that the vertical field of view should at least allow a glimpse of the bonnet (about 15° below the horizon), and that the sign should not disappear before 0.5 s before passing, the vertical field of view required to read a sign can be calculated.

This example shows that a list of functional specifications can be derived on the basis of data that is available in the literature combined with reasonable assumptions and common sense. Obviously, other assumptions could be made. For instance, it could be found in an experiment that a sign has to be visible up to 0.1 s before it is passed. If such relevant data becomes available in the literature, the corresponding assumptions can be modified, and the functional specifications can be adapted. Since all data and formulas are contained in a spreadsheet (Excel '97), the new data can introduced readily.

3 FUNCTIONAL SPECIFICATIONS PER EDT

In the following paragraphs functional specifications are assigned to all 17 EDTs.

3.1 EDT 1, Choosing speed in accordance with legal speed limits

Resolution

Speed limits are indicated by signs. Signs are to be legible from a certain distance. If one assumes a standard amount of time to read and interpret a speed sign [say 3 s (Odescalchi, Rutley & Christie, 1962)], the legibility distance increases with speed (see Table I). The resolution that is required for a legible sign depends on the distance to the sign and the size of its numbers. As a rule of thumb, the minimum number of pixels required to read a number is about 5 (Alferdinck, 1990; CIE, 1988). In general, the type of road determines the size of a sign (see Table I). The size of a number is about 1/3 of the size of a sign. Using these data, the resolution that is required for legible traffic signs can be calculated:

$$\text{resolution (pix/deg)} = \frac{5}{\arctan \dfrac{\text{letter size (m)}}{\text{preview time (s)} * \text{v (m/s)}}} \qquad \textbf{(1)}$$

Table I The resolution required for legible speed signs.

Design speed (km/h)	Design speed (m/s)	Distance (m)	Size of sign (m)	Size of number (m)	Resolution (pixels/deg)
30	8.333	25	0.4	0.13	16
50	13.89	41.7	0.6	0.2	18
80	22.22	66.7	0.8	0.27	22
120	33.33	100	1	0.33	26

Field of view

The field of view required for reading a traffic sign depends on the shortest distance required to read the sign. Generally, the height and lateral distance between the shoulder of the road and the edge of a sign depends on the type of road, see Table II. Within the build-up area, the minimum height of a sign is 2.2 m, at a minimum lateral distance to the road of 0.6 m. Outside the build-up area, the minimum height is 1.5 m, while the lateral distance depends on the presence of an emergency lane: without emergency lane, lateral distance is 1.8-3.6 m, with an emergency lane (1.8 m wide), minimal lateral distance is 0.6 m. To calculate the required field of view, the position of the driver on the road (about 1.8 m from the shoulder of the road), and the Time To Coincidence (TTC) at the moment of disappearance (say 0.5 s) should be taken into account. The minimum horizontal field of view can be calculated:

$$\text{horizontal field of view (deg)} = 2 * \text{atan}\left(\frac{\text{lateral distance (m)} + \frac{\text{size of sign (m)}}{2}}{\text{v (m/s)} * \text{ttc (s)}}\right) \quad \textbf{(2)}$$

The required vertical field of view (above the horizon) depends on the height of the sign relative to the height of the viewpoint (average eye height in 4 wheel drive vehicles: 1.46 m, Korteling, Osinga & Verwey, 1990), and can be calculated along similar lines:

$$\text{vertical field of view (deg)} = 20 + \text{atan}\left(\frac{\text{height of sign (m)} + \frac{\text{size of sign (m)}}{2}}{\text{v (m/s)} * \text{ttc (s)}}\right) \quad \textbf{(3)}$$

Assuming that the vertical field of view should be large enough to include a glimpse of the bonnet, the required field of view should be increased with approximately 20°.

Table II The field of view required to read a sign at TTC = 0.5 s.

Design speed (km/h)	Lateral distance of viewpoint to centre of sign (m)	Height of centre of sign relative to viewpoint (m)	Horizontal field of view (deg)	Vertical field of view (deg)
30	2.6	0.9	64	33
50	2.7	1.2	42	30
80	2.8	0.4	28	22
120	4.1	0.6	28	22

Environment

Different types of signs, with their size, height and lateral position in accordance with the design rules for the different road categories. Furthermore, the roads should (or sometimes should not!) be presented with their prototypical layout, so that the driver can develop a sense of the relation between road category and legal speed limit (i.e., 'self-explaining' roads.)

Moving objects

Moving objects are not required in this EDT.

Atmospherical effects

Atmospherical effects are not required in this EDT. In case of fog or heavy rain, EDT 3, adapting speed to longitudinal control disturbances, or EDT 16, perception of and responding to the proximal environment, applies.

Mirrors

Mirrors are not required in this EDT.

Active components

This EDT does not require any active components. Speed is adapted gradually, and accelerations and decelerations are generally small.

Sound system

Auditory cues are used to assess and maintain speed. The sound system should at least present the following sound sources correctly: wind, wheels and engine.

Summarising, the functional simulator requirements involved in EDT 1: choosing speed in accordance with legal speed limits, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	16	64	31	Signs, road layout	no	no	no	no	yes
50	18	42	27	Signs, road layout	no	no	no	no	yes
80	22	28	19	Signs, road layout	no	no	no	no	yes
120	26	28	18	Signs, road layout	no	no	no	no	yes

3.2 EDT 2, Adapting speed and steering to lateral control disturbances

Safe driving requires that the speed is chosen in accordance with factors that affect lateral control performance. This means that the driver has to detect factors that affect steering performance (e.g. sudden wind gusts, changes in lane width, insufficient road friction, dense fog, curves) and adjust speed accordingly. One of the important factors that affect lateral control is curve radius. During the approach of a curve, speed has to be adapted to the curvature of the road in such a way that the required speed is reached on entrance of the curve.

Resolution

Adapting speed and steering to (possible) lateral disturbances requires that the source of the disturbance is detected and recognised in time (say 5 s). Sometimes signs are used to warn the driver, which have to be read in time (say 3 s). Since most physical indicators of possible lateral disturbance are rather large compared with the signs warning for these disturbances, it is assumed that the required resolution is primarily determined by the legibility of signs, see Table I.

Field of view

In this EDT, a large field of view is mainly needed when negotiating curves. When negotiating a curve, the driver not only has to be able to assess curve characteristics, but he should also be able to observe other vehicles. Thus, in curves, the required field of view is primarily related to the stopping distance. According to the design rules for curves (Beijers, 1982), the viewing angle is defined as the angle between the driver's momentary direction of travel and the furthest point that can be observed in the curve. The viewing angle should allow the vehicle to be stopped when a stationary vehicle comes in sight. Unfortunately, Beijers (1982) does not present the formula that allows the viewing angle to be calculated, but only refers to graphical representation and the 'obstacle distance', i.e. the distance of an object restricting the view of the curve to the inner curve radius (Beijers, 1982, Figures 3-21). Using the data in this graph, the viewing angle can be calculated using the following formula:

$$\text{viewing angle (deg)} = \arcsin\left(\frac{\text{radius (m)} - \text{obstacle distance (m)}}{\text{radius (m)} + \text{lateral distance (m)}}\right) \qquad \textbf{(4)}$$

Table III Horizontal viewing angles for different combinations of speed and curve radius.

Speed (km/h)	Radius (m)	Viewing angle (deg)	Speed (km/h)	Radius (m)	Viewing angle (deg)
120	2000	4.4	70	500	7.5
	1000	8.8		400	9.3
	600	15.1		300	12.6
				200	19.3
				150	25.1
				125	29.8
				100	37.3
				80	46.8
90	900	5.9	50	250	9.3
	500	11		150	15.9
	400	13.9		125	18.8
	300	18.6		100	24
	200	28.1		80	29.1

Beijers does not refer explicitly to 80 km/h and 30 km/h roads, but by extrapolation of his Figure 3-21, the required viewing angles are estimated.

Environment

Different types of signs, with their size, height and lateral position in accordance with the design rules for the different road categories. Objects that cue possible lateral disturbances, i.e. changes in road width, curves, etc.

Moving objects

Approaching or overtaken trucks may generate wind gusts that disturb lateral control.

Atmospherical effects

When the view of the lane is restricted by fog, heavy rain or darkness, lateral control performance is attenuated, and speed has to be adapted accordingly. These conditions should be included in this EDT.

Mirrors

Mirrors are not required in this EDT.

Active components

An active steering wheel may provide kinesthetic feedback on lateral disturbances. A simple moving base (modest amplitudes and medium accelerations) with at least 3 Degrees Of Freedom (DOF): yaw, tilt and sway is required to provide kinesthetic cues on wind gusts, (changes in) superelevation and reduced road friction, as well as information on lateral accelerations.

Sound system

Auditory cues can indicate the presence of wind gusts and may be used to assess speed. The sound system should at least present the following sound sources correctly: wind, wheels and engine.

Summarising, the functional simulator requirements involved in EDT 2: Adapting speed to possible lateral control disturbances, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	16	64	31	signs	yes	fog, rain	no	active steer, 3 DOF mov. base	yes
50	18	42	27	signs	yes	fog, rain	no	active steer, 3 DOF mov. base	yes
80	22	28	19	signs	yes	fog, rain	no	active steer, 3 DOF mov. base	yes
120	26	28	18	signs	yes	fog, rain	no	active steer, 3 DOF mov. base	yes

3.3 EDT 3, Adapting speed to possible longitudinal control disturbances

Longitudinal control disturbances prevent the driver from proceeding at the same speed. In anticipation of possible longitudinal control disturbances, e.g. when expecting traffic jams, in the neighbourhood of schools and at bus-stops etc., speed should be reduced. The application of this EDT requires insight in traffic situations that indicate that a longitudinal disturbance may occur.

Resolution

In this EDT, the resolution should be sufficient to identify *possible* longitudinal disturbances, and should allow speed to be reduced before the possible disturbance is reached. Assuming that after a reaction time of 2 s [which encompasses 90% of the reaction times of unalerted drivers (Taoka, 1989)], speed is reduced by decelerating gently (2.0 m/s²). This allows the distance to the possible disturbance to be calculated (see Table IV):

$$\text{distance (m)} = \text{rt (t)} * \text{v (m/s)} + \frac{\text{v}^2 \text{ (m/s)}}{2 * \text{a (m/s}^2)} \quad \textbf{(5)}$$

The required resolution not only depends on the distance at which the possible disturbance is to be observed, but on the objects that signal a possible disturbance as well. On highways and roads outside built-up areas, the smallest objects are generally cars [1.7×1.5 m (h×v)]. Within the built-up area, little children and pets [0.75×0.3 m or 0.3×0.75 m (h×v)] are likely to be the smallest objects the driver may consider to stop for. The Johnson-criterion states that identification of an object requires that it is represented by at least 8 pixels (see Padmos & Milders, 1992). Based on this, the resolution that is needed for the identification of a longitudinal disturbance can be calculated:

$$\text{resolution (pix/deg)} = \frac{8}{\arctan\left(\frac{\text{object size(m)}}{\text{distance(m)}}\right)} \quad \textbf{(6)}$$

Table IV The resolution that is required for the detection of a stationary longitudinal disturbance at the stopping distance needed when decelerating at 2.0 m/s².

Design speed (km/h)	Stopping distance (m)	Size of smallest object (m)	Required resolution (pix/deg)
30	340	0.3	158
50	760	0.3	354
80	168	1.5	156
120	344	1.5	320

Field of view

Traffic situations that indicate a possible longitudinal disturbance are generally observed along the drivers path. Therefore, only a small field of view is required (say 40×30°).

Environment

Apart from a stationary object blocking the driver's path (e.g. another vehicle, a child, etc.) rather complex situations are to be simulated. Detecting possible longitudinal disturbances requires insight in several traffic situations (e.g children that may cross the street at the zebra crossing in front of a school). Therefore, a very complex environment is required in this EDT, covering several types of (possible) longitudinal disturbances, combined with the traffic situations that indicate the possibility that such disturbances may occur.

Moving objects

Objects that suddenly appear on the driver's path.

Atmospherical effects

When the drivers view ahead is restricted by heavy rain or for, or during night time driving, speed may have to be reduced. These conditions should be included in this EDT.

Mirrors

No mirrors are required in this EDT.

Active components

No active components are required in this EDT. Since the driver is merely anticipating on a longitudinal control disturbance, deceleration is generally slow and gradual.

Sound system

Auditory cues may be used to assess speed. The sound system should at least present the following sound sources correctly: wind, wheels and engine.

Summarising, the functional simulator requirements involved in EDT 3: Adapting speed to possible longitudinal control disturbances, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	158	40	30	complex	yes	fog	no	no	yes
50	354	40	30	complex	yes	fog	no	no	yes
80	156	40	30	complex	yes	fog	no	no	yes
120	320	30	30	complex	yes	fog	no	no	yes

3.4 EDT 4, Voluntary stopping and parking

Voluntary stopping and parking requires the detection of situations or signs that allow stopping or parking. Note that we do not consider the parking manoeuvre itself here. This aspect of parking is covered in EDT 16, perception of and responding to the proximal environment and in EDT 17, perception of and responding to vehicle behaviour.

Resolution

The resolution that is required in this EDT is primarily determined by the legibility of signs, and is similar to EDT 1: choosing speed in accordance with legal speed limits.

Field of view

This task requires that signs can be read at short TTCs (0.5 s). The required field of view can be found in Table II.

Environment

Learning where it is allowed to stop and/or park is an important aspect of this EDT. The rules regarding stopping and parking are related to the traffic environment, i.e. stopping is not allowed in tunnels, on bicycle lanes, within 5 m from zebra crossings, etc. Therefore a very complex environment is required in this EDT, covering at least the majority of traffic situations in which stopping or parking is not allowed, and a number of places that are suitable for this purpose.

Moving objects

No moving objects are required in this EDT. In situations where there is a following vehicle and the driver wants to stop or park, EDT 5 (managing following vehicles) applies.

Atmospherical effects

Atmospherical effects are not required in this EDT.

Mirrors

A rear view mirror is required when stopping and parking, to monitor following traffic.

Active components

No active components are required in this EDT.

Sound system

A sound system is not required in this EDT, the vehicle control aspects of stopping and parking, and the sound system involved in this task are part of EDT 17: perception of and responding to vehicle behaviour.

Summarising, the functional simulator requirements involved in EDT 4: voluntary stopping and parking are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj	Atm. eff.	Mirrors	Act. comp.	Sound
30	16	64	31	complex	no	no	rear	no	no
50	18	42	27	complex	no	no	rear	no	no
80	22	28	19	complex	no	no	rear	no	no
120	26	28	18	complex	no	no	rear	no	no

3.5 EDT 5, Managing following vehicles

When being followed by a rear vehicle, the driver has to restrict his level of deceleration.

Resolution

The required resolution is primarily determined by the rear-view mirror. The resolution should allow the distance and relative speed of the rear vehicle to be estimated reliably. Since rear-view mirrors are generally plane, there is no reduction factor that has to be taken into account. When calculating the angular size and rate of expansion of a rear vehicle in respect to the driver, a correction has to be made for the additional optical pathway to and from the rear-view mirror (about 2 * 0.3 m). The angular size of a vehicle that is observed in the rear view mirror can be calculated as follows:

$$\text{angular size (deg)} = 2 * \arctan \frac{0.5 * \text{size (m)}}{\text{distance (m)}} \qquad \textbf{(7)}$$

A rear vehicle (1.7×1.5 m) generally follows at about 2 s, and the distance to the rear vehicle thus depends on the design speed of the road, see Table V. The resolution required for the identification of a rear vehicle can be calculated using formula 6.

Table V The resolution required for the identification of a vehicle following at 2 s.

Design speed (km/h)	Design speed (m/s)	Optical distance (m)	Visual angle (deg)	Resolution (pix/deg)
30	8.333	17.3	5.6	1.4
50	13.89	28.4	3.4	2.3
80	22.22	45	2.2	3.7
120	33.33	67.3	1.4	5.5

Field of view

The field of view that is required for the detection of a rear vehicle is determined by two variables: the size of the rear-view mirror, and the position of the rear-view mirror in the visual field of the driver. Since the rear-view mirror itself is relatively small [i.e. about

$17 \times 7°$, $h \times v$ (Korteling et al., 1990)], the required field of view is primarily determined by the position of the rear-view mirror [the nearest edge of the rear view mirror is at 23° to the left, the top is about 5.5° above the horizon (Korteling et al., 1990)]. If the rear-view mirror is to be observed at its correct spatial position the, required field of view is at least 80°.

Environment

This EDT requires a that following vehicle is present in the environment.

Moving objects

A following vehicle. Since this EDT is critical in dense traffic, several other vehicles near the own vehicle may be required as well.

Atmospherical effects

No atmospherical effects are required in this EDT.

Mirrors

A rear-view mirror is required to monitor the following traffic.

Active components

Active components are not required in this EDT.

Sound system

A sound system is not required in this EDT.

Summarising, the functional simulator requirements involved in EDT 5: being followed by a rear vehicle, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	1.4	80	25	rear vehicle	yes	no	rear	no	no
50	2.3	80	25	rear vehicle	yes	no	rear	no	no
80	3.7	80	25	rear vehicle	yes	no	rear	no	no
120	5.5	80	25	rear vehicle	yes	no	rear	no	no

3.6 EDT 6, Managing overtaking rear vehicles

While being over taken by a rear vehicle, the driver is not allowed to accelerate, unless he is accelerating from a stopped position (e.g. from a traffic-light), when the driver is on a four-lane motorway, or when he is negotiating a roundabout. This task requires that the overtaking vehicle can be detected, and that its position (rear and left of the driver, at the 7 or 8 o'clock position) and/or TTC can be estimated. The overtaking vehicle will primarily be perceived in the left- and rear-view mirrors. To allow a larger field of view, left-view mirrors generally reduce the optical image, whereas rear-view mirrors do not. A standard left view mirror has a radius of 1250 mm, and for the average viewing distance of 800 mm, this results in a reduction factor of 2.3 (Padmos & Moraal, 1977; Koutstaal, 1967). We will assume that a vehicle is overtaking when its TTC is less than 4 s, and that its approach speed is 20% of the design speed of the road.

Resolution

The resolution that is needed for the detection of an overtaking vehicle is primarily determined by the detection of its TTC. In the perception of TTC, perception of angular size and rate of expansion are involved. Since the ratio of angular size and rate of expansion is equal to the TTC (Hoyle, 1958; Lee, 1976) of the approaching object, the rate of expansion of an object with TTC > 1 s is always smaller than its angular size. Therefore, the resolution required in the perception of TTC depends on the perception of rate of expansion. The rate of expansion can be calculated using formula 8, and has to be corrected with the reduction factor (2.3).

$$\text{rate of expansion (deg/s)} = \frac{\text{size (m)} * \text{relative speed (m/s)}}{\text{distance}^2\ \text{(m)} + 1/4\ \text{size}^2\ \text{(m)}} \qquad \textbf{(8)}$$

The resolution that is required for accurate perception of rate of expansion of an object is not known, but it should at least allow the object to expand smoothly. Due to aliasing, objects can only expand one pixel at a time. We assume that in systems without anti-aliasing, an expansion of 6 pixels per second is the minimum that is required for accurate perception of rate of expansion. With anti-aliasing, an approaching object expands smoothly, even when its rate of expansion is only a few pixels per second. Therefore, a resolution of 2 pixels per second is considered sufficient.

Table VI The resolution required for the accurate detection of an overtaking vehicle that is observed in the left-view mirror.

Design speed (km/h)	Design speed (m/s)	Rel. speed (m/s)	Distance (m)	Angular size (deg)	Angular speed (deg/s)	Resolution for ang. speed (pix/deg)	Resolution for ang. speed (pix/deg) *
30	8.333	1.7	8.3	6.3	1.6	3.8	1.3
50	13.89	2.8	12.7	3.8	0.95	6.3	2.1
80	22.22	4.4	19.3	2.4	0.59	10.1	3.4
120	33.33	6.7	28.3	1.6	0.4	15.1	5

* when an anti-aliasing system is present

Field of view

Similar to a rear-view mirror, the field of view that is required for the detection of overtaking vehicles is determined by two variables: the size of the left-view mirror, and the position of the left-view mirror in the visual field of the driver. Since the left-view mirror itself is relatively small, the required field of view is primarily determined by its spatial position. Since left-view mirrors are observed at relatively large visual angles (approximately 35° to the left, 15° below the horizon) a correct spatial presentation requires a field of view of at least 70°.

Environment

The environment should allow overtaking, i.e two lane roads at minimum.

Moving objects

An overtaking vehicle is required in this EDT.

Atmospherical effects

No atmospherical effects are required in this EDT.

Mirrors

Left- and rear-view mirrors are required to monitor the overtaking vehicle.

Active components

This EDT does not require any active components.

Sound system

A sound system is not required in this EDT.

Summarising, the functional simulator requirements involved in EDT 6: being overtaken by a rear vehicle, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	3.8	70	30	rear vehicle	yes	no	left	no	no
50	6.3	70	30	rear vehicle	yes	no	left	no	no
80	10.1	70	30	rear vehicle	yes	no	left	no	no
120	15.1	70	30	rear vehicle	yes	no	left	no	no

* with an anti-aliasing system, the required resolution decreases with a factor 3.

3.7 EDT 7, Lane change/merging

In a lane-change manoeuvre, the presence, the time lag or time headway, and the TTC of objects in the lane the driver wants to move are relevant. Four different situations can be discriminated: 1) if there is a rear vehicle in the lane the driver wants to move into (left- or right-hand lane), 2) when there is a rear vehicle in the lane the driver wants to move into, signalling to move into the present lane of the driver, 3) when there is a lead vehicle in the lane the driver wants to move into, 4) when there is a lead vehicle in the lane the driver wants to move into, that is signalling to move into the drivers current lane. In each case we assume that the time lag at the end of the manoeuvre should at least be 1s.

Resolution

The resolution required in this EDT is primarily determined by the situations in which the other vehicles are observed in the mirrors. The required resolution can thus be calculated using formulae 7 and 8, and can be found in Table VI.

Field of view

The field of view required in this EDT is determined by the size of the dead zones left and right of the vehicle. When changing lanes, the driver has to look over his shoulder to check whether or not there is a vehicle in the dead zone. The deadzone ranges from 90° to the left or right of the driver, up to the zone covered by the left- or right mirror (about 30° each). If the driver has to be able to view the entire deadzone, a field of view of 300° is required.

Environment

The environment should present several vehicles.

Moving objects.

At least two moving vehicles are required in this EDT.

Atmospherical effects

No atmospherical effects are required in this EDT.

Mirrors

Left-, rear- and right-view mirrors are required in this EDT.

Active components

An active steering wheel may provide kinesthetic feedback on the lane change manoeuvre. A simple 1 DOF moving base (sway, modest amplitude and medium acceleration) is required to provide kinesthetic cues on lateral accelerations. More vigorous aspects of lane change manoeuvres are covered by EDT 17; perception of and responding to vehicle behaviour.

Sound system

A sound system is not required in this EDT.

Summarising, the functional simulator requirements involved in EDT 7: lane change/merging, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	3.8	300	35	vehicle(s)	yes	no	left, rear, right	active steer, 1 DOF mov. base	no
50	6.3	300	35	vehicle(s)	yes	no	left, rear, right	active steer, 1 DOF mov. base	no
80	10.1	300	35	vehicle(s)	yes	no	left, rear, right	active steer, 1 DOF mov. base	no
120	15.1	300	35	vehicle(s)	yes	no	left, rear, right	active steer, 1 DOF mov. base	no

3.8 EDT 8, Car following

The EDT car following refers to the case where a lead-vehicle is in the same lane as the driver's car and it is driving with a lower or the same speed as the own vehicle. In this task, two stages can be discriminated. In the first stage, a lead vehicle is approached while decelerating to the speed of the lead vehicle, resulting in the preferred time headway. In the second stage, the lead vehicle is followed at a constant time headway.

Resolution

Stage 1 of the car following task, i.e. decelerating in respect to a lead vehicle until the (constant) desired time headway is reached, is the most critical stage. The TTC at which a driver initiates the deceleration manoeuvre is not known, but we assume that a TTC of 4 s is reasonable. Assuming that relative speed that is 20% higher than the approached vehicle (which is driving at the design speed of the road), and that the driver wants to arrive at the desired time headway, the distance at which the deceleration is initiated can be calculated:

$$\text{distance (m)} = \text{TTC (s)} * \text{rel. speed (m/s)} + \text{headway (s)} * \text{design speed (m/s)} \qquad \textbf{(9)}$$

Note that the speed in the latter part of formula 9 refers to the speed of the lead vehicle! The resolution that is required in this EDT should allow the TTC of the lead vehicle, to be accurately perceived at the distance the deceleration is initiated. Assuming that this requires that the rate of expansion of the lead vehicle (size 1.7 m) is at least 6 pixels per second, see EDT 6, the required resolution can be calculated using formulae 7 and 8:

Table VII The resolution required in the car-following task

Design speed (km/h)	Design speed (m/s)	Relative speed (m/s)	Distance at initiation of deceleration (m)	Angular size (deg)	Rate of expansion (deg/s)	Resolution (pix/deg)
30	8.333	1.7	15	6.5	0.72	8.3
50	13.89	2.8	25	3.9	0.43	13.9
80	22.22	4.4	40	2.4	0.27	22.2
120	33.33	6.7	60	1.6	0.18	33.2

Field of view

If the lead vehicle is to be just visible when following at a short time headway (1 s), the field of view required in the car following task is determined by the distance (time headway * speed) and the size (1.7 m) of the lead vehicle:

$$\text{field of view (deg)} = 2 * \arctan \frac{\left(\frac{\text{size}}{2}\right)}{\text{distance (m)}} \qquad \textbf{(10)}$$

Environment

The environment should present a lead vehicle.

Moving objects

Yes, a lead vehicle is required in this EDT.

Atmospherical effects

Atmospherical effects are not required in this EDT.

Mirrors

No mirrors are required in this EDT.

Active components

No active components are required in this EDT.

Sound system

A sound system is not required in this EDT.

Summarising, the functional simulator requirements involved in EDT 8: car following, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj	Atm. eff.	Mirrors	Act. comp.	Sound
30	8.3	11.6	20	vehicle	yes	no	no	no	no
50	13.9	7	20	vehicle	yes	no	no	no	no
80	22.2	4.4	20	vehicle	yes	no	no	no	no
120	33.3	2.9	20	vehicle	yes	no	no	no	no

3.9 EDT 9, Obstacle avoidance for slowly driving or stationary objects in the same lane as the driver

This EDT refers to the case where the driver is confronted with a stationary or slowly moving object on his path. In some cases, the obstacle may be avoided (EDT 12, overtaking). The worst case scenario, avoiding stationary objects without possibility to overtake, is considered here.

Resolution

In an experiment on braking behaviour (Van der Horst, 1991), drivers had to perform a braking manoeuvre to stop for a stationary vehicle. The TTC at the moment the brake pedal was pressed (TTC_{br}) was found to increase slightly (and linearly) with approach speed. TTC_{br} was 2.1 s at 30 km/h, and 2.4 s at 50 km/h, by extrapolation we estimate that TTC_{br} is about 3 s at 80 km/h, and 3.5 s at 120 km/h. TTC_{br} should be increased with a reaction time of 2 s (Taoka, 1989) to calculate the resolution required in this EDT.

Table VIII The resolution required for avoiding stationary or slowly moving obstacles.

Design speed (km/h)	Design speed (m/s)	TTC	Angular size (deg)	Rate of expansion (deg/s)	Resolution (pix/deg)
30	8.333	4.1	2.9	0.69	4.3
50	13.89	4.4	1.6	0.36	8.2
80	22.22	5	0.88	0.18	17.1
120	33.33	5.5	0.53	0.1	31

Field of view

Similar to EDT 3, adapting speed to possible longitudinal control disturbances, the field of view that is required in this EDT is small, $40 \times 30°$ will do just fine.

Environment

The environment should contain several types of slowly moving or stationary objects (e.g. agricultural vehicles, pedestrians/children, parked vehicles on the driving lane, etc.).

Moving objects

Several moving objects are required in this EDT.

Atmospherical effects

Avoiding obstacles in the same lane as the driver is difficult in degraded visibility conditions, i.e. with fog and heavy rain. These conditions should therefore be included in this EDT.

Mirrors

No mirrors are required in this EDT.

Active components

An active steering wheel may provide kinesthetic feedback during the avoidance manoeuvre. A simple moving base (modest amplitude and medium acceleration) with at least 4 DOF: pitch, yaw, tilt and sway is required to provide kinesthetic cues on the rate of deceleration and on vehicle behaviour during the avoidance manoeuvre. In vigorous avoidance manoeuvres, EDT 17, perception of and responding to vehicle behaviour, applies, and a more complex moving base is required.

Sound system

A simple sound system to provide feedback on speed and rate of deceleration. It should at least correctly present the following sound sources: wind and wheel, wheel slip and engine.

Summarising, the functional simulator requirements involved in EDT 9, obstacle avoidance for slowly moving or stationary vehicles, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	4.3	40	30	vehicles	yes	fog, rain	no	active steer, 4 DOF mov. base	yes
50	8.3	40	30	vehicles	yes	fog, rain	no	active steer, 4 DOF mov. base	yes
80	17.1	40	30	vehicles	yes	fog, rain	no	active steer, 4 DOF mov. base	yes
120	31	40	30	vehicles	yes	fog, rain	no	active steer, 4 DOF mov. base	yes

3.10 EDT 10, Passing

Passing is only allowed under certain circumstances, e.g. when the vehicle that is passed is filtered, on roundabouts, in traffic jams, tram-cars, etc. It refers to a lead vehicle with a lower speed in the lane left of the driver. Since this generally occurs at lower speeds, there is no subdivision in road categories.

Resolution

The resolution required in this EDT should at least allow the type of lead vehicle to be determined, and should allow its position in the lane to be perceived. Suppose the lead vehicle (size 1.7 m) is stationary, and that the driver is approaching at50 km/h. When passing, the TTC (or time to passage) is less than 1 s. The angular size of the lead vehicle can be calculated using formula 7, and is 7.0°. Assuming that the vehicle should at least be presented by 8 pixels (the Johnson criterion), the required resolution is 1.2 pix/deg.

Field of view

The field of view should allow the lead vehicle to be in sight during the entire passing manoeuvre, i.e until the lead vehicle is in the rear. This requires a horizontal field of view of at least 270°. The vertical field of view is not so relevant in this task (about 30° will be sufficient).

Environment

The environment should present different types of vehicles that may be passed, such as trams, and should present intersections with filtering lanes, roundabouts, etc.

Moving objects

At least a lead vehicle is required in this EDT.

Atmospherical effects

No atmospherical effects are required in this EDT.

Mirrors

Mirrors are not required in this EDT.

Active components

No active components are required in this EDT.

Sound system

A sound system is not required in this EDT.

Summarising, the functional simulator requirements involved in EDT 10: passing, are as follows:

Resol.	FOV(h)	FOV(v)	Environment	Mov. obj	Atm. eff.	Mirrors	Act. comp.	Sound
12	270	30	vehicle	yes	no	no	no	no

3.11 EDT 11, Obstacle avoidance with oncoming vehicles

Avoiding oncoming vehicles is relevant when initiating or aborting an overtaking manoeuvre. When there is an oncoming vehicle, the driver must make sure to stay within the lane boundaries. When the driver is overtaking and the TTC of the oncoming vehicle does not allow the overtaking manoeuvre to be continued, the overtaking manoeuvre should be aborted. In both these situations, the oncoming vehicle has a relatively short TTC (say less than 4 s). This task is not relevant on highways.

Resolution

Since a normal lane-change manoeuvre takes about 4 s (Van Winsum, personal communication), we assume that the resolution of the display should at least allow the perception of an oncoming vehicle with TTC = 4. The size of the vehicle is 1.7 m, and the relative speed is 2 * the design speed of the road. Based on these data, the resolution required for the detection of oncoming traffic can be calculated using formulae 7 and 8, see Table IX.

Table IX The resolution required for obstacle avoidance with an oncoming vehicle in the left lane.

Design speed (km/h)	Design speed (m/s)	Distance (m)	Angular size (deg)	Angular speed (deg/s)	Resol. for speed (pix/deg)
30	8.33	66.7	1.5	0.37	16.4
50	13.89	111.1	0.88	0.22	27.4
80	22.22	177.8	0.55	0.14	43.8

Field of view

We assume that the driver should at least be able to see the oncoming vehicle until it is passing him. In this way, the driver can safely initiate an overtaking manoeuvre. If the rear bumper of the oncoming vehicle is to be observed up to the moment it has reached the front bumper of the own vehicle, the required horizontal field of view is about 100°.

Environment

The environment should contain an oncoming and a lead vehicle.

Moving objects

An oncoming and a lead vehicle are required in this EDT.

Atmospherical effects

Detecting oncoming vehicles is difficult in degraded visibility conditions, i.e. with fog, heavy rain or during the night. These conditions should therefore be included in this EDT.

Mirrors

No mirrors are required in this EDT.

Active components

An active steering wheel may provide kinesthetic feedback during the avoidance manoeuvre. A simple moving base (modest amplitude and medium acceleration) with at least 3 DOF: yaw, tilt and surge is required to provide kinesthetic cues lateral accelerations and on the vehicle behaviour during the avoiding manoeuvre.

Sound system

The sound system should provide feedback on speed, rate of deceleration and wheel slip. It should at least present the following sound sources correctly: wind and wheels, wheel slip, and engine.

Summarising, the functional simulator requirements involved in EDT 11: obstacle avoidance with oncoming vehicle, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	16	100	30	complex	yes	fog, rain, night	no	active steer, 3 DOF mov. base	yes
50	27	100	30	complex	yes	fog, rain, night	no	active steer, 3 DOF mov. base	yes
80	44	100	30	complex	yes	fog, rain, night	no	active steer, 3 DOF mov. base	yes

3.12 EDT 12, Overtaking

This EDT refers to situations where the driver wants to overtake a lead vehicle. The minimum distance to the overtaking vehicle that is required for a safe overtaking manoeuvre is substantial. It depends on the time required for the overtaking manoeuvre (about 10 s) and the relative speed of the oncoming vehicle (2× design speed of the road), and may be as large as 444 m at 80 km/h roads (at 120 km/h roads, there generally is no oncoming traffic).

Resolution

We assume that the resolution of the display should to allow the perception of the oncoming vehicle at the minimum distance required for a successful overtaking manoeuvre. We will disregard the rate of expansion since the expansion of an oncoming vehicle at TTC = 10 s is at or below the detection limit. The resolution required for the detection of oncoming traffic can be calculated using formulae 6 and 7, see Table X.

Table X The resolution required for an overtaking manoeuvre.

Road type & Design speed (km/h)	Design speed (m/s)	Distance (m)	Angular size (deg)	Resol. for size (pix/deg)
30	8.33	166.7	0.58	10.3
50	13.89	277.8	0.35	17.1
80	22.22	444.4	0.22	27.4

Field of view

We assume that the driver should at least be able to see the oncoming vehicle until it is passing him. In this way, the driver can safely initiate an overtaking manoeuvre. If the rear bumper of the oncoming vehicle is to be observed up to the moment it has reached the front bumper of the own vehicle, the required horizontal field of view is about 100°.

Environment

At least two vehicles should be presented in the environment: the oncoming vehicle and the overtaken vehicle. Since an important aspect of overtaking is to learn where it is allowed and where it is not allowed, a complex environment should be presented, containing different types of lane markings, pedestrian crossings, intersections, etc.

Moving objects

At least two vehicles are required in this EDT.

Atmospherical effects

Fog, heavy rain and in the dark, perception of oncoming traffic may be degraded. This substantially increases the difficulty of this EDT.

Mirrors

Yes, left-, rear- and right-view mirrors are required when practising this EDT.

Active components

No active components are required in this EDT. EDT 17, perception of and responding to vehicle behaviour, covers the vehicle control aspects of the avoidance and/or manoeuvres of this EDT.

Sound system

A sound system is not required in this EDT. EDT 17, perception of and responding to vehicle behaviour, deals with the sudden braking and avoidance manoeuvres that may have to be made.

Summarising, the functional simulator requirements involved in EDT 12: overtaking, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	45.4	100	20	vehicles	yes	fog, rain, night	left, right, rear	no	no
50	75.6	100	20	vehicles	yes	fog, rain, night	left, right, rear	no	no
80	10.3	100	20	vehicles	yes	fog, rain, night	left, right, rear	no	no

3.13 EDT 13, Approaching an intersection

During the approach phase of an intersection, the driver detects the intersection in front, and, at a certain distance, starts to release the foot from the accelerator pedal. This is because for any intersection there is always a chance that the driver must come to a full stop. This EDT does not apply to highways.

Resolution

We assume that an intersection should be detected at TTI = 7 s. Detection of an intersection can only occur if the resolution of the display is sufficient to present the crossing roads with at least 1 pixel. Assuming an eye height of 1.46, the average eye height of a driver in 4WD vehicles, the distance from the intersection at TTI = 7 and the width of the crossing road, the visual angle spanned by the crossing road can be calculated:

$$\text{vis. angle (deg)} = \arctan\left(\frac{\text{eyeheight (m)}}{\text{distance (m)}}\right) - \arctan\left(\frac{\text{eyeheight (m)}}{\text{distance (m)} + \text{road width (m)}}\right) \quad \textbf{(11)}$$

Table XI The resolution required for the detection of a crossing road, assuming that it is represented by at least 1 pixel at TTI = 7.

Design speed (km/h)	Design speed (m/s)	Distance at TTI = 7 (m)	Width cross road (m)	Vis. angle cross road (deg)	Req. resolution (pixels/deg)
30	8.33	58.3	3.6	0.083	12
50	13.89	97.2	7.2	0.059	16.9
80	22.22	155.6	7.2	0.023	42

Field of view

Since it merely involves the detection of an intersection, a small field of view (say 40×30°) is sufficient in this EDT.

Environment

A complex environment should be presented, with different types of intersections, traffic lights, signs, pedestrian crossings, other traffic participants, objects that obscure the intersection, etc.

Moving objects

Other traffic participants are required in this EDT.

Atmospherical effects

Fog and heavy rain may degrade the perception of intersections. This increases the difficulty of this EDT.

Mirrors

A rear-view mirror is required to monitor rear vehicles.

Active components

No active components are required in this EDT. Since the driver is merely reducing speed by releasing the foot from the accelerator pedal, deceleration will be slow and gradual.

Sound system

A sound system is not required in this EDT.

Summarising, the functional simulator requirements involved in EDT 13, approaching an intersection, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	14.7	40	30	complex	yes	fog, rain	rear	no	no
50	20.5	40	30	complex	yes	fog, rain	rear	no	no
80	51	40	30	complex	yes	fog, rain	rear	no	no

3.14 EDT 14, Negotiating an intersection

When the TTI is less than 4 s, the driver is no longer just approaching an intersection, but he has to decide whether he should stop or go.

Resolution

Deciding whether to stop or go requires accurate perception of the TTI. The resolution required in this task is similar to EDT 9, obstacle avoidance for stopped or slowly driving vehicles.

Field of view

The field of view required in this EDT should at least allow crossing traffic (TTI = 7) to be perceived when the driver has stopped at the intersection. This implies that the required field of view is about 180°. In the Netherlands, however, separate bicycle lanes are frequently found. When turning right at an intersection, these lanes are crossed, and the driver has to assess whether or not there are any bicycles approaching. Assuming that the vehicle has already turned about 45° into the curve, the field of view should allow the driver to look about 45° backwards, increasing the required field of view to 225°.

Environment

A complex environment is required in this EDT, with several types of intersections, traffic lights, signs, etc., modelled according to the design rules for that particular road category.

Moving objects

Other traffic participants.

Atmospherical effects

This EDT does not require any atmospherical effects.

Mirrors

A rear-view mirror (to monitor rear vehicles) is required in this EDT.

Active components

No active components are required in this EDT. EDT 17, perception of and responding to vehicle behaviour, covers the vehicle control aspects of the avoidance and/or manoeuvres of this EDT.

Sound system

A sound system is not required in this EDT.

Summarising, the functional simulator requirements involved in EDT 14: negotiating an intersection, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	43	225	30	complex	yes	no	rear	no	no
50	8.3	225	30	complex	yes	no	rear	no	no
80	17.1	225	30	complex	yes	no	rear	no	no

3.15 EDT 15, Conflict because of right-of-way rule violation by other traffic participant

When there is an a traffic participant that does not stop at an intersection, and a collision is imminent, the driver must make an emergency braking manoeuvre.

Resolution

Right-of-way conflicts typically occur at short TTIs (say less than 3 s). Using formula 7 and 8, the required resolution can be calculated:

Design speed (km/h)	Design speed (m/s)	Distance at TT I = 3 (m)	Vis. angle (deg)	Ang. speed (deg/s)	Resol. speed (pix/deg)
30	8.33	25	3.9	1.3	4.6
50	13.89	41.7	2.3	0.78	7.7
80	22.22	66.7	1.5	0.49	12.3

Field of view

In rule-of-way violations, the field of view should at least allow a view of the conflicting vehicle. Since the TTI of the conflicting vehicle is similar to the driver's TTI, the difference in approach speed of the two vehicles determines the field of view that is required. Assuming that both vehicles are driving at the design speed of their road category, and that the crossing traffic is always driving at a 80 km/h road, the required field of view can be calculated.

Environment

A complex environment is required in this EDT, with different types of intersections, traffic lights, signs, other traffic participants, etc.

Moving objects

This EDT requires other, conflicting, traffic participants.

Atmospherical effects

Atmospherical effects are not required in this EDT.

Mirrors

A rear view mirror is required to monitor rear vehicles

Active components

No active components are required in this EDT. EDT 17, perception of and responding to vehicle behaviour, covers the vehicle control aspects of the avoidance and/or braking manoeuvres in this EDT.

Sound system

A sound system is not required in this EDT. EDT 17, perception of and responding to vehicle behaviour, deals with the sudden braking and evasive manoeuvres may have to be made in EDT 15.

Summarising, the functional simulator requirements involved in EDT 15: conflict because of right-of-way rule violation by other traffic participant, are as follows:

Design speed (km/h)	Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
30	5	140	30	complex	yes	no	rear	no	no

50	8	120	30	complex	yes	no	rear	no	no
80	12	90	30	complex	yes	no	rear	no	no

3.16 EDT 16, Perception of and responding to the proximal environment

This EDT involves the accurate perception of the environment close to the vehicle in relation to the physical vehicle dimensions. Assessment of the proximal environment directly affects driving behaviour (may require immediate control actions) when the driver is manoeuvring (turning, parking in a garage or between other vehicles, narrow passages, etc.) or when he is in an area without paved or unpaved roads that lead to the area of destination (terrain).

Resolution

The most critical aspect in the assessment of the proximal environment is the perception of the characteristics of the sub-soil up to 10 m from the vehicle. In the assessment of the characteristics of the sub-soil, e.g. determining whether it is wet, soft or slippery, the driver relies on highly specific cues and minute details. For instance, the structure of the sand, the type of vegetation and the shining of glazed frost or fresh mud may all be used in determining the type of subsoil that will (or will not) be negotiated. Needless to say that such minute details require images with a high resolution, preferably comparable to the resolution of the human eye, about 60 pixels/deg (Padmos & Milders, 1992).

Field of view

The field of view required in the assessment of the proximal environment should be comparable to the drivers normal field of view. When determining if a narrow passage can be negotiated, or when manoeuvring in a confined space the driver must be able to see every corner of his vehicle, including the rear. This requires a 360° horizontal field of view, and a 50° vertical field of view. Some drivers increase their field of view even further by sticking their head out of the window to see whether or not the wheels are on the right track.

Environment

A highly complex environment is required in this EDT. Presenting subtle and minute textures, a detailed 3D surface-structure and complex vegetation is beyond the capacity of the currently available low-cost simulation systems. Furthermore, since binocular vision plays an important role in the perception of the 3D structure of the proximal environment, the environment should be presented stereoscopically.

Moving objects

No moving objects are required in this EDT.

Atmospherical effects

During the night, the perception of the proximal environment is difficult. Rain and fog do not hamper the perception of the proximal environment, since they generally allow at least 10 m of free sight.

Mirrors

Left-, right- and rear-view mirrors are required in this EDT.

Active components

Since this EDT merely concerns the assessment of and anticipation on the characteristics of the proximal environment, no active components are required.

Sound system

Auditory cues are used to assess information on speed. The sound system should at least present the following sound sources correctly: wind, wheels and engine.

Summarising, the functional simulator requirements involved in EDT 16: perception of and responding to the proximal environment, are as follows:

Resol.	FOV(h)	FOV(v)	Environment	Mov. obj	Atm. eff.	Mirrors	Act. comp.	Sound
60	360	50	highly complex	no	night	left, right, rear	no	yes

3.17 EDT 17, Perception of and responding to vehicle behaviour

This EDT involves the perception of the vehicle behaviour as determined by the driver's control actions or by disturbances caused by the structure and layout (slopes, bumps) of the road or subsoil over which one drives or by abrupt and strong manipulation of the vehicle controls (emergency reactions). Based on this, correct control actions have to be initiated by adequate manipulation of the control devices.
In the perception of vehicle, attitude visual proprioception plays an important role. The static attitude of the vehicle in space, i.e its yaw, bank and pitch angles, can be perceived visually. Changes in vehicle attitude (at least the slow, graduate changes with a low temporal frequency) are also picked-up by the visual system. The vestibular and somatosensory systems may register static bank and pitch angles, as well as the more vigorous changes in vehicle attitude (i.e. the higher frequency components) and linear accelerations.

Resolution

Since attitude information is primarily picked-up in the peripheral field of view, where the resolution of the visual system is relatively low, image resolution does not need to be high (say 10 pix/deg).

Field of view

Picking-up information on (changing) vehicle attitude requires a large field of view. Since the horizon plays an important role in the perception of bank and pitch, the vertical field of view should be similar to the vertical field of view that is normally available to the driver (at least 40°). It has been found that the visual component of perceived self-tilt improves with horizontal field of views up to 180°, although for a field of view of 100° perceived self tilt is reasonable (Groen, personal communication).

Environment

It has been found that visual perception of changing attitude improves in complex environments (Groen, 1997). If the visual information on vehicle attitude is sufficiently complex it may even dominate vestibular information on vehicle attitude. Thus, to allow optimal visual perception of orientation, a complex environment should be presented.

Moving objects

Moving objects are not required in this EDT.

Atmospherical effects

Atmospherical effects are not required in this EDT.

Mirrors

This EDT requires the use of left-, right- and rear-view mirrors.

Active components

The vestibular system picks-up bank and tilt angles, swift and vigorous changes in attitude and linear accelerations. This type of information is especially relevant in terrain driving, when driving on slippery surfaces, and for rough driving in general. The complexity of the moving base, i.e. its degrees of freedom, excursion angles and response times, depends on the type of manoeuvres that are performed. In terrain driving, where large pitch and bank angles and vigorous manoeuvring frequently occurs, a sophisticated 6 DOF motion base (large amplitude and fast accelerations) with seat-shaker and an active steering wheel are required. The linear DOFs for the transient components of accelerations and rotatory DOFs for transient rotatory accelerations (e.g. when driving through a ditch) and sustained linear accelerations (e.g., in curves, when braking) and changes in orientation (on slopes).

Sound system

The sound system should at least present the following sound sources: wind and wheels, wheel slip, engine noise, gear changes and interactions with objects and subsoil (e.g. bushes, pebbles, etc.). The sound should be correctly related to the characteristics of the source, in intensity, spectral composition, pitch and spatial position.

Summarising, the functional simulator requirements involved in EDT 17:perception of and responding to vehicle behaviour, are as follows:

Resol.	FOV(h)	FOV(v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Active components	Sound
10	100	40	complex	no	no	left, right, rear	6 DOF, seat shaker, active steer	yes

All functional specifications are summarized in the Appendix.

4 DISCUSSION

The purpose of the present part of the *ELSTAR* project is to develop and to applicate methods for deriving functional specifications for simulators in order to compose low-cost simulator configurations with an optimal ratio between benefits (savings) and costs. As a part of this work, the present report shows a way to derive functional specifications for each of the 17 EDTs.

The derivation of functional simulator specifications is both a relatively simple and a complicated process. It can be relatively simple because some of functional specifications that are required in an EDT can be found in the literature (e.g legibility, preview distances, stopping distances, etc.). This data, and the input data in the description of the EDT can be used to calculate functional specifications using elementary mathematics. Problems arise, however, when there is no, or limited, data available in the literature to guide the derivation of functional specifications. In many cases, an educated guess had to be made on the nature of the parameters that were relevant in this process. Thus, it can not be warranted that the derived functional specifications are always 100% correct.

Notwithstanding the difficulties, the present approach derives functional specifications in a systematical way and as accurately as possible. The process that leads to the definition of functional specifications is clear, and new data can be introduced readily when it becomes available. Since all data and formulae are contained in a spreadsheet, introducing new data is a matter of minutes.

Most of the sensory input that is needed during driving is visual. Most visual input is derived from the immediate surroundings of the vehicle (ranging from a few hundreds of metres in front to several decades to the rear, left and right) including the mirrors. This visual information is complex (often detailed), dynamic and sometimes has to be presented over a large field of view and in the mirrors. Efficient, low-cost simulation of this complex and abundant information may be one of the major topics of the oncoming *ELSTAR* activities. Moreover, the dynamics of the simulated vehicle itself will impose requirements with regard to the feeling of vehicle attitude, forces on the vehicle control devices and perception of visual flow.
The list of all functional specifications for all EDTs presented in Appendix A shows remarkable results. For instance, there are large differences in functional specifications within EDTs. At higher speeds the functional requirements are generally higher than at lower speeds. To reduce simulator cost, one could choose only to train an EDT at lower speeds, which decreases the functional specs that are required. Similarly, apart from EDTs 7, 10, 14, 15 and 16, only a relatively small field of view (less than 100°) is required.
The complexity of the environment varies from relatively simple ('rear vehicle', in EDT 5 and 5) to highly complex (EDT 16). Note that even simple environments, as the 'rear vehicle' in EDT 5 should be presented in a natural context, i.e. a lane with road markings, road-side poles, some trees, houses, some reference points on the horizon, etc. (see Korteling, 1990) for a list of elements that should be present in a driving environment). Therefore, even 'simple' environments are in fact relatively complex. The other end of the spectrum is represented by EDT 16, which has exceptionally high functional requirements. The 60 pixels per degree resolution that is required in EDT 16, is almost not feasible with the current simulator hardware, at least, not for a reasonable field of view. Terrain driving, one of the major aspects of EDT 16, requires accurate representation of various terrain types, including mud, rock, vegetation, etc. It is not known which cues are used in terrain driving, and it is doubtful whether all the relevant cues can be rendered.
Moving objects are required in almost all EDTs, and interaction with other traffic participants is an important aspect of driving. The behaviour of traffic participants should be modelled realistically, i.e. they should show aggressive, hesitating or even erroneous driving behaviour. Furthermore, these traffic participants should frequently be on a conflict course, forcing the student driver to make a quick decision. The latter aspect is one of the major advantages of driving simulation over the conventional driver education. In real life, much time is spent 'waiting' for relevant traffic situations to occur. In the simulator, these situations can be presented over and over again at will.
When an EDT requires left or right-hand mirrors, a large field of view is needed to present the mirrors at the correct spatial location. A correct spatial position is required for learning the motor patterns associated with proper use of the mirrors. However, there may other ways to learn such patterns, for instance by using an indicator light located at the position of the mirror that tells whether or not it is safe to initiate a manoeuvre. Scanning these indicators may allow these motor patterns to be developed. Whether or not this is a valid alternative remains to be investigated.
Many EDTs require active components, ranging from an active steer to a 6 DOF moving base. Since a moving base is an important cost driver in low-cost driving simulation, its use

should be carefully considered. A moving base provides cues regarding vehicle dynamics, road feel and vehicle attitude, especially for the more vigorous manoeuvres. This is especially relevant in extreme situations where accurate vehicle handling is essential, such as for instance in EDT 17 (perception of and responding to vehicle behaviour). In the other EDTs, vehicle handling is generally subordinate to the other aspects task, i.e. cognitive and procedural skills. In light of its high cost, the need for a moving base in low-cost driving simulation is arguable.

It should be noted that the functional specifications presented here need to be related to the cost of the hardware that is required to meet these functional specifications. This requires an additional analysis, which is performed in a next phase of the present workpackage. This will be described in a forthcoming TNO report, which will also include an analysis of the cost of simulator hardware and the potential savings per EDT that can be achieved by simulator training.

5 CONCLUSIONS

The present report describes the functional driving simulator specifications for 17 elementary driving tasks that in combination constitute the complete driving task. These functional specifications were generated using literature data and in case relevant parameters were not available in the literature, an educated guess. The results indicate the most relevant functional simulator specifications of a set of subtasks that cover the entire driving task. Using this database, the cost of simulator hardware required to train a subset of driving tasks will be specified, and a cost-benefit analysis for low-cost driving simulators will be made. Ultimately, this will allow a cost-effective low-cost driving simulator to be developed that allows a large portion of driver training programme to be trained on the simulator with minimal hardware investments.

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APPENDIX Comprehensive list of functional specifications per EDT

Functional simulator specifications per EDT, subdivided for different road categories when necessary.

EDT	Road cat.	Resol.	FOV (h)	FOV (v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
1	30	16	64	31	Signs, road layout	no	no	no	no	yes
1	50	18	42	27	Signs, road layout	no	no	no	no	yes
1	80	22	28	19	Signs, road layout	no	no	no	no	yes
1	120	26	28	18	Signs, road layout	no	no	no	no	yes
2	30	16	64	31	signs	yes	fog, rain	no	active steer, 3 DOF	yes
2	50	18	42	27	signs	yes	fog, rain	no	active steer, 3 DOF	yes
2	80	22	28	19	signs	yes	fog, rain	no	active steer, 3 DOF	yes
2	120	26	28	18	signs	yes	fog, rain	no	active steer, 3 DOF	yes
3	30	15.8	40	30	complex env.	yes	fog	no	no	yes
3	50	35.4	40	30	complex env.	yes	fog	no	no	yes
3	80	15.6	40	30	complex env.	yes	fog	no	no	yes
3	120	32	30	30	complex env.	yes	fog	no	no	yes
4	30	16	64	31	complex env.	no	no	rear	no	no
4	50	18	42	27	complex env.	no	no	rear	no	no
4	80	22	28	19	complex env.	no	no	rear	no	no
4	120	26	28	18	complex env.	no	no	rear	no	no
5	30	1.4	80	25	rear vehicle	yes	no	rear	no	no
5	50	2.3	80	25	rear vehicle	yes	no	rear	no	no
5	80	3.7	80	25	rear vehicle	yes	no	rear	no	no
5	120	5.5	80	25	rear vehicle	yes	no	rear	no	no
6	30	3.8	70	30	rear vehicle	yes	no	left	no	no
6	50	6.3	70	30	rear vehicle	yes	no	left	no	no
6	80	10.1	70	30	rear vehicle	yes	no	left	no	no
6	120	15.1	70	30	rear vehicle	yes	no	left	no	no
7	30	3.8	300	35	vehicle(s)	yes	no	left, rear, right	active steer, 1 DOF	no
7	50	6.3	300	35	vehicle(s)	yes	no	left, rear, right	active steer, 1 DOF	no
7	80	10.1	300	35	vehicle(s)	yes	no	left, rear, right	active steer, 1 DOF	no
7	120	15.1	300	35	vehicle(s)	yes	no	left, rear, right	active steer, 1 DOF	no
8	30	8.3	11.6	20	vehicle	yes	no	no	no	no
8	50	13.9	7	20	vehicle	yes	no	no	no	no
8	80	22.2	4.4	20	vehicle	yes	no	no	no	no
8	120	33.3	2.9	20	vehicle	yes	no	no	no	no

EDT	Road cat.	Resol.	FOV (h)	FOV (v)	Environment	Mov. obj.	Atm. eff.	Mirrors	Act. comp.	Sound
9	30	4.3	40	30	vehicles	yes	fog, rain	no	active steer, 4 DOF	yes
9	50	8.3	40	30	vehicles	yes	fog, rain	no	active steer, 4 DOF	yes
9	80	17.1	40	30	vehicles	yes	fog, rain	no	active steer, 4 DOF	yes
9	120	31	40	30	vehicles	yes	fog, rain	no	active steer, 4 DOF	yes
10	0	1.2	270	30	vehicle	yes	no	no	no	no
11	30	16	100	30	complex	yes	fog, rain, night	no	active steer, 3 DOF	yes
11	50	27	100	30	complex	yes	fog, rain, night	no	active steer, 3 DOF	yes
11	80	44	100	30	complex	yes	fog, rain, night	no	active steer, 3 DOF	yes
12	30	10.3	100	20	vehicles	yes	fog, rain, night	left, right, rear	no	no
12	50	17.1	100	20	vehicles	yes	fog, rain, night	left, right, rear	no	no
12	80	27.4	100	20	vehicles	yes	fog, rain, night	left, right, rear	no	no
13	30	14.7	40	30	complex env.	yes	fog, rain	rear	no	no
13	50	20.5	40	30	complex env.	yes	fog, rain	rear	no	no
13	80	51	40	30	complex env.	yes	fog, rain	rear	no	no
14	30	4.3	225	30	complex env.	yes	no	rear	no	no
14	50	8.3	225	30	complex env.	yes	no	rear	no	no
14	80	17.1	225	30	complex env.	yes	no	rear	no	no
15	30	5	140	30	complex env.	yes	no	rear	no	no
15	50	8	120	30	complex env.	yes	no	rear	no	no
15	80	12	90	30	complex env.	yes	no	rear	no	no
16	0	60	360	50	highly complex env.	no	night	left, right, rear	no	yes
17	0	10	100	40	complex env.	no	no	left, right, rear	6 DOF, seat shaker, active steer	yes

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Low-cost simulators 3b: Specification of functional requirements for driver training simulators

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14. SUPPLEMENTARY NOTES

15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTES))

To investigate the possibilities for application of low-cost simulators within military training courses, the research project called ELSTAR (European Low-cost Simulation Technology for the Armed forces) is carried out under contract of the Ministries of Defence of the five participating countries of Research Technology Project (RTP) 11.8, viz. Belgium, France, Germany, Greece, and The Netherlands. In the first workpackage (Analysis of military training), four training areas were selected for further research, i.e. driver training, UAV crew training, infrared and image intensifier operation training, and mission management training. This selection was based on expert-scores on the ELSTAR taxonomy, the results of global task-, training-, and cost-utility analysis, and expert judgements on the generic value and complementarity of the knowledge that would be acquired.
One of the basic premises of the ELSTAR approach for developing low-cost training systems is to identify and select those critical task elements that can be simulated at low cost with high fidelity and training value. Therefore, in workpackage 3 (Simulator requirements) of the ELSTAR project, an elaborate investigation of the task- and training requirements and the functional specifications of the selected training system. In ELSTAR Wp 3b, 17 so-called 'elementary driving tasks' have been identified (Van Winsum & Korteling, 1998). Elementary driving tasks are defined such that they are relatively independent of each other. This relative independency allows the construction of (complex) higher-order subtasks just by combining these elementary tasks.
The present report describes the derivation of the functional simulator requirements to train each elementary driving task. This is done for six most relevant functional simulator specifications, i.e. display resolution, field of view, complexity of the environment, etc. For each elementary driving task the line of thought and the data leading to the definition of a functional specification is described. Since not all relevant data is available in the literature, this process inherently involves the use of 'rules of thumb' and 'educated guesses'. Since the process is transparent, new relevant data can be introduced readily at the appropriate elementary driving tasks The result of the process is a matrix of elementary driving tasks and functional specifications that allows an elementary driving task to be related to specific simulator specifications.
By relating these functional specifications to hardware components, it becomes possible to easily explore the costs of various simulator configurations. Combined with an analysis of the cost of conventional training, cost effective low-cost driving simulators concepts may be developed. The present report describes the minimal functional requirements (costs) per elementary driving task, whereas the relationship between elementary driving tasks at one hand and training needs and -investments (savings) at the other, and the development of one or several low-cost simulator concepts for driver training will be subsequently reported.

16. DESCRIPTORS Simulators Training Vehicle Driving	IDENTIFIERS Specifications

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