TNO-report
TM-97-A087

TNO Human Factors
Research Institute

Kampweg 5
P.O. Box 23
3769 ZG Soesterberg
The Netherlands

Phone +31 346 35 62 11
Fax +31 346 35 39 77

title

Low-cost simulators 1d: generic training simulators for military applications

authors
J.E. Korteling
A.S. Helsdingen

date
30 December 1997

ELSTAR
Euclid RTP 11.8 Low-cost Simulators
European C0-operation for the Long term In Defence

number of pages : 35 (incl. appendices, excl. distribution list)

TNO Human Factors Research Institute
is part of TNO Defence research
to which also belong:
TNO Physics and Electronics Laboratory
TNO Prins Maurits Laboratory

Netherlands Organization for
Applied Scientific Research

titel:	Low-cost simulatoren 1d: generieke trainingssimulatoren voor militaire toepassingen
auteurs:	Dr. J.E. Korteling en drs. A.S. Helsdingen
datum:	30 december 1997
opdrachtnr.:	A96/CO/363
IWP-nr.:	788.1
rapportnr.:	TM-97-A087

Het EUCLID programma stimuleert de ontwikkeling en kosten-effectieve produktie van systemen die voorzien in de toekomstige Europese militaire behoeften. Eén van de Research Technologie Projecten (RTP) 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 dat wordt uitgevoerd in opdracht van de ministeries van defensie van de vijf participerende landen van RTP 11.8 (België, Frankrijk, Duitsland, Griekenland en Nederland) wordt *ELSTAR* genoemd, een acroniem voor: *European Low-cost Technology for the ARmed forces*. Dit rapport bevat het verslag van het eerste deel van werkpakket 1 van het ELSTAR project.
In het eerste deel van dit project (werkpakket 1a) werd militaire taaktaxonomie van ca. 100 taakdomeinen geconstrueerd. Met deze taxonomie werden oordelen van training- en simulator-experts verzameld over ieder taakdomein en met betrekking tot 15 verschillende criteria die geschiktheid voor low-cost simulatie en kennisontwikkeling weerspiegelden. Dit leverde een compacte set van 9 militaire trainingsgebieden op die de 29 taakdomeinen representeerde welke geselecteerd waren voor verder onderzoek.
Deze 9 trainingsgebieden werden in werkpakket 1b en 1c verder onderzocht. Dit behelsde het uitvoeren van taak- en cost-utility analyses op specifieke trainingsprogramma's die de 9 trainings-gebieden representeerden. Het onderhavige rapport beschrijft de selectie van 4 van deze 9 trainingsgebieden en levert de globale functionele specificaties van generieke trainingssimulatoren die zouden kunnen worden toegepast binnen deze trainingsgebieden. Deze selectie is gebaseerd op een deel van 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.
De resultaten laten zien dat rijvaardigheidstraining, UAV crew training, training van het gebruik van infrarood en image intensifier apparatuur en missie management training het meest geschikt zijn voor verder onderzoek naar de mogelijkheden voor toepassing van low-cost simulatoren. Hiervoor worden functionele specificaties opgesteld die de globale simulatorkenmerken beschrijven en aangeven welke taakclusters waarschijnlijk op low-cost basis kunnen worden gesimuleerd. In volgende werkpakketten zullen meer gedetailleerde systeemeisen worden gespecificeerd.

CONTENTS Page

Rep.No. TM-97-A087

TNO Human Factors Research Institute
Soesterberg, The Netherlands

Low-cost simulators 1d: generic training simulators for military applications

J.E. Korteling and A.S. Helsdingen

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 part of this investigation, i.e. workpackage 1a, a taxonomy constituting 100 military task domains (ELSTAR Taxonomy) was a.o. developed and these 100 domains were evaluated on 15 criteria relevant for low-cost simulator applications and R&D. This resulted in a concise set of 9 military training areas that represented 29 task domains that were selected for further study.

These 9 training areas were then further investigated in workpackage 1b and 1c. This involved task- and cost-utility analyses on specific training courses that were considered representative for the 9 selected training areas. The present report describes the selection of 4 training areas out of these 9 training areas, and provides the global functional specifications of generic training simulators that could be applied in training programmes within these areas. This selection is based on scores on the ELSTAR taxonomy, the results of the task-, training-, and cost-utility analysis, and expert judgements on the generic value and complementarity of the knowledge that will be acquired.

The results show that driver training, UAV crew training, infrared and image intensifier operation training, and mission management training will be most suitable for further research into the possibilities for the application of low-cost simulators. Functional specifications that are drawn up for training systems for these training areas, indicate the global simulator requirements and which task clusters may be simulated at low-cost. In subsequent workpackages, more detailed requirements for the selected training systems will be specified.

Rap.nr. TM-97-A087

TNO Technische Menskunde
Soesterberg

Low-cost simulatoren 1d: generieke trainingssimulatoren voor militaire toepassingen

J.E. Korteling en A.S. Helsdingen

SAMENVATTING

Dit rapport bevat het verslag van het vierde deel van werkpakket 1 van een omvangrijk research project dat wordt uitgevoerd in opdracht van de ministeries van defensie van de vijf participerende landen van EUCLID RTP 11.8 (België, Frankrijk, Duitsland, Griekenland en Nederland) Het project heet *ELSTAR*, een acroniem voor: *European Low-cost Technology for the ARmed forces*. Hierbij wordt onderzoek gedaan naar de ontwikkeling van een nieuwe klasse trainers met een hoge kosten-baten verhouding.

In het eerste deel van dit project (werkpakket 1a) werd o.a. een taxonomie van 100 taakdomeinen ontwikkeld die met behulp van 15 criteria, relevant voor low-cost simulatie, werden beoordeeld. Dit leverde een compacte set van 9 militaire trainingsgebieden op die de 29 taakdomeinen representeerde welke geselecteerd waren voor verder onderzoek.

Deze 9 trainingsgebieden werden in werkpakket 1b en 1c verder onderzocht. Dit behelsde het uitvoeren van taak- en cost-utility analyses op specifieke trainingsprogramma's die de 9 trainingsgebieden representeerden. Het onderhavige rapport beschrijft de selectie van 4 van deze 9 trainingsgebieden en levert de globale functionele specificaties van generieke trainingssimulatoren die zouden kunnen worden toegepast binnen deze trainingsgebieden. Deze selectie is gebaseerd op een deel van 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.

De resultaten laten zien dat rijvaardigheidstraining, UAV crew training, training van het gebruik van infrarood en image intensifier apparatuur en missie management training het meest geschikt zijn voor verder onderzoek naar de mogelijkheden voor toepassing van low-cost simulatoren. Hiervoor worden functionele specificaties opgesteld die de globale simulator kenmerken beschrijven en aangeven welke taakclusters waarschijnlijk op low-cost basis kunnen worden gesimuleerd. In volgende werkpakketten zullen meer gedetailleerde systeemeisen worden gespecificeerd.

1 INTRODUCTION

The EUCLID program focuses on the European development and production of cost-effective systems that can fulfill future military needs. One of the Research Technology Projects (RTP) within EUCLID is RTP 11.8, entitled: ***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, which 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), is called ***ELSTAR,*** an Acronym for: ***European Low-cost Simulation Technology for the ARmed forces.*** The present report describes the fourth, and final part of workpackage 1 of this project.

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. 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, 29 domains were considered very appropriate for further investigation. It should be noted, however that, because of the so-called "knowledge-generation" criteria, the actual number of domains appropriate for low-cost simulation *application* was still higher. This high number reflects a.o. the potential value of (low-cost) simulation for new future applications. In order to further investigate the opportunities for low-cost simulation, A concise set of 9 military training areas was defined that represented the selected task domain. 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).

The remainder of the present work package consisted of three steps. In workpackage 1b for each military training area, more detailed data were acquired with respect to task- and cost-utility information (Helsdingen, Korteling & Van den Bosch, 1997, 1998). Subsequently, these data were analysed in the 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.

The present report describes the selection of 3-5 training areas and the global functional specifications of generic training simulators that could be developed for training programmes within these areas. These simulators will be the focus of further research, which ultimately (after 4 subsequent workpackages) aims at a handbook comprising guidelines for low-cost simulator development, acquisition, and its application.

The selection method involved objective and quantitative data as well as expert judgement. This was realized by a multi-dimensional approach involving all relevant information available and attained so far. This involved the consideration of the scores on the military task taxonomy, the field inventory, the training analyses, the cost-utility analyses, and expert judgements. Thus for each training area, six different scores were obtained and aggregated in order to come to a final decision about training systems to be further studied.

2 SELECTION METHOD

2.1 Introduction

The present chapter specifies the method that was used to select the training systems for further study. This involved scores that were mainly derived from previous parts of the project. In addition, some practical and expert considerations were included. Hence, the method is based on objective and quantitative data as well as on information relating to subjective judgement. Six kinds of data were considered, together involving all relevant information available and attained so far. This includes: the scores of the relevant task domains in the military task taxonomy on 8 criteria (Korteling, Van den Bosch & Van

Emmerik, 1997; Korteling et al., 1997), the results of the training and cost-utility analyses on the relevant task domains (Van den Bosch, Korteling & Van Winsum, 1997; Van den Bosch et al., 1997) which were based on the data gathered in the field inventory (Helsdingen, Korteling & Van den Bosch, 1997, 1998). Also taken into account were data derived from expert opinions on the generic nature and the complementarity (non-redundancy) of the technological problems that would be encountered and the knowledge that would be acquired.

2.2 Score 1: Scores on the selected task domains of the ELSTAR taxonomy

In the first part of the ELSTAR project, a methodology was presented for a first selection of military task domains that are considered most suitable for application of low-cost simulator training (Korteling, Van den Bosch & Van Emmerik, 1997; Korteling et al., 1997). The first score for the final selection was based on the same data that were already gathered and used in this part of this project.

In WP1.a a comprehensive taxonomy of military tasks was constructed. This ELSTAR taxonomy was structured according to six main military functions (MANOEUVRING INTELLIGENCE, etc...) and included a 100 military task domains.

In order to accomplish a preliminary selection of military task domains appropriate for low-cost simulation research, a number of selection criteria was formulated belonging to the following four main categories: training need, simulation need, generation of knowledge, and simulation feasibility. For the present preselected nine training areas, a high technological complexity of simulation was considered to produce a high cost-reduction potential (by low-cost simulation R&D). In contrast, the first selection, based on the task taxonomy scores of WP1a, involved a first global selection of domains suitable for low-cost simulation. For this purpose, high technological complexity was scored negative. Therefore, for the present purpose (i.e., selecting the training areas with the highest potential benefit of dedicated R&D out of these training areas that were already considered as suitable for low-cost simulation applications), the 6 *simulation feasibility* scores of the task taxonomy were not taken into consideration. The remainder of the taxonomy criteria is presented below. An elaborated explanation of these criteria can be found in the TNO report by Korteling, Van den Bosch, and Van Emmerik (1997) or the ELSTAR deliverable by Korteling et al. (1997).

1 *Training need*

1.1 High amount of training (time) needed to reach the training objectives

1.2 High number of trainees

1.3 High future significance

2 *Simulation need*

2.1 Unsafe to train without simulators

2.2 Impractical to train without simulators

2.3 Potentially effective to train with simulators, that is, *extra* training benefit

3 *Generation of knowledge*
3.1 At present satisfying simulator solutions are generally lacking
3.2 The problems to be solved for adequate simulation are challenging (non-trivial)

All task domains of the ELSTAR taxonomy were scored by consulting military and simulator experts with respect to the 8 aspects described above. The experts assigned to each task domain a minus (-), a zero (0) or a plus (+) for each criterion, where a + indicates good opportunities for low-cost simulation.

The scores on these 8 criteria served as input for the first selection measure (in the following referred to as "taxonomy score") of the present selection of generic training systems for further research. For this purpose, the score for each training area was derived from the total number of +, 0, and - symbols. A + counted as 1, a 0 as zero and a - as -1[1]. For the training areas covering more than one task domain (e.g., navigation) the mean score over all task domains was taken. This means that the maximum and minimum raw scores that could be attained were 8 and -8 points, respectively.

2.3 Score 2-4: Results of the training and cost-utility analyses on the selected training areas

The data for score 2-4 were based on the results of the previous ELSTAR deliverable (Van den Bosch, Korteling & Van Winsum, 1997; Van den Bosch et al., 1997). For more information about the method and basic assumptions pertaining to these data the reader is referred to these reports.

2.3.1 Score 2: Training analysis

In WP1.c training analyses were carried out on a representative set of critical subtasks for all 9 training areas that were inventorized and studied in WP1.b. The data that were gathered in WP1.b always pertained to one specific training programme at a specific training school that was considered relevant for the training area as a whole. This training programme was termed: the "common basis". The training analyses provided descriptions of the most critical knowledge and skills to be trained for the relevant tasks of these common bases. In addition, the most critical characteristics of the training environment to be simulated were described. This information was used as the second measure for appropriateness for further study. On the basis of the information provided in (Van den Bosch, Korteling & Van Winsum, 1997; van den Bosch et al, 1997) scores in terms of +, 0, or - were given, indicating [1] the need for simulation and [2] the complexity of the required simulations (high, medium or relatively low research challenge) for the relevant training. If both these aspects were considered

---

[1] Double + (++) was scored as 1. With regard to the mission management training area, the taxonomy scores of army, air force, and navy were averaged.

positive for the relevant training domain of the studied training programmes a + was given, one positive and one negative outcome of an evaluation resulted in a 0, and two negative outcomes resulted in a –.

2.3.2 Score 3: Utility analysis

In WP1.c cost-utility analyses were carried out on a representative set of critical subtasks for all 9 training areas that were inventorized and studied in WP1.b. The utility analyses were based on three different categories of information:

- Military value of the training area. This means how important the training is to the armed force, branch or special weapon to fulfil its typical mission. The more important an area is, the more it will be appreciated to develop low-cost simulators.
- Importance of training difficulties to overcome. This means how much effort it takes to train the required skills of a training area. The more difficult, the more low-cost solutions will be welcome.
- Availability of simulation technology. This means that if there is already simulation technology available (or in use), it will be a challenge to come up with better and cheaper solutions. If there is no simulation technology available, the possibilities to produce low-cost solutions are minor.

These main categories were further subdivided into lower-level utility criteria. This resulted in the following criteria tree that was applied to each common basis training programme.

- **Military Value of Task Domain/Training**
  - Combat/Mission Readiness
  - Lifetime of Training domain
  - Quantity of Students
  - Future Significance
- **Importance of Training Difficulties to Overcome**
  - Complexity of Instruction
  - Content of Training
  - Skills of Instruction
  - Availability of Training Resources
  - Environmental Restrictions
  - Training and Exercise Logistics
  - Instructors
  - Time Constraints
- **Availability of Simulation Technology**
  - Hardware
  - Software
  - Implementation.

For each training programme within a training area these criteria for utility were scored according to five scoring levels: 4 = highest justification for further low-cost simulation research and 0 = lowest justification (Van den Bosch, Korteling & Van Winsum, 1997; Van den Bosch et al., 1997). The results were separately calculated for 5 training programmes > 100 students per year (area 1, 2a, 3, 5, and 8) and training programmes < 100 students per year (area 2b, 4, 6, 7, and 9)[2]. Hence this resulted in a two utility rankings ranging from 1 (highest ranking) to 5 (lowest ranking), see: Van den Bosch, Korteling, and Van Winsum (1997), Van den Bosch et al. (1997).

2.3.3 Score 4: Cost analysis

Just like the utility analyses, the cost analyses of WP1.c were used for the selection of training systems for further study. The cost analyses considered the cost reduction potential with regard to the simulators for training, which is determined by simulation technology and personnel involved (mainly students and instructors). The following cost categories were used:

- number of students per year
- simulator hardware cost
- simulator software cost
- infrastructure cost
- updates of hardware and software in the years 6, 11, 16, and 20 life cycle years calculated in % from the procurement value
- instructor cost per student
- simulator maintenance per student
- student salaries for two types of students
- infrastructure operating cost.

The higher the cost, the more justification for low-cost simulation. Again, the results were separately calculated for training programmes > 100 and < 100 students per year, which produced two raw cost rankings, ranging from 1 (highest ranking) to 5 (lowest ranking).

2.4 Score 5: Genericity

Some tasks have very specific characteristics which have limited relevance to other tasks within a training area or domain. This also means that the knowledge that is generated by studying such tasks can not be generalized to other tasks within the same training area or domain. For example, weapon systems all have very specific interfaces and demand idiosyncratic ways of operation.

---

[2] In WP1.b, Area 2 was divided into 2a (APN helicopter) and 2b (APN fixed-wing) which were handled separately in the cost-utility analyses but were handled in combination in the present results chapter (by taking the average of the scores).

Furthermore, some task domains or training areas are broader than others and cover tasks that are common in many branches of military operation, e.g. vehicle driving or fault diagnostics. In order to cover both aspects, all training areas were evaluated with regard to [1] the *homogeneity* of the training domain, which indicates the generic nature of specific training programmes (such as the common basis) within the training domain as a whole, and [2] the *broadness* of the domain with regard to the operational missions of the armed forces. Both aspects determine the genericity of knowledge that relates to training systems used for training programmes within training domains. If both these aspects were considered positive for the relevant training domain of the studied training programmes a + was given, one positive and one negative outcome of an evaluation resulted in a 0, and two negative outcomes resulted in a -.

2.5 Score 6: Complementarity

Different training areas may overlap in the kinds of technological and functional requirements for simulation. Selecting overlapping areas would result in investigating similar questions and would thus lead to a high degree of redundancy in the project. In order to prevent unnecessary redundancy, the degree of overlap among the different training areas was taken into account. Because the final selection of training systems for further study would be based on a subset of 3-5 training areas of the present 9 training areas, determining the degree of overlap for each training area in relation to all other training areas was not considered to be effective. In that case, the resulting scores for each training area would be based on complementarity with irrelevant training areas, i.e., the training areas that finally would not be selected for further study. Therefore, it was decided to evaluate complementarity after a first selection of the training areas was made.

2.6 Construction of total scores and selection

In order to make the measures with quantitative scores (taxonomy, utility, and cost) comparable to the ordinal measures, the former scores were transformed into +, 0, and - in the following manner:

- for the taxonomy scores, the highest two scores were transformed to +, the lowest two scores to -, and the scores in between to 0;
- with respect to utility and cost, the raw scores 1-2 were transformed to +, the raw scores 2,5-3,5 were transformed to 0 and the raw scores 4-5 were transformed to -.

Subsequently, the sum of the total set of plus, zero and minus scores was calculated for each training area. Training areas with a compound score > 0 were preselected.

A matrix was then constructed in order to estimate the degree of complementarity among all pairs of selected training areas. The degree of complementarity was estimated by simulation experts. Scoring of complementarity was conducted according to the following schema:

- score +: complementary
- score 0: partly overlapping
- score -: greatly overlapping.

Finally, the combination of training areas with the lowest degree of overlap was selected for further study.

3 RESULTS

Table I shows the raw scores on the selection criteria for each training course. The first column indicates taxonomy scores: the Stinger and M109 training courses had the highest total score, whereas the mission management training course scored lowest.

The training analyses scores showed that only two training areas were considered not to be suitable for low-cost applications, these training areas were M109 and fault diagnostics. Utility analysis yielded scores that were highest for M109 and fault diagnostics, and lowest for FAC training and driving. Cost analysis resulted in a high score for driving and navigation, and low scores for fault diagnostics and mission management training. Finally, the criterium genericity, showed that further research into low-cost simulation opportunities for Stinger, M109 and FAC training courses was not expected to yield results and knowledge applicable to the whole task domain or other training areas.

Table I Raw scores on the selection criteria.

		Taxonomy	Training analysis	Utility analysis	Cost analysis	Genericity
1	Driving	6	+	5	1	+
2	Navigation[3]	5.5	0	2.5	1.5	+
3	II/IR	6	+	3	3	0
4	UAV	5	+	4	2	0
5	Stinger	7	+	4	4	-
6	FAC	5	+	5	3	-
7	M109	7	-	1	4	-
8	Fault diagnostics	4	-	1	5	0
9	Mission management	4,5	+	2	5	0

[3] Navigation scores were calculated by taking the average of two scores, one from rotary wing training and one from fixed-wing training.

Table II shows the transformed scores on every criterion for each training area. Five training areas had a total score of 0 or higher:

- driving;
- navigation;
- infrared and image intensifier operation;
- UAV operation;
- mission management.

Table II Transformed scores on each criterium.

		Taxonomy	Training analysis	Utility analysis	Cost analysis	Genericity	Total score
1	Driving	0	+	-	+	+	2
2	Navigation	0	0	0	+	+	2
3	II/IR	0	+	0	0	0	1
4	UAV	0	+	-	+	0	1
5	Stinger	+	+	-	-	-	-1
6	FAC	0	+	-	0	-	-1
7	M109	+	-	+	-	-	-1
8	Fault diagnostics	-	-	+	-	0	-2
9	Mission management training	-	+	+	-	0	0

These five training areas were then analysed on their complementariness (see Table III). Navigation training for helicopter or fighter bomber pilots, includes navigational tasks that were also covered by II/IR training course, and platform control tasks that were covered by driving and UAV training. Specific issues related to control of a flying platform, were to some extent covered by UAV training. Thus, navigation training had overlap with driving, UAV, and II/IR training.

The other training areas were considered to be complementary. More in specific: leaving out navigation would eliminate all "0" and "-" from Table III, thus resulting in a completely complementary, non-overlapping set of training areas. This set of training areas selected for further research comprised: *Vehicle driving, II/IR operation, UAV operation,* and *Mission management training*.

Table III Complementary matrix for training areas that scored 0 or above on the former criteria.

		1 Driving	2 Navigation	3 II/IR	4 UAV	9 Miss. man.
1	Driving		0	+	+	+
2	Navigation	0		0	-	+
3	II/IR	+	0		+	+
4	UAV	+	-	+		+
9	Mission management	+	+	+	+	

4 FUNCTIONAL SPECIFICATIONS

The present chapter presents the global functional specifications for generic low-cost training systems that may be applied within the 4 selected training areas (1, 3, 4, and 9). The specifications are an elaboration of the results of the training analyses performed in WP1.c (ELS-DEL/1-C). The specifications are not based on explicit assumptions as to the types of trainees, the kinds of training trajectories, the possible use of other (advanced) training devices, etc. Thus, they are very global and only intended to provide the reader with an idea of the kind of training systems with which the study will continue in the next workpackages.

4.1 Driver training simulator

Given the relatively low exploitation costs of most kinds of wheeled vehicles, the basic assumption is that only limited-scale simulations (i.e. no full-scale simulations) can be cost-effective. Such a limited-scale simulation system should only provide for the possibility to train basic skills of the drivers course (i.e., with full transfer of training *and* with high training effectivity).

4.1.1 Tasks to be trained

For driver training three main tasks (task clusters) were selected:

1 *Basic functions of vehicle control*
The most important training goals of these subtasks involve learning how the vehicle operates, the movement-force control characteristics of the controls, and how it responds to these control actions. The driver has to be trained to start the engine and use the gear properly, to decelerate gently for a traffic light or a decelerating lead vehicle and to negotiate curves, intersections and small roads, and to park the vehicle without hitting obstacles. These basic functions can be circumscribed as follows:

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

2 *Traffic participation*
The most important training goals of this subtask concern the training of cognitive skills and of perceptual-motor skills.
The cognitive skills include the application of knowledge of traffic rules and regulations and the accurate and fast recognition of traffic situations that demand a safe response of the driver. For the training of the cognitive skills the environment to be presented has to be rich enough to train a sufficient amount of different relevant traffic scenarios.
The perceptual-motor skills refer to how and when the response of the driver to other objects is executed, to estimate gaps in the traffic stream while negotiating intersections, to evaluate whether overtaking is safe and so on. All this requires the training of recognizing the spatial and temporal characteristics of the vehicle in relation to other objects.

3 *Terrain driving*
In terrain driving, depth cues at close range are more important compared to the tasks of vehicle control and traffic participation. For example, the quality of the subsoil, the depth of potholes, ditches and the hight and solidity of obstacles must be evaluated accurately in order to choose the right speed and gear. Thus, terrain driving may require stereoscopic presentation of visual information with a very high level of detail. Terrain driving will require substantial expenses with regard to [1] the complexity and amount of detail in visual databases, [2] the capacity of the image system, [3] the dynamic vehicle model and vehicle-terrain interactions, and [4] the motion system.
Therefore, the chance that this subtask can be trained efficiently (and with a high transfer of training) on a low-cost simulator is considered to be low.

4.1.2 Functional specifications

Image system requirements

For traffic participation training, the horizontal field of view (FOV) needs to be large, while the information of the rearview mirrors must be available in some form as well. Under normal circumstances a vertical FOV of around 40 degrees should be sufficient. The outside image may be controlled and activated by a head tracker such that the potential visual field is quite large, without having to put extreme demands to the capacity of the image generator, given a sufficient resolution.

The critical objects required for driving, such as traffic signs and traffic lights, must be visible and recognizable from a distance of at least a few hundred metres in front. The resolution of rearview images may be lower.
The estimation of distance and speed of objects, and especially time to reach objects, is an important cue for driver control actions. It is therefore important that the optic expansion of relevant objects is fluent and accurate. This means that the frame rate must be sufficient, that the resolution must be high enough and that the graphical simulation of the size of objects as a function of distance and angle must be accurate.

Databases

A static road layout with all usual kinds of curvatures is needed for training steering and speed control during curve negotiation. For this, an accurate vehicle model that responds realistically to driver control actions and road friction is indispensable. The driver has to be trained to adjust speed for several different kinds of road curves and to detect the relevant characteristics of the road segments well in advance.
With regard to the training of traffic participation, all types of road and road furniture have to be presented such that the driver learns to recognize the restrictions it puts on the maximum velocity and the types of other traffic that can be expected on roads of that type. Also, the driver has to be able to decide under time pressure whether it is safe to merge into another traffic lane, to give right of way, to pass, etcetera. This requires the simulation of other traffic participants who behave realistically and who provoke situations in which the driver is confronted with these decisions.

Vehicle control

Vehicle controls, for example a steering wheel, a brake, an accelerator, a clutch and a gearstick, have to be represented realistically in a mockup, together with instruments in a dashboard panel that give feedback of speed that may be required for gear switching. For training steering and speed control during curve negotiation, control force and displacement (force-distance diagram) of the break, gas and gear pedals, the gear box and the steering wheel match those of the actual vehicle in similar circumstances. The reaction of different control mechanisms when they are released, should match reality. Possible dependence on driving speed of control force should also be implemented in the simulator. Above all, for vehicle control training, an accurate vehicle model that responds realistically to driver control actions and road friction is indispensable.

Other systems

For training procedures such as starting, driving off and gearing it is required to have a mockup. The interior of the cabin should be a replication of the original vehicle.
Especially for vehicle control, auditive cues are important. In this respect, auditive feedback of engine noise that covaries correctly with gear switching and rotations per minute is an

important cue for the training of vehicle control. The amplitude and frequency of noises and sounds shall be realistic. Sounds to be simulated should be correctly related to speed and engine rotation speed for intensity, pitch, and timbre. If appropriate, sounds should be correctly related to engine load for intensity, pitch, and timbre. The sound effects should reflect the following sources: wind and wheels, engine, cabin resonance, changing gears. These sources should be recognizable as for direction and character. If relevant, the system should present special sounds when starting the engine, or when driving against obstacles (sound of crashing). If applicable, sound should be synchronized with image and mechanical motion.

The system includes vibrations but longitudinal mechanical motion cueing must be simple. A vibration system masks the absence of mechanical movement. If a fixed-base system is chosen, vibration feedback should be given. Such a system shall at least provide vibration information, that is related to the frequency and amplitude of motor vibrations, through the seat (and possibly through control apparatus). Other sources of vibration (surface of the road, gearbox) do not have to be present in naturalistic way.

4.2 II and IR image simulator

Modern warfare more and more requires forces to be able to operate at night and under poor sight conditions. In this connection II and IR equipment is used by the commander and gunner of a tank. They are used in a complementary way, that is: both systems have certain characteristics (possibilities and limitations) that make that they can be used very effectively in *combination.*

4.2.1 Tasks to be trained

At low illumination levels, image intensifiers provide a fairly clear picture of the environment, with a range of a few hundred metres. Such devices are therefore often used to achieve platform mobility (platform movement and navigation functions) during the night. Thermal sight equipment, utilizing infra-red technology, detects temperature differences in the environment and displays the shape of heat-emitting objects. Such devices are used for detection, identification, and engagement of targets during night- and daytime. When thermal differences are minimal (e.g. late at night) II equipment can also be used for target detection purposes, etc.

Two main subtasks of the task of a tank commander are relevant in the context of the use of II and IR optical equipment:

1 *Observation and navigation*
In “observation and navigation”, the commander determines the tank’s whereabouts and inspect its surrounding environment. The training objective directly related to this training area is that the commander must be trained to use the image intensifier equipment to inspect

the (immediate) environment of the tank, to determine the appropriate path to achieve a given or desired position, and to give directions to the driver accordingly. He must be trained to perform this task in different environments and situations, including rugged terrain, (flat) country roads, urban areas with traffic, and hostile or unknown areas with possible targets. In addition, the task must be trained under different tactical conditions (friendly, tactical engagement).

2 *Target acquisition*
In "target acquisition", the tank commander must constantly scan the environment for possible targets, using the assistance of IR or other optical equipment such as image intensifiers. The latter are used simultaneously to scan the environment for objects that can not (easily) be detected with thermal image. Once an object (vehicle, helicopter, warrior, squad) is detected, the commander must determine its type, direction, and whether it is a friend or foe. In that case IR and II equipment is often used in a complementary way, i.e., detection with one and identification with the other. The range of view in target acquisition is mostly larger than in navigation tasks. Target acquisition is typically performed under high-threat conditions, in all kinds of environments, including rugged terrain, (flat) country roads, and urban areas. For target acquisition purposes, thermal image devices are not only used during night time, but also during day time when the enemy uses camouflage.

Training tank commanders to perform these functions in a simulated task environment demands the generation of the critical cues for both image devises. The characteristics of a low cost simulator for the dedicated training of using these optical devices in observing and navigation and in target acquisition will mainly be determined by the imaging device requirements (as part of the operating environment) and by the cueing requirements as provided by the imaging system, the visual databases (including mathematical models), and the operational scenarios. Below, this will be discussed for both main tasks of the tank commander. Possible additional, and more secondary, systems will not be discussed.

4.2.2 Functional specifications

General operating environment requirements

- The visual quality of the display (image size, resolution, brightness, field-of-view, etc) should be identical to the original equipment. This can be achieved by using an original display in a trainer (e.g. II equipment and an outside display with very low luminance levels; for IR equipment this option seems less feasible), or by a high-fidelity simulation of the major visual characteristics of II and IR images.
- The controls and displays (metres, levers, buttons) do not necessarily have to be high-fidelity, because they are not essential to the critical aspects of the task: i.e., visual information processing.
- Both the II and IR equipment should be available at any time because it has to be used in combination.

Scenario and visual cueing requirements

In order to provide a valid learning environment for training of navigational skills, a simulator must be able to generate the visual cues that are relevant to navigation and target acquisition in sufficient quantity and with a sufficient level of detail. The scenario and visual cueing requirements must involve conditions of tactical engagement.
For target acquisition, IR equipment is of major importance, although II equipment may be very useful as well. In order to provide a valid learning environment for training in thermal image target acquisition, a simulator must be able to generate the relevant visual characteristics of thermal images of all kinds of terrain and objects. In order to be able to scan and search visually, this has to be presented over a large field of regard. The visual information generated by the real device is determined by a number of factors, including: the quality of the thermic sensor, the heat-absorbing and heat-emitting qualities of terrain and objects, and thermal conditions (time of day, humidity, wind direction and speed, atmospheric pressure, etc.). Especially when images need to be presented from a moving point of view (e.g. a riding tank), then the constantly changing images need to be generated in real time. This, however, is not feasible with the present and near-future state of the art in technology.
However, in a training simulator, only part of the effects of these factors on the image should be simulated. At this stage of analysis, full-fidelity simulation does not seem to be necessary for purposes of (initial) training. It seems a little far fetched that only simulated images that resemble real images with regard to all dynamic and relational properties that may be encountered in reality. The number of relevant combinations for the nature of IR images, as determined by terrain characteristics, target properties and behaviour, time of day, humidity etc is almost infinite. This means that the variety of real images is also infinite. Training should therefore focus on the most essential features of the images and on the interpretation of these features in relation to realistic scenarios. In addition, real images may be presented with video as well. In times of conflict, a tank commander must be able to detect and identify objects and vehicles on their thermal pattern, as registered by IR equipment supplemented by II.

The cues that are relevant differ for each type of environment. Below, two main environmental categories are discussed:

1 Navigation and target acquisition in *rugged terrain* requires the following database elements:

- all kinds of surfaces such as terrain, rocks, paved road, dirt road
- static objects that are closely associated with these surfaces such as rocks, grass, small plants, lamp posts, etc.
- other static objects such as trees, bushes, buildings, bridges, rocks, shacks, concealed parked tracked vehicles, friendly and enemy artillery installations, etc.
- dynamic objects, e.g. friendly or hostile weapon platforms, other battlefield vehicles, infanterists, etc.
- obstacles such as fissures, fences, etc.

2 Navigation and target acquisition in *urban areas and non-residential country roads* requires the following database elements:

- roads and road elements (delineation, roundabouts, bridges, intersections, poles, traffic signs)
- static objects such as buildings along the road, bridges, cross-roads, intersections, road blocks, railways, etc.)
- relate features and objects, perceived through his optical device, to symbols on a map, so that position can be localized
- dynamic objects (oncoming and passing vehicles, friendly or hostile weapon platforms, snipers, etc.)
- obstacles such as road blocks, etc.

Especially the friendly or hostile elements, such as weapon platforms or snipers should be positioned and located at realistic positions in the database and behave as real actors.
During times of conflict or war, the commander must be able to navigate solely by using optical devices (e.g. II, IR, periscope, video). Fortunately, the road dynamic scenes are much less complex during tactical engagement operations than during peace time (no pedestrians, cyclists, cars; only friendly and enemy (military) vehicles). This means that the training scenarios do not need the complex representation of other civilian traffic.
Target acquisition is a task that is typically performed under high threat conditions. Especially for IR equipment training, the field training is therefore difficult to realize because during peace time the thermal scene of urban areas is much too complex (too many cars, pedestrians, and other heat sources). In the future, simulation may be used to create scenes of urban areas under conditions of tactical engagement, thus opening training possibilities that are hitherto not feasible.

4.3 UAV crew training simulator

The common basis for this training area was the training of the external pilot. This training course was selected because it was not possible to get access to detailed information about the training of internal pilots, image interpreters (analysts), and crew commanders. However, it is likely that low-cost simulator training for these latter internal crew members is much more feasible and fulfils a higher training need. The fact that these operators perform their task in a degraded operational environment (e.g. no sense of vehicle movement, limited visual information) indicates that the technological demands required to simulate task-relevant cues are lower than for simulations of manned systems. Therefore, the tasks to be trained and the functional specifications will concern a generic trainer for internal UAV operators.

4.3.1 Tasks to be trained

The (internal) control station crew of a UAV system usually consists of a commander, an image analyst/operator and a platform operator/navigator; these functions may be automized

and performed by fewer persons. This crew has to be thoroughly trained for different kinds of missions (such as reconnaissance and battle-damage assessment) in a variety of environmental and tactical conditions. Establishing a training program using the operational system itself (field training) has practical, financial, didactic, and legal drawbacks. Practical problems of field training are, for instance, obtaining or designing (sufficiently large and realistic) practice locations, reserving locations well in advance, setting up (concealed) targets, and realizing critical environmental- and tactical conditions. Financial drawbacks of field training are that high investments in terms of money and man power are required, and the danger of damage as a result of equipment failures or human errors. Didactic drawbacks are poor transfer of training due to unrealistic and static scenario's, and waste of training time during periods of poor weather conditions. Furthermore, field training generally has poor possibilities for performance measurement and feedback. Finally, realization of field training may be hampered by legal restrictions (e.g. obtaining flight authorization, mandatory deployment of a chase plane).
These problems ask for training aids that are less dependent on laws, training areas, expensive equipment and environmental and weather conditions. However, one problem often encountered in the area of training simulators is that affordable (low-cost) simulators show low fidelity. In many cases this leads to moderate or low training value *or* to huge financial or technological investments that have to be made in order to attain sufficient training effectivity. For the simulation of unmanned vehicles the real operational control information and information presentation is already simplified and degraded relative to manned interfaces. Therefore, technological demands to realistically simulate tasks are lower, which means that affordable and high fidelity simulation will be much more within reach given the present, and near-future, state of the technology.

Functional specifications for a UAV crew trainer can be divided into two major components. The first being simulation of the *outside image* with realistic databases and training scenarios, which is mainly relevant for the image analyst/sensor operator. Also, simulation of the *platform control* facilities has to be considered, such as the system monitoring and navigation displays and controls, which are most relevant for the platform operator/navigator. In addition, some general requirements can be formulated.

4.3.2 Functional specifications

Outside image

Image analysts have to monitor, analyse and interpret sensor images and may control some major image parameters such as zoom-factor, contrast and viewing direction. This is primarily a perceptual-motor task. The simulated outside image should be an exact duplication of real sensor images (resolution, field of view, field of regard, update and refresh rates, contrast ratios, etc.). For video images, this requirement must be feasible given the present state of technology since the operational environment for unmanned systems operators is already degraded relative to that of manned systems. Therefore, the technological demands required to simulate all task-relevant information are relatively low. For IR sensor requirements, the reader is referred to § 4.2 of this report. For radar images, also a high resemblance with regard to the critical visual cues of real images is required. Partly depending of the kinds of missions, visual databases for video, IR or radar images should contain the following elements:

- all kinds of landscapes and surfaces such as rugged terrain, urban areas, mountains, swamps, agricultural areas, woods and forests, etc.
- static large objects that such as rocks, bushes, and trees, buildings, shacks, rivers, lakes, mountains, paved and unpaved roads, railways, bridges, etc.
- dynamic objects, e.g. friendly or hostile weapon platforms, vehicles, persons, etc.

From the perspective of tactical training, especially hostile weapon platforms, vehicles, barricades, troops etc. should be presented in a lifelike way according to realistic operational scenarios. The simulated environments that have to be explored should reflect plausible tactical concepts and physical situations that may be encountered in real warfare and that are maximally relevant to the kinds of missions the system is intended for.

One possible solution to produce high fidelity images for all kinds of sensors is to use prerecorded sensor information. This, however, has two major drawbacks: [1] prerecorded sensor images cannot be used in an interactive way, and [2] the production of a sufficient number of relevant operational scenario's that are characterized by a very high number of possible tactical and physical characteristics. This actually implies that the use of prerecorded images is only relevant for the individual passive perceptual tasks of the image analyst. That is, the image analyst is then trained in watching a monitor presenting these images. This can be done with the help of an instructor or by computer-based instruction. Both ways of training do not fulfill the criteria of (interactive)simulation, since there are no operator activities involved that can affect the course of events and/or what can be seen by the operator. This means that all other subtasks, involving image sensor control and communication of the image analyst with navigator and mission commander cannot be trained such that still an additional crew training facility will be needed.

Platform control

Platform control involves the control of the flight vector (magnitude, direction) of the sensor platform on the basis of information from displays such as the air speed indicator, clock, compass, altitude- and attitude indicator, vertical speed indicator, and displays providing information about the environment below such as a digital geographic map (displaying a.o. the camera footprint). Not all of these displays necessarily are implemented in all UAV systems, but most of them will be. The task mainly involves flight (i.e., keeping the platform in the air) and navigation (steering the platform to specific locations while taking threat conditions into account). In UAVs the platform control tasks are always to a certain degree automated. Therefore, launch and recovery are completely procedural tasks in which the operator has to execute system settings and perform checks in a strict and fixed order. The actions involved in cruise flight are often limited to the setting of way points, which determine the flight path, and monitoring the system parameters (e.g., oil temperature or fuel). The system itself usually will check whether the entered way points are aerodynamically possible to achieve. In case of unexpected events or technical failures, the task may become more heterogeneous, requiring problem solving skills and perceptual motor skills both to be carried out under time pressure. For example, the predetermined flight path has to be adapted with the keyboard, mouse or joystick.

Simulation of these task elements requires a correct, and rather complicated, model of the movement dynamics of the UAV under varying conditions of wind speed and direction, air temperature and simulated system failures. In addition, the model must provide correct input to the flight and navigation indicators. However, the rather subtle perceptual-motor interactions with the system requiring the coupling between the control panel actions and perceived movements of the platform as required for example in landing a manned aircraft, are not required in UAV platform control. Therefore, the dynamic model may be a little more crude than what is required in high fidelity simulators for manned aircraft training. The higher the perceptual-motor demands of tasks, the higher the dynamic model requirements. When, for example, the platform can be steered with joysticks (or comparable analog controls) on the basis of visual inputs from an outside display, the perception-response coupling between the control panel actions and the calculated movements of the platform, and the resulting visual presentation of the platform's dynamic behaviour to the perspective of the external pilot, must be highly realistic and thus the dynamic model should come very closely mimic the behaviour of a manned system. Other display and control requirements are discussed below.

General requirements

The control environment of unmanned systems is stationary, which means that vibrations and other, more longitudinal, motion cues are not available to the operator. Therefore, motion information, as provided by motion platforms and/or seat shakers, is not needed for training simulators.

It is in general not difficult and expensive to duplicate the console, including all relevant controls and displays (except the outside image). Therefore, in order to create a training environment that is as realistically as possible (also for the crew commander), the console and the inside of the cabin should be an exact replication of the original system. In addition, control force loadings of control instruments (usually joysticks), sound displays and cabin light conditions must resemble those of the original system.

4.4 Mission management simulator

Full troop exercises are becoming too expensive and are no longer socially accepted when they take place outside the military training grounds. This means that training opportunities in the field are limited. In order to maintain a certain degree of operational readiness, new training methods have to be developed for training of battalions and their commanding officers.

Within the ELSTAR project, training of the commanding officers was covered by one of the training areas under investigation, i.e. mission management at the warrior or staff level. Since the skills to be trained are mainly cognitive and based on abstract information (verbal, quantitative, maps), the technological challenges for the development of mission management trainers mainly involve scenario generation, the validity of the models, and instruction and feedback facilities.

4.4.1 Tasks to be trained

The operations officer has to prepare and lead the operations of a battalion. These operations include both defensive and offensive tactical manoeuvres, in low and high intensity conflict situations. A tactical plan has to be made, taking into account all limitations and possibilities provided by the own means, the environment, the enemy and the mission that is imposed. The plan then has to be briefed to the subordinate commanders, and during execution of the plan, adjustments have to be made as a result of a constantly changing situation.
Planning and executing the missions of a battalion involves four principal tasks: [1] time management, [2] tactical planning, [3] tactical field briefing, and [4] command and control (ELSDEL1b). Within these tasks, several subtasks can be identified, however, for the present, this subdivision is not necessary.

1 *Time management*
When the operations officer receives an (warning) order, he has to start planning the actions of the battalion and command post. This involves making an inventory of critical moments, calculating and determining the times of movements and the time needed to go back and forth between briefing points of lower and higher control levels, taking into account the environmental conditions and the (technical) capabilities of the units. Next, a timetable has to be constructed, using the critical path method. In this timetable, briefings and movements are defined in real time.
The training of the operations officer for the task of time management should include acquiring knowledge of capacities of own forces, and the possible impact of environment and enemy forces upon performance of own forces, and skills in preparing comprehensive and logically consistent mission time tables. As a result of their prior military experience, trainees are usually very well informed about aspects of military material and warfare.

2 *Tactical planning*
Tactical planning incorporates making a tactical analysis and choosing the best solution. The tactical analysis is the study of the main determining elements in the tactical plan, in order to make up a list of possible manoeuvres from which the best solution can be chosen. Determining elements are for example the mission, the enemy situation, the own means (units and their equipment) and the environment.
For the task of tactical planning the operations officer has acquire skills in producing and evaluating alternative mission plans and to select the best, knowledge of military warfare techniques and history in order to prevent "classic" mistakes in the tactical plan, knowledge

of capacities of enemy forces, and knowledge of capacities of own forces, taking into account the possible impact of enemy forces and the environment on performance of own forces.

3 *Tactical field briefing*

Tactical field briefing is to instruct and inform the lower level units about the mission. The operations officer will brief the subordinate commanders at the site where the action will take place. Tactical field briefing includes choosing the exact spot to give the briefing, orientation, preparing the order, giving the order, and checking.

A competent operations officer should have skills in briefing lower level control, which include: the selection of a proper briefing spot, to effectively and efficiently communicate the selected plan, and to discuss "what-if" scenarios.

4 *Command and control*

Once the mission plan has been made and translated into orders for the subordinate units, it will have to be implemented. During this phase, the operations officer has to observe all activities of the troops and adapt the mission plan if enemy threat or new higher-level orders require so.

For this command and control task, the operations officer has to acquire skills in mission management, such as requesting and providing information from lower- and higher-level control, (rapidly) evaluating incoming information, developing and issuing plan adjustments on-line, and exchanging information with same-level control in coordinated missions.

4.4.2 Functional requirements

Training of time management [1] and tactical planning [2] skills does not require advanced training aids. These skills can be trained in a traditional learning environment, simply with a map, calculator, paper and pencil. This type of training does not provide opportunities for cost-reduction by implementation of low-cost simulator systems.

The task of tactical field briefing [3] requires skills in briefing lower-level control. This can best be done either in the field (choosing a proper briefing spot) or in a setting with real public (communicating plans), such as role playing instructors or representative soldiers.

Acquiring mission management skills, required for the command and control task [4], can be realized by field training with full troop exercises or by symbolic exercises, where troops are represented as symbols on a map, the instructor controls the scenario, and has to implement the outcome of the officer's actions on the situation. Both of these training methods have drawbacks: full troop exercises are expensive in terms of money and effort, and symbolic training is not very flexible and dependent on the instructor's skills in judging situations and impact of specific manipulations on this situation.

Therefore, training of mission management skills, higher training efficiency and cost-reduction can be realized with simulation. The challenge for simulation is to model the behaviour of military units involved (both friendly and enemy). Furthermore, a simulation should include different scenarios of several types of missions, and provide the instructional facilities such as scenario generation and control, feedback, and performance measurement.

Below, the focus will be on the functional specifications that are related to the training of the command and control task, i.e. training of mission management skills.

General operating environment requirements

Mission management mainly requires cognitive processes to be trained such as obtaining and providing information, combining information sources, acknowledging events that may threaten mission success, unfolding adequate responses, and implementing and directing plan adjustments. The tools and instruments that the officer has in the operational environment can be implemented in a simulator system. These tools and instruments include:

- a (digital) map,
- communication equipment (visual displays for written messages, auditory displays for verbal messages),
- reconnaissance information (enemy location and movement, environmental factors such as terrain, weather, roads) presented on screen or through verbal messages,
- information on military procedures and rules of engagement, most of the time available in documents, and
- input devices such as keyboard, mice.

Scenario requirements

In order to provide a valid learning environment for the training of management skills, the scenario should bear great resemblance with the real-life operational situation. This means that the simulation database has to contain information on:

- terrain of battle field,
- roads and road elements,
- static objects such as houses, buildings,
- dynamic objects such as own forces' vehicles, enemy vehicles,
- weather phenomena and time-of-day,
- impact of several weapon types on environment and enemy equipment,
- vehicle movement characteristics,
- behaviour of enemy forces,
- supplies of weapons, ammunition, food, medical support, and
- logistical constraints.

The database does not have to contain visual information of the environment, since the trainee will not use direct visual information. Instead, the information presented to the trainee is indirect, an abstract form of information. The dynamic model uses information on the environmental factors to calculate the impact of actions upon the situation in the battlefield, in real-time, reflecting the real situation as closely as possible.

Instruction facilities

The instructor has to be able to generate and control the scenario, change settings during a training session, monitor behaviour and performance of the trainee, and give the trainee instructions or feedback. The instructor can be supported by a closed video circuit to monitor the trainee, communication equipment to instruct the trainee, the hard- and software to interfere in the scenario, and a performance measurement system, that provides "play-back" opportunities for evaluation.

4.5 General instruction facilities

Training simulators not only have to mimic an interactive system, they also need facilities aiding the instruction process itself. These facilities are mostly concentrated at the instructor operation station (IOS). Below, a very brief overview is provided of the most common elements constituting the instruction facilities.

4.5.1 Student monitoring

- The control panel shall be positioned such that the instructor can operate his instruction system and simultaneously is able to observe the actions of the trainee. All information displays and all controls for the instructor must be perceivable and operationable from one central point.
- When relevant, the instructor shall have at his disposal the same outside world image and the same information from other displays as the student, such that he can evaluate the behaviour and take over control.
- All metres, instruments, and displays of the trainees console should be clearly visible (direct or indirect on the console).
- Due to de restrictions in the outside world information, the instructor should have additional means, with which he can have a right impression of the system in relation to its immediate environment (for example bird's-eye-view).
- Instructors shall have at their disposal briefing facilities including record and replay systems.

4.5.2 Simulator operation

- The instructor must have at his disposal preprogrammed scenarios which are didactically considered (in which decisions must be made, and which teach something relevant). He shall be able to design and store training scenarios in advance of the simulator session and to activate these scenarios during training sessions. The scenario-operation procedures must be simple (selecting one of the alternatives with one push of a button). Similarly, exceptional and complicated circumstances must be easy to control.

- The instructor must be able to easily select and set at least the position of the system in the database and to manipulate the outside environment with respect to all relevant conditions, such as weather or tactical conditions.
- The instructor must be enabled to easily select and generate the most relevant malfunctions and to switch on and off all indicators/displays in the console (for example oil pressure). He must be able to adjust internal system parameters such as fuel level or amounts of ammunition. Disturbances enforced this way must be continuously visible on the instructors panel.
- Selection and full recording and replay of parts of the training session should be possible. Reproduction of recorded parts must be possible (separately).
- The simulator should be equipped with facilities for administration of: student, class, platoon, driving school, certificate of theory exam, training sofar, lessons, hours, kilometres, performance data.

This data should be presented in a comprehensible way by means of a monitor screen a printer.

4.5.3 Automated instruction and performance measurement

For simulators, automation of components of the instructor's task is in principle possible. To which extent this may be implemented effectively depends on a large number of factors. In brief, this depends on the amount of knowledge on the involved task and possibilities concerning:
- exact defined measures for the quality of the behaviour (per task, per individual or per team)
- criteria for the different sorts of optimal, correct and fault behaviour
- feedback systems and procedures adjusted to the nature of the registered behaviour
- training modules which offer a training condition and accompanying instruction and feedback on the basis of selected training objectives
- a training model that makes a diagnosis of the registered behaviour, on the basis of which it closes, repeats, or invokes new training modules (Korteling, 1991).

5 DISCUSSION

5.1 General discussion

Four training areas are selected for further research into low-cost simulation. These training areas are:
- driver training,
- training the use of image intensifier and infrared equipment,
- training of UAV crew, and

- training of mission management.

These training areas offer great opportunities for the implementation of low-cost simulation: training can occur more efficiently and/or at lower cost when simulators will be used.

The selection is based on six different measures, viz. taxonomy scores, scores based on the training-, the utility- and the cost analyses (performed in WP1.c of this project) and expert opinions on the generic nature and complementarity of the foreseen technological problems and knowledge that will be acquired. These measures show some overlap, thus all issues that are related to low-cost simulation are covered by one or more criteria. Furthermore, they have distinct effects on the selection process, as will become clear by the examples given below.

The training need criterion is included in the taxonomy score and in the utility score as well. However, "training need" refers to the need (amount) of the required training itself, whereas "utility" refers to the military value of the task domain and training. Training need is specified by the amount of trainees, training time and future significance. Utility scores are, on the other hand, based on many other measurements such as importance of training difficulties to overcome, and availability of simulation technology. In addition, the utility (and cost) scores are based on explicit data gathered about one specific training course (the "common basis") within a much broader training area, whereas the taxonomy scores are derived from global opinions of military and simulation experts about complete military domains. These different combinations of factors makes that training need constitutes a significantly different score than utility.

The same kind of argument holds for the resemblance between the generation of knowledge criterion incorporated in the taxonomy score, the complexity of simulation (research challenge) that is considered in the training analysis score, and the expert opinion score on complementarity of training areas. These three issues all refer to the knowledge that can be acquired through research into the possibilities for simulation for a specific training area. The ELSTAR taxonomy criterion takes into account lack of existing satisfying simulators and problems to be solved for adequate simulations in the scores on generation of knowledge. However, the training analysis score considers complexity of the required simulations as a basis for knowledge generation, whereas the expert opinion score on complementarity of training areas considers the overlap between training areas. Thus, although all three scores refer to knowledge generation opportunities, the basic considerations for the scores are significantly different, rendering distinct scores.

The selected training areas cover a broad range of military tasks. Thus, the results of further research into these areas will also be applicable for many other military training courses. Below, each selected generic training system will be briefly discussed.

5.2 Driver training simulator

The rationale for selecting driver training as a suitable area for implementation of low-cost simulation, is the high costs of training, the genericity of the training area, the high need for simulation, and the complexity of the required simulations. The high costs of training are mainly caused by the high number of trainees per year, and the high need for instructor support. Despite the relatively low cost of the conventional training system (for most wheeled vehicles) a simulator can be cost-effective because it reduces the need for instructor support. The low costs of the conventional systems, however, stresses the need for a specific low-cost simulator system, and this makes driver training a very challenging area.

The driver task requires many skills to be trained. Perceptual motor and procedural skills prevail in the task of vehicle control, whereas the task of traffic participation entails cognitive and perceptual motor skills. This broad range of skills that is involved in driver training will make the results of further research into this area applicable for more training areas, such as navigation and air platform control in low-altitude flight.

5.3 II and IR image simulator

The selection of the II and IR training area is based on the complementarity criterion, on the significance of the equipment in warfare, and on the complexity of simulation. The scores on the other criteria are considerably lower than those for navigation training. Still, because of the overlap that exists between navigation training and other high scoring training areas, navigation training was excluded from further research. II and IR training is complementary to many tasks such as driving, UAV control, and mission management. The equipment is applied in many different task domains. This means that research into simulation opportunities for II and IR training will provide new and unique knowledge that is broadly applicable.

Another argument that favours the selection of this training area, is that modern warfare more and more requires forces to operate at night and under poor sight conditions. The use of II and IR equipment will therefore increase, rendering a higher need for training in this area. This trend applies to both the Army and Air force: in the Army tank crew and other artillery units operate with the use of optical equipment, in the Air force, the forward air controller or helicopter pilots must be able to operate under poor sight conditions, with the use of II and IR equipment.

The simulation of operational situations in which II and IR equipment is used, involves two different aspects. First of all, the images have to be either simulated or an original display has to provide images, and secondly, the (battle field) situation itself has to be simulated for training purposes. Navigation and target acquisition using II and IR equipment, have to be trained in realistic situations. This two-fold simulation problem makes the training area challenging, that is: knowledge on both simulation of visual images and on battle field simulation will be acquired.

5.4 UAV crew training simulator

Modern warfare becomes increasingly dependent on information technology, i.e. the acquisition, processing, and distribution of information. Unmanned air vehicles (UAVs) will play an indispensable role in this development. In addition, UAVs will be used more and more in missions that are dangerous, dirty, or dull in nature. Simulation is considered to be of most interest for training the tasks of the crew of the control station of an unmanned vehicle. The training offers great opportunities for specifically low-cost simulation, since the operators perform their task in a degraded operating environment. This operating environment of the real-life system can therefore be simulated with high fidelity at low-cost.

The different types of skills that are involved in the training of the UAV crews, offers good opportunities for the generation of knowledge that can find widespread application in other training areas. Although the tasks of the UAV crew show substantial resemblance to vehicle control and navigation tasks (such as driving and air platform control), there exist one major difference between both kinds of tasks: vehicle control tasks deal with direct control and direct sensing, whereas UAV control tasks involve remote control and remote sensing. The skills involved in manned vehicle control tasks are therefore different in nature from the skills involved in UAV platform control, and consequently the learning environments for simulators differ significantly.

5.5 Mission management simulator

The training area mission management was selected because it shows a high military value, there are important training difficulties to overcome, and the training area offers a great cost-reduction potential by implementation of a simulator system. Also, training in the field (full troop exercises) are no longer socially accepted because of high cost, safety hazards, and environmental burden. The training area is highly complementarity to other training areas, which means that research into this area will generate new and unique knowledge. This high complementarity is caused by the high cognitive/procedural demands of management (staff) tasks and by the fact that these tasks are usually performed in teams, requiring communication and coordination between members.

The challenges for simulation in this area are not of technological nature, but relate to difficulties with developing real and critical, interactive battle field scenarios, in which the behaviour of own forces, enemy forces and environmental factors are adequately modelled. Also scenarios should be developed such that they require the application of the knowledge and skills that is most relevant in staff operations. Furthermore, since mission management training usually involves actions of teams, performance measurement is not easy and will create unique new research questions.

5.6 Conclusions and continuation

From the apparent unlimited range of military task domains, a selection could be made for 4 training systems, that together cover a large area within the entire field of military tasks. The selection process was divided into separate parts, to collect relevant data, process and interpret that data, and draw conclusions. Throughout the whole selection process, there existed a balance between the objective, quantitative data on training courses, and subjective expert opinions; both types of information were taken into account.

The selected training systems were briefly discussed in the present report, as for the training objectives and the functional specifications. For some training systems, an indication is given which tasks may or may not be trained effectively on a low-cost simulator, but these are just preliminary ideas. Some tasks require complex simulation of cues, that might not be feasible at low-cost, as with terrain driving. However, these tasks do create relevant research problems, and further investigation into low-cost possibilities for these tasks, might render important new knowledge. Further research is needed to come to decisive answers on these matters.

In workpackage 3, an elaborate investigation of the task- and training requirements of the selected training areas, must render more detailed descriptions of these training systems. Furthermore, the information collected in the present workpackage, should be combined with the results from workpackage 2 (analysis of low-cost technology). That way, more detailed requirements for the selected training systems will be specified.

REFERENCES

Helsdingen, A.S., Korteling, J.E. & Van den Bosch, K. (1998). *Low-cost simulators 1b: task- and cost-utility data of a driver training and UAV-operator training course* (Report TM in preparation). Soesterberg, The Netherlands: TNO Human Factors Research Institute.

Helsdingen, A.S., Korteling, J.E. & Van den Bosch, K. (1997). *Analysis of military training: field inquiry*. EUCLID RTP 11.8, ELSTAR Technical Report WP1.b. ELS-DEL/1-B, index 3.

Korteling, J.E. (1991). Measurement of driver performance in training simulators. *Proceedings of the "Strategic Highway Research Program and Traffic Safety on Two Continents" Conference Part 4,* Gothenburg, Sweden: September 18-20, 1991.

Korteling, J.E., Van den Bosch, K. & Van Emmerik, M.L. (1997). *Low-cost simulators 1a: literature review, analysis of military training, and selection of task domains* (Report TM-97-A035). Soesterberg, The Netherlands: TNO Human Factors Research Institute.

Korteling, J.E., Van den Bosch, K., Van Emmerik, M.L., Van Berlo, M.P.W. & Von Baeyer, A. (1997). *Analysis of military training: literature review and preliminary selection of military fields*. EUCLID RTP 11.8, ELSTAR Technical Report WP1.a. ELS-DEL/1-A, index 2.

Van den Bosch, K., Korteling, J.E. & Van Winsum, W. (1997). *Low-cost simulators 1c: training analyses of 9 military training areas* (Report TM-97-A069). Soesterberg, The Netherlands: TNO Human Factors Research Institute.

Van den Bosch, K., Von Baeyer, A., Korteling, J.E. & Van Winsum, W. (1997). *Analysis of military training: training- and cost-utility analyses*. EUCLID RTP 11.8, ELSTAR Technical Report WP1.c. ELS-DEL/1-C, index 3.

Soesterberg, 30 December 1997

Dr. J.E. Korteling
(First author, Project leader)

REPORT DOCUMENTATION PAGE

1.	**DEFENSE REPORT NO.** TD 97-0487	2.	**RECIPIENT ACCESSION NO.**	3.	**PERFORMING ORGANIZATION REPORT NO.** TM-97-A087
4.	**PROJECT/TASK/WORK UNIT NO.** 788.1	5.	**CONTRACT NO.** A96/CO/363	6.	**REPORT DATE** 30 December 1997
7.	**NUMBER OF PAGES** 35	8.	**NUMBER OF REFERENCES** 7	9.	**TYPE OF REPORT AND DATES COVERED** Interim

10. TITLE AND SUBTITLE

Low-cost simulators 1d: generic training simulators for military applications

11. AUTHOR(S)

J.E. Korteling and A.S. Helsdingen

12. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

TNO Human Factors Research Institute
Kampweg 5
3769 DE SOESTERBERG

13. SPONSORING AGENCY NAME(S) AND ADDRESS(ES)

Director of Defence Research and Development
Plein 4
2500 ES DEN HAAG

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 part of this investigation, i.e. workpackage 1a, a taxonomy constituting 100 military task domains (ELSTAR Taxonomy) was a.o. developed and these 100 domains were evaluated on 15 criteria relevant for low-cost simulator applications and R&D. This resulted in a concise set of 9 military training areas that represented 29 task domains that were selected for further study.
These 9 training areas were then further investigated in workpackage 1b and 1c. This involved task- and cost-utility analyses on specific training courses that were considered representative for the 9 selected training areas. The present report describes the selection of 4 training areas out of these 9 training areas, and provides the global functional specifications of generic training simulators that could be applied in training programmes within these areas. This selection is based on scores on the ELSTAR taxonomy, the results of the task-, training-, and cost-utility analysis, and expert judgements on the generic value and complementarity of the knowledge that will be acquired.
The results show that driver training, UAV crew training, infrared and image intensifier operation training, and mission management training will be most suitable for further research into the possibilities for the application of low-cost simulators. Functional specifications that are drawn up for training systems for these training areas, indicate the global simulator requirements and which task clusters may be simulated at low-cost. In subsequent workpackages, more detailed requirements for the selected training systems will be specified.

16. DESCRIPTORS	IDENTIFIERS
Defence	Instruction
Driving	Low-cost Simulators
Image Intensifiers	Military Applications
Military	Simulation
Simulators	
Training	

17a.	**SECURITY CLASSIFICATION (OF REPORT)**	17b.	**SECURITY CLASSIFICATION (OF PAGE)**	17c.	**SECURITY CLASSIFICATION (OF ABSTRACT)**
18.	**DISTRIBUTION AVAILABILITY STATEMENT** Mailing list only			17d.	**SECURITY CLASSIFICATION (OF TITLES)**