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# ELSTAR

European Low-cost Simulators for the Training of Armed forces

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## Low-cost simulators

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# *Management summary*

The EUCLID program enables the European Industry to develop and produce in a cost-effective way the systems that can fulfil future European 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, can provide superior benefit-to-cost ratios when compared to full fidelity simulators. The 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*.

Because training simulators are intended to teach people practical skills, transfer of training is *the* critical and conclusive issue in research, development, and application of simulators. Training value, of course, assumes high transfer of training to later phases of training or to the operational tasks and systems. The ELSTAR approach for developing low-cost training simulators is to identify the critical task elements and to select those that can be easily simulated with high fidelity. This approach calls for:

1. selection of military task domains that are suitable for cost-effective simulator training,
2. aggregation of (sub)tasks and critical cues that can easily be 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 the low-cost training simulator.

In general, costs involved in achieving higher fidelity and completeness of simulation shall not exceed the benefits of higher transfer of training. Thus, the ELSTAR approach will often lead to part-task simulator training, rather than a full-mission training device. The prospect of this approach is that recognised advantages of simulator training (such as better feedback or automatic performance measurement) are available for those part-tasks that can be efficiently simulated, whereas more conventional training methods and techniques will be applied to train those part-tasks that can not be trained (cost-)effectively on a low-cost training simulator.

As a first step, the ELSTAR project aims at the selection of military task domains that may be conceived as the most promising for application of low-cost simulation technology and for the generation of relevant knowledge (by relating to the most prominent questions).

For this purpose a military task taxonomy was constructed, termed the ELSTAR taxonomy of military task domains, consisting of about 100 task domains (see appendix A3). With this taxonomy judgements from training- and simulator experts were obtained on each task domain and on 15 different criteria. These criteria reflected prospects for low-cost simulation and knowledge generation (i.e., training need, simulation need, generation of knowledge, simulation simplicity).

The ELSTAR taxonomy appeared effective in obtaining the required information on prospects for low-cost simulation. On one hand, the taxonomy proved to be an analytical and comprehensive overview of the most relevant dimensions of the operational field in relation to simulator training. On the other hand, the taxonomy matched with the way military training specialists see their field and it translated easily

to concrete military activities and functions.

On the basis of the expert-judgements, 29 domains were considered very appropriate for further investigation. This high number signifies a/o. the potential value of (low-cost) simulation for future applications. Only few procedural task domains have been selected for further study, presumably because these tasks present relatively minor problems with regard to low-cost simulation (and thus satisfying solutions are already often available). Tasks demanding cognitive/social- and perceptual-motor skills form therefore the majority of the selection. The development of appropriate low-cost simulators for these tasks require vital, and challenging problems to overcome. All task domains pertaining to the main function 'Command and Control' were selected. Task domains pertaining to the main function 'Providing mobility and survivability' appeared less appropriate for further investigation. The reason for this is that on one hand, the search- and identification tasks, primarily involves perceptual skills (interpretation of perceptual information such as visual- or infrared images or sonar patterns) without the need for real-time *interaction* with a system or an environment. In addition, other tasks may be procedural and thus rather easy to be simulated. Finally, these kinds of tasks also may require direct interaction with the real environment (e.g., detonating mines, or removing obstacles). It is very unlikely that these tasks can be simulated with the present and near-future state of technology.

In order to further investigate the opportunities for low-cost simulation, a representative and concise set of 9 military training area's was identified and defined that covered the selected task domains. This was done by elimination of some redundant domains and by combining strongly related domains. In brief, these area's involve:

1. wheeled vehicle control,
2. air platform navigation,
3. infra red and image intensifier equipment,
4. control of unmanned vehicles,
5. line of sight/guided/fire-and-forget/single-unit weapon systems,
6. line-of-sight /guided / fire-and-forget /co-ordinated-unit weapon systems,
7. non line-of-sight / non-guided / fire-and-forget/ single-unit weapon systems,
8. fault diagnosis in complex systems, and
9. command and control on warrior or staff level.

The remainder of the present Work Package 1 consists of three steps:

- For each military training programme / area, more detailed data will be acquired with respect to task- and cost-utility information.
- Subsequently, the results will be used to verify whether, and to what degree, the selected task domains are indeed interesting for low-cost simulator development and application.
- Finally, a set of 3-5 task domains will be selected for further research, which ultimately (after 4 subsequent work-packages) aims at a handbook comprising guidelines for low-cost simulator development, acquisition, and its application.

# Chapter 1

## 1. INTRODUCTION

### 1.1. Background

In order to ensure independence of Europe in the field of advanced technology for military applications, the EUCLID program enables the European Industry to develop and produce the systems that can fulfil future European 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, can provide training value at an order of magnitude advantage in performance to overall cost ratios when compared to full fidelity simulators". The research project which is carried out under contract of the Ministries of Defence of the five countries participating in 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 main objective of ELSTAR is to identify, within the full spectrum of training for military tasks, those opportunities for applying low-cost simulation technologies with a maximal ratio of training value to (life-cycle) cost of the training system. Training value, of course, assumes high transfer of training to later phases of training or to the operational tasks and systems.

Training needs are dependent on (emerging) military tasks, operational concepts, maintenance concepts, training concepts etc., which may differ between services and nations. The simulation technology to be developed and reported should accommodate these different needs by focusing on the common elements in the training needs of services and nations. The identified needs have to be compared to an inventory of existing and emerging low-cost technologies. In this comparison cost has to be balanced with training value, i.e. training transfer. On this basis, the most promising training concepts in which low-cost simulation technologies are applied, can be developed. Transfer of training (ToT) is the central factor for deciding on the acceptability of reductions in overall fidelity, given estimations of fidelity reduction when applying commercially available or soon available technologies instead of special purpose solutions. However, fidelity of the simulation is not the only issue. Low-cost solutions for generating terrain data-bases, for delivering instruction, for developing training and test scenarios, for managing the instructional process and for organising training, are issues that should not be neglected in this respect.

According to the ELSTAR approach, simulation has to be viewed primarily from the operational perspective, and not so much from the technological point of view. It should have an identifiable added value to the execution of military tasks. The analysis is divided over five work-packages, starting from the military tasks and relevant skills to be trained, maintained or tuned to a specific mission. The main purpose of ELSTAR is:

- to identify missions, operational functions, tasks or activities which are liable to apply to low-cost simulation techniques;
- to investigate existing and emerging low-cost technologies;

- to make estimates of training transfer which could be reached by using these technologies and
- to verify these estimates through testing on a demonstrator.

Work Package 5 will conclude with a handbook comprising guidelines for low-cost simulation acquisition and application on the basis of the knowledge acquired in the ELSTAR project.

## 1.2. General methodology of Work Package 1

Work Package 1 of ELSTAR is termed: *Analysis of Military Training*. This analysis involves the identification of missions, operational functions, tasks or activities that are the most promising for low-cost simulation application. The gathering of relevant and sufficient information for task-, training- and cost-utility analyses in WP1 is not easy. This is caused by the fact that the number of different trainings over the three services in the five counties is very high. Moreover, in order to be able to perform these analyses much detailed information for each trained task is needed, such as: information concerning missions, functions, training objectives, sub-tasks, operational scenario's, critical spatial and timing relations among scenario- and task components, critical procedural, perceptual, and cognitive cues, target groups and existing skills of these groups, duration of training for component skills, skill retention, life cycle costs of equipment, personnel costs, etc. Therefore, first a selection will be made of a number of task domains on the basis of global criteria (WP1a) and subsequently more specific information will be obtained only concerning this limited number of selected domains.

In this connection, activity WP1.a involves an overview of the literature on (low-cost) simulation and a preliminary, global analysis and assessment of the full spectrum of the military training field with regard to the prospects of low-cost simulation techniques (including literature study).

The present report accounts for this part of the project. Based on literature reviews and on consultation of military subject matter experts, this report describes a first selection of a number of global military training needs. This selection is based on a global assessment of cost-utility and a number of training characteristics that may be presumed to meet the training objectives. More specifically, the present report involves a literature review of training methodology including training evaluation, such as performance measurement and transfer of training (ToT), training trajectory design and implementation of training tools into training programs (Chapter 2 - 6). Subsequently, a global front-end analysis of Military training is reported in order to select training domains that are most promising with regard to the prospects of generic and cost-effective application of low-cost simulator techniques. The methodology for this selection among alternative solutions will be described in Chapter 7 and the results in Chapter 8. Finally, Chapter 9 presents an overall discussion with general conclusions.

# Chapter 2

## 2. MAIN CONCEPTS RELATED TO LOW-COST SIMULATION

### 2.1. Introduction

The use of simulation as a training tool has found widespread application and has proven effective in many settings. To maximise their effectiveness, simulator facilities have been instrumented at high costs to represent the operational equipment as faithfully as possible. Ironically, when the training procedures from the operational system are implemented on the simulator as well, the simulator might lose much of its additional training value and possibly yield sub-optimal training results as a consequence. Shortly, the simulator is used as a rigid substitute for the operational system rather than as an effective training device. (Hays, Jacobs, Prince, & Salas, 1992; Lintern, Sheppard, Parker, Yates, & Nolan, 1989).

Besides facilitating effective and efficient training, this should be achieved in the most cost-effective way: gaining the best training result at the lowest costs (in money, time, and personnel). This point of view is germane to the issue of low-cost simulation. As the aim for realism is associated with high expenses, it is necessary to investigate what level of realism is needed to obtain good training results. Besides, the role of other factors contributing to training efficiency has to be investigated as well (e.g. training design, type and amount of feedback). In many cases it seems that striving towards realism is the main goal in designing and developing training simulators. Rather than on achieving realism, however, the focus should be on meeting training needs of the target group. Of course, in many situations, both these aims may go very well together.

### 2.2. Fidelity

Simulator-based training is a kind of off-the-job training. Obviously off-the-job training should possess some similarity to the operational task and task environment, but to what extent is not yet clear. Similarity in simulation is captured by the term fidelity. Usually two types of fidelity are distinguished:

- *Physical fidelity* denotes to what extent the simulator mimics the real equipment in terms of information presentation and control characteristics (how the system behaves). As such, it can be assessed objectively by measuring physical variables such as accelerations, contrast ratios, force characteristics, etc.
- *Functional fidelity* can be defined as the similarity between the trainee's behaviour in the simulated task (perceptual, motor and cognitive processes) and in the operational task under similar conditions (although other definitions exist). This "behavioural similarity" is especially important in research simulators. Among subjects performing a task in a simulator and in the real system under similar operational conditions, behavioural similarity can be absolute or relative (Korteling & Van Randwijk, 1991).

In (low-cost) training simulation, functional fidelity also seems to be the more important because realisation of high physical fidelity entails a great deal of expense whereas proportional growth of training efficiency is not necessarily warranted. Still the question can be asked to what extent high behavioural similarity leads to high transfer of training. This issue is related to validity, the ultimate issue in the field of training simulation (see next paragraph).

Functional fidelity is a concept that will not easily be translated into physical terms. Nonetheless, a relation between functional and physical fidelity could be suggested. When a simulator has full physical fidelity, it cannot be distinguished from the real equipment. Hence, its functional fidelity can also be considered complete. On the other hand, it may be assumed that a simulator that bears no physical resemblance whatsoever to the operational system will not possess functional fidelity as well. Several authors, however, conclude that deviations from physical fidelity do not necessarily lead to substantial decrease of functional fidelity (e.g. Boer, 1991; Lintern et al., 1989; Patrick, 1992). This makes sense mostly for simulation of those task environments in which the complexity of the operational system can affect training results negatively.

## 2.3. Validity

Another important term in simulation-based training is validity (in the literature often encountered as "functional validity"). This term refers to the extent to which skills acquired in the simulator transfer to the operational equipment. Validity is affected by functional fidelity (behavioural resemblance), quality of training (i.e., the training methods, the contents of training, the way in which feedback is provided, etc.), type of task, and trainee level. As a consequence it is hardly possible to specify an a priori value of simulator validity. With any change in training method, (part) training task or group of trainees, the measure representing functional validity will almost surely change as well.

It is impossible to think of the validity of a training device without reference to transfer. Transfer of training (ToT) denotes the extent to which learning of a certain training task (A) influences learning or performance on an operational task (B). When task A is chosen inconsiderately or the training system has been designed inappropriately, transfer to task B might even be negative. In the next chapter, a more thorough review of transfer is given.

There is yet another type of validity that mainly relates to physical fidelity. This is called face validity (or realism), the extent to which a trainee perceives the simulator and the simulated task as a realistic duplicate of the operational system. Face validity is important in such a way that it will help to motivate a trainee to participate in what he feels is a relevant task.

## 2.4 The relation between fidelity and validity

Before determination of the level of fidelity required to obtain sufficient validity, a number of factors has to be considered (Boer, 1991; Orey, et al., 1995; Reigeluth & Schwartz, 1989). Although related, these factors might conflict because they do not all attach the same importance to fidelity.

- *Task environment:* If the task environment is very complex, high physical fidelity will be undesirable (initially) as the trainee probably will experience difficulties with the complexity of the simulation. In less complex task environments this is not a problem.

- *Transfer:* the desired level of transfer is dependent on the task. Training can be meant to transfer to a relatively uniform operational task (near transfer), or to a diversity of practical situations (far transfer). The appropriate level of fidelity will be highest in the former situation.
- *Mental load:* the trainee might experience difficulty with learning when too much detail is presented in high-fidelity simulation. Depending on trainee characteristics a lower level of physical fidelity may be suitable.
- *Attractiveness:* the level of fidelity can contribute to the attractiveness of simulation. Hence it can increase motivation of trainees. However, a dull task will remain a dull task even when simulated with high-fidelity.
- *Costs:* In practice, the "desired" level of fidelity is often determined by the available financial means.

## 2.5. Retention of training

Once a satisfactory level of performance has been attained, it has to be maintained also. Skills that are not performed or practised anymore after completion of training will deteriorate. Retention is affected by a number of factors. In general it can be stated that forgetting is related to time. The longer the retention interval (the time a skill has not been used), the more will be forgotten. This general relationship is not equally strong for different type of tasks (see also § 3.3). It has been shown for example that procedural skills show much more decay over time than perceptual-motor skills (Van den Bosch & Verstegen, 1996; Wickens, 1992). The extent to which the learned material is meaningful (and can be related to existing knowledge) is important for good retention of skills. Another factor of importance is the degree of automatisation of task performance. High automatisation reduces the rate of forgetting. Automated performance occurs only after sufficient practice beyond the point in training at which performance is merely error free. Furthermore it may be expected that individual differences are a determinant of retention. Wickens (1992) notices that faster learners show better retention than slower learners. This is related to the efficient use of chunking strategies. Faster learners seem to be able to 'chunk' effectively, that is, they can easily create associations between items that are already known. This way, new knowledge is related to already existing knowledge, hence retention will be facilitated.

# Chapter 3

## 3. MEASURING TRANSFER OF TRAINING

### 3.1. Measures of ToT

A standard way of assessing transfer of training (ToT) is to compare the amount of training on the operational system (on-the-job) needed by an experimental group that first trained a specified amount of time on the simulator (off-the-job), with the amount of on the job training needed by a control group that received training only on the real equipment. As a consequence of preceding simulator training, the experimental group is supposed to reach the determined level of performance in less on-the-job training time than the control group that received no prior simulator training. These savings can be expressed in a percentage.

Percentage of transfer ( %T) is specified by the following formula:

$$\%T = \frac{T_c - T_e}{T_c} \times 100\%$$

where:

$T_c$ on-the-job training time needed by the control group

$T_e$ on-the-job training time needed by the experimental group after completing the simulator training program.

From a transfer percentage of 100 it can be inferred that $T_e$ is 0. Accordingly no extra on-the-job training is required after completing simulator training. When $T_e$ increases, %T will decrease. At the moment when $T_e$ equals $T_c$ , percentage of transfer is 0, meaning that simulator training is not effective at all. This indicates that a critical examination of simulator and training program is needed. Negative values for %T are also possible in case that simulator training actually interferes with the acquisition of task relevant skills. Generally %T increases with each added unit of simulator training time (with decrement of added value). When training continues long enough, theoretically %T might eventually decrease. This could be due to over-learning of small errors that arise from sub-optimal validity.

A problem with %T is that it takes into account neither the amount of training time spent in the simulator nor any difference in costs between simulator training and on-the-job training. This means that although transfer may still be positive, the invested time in the simulator can exceed the savings ($T_c$ - $T_e$).

A more complete measure is the transfer effectiveness ratio (TER) because it does reckon with the time spent in the simulator according to the following formula:

$$TER = \frac{T_c - T_e}{T_s}$$

where:

$T_c$ on-the-job training time needed by the control group

$T_e$ on-the-job training time needed by the experimental group after completing the simulator training program

$T_s$ simulator training time needed by the experimental group.

- A TER of 1.0 indicates that time savings for on-the-job training are equal to the amount of time spent in the simulator.
- Above this value, training with the simulator is more effective than it is with the real equipment only. This means that total training time for the experimental group ($T_s + T_e$) is shorter than for the control group ($T_c$).
- In case of a TER below 1.0, total training time in the experimental group ($T_s + T_e$) is higher than $T_c$ meaning that one unit of simulator training is less effective than one unit of training with the operational equipment. There are, however, a number of reasons to continue simulator training despite a low TER: simulators may provide a safer environment for training, the operational equipment may be too complex for training certain skills or the task environment may be too stressful, the simulator can be used to prepare personnel for certain relevant conditions that rarely occur in the operational setting (e.g. emergency situations, unusual system malfunctions), and simulator training may be cheaper than training on the operational system and for that reason still be cost effective.

The effectiveness of training cost is expressed via the CER (cost effectiveness ratio). It is a ratio of TER to the training cost ratio (TCR).

$$TCR = \frac{C_s}{C_c}$$

$C_s$ cost of simulator group training (per hour)

$C_c$ cost of control group training (per hour)

The formula for the CER is as follows:

$$CER = \frac{TER}{TCR}$$

Cost effective training can be achieved with CER values above 1. For a CER smaller than 1, however, simulator training might still be effective for reasons of safety. A safety effectiveness ratio is more difficult to calculate because it requires estimation of accident probabilities, costs of consequential damage to the environment and determination of the value of human life. This is an issue, however, that goes beyond the scope of the present report.

For different durations of simulator training, CER, TER as well as %T will change. A small (fictional) example will illustrate this.

*Example:*

A control group needs 20 hours of on-the-job training to reach acceptable performance. After completing 8 hours of simulator training an experimental group only needs 16 hours of additional on the job training to reach the same level of performance.

**%T = 20% ; TER = 0.50.**

Operating cost of the simulator have been figured out to be 15% of costs associated with the operational equipment.

**TCR = 0.15; CER = 0.50 / 0.15 = 3.33**

After 11 hours of simulator training only 15 hours of additional training are needed.

**%T increases to 25%. TER, however, decreases to 0.45. The value for CER (0.45 / 0.15) is 3, so cost effectiveness can still be achieved.**

## 3.2. Methodological aspects of ToT assessment

For any given duration of simulator training, values of %T, TER and CER can be plotted in a graph. Generally TER shows a diminishing efficiency for each added time unit of simulator training whereas the value of %T increases until a certain limit. Calculation of the CER will help to determine the optimal duration of simulator training.

In practice this is a very complicated job. To obtain the curves of TER and %T, many measurements are needed. Data collection on each separate skill level requires a new group of subjects. Therefore, large numbers of subjects have to be involved. Apart from the concern whether sufficient numbers of representative subjects are available, all groups need to be trained to a different level of skill before they are transferred to the operational system. This effort is extremely time consuming and expensive. Above all, it may be expected that generalisability is low, as curves for one training program probably do not apply to other training programs involving other skills, other trainee groups, other training methods, other simulator configurations, etc.

Before transfer can be measured anyhow, it has to be assured that assessment of the variables affecting performance in both the real system and the simulator is possible in such a way that these measurements can be compared. Unfortunately, one of the reasons to use a simulator in the first place is that the operational system often is not suited to provide adequate performance measurement.

Another salient problem with transfer studies is described by Su (1984). He states that it is often not adequate to conduct a transfer study because no control group (trained on the operational equipment only) can be formed. This definitively holds true for advanced aircraft training or power-plant troubleshooting where naive control subjects could cause a lot of damage. This problem usually is avoided by investigating quasi-transfer of training (QToT), also called simulator-to-simulator method (Korteling & Van Randwijk, 1991; Lintern, Roscoe & Sivier, 1990). In QToT studies, a control group is trained with the (completely operational) simulator while the experimental groups receive training in an incomplete configuration, systematically lacking only one element (e.g. colour, sound or motion cues). Subsequently, all groups are tested on the complete simulator. The differences in performance between control and experimental groups are used to provide relative estimates of the contribution of each simulator element to transfer.

## 3.3. Factors affecting ToT

Although general agreement exists on the idea that physical and functional fidelity, and transfer are somehow related, the exact nature of this relation is still debated on. Two contrasting views are discernible (Boer, 1991):

- One approach considers high physical fidelity to be a necessary condition for the occurrence of transfer. In this view, even small deviations from maximum fidelity result in a relatively large decrease in transfer rates.
- On the other side, a human factors standpoint holds that high-fidelity is not always that important. Reasonable levels of transfer may be attained with relatively low-fidelity. The aim at higher fidelity is merely associated with higher costs while effects on transfer are considered variable.

### 3.3.1. The relation between physical fidelity and transfer

Neither one of these views is completely correct because they fail to take into account any of the other factors that mediate the relation between physical fidelity and transfer (see e.g., § 2.4). Apart from the factors mentioned in § 2.4, it may be expected that this relation differs for different types of tasks (i.e. procedural, cognitive, or perceptual-motor), differences in trainee level, and differences between criterion- and maximum performance, in other words, it might change during training. Therefore, some tasks need a high-cost, high-fidelity training approach while others do not.

### 3.3.2. Tasks and skills

The level of physical fidelity needed in cost effective simulation is dependent on the type of task to be trained. Each task or task component must be performed in a certain task environment. The complexity of this environment largely determines the costs associated with high-fidelity simulation. Procedural and cognitive tasks usually are confined to a restricted environment. Interaction with the outside world, if any, is abstracted through instrument displays. Therefore, their simulation can be achieved at relatively low expenses.

High-fidelity simulation of perceptual-motor tasks on the other hand is much more difficult as their environment is in fact the "real" world in which the trainee has to be able to move around. Realism of the simulation can only be enhanced by accurate presentation of visual, acoustic and motion cues.

The previous discussion did not address questions about the necessity of high-fidelity simulation to achieve transfer. In this light, the commonly held view is that not much of an issue should be made of it when the costs are relatively low (i.e. in procedural and cognitive training). However, it plays a major part in the simulation of perceptual-motor tasks because of the high costs attached to high-physical fidelity in those tasks. A decrease in physical fidelity may consequently enhance cost-efficiency.

*Procedural skills*

In procedural skills, the primary activity to be performed involves the execution of an algorithmic sequence of discrete actions (Van Rooij, De Vries, Buitelaar, Ligthart, Brouwer & Verwey, 1997). Procedural skills are needed, for example, in simple diagnosis and troubleshooting tasks, maintenance tasks, and during the start-up or shut-down of a system. With regard to training most effort has to be directed to maintain these skills at sufficient levels of performance. In other words, although these skills are mastered relatively easy they are not retained very well (Van Rooij et al., 1997; Wickens, 1992).

Retention can be helped if the trainee has the opportunity to form a correct mental model of the task. This will help to attach meaning to the different steps in the procedure (Van den Bosch & Verstegen, 1997). Provided that the relevant relations between different task components are present in the simulator, the appearance of the simulator is supposed to be subordinate to proper selection of training strategies. With their adequate implementation, low-cost, low-fidelity simulators that differ from the operational system and thereby can enhance insight in the underlying task structures might be especially valuable in later stages of procedural training or recurrence training.

*Cognitive skills*

Cognitive skills are needed in tasks that are more complex and uncertain than procedural tasks. As a consequence, no pre-specified steps can be described on which appropriate actions should be based. Instead these tasks depend on the use of problem solving heuristics and decision making strategies (Van Rooij et al., 1997). Generally a number of factors must be considered and integrated to arrive at a certain decision. Examples of tasks requiring cognitive skills are medical or fault diagnosis, troubleshooting tasks, (safety) judgement and complex monitoring and control tasks. According to Van Rooij et al. (1997) cognitive skills are better retained than procedural tasks although more effort has to be invested in the initial training stages.

According to Patrick (1992) cognitive- as well as procedural tasks are well suited for training on low-cost, low- (physical) fidelity simulators. In a study by Cox et al. (1965) for example, various simulations differing in degree of physical fidelity were compared with regard to their effectiveness at training army personnel on a procedural task. No differences were found between groups that trained on either the real equipment, a realistic simulator, or a simple cardboard model. These kinds of findings have been obtained by Grimsley (1969), and Johnson (1981).

*Perceptual-motor skills*

In tasks such as car driving, aircraft control or target acquisition tasks, perceptual-motor skills are indispensable. These tasks mainly require perceptual inputs on which motor outputs have to be based. The role of both components (perception and motion) can vary considerably between tasks. Some activities are merely perceptual such as sonar or radar monitoring tasks and do not really involve motor responses. It could even be argued that these activities classify under the header of cognitive tasks (diagnosis). In this view, an argument is made by Boer (1991). He points out that most perceptual-motor tasks in fact require a combination of different types of skills. The established transfer percentages in different experiments may then be attributed mainly to mastery of the procedural or cognitive task elements involved, whereas perceptual-motor actions learnt during training failed to transfer to the real system. This yields no evidence on the role of fidelity in learning perceptual-motor tasks.

The issue of fidelity is especially controversial in perceptual-motor tasks. Because of its complexity, the outside world obviously can not be simulated with complete physical fidelity. The question to be asked is if any attempt to do so partially, does in fact enhance physical fidelity (let alone functional fidelity). Ample evidence exists that addition of "realistic" wide field-of-view imagery or a motion system to a simulator can increase the occurrence of motion sickness (Bles, Korteling, Marcus & Riemersma 1991; Boldovici, 1992; Fowlkes, Kennedy & Lilienthal, 1987; Hamilton, Kantor & Magee, 1989; Roscoe, 1991). While face validity may have been satisfied, the relevant aspects of physical fidelity often are not reproduced by these systems. Therefore, this fact alone does not justify the conclusion that physical fidelity is not relevant to simulation of perceptual-motor tasks.

Besides the skills discussed above, there are two other type of skills relevant to task performance that can be distinguished: time-sharing skills, and team or task-sharing skills.

*Time-sharing skills*

The combined execution of several qualitatively different tasks also requires the combination of different individual skills (i.e., procedural, cognitive, and perceptual-motor). Whereas some persons are able to do so efficiently even under high workload conditions, others fail relatively early. According to Wickens (1992) these inter-individual differences cannot completely be accounted for in terms of differences in automaticity of single-task skills. Therefore, an additional skill related to time-sharing is suggested. Time-sharing skills become particularly crucial if there are dependencies or correlations between different tasks or task components. A methodological problem with time-sharing skills is that they seem to be related to specific combinations of tasks and not generalisable to other task pairs.

*Team or task-sharing skills*

Interest in team skills has only recently evolved. Many complex tasks involve effective team performance. These tasks require co-operation between team members, exchange of information and, allocation of (sub)tasks. Especially in conditions of high task load, good communication can prevent conflicts and misunderstandings. The emergence of technologies like networked simulation have stimulated military interest in aspects of team performance (Van Rooij et al. 1997). Task-sharing skills are supposed to be more general, and thus less associated with specific combinations of tasks, than time-sharing skills.

### 3.3.3. Trainee level

The shape of the transfer percentage function (figure 1) indicates that the efficiency of simulator training diminishes with longer duration of training. That is, in the first stage of training, transfer is highest. When in the course of a training program, the trainee develops several skills, it may be expected that the development of these skills will help him to combine the available cues more optimal and make use of them more subtly. In other words, this will change his training needs. If the simulator cannot properly adapt to these changing needs, its efficiency will rapidly diminish.

Consequently, it can be stated that subsequent training stages require different levels of fidelity and different training strategies to attain optimal training profit.

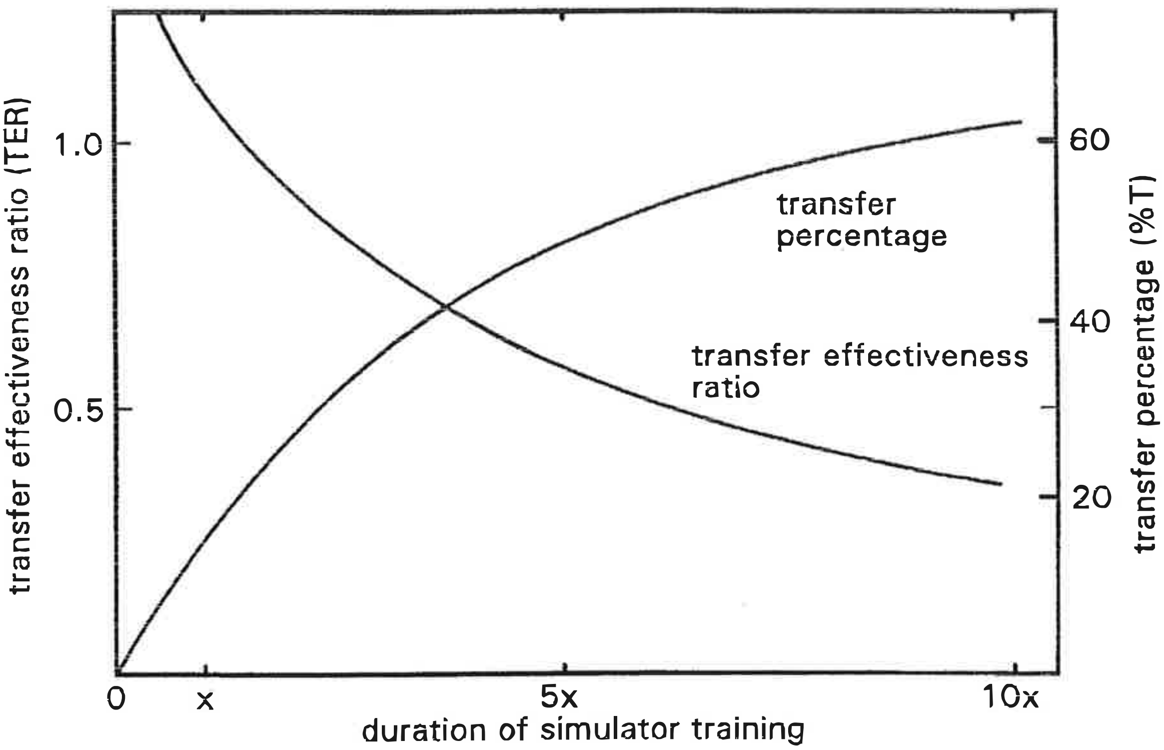


***Figure 1:*** *The transfer percentage function, showing that increase in transfer is accompanied by a decrease in transfer efficiency*

Fitts and Posner (1967) distinguish three stages in the development of skills:

- The *verbal-cognitive stage* is the first stage in which the trainee receives necessary information related to the task environment and task performance. In this stage, simple mock-ups, diagrams etc. combined with verbal descriptions of the task will suffice.
- This stage is followed by the *associative stage* in which the trainee has to learn to integrate this knowledge into behavioural patterns. Training serves as a mechanism to evaluate and change these patterns. High functional fidelity is important to achieve transfer.
- However, it is not until the final, *autonomous stage* that high physical fidelity becomes also important. The behavioural patterns have to be automated, to speed up performance and reduce workload. This process takes very long.

While this model probably applies to perceptual-motor tasks, several authors indicate that procedural and cognitive tasks relate to fidelity and trainee level in a different way (Alessi & Trollip, 1985; Van den Bosch & Verstegen, 1996; Chase & Simon, 1973). They suggest that in the initial stages of cognitive and procedural task training, higher physical fidelity is needed than later on. In these tasks the physical characteristics (appearance) of the stimuli do not form a relevant part of the task performance, therefore advanced trainees can do as well without them. For beginners, however, the appearance of the stimuli is expected to be helpful to form a mental representation of the task.

### 3.3.4. Difference between criterion and maximum performance

According to Boer (1991), who focuses on perceptual-motor tasks, the necessary level of physical fidelity (in the simulation of complex, multi-skill tasks) depends on the difference between criterion performance and the maximally attainable performance. As the criterion performance on the simulator (training goal) approaches the maximally attainable performance with the operational system, required training time will rapidly increase. This has consequences for training. Initially, satisfactory transfer can be attained with low-fidelity simulators. Later stages of perceptual motor training require higher levels of fidelity and possibly a different approach to training to achieve efficient simulation. Consequently, low-fidelity simulators can be used only in a limited part of the training program. After the initial stage, high-fidelity is necessary to achieve the criterion level without prolonged additional training on the operational system.

When the criterion level is low, it can be reached earlier. In this case training involves the first stage (verbal-cognitive) and possibly the second stage (associative), therefore, low to medium levels of fidelity will suffice for simulation.

Boer (1991) goes on to conclude that for initial training, meant to teach the basics of a task, satisfactory results can be attained with low-fidelity simulators. When training of perceptual-motor skills is considered, however, acceptable transfer is more difficult to achieve because the necessary levels of fidelity may not be reconcilable with any form of efficient training.

### 3.3.5. Training strategy

Although many experimental data have been accumulated, the issue of fidelity remains controversial. Part of this conflict will resolve with proper (i.e. consistent) use of the relevant vocabulary. For the remainder it might be useful to look into other directions also to improve training results. A possible increase of simulator efficiency can be expected from changes in training strategy. Because no changes in hardware are involved, this is a promising low-cost simulation approach (Van den Bosch, 1995; Kieras & Bovair, 1984).

## 3.4. Validation research: mechanical motion

With regard to validation of military training simulators there still remains a lot of work to be done. To date, few empirical studies have been undertaken to investigate the transfer of learning skills on a simulator to operational skills. A quick sample of data concerning about 35 military training simulators for airforce, army, and navy by the present authors indicated that empirical data exists only for two tank driving simulators (Veltman & Korteling, 1993). For one of these validated simulators initially transfer appeared to be negative (Breda & Boer, 1988). Effective training was only realised after substantial modifications of the image system, the visual databases, the motion system, and the training program.

In the field of military training, instructors tend to be positive about their simulator in terms of its effectiveness and efficiency, although they generally recognise that the retention of skills trained on the simulator may be poor. Unfortunately, feedback obtained from field exercises and feedback provided by the training system is rarely used to improve (simulator) training programs in a systematic manner.

Probably the most debated topic related to simulator validation concerns the benefit of mechanical motion cues. In the absence of relevant ToT studies, research on mechanical motion is largely limited to studies that have investigated the effect of a moving-base on (training) task performance instead of transfer data (e.g., McLane & Wierwille, 1975; Ricard & Parrish, 1984). This has contributed to more controversy in the debate on mechanical motion cueing. Lintern, Thomley-Yates, Nelson & Roscoe (1987) for example, argue that good training task performance does not necessarily imply high transfer to the operational tasks. Boldovici (1992) presented an elaborate literature review and concluded that the transfer of training data did not justify a general preference for the use of motion-based simulators over fixed-base simulators (e.g., Sticha, Singer, Blacksten, Morrison, & Cross, 1990). Apart from that, the role of a motion platform can differ per task (part), which severely limits the generalisability of experimental results.

Most research has been conducted in the areas of aviation and car driving. Motion systems for *maritime training simulation* are generally not considered useful because of the relatively small influence of mechanical motion on the control of ships. This holds especially for larger ships that possess a relative inertia which causes the effects of a steering input to become perceptible only some time after its execution (Bles et al., 1991).

In *flight simulation*, mechanical motion information will only be useful to learn to react on external disturbances or for training those systems with unstable vehicle dynamics such as a helicopter. (In these systems, mechanical information can be considered as a primary cue instead of as complementary to visual information.) Tasks that are supposed suitable for training with a moving base are emergencies (engine failure) and aircraft landing (Bles et al., 1991).

Blaauw (1982) compared *driving* behaviour (on a straight road) of subjects in an instrumented car with driving behaviour in a fixed-base maquette simulator. This particular simulator turned out to have absolute as well as relative validity with regard to longitudinal control. For lateral control the simulator had only relative validity. From studies that compared driving in a fixed-base simulator with a moving-base simulator, Bles et al. (1991) conclude that appropriate mechanical motion cues can be useful when training emergency braking, hillside accelerating, making sharp turns, terrain driving and special circumstances such as heavy cross winds and aquaplaning. Because this involves only a few part tasks, a full scale moving base will probably not be cost-efficient. When the goal of mechanical motion information is to enhance simulator credibility (face validity), the presentation of vibrations by means of a "seat shaker" will do reasonably well. The requirements for physical fidelity of these vibrations is low because most vibrations do not substantially affect actual steering behaviour.

# Chapter 4

## 4. THE ELSTAR APPROACH

### 4.1. Low-cost specification method

As is clear form the previous chapter, selection and specification of the functionalities of training simulators is a complex issue involving many factors related to military tasks and skills to be trained, training and instruction principles, the state of the art of simulation technology, and costs of equipment, buildings, staff etc. Therefore, the present chapter provides a reference framework entailing a general multi-disciplinary approach for the selection of suitable tasks and the formation of guidelines and generic principles for the design of low-cost simulators.

According to the ELSTAR methodology, low-cost simulator specification starts with functional system analysis, i.e., the description of the elements, aims, boundary conditions and factors involved in the execution of a certain task within a mission. Hence, the first problems to be solved are mainly functional and not physical. In subsequent stages the outcome of this process has to be related to the physical domain. This involves the combination of functional requirements with technical knowledge concerning the state-of-the-art of simulator technology. The sequence that has to be followed can be conceived as follows: mission analysis, task analysis, training analysis, cost-utility analysis, training program development, functional specification, technical specification, validation research. This process cannot be carried out in a strict sequential order. For pragmatic and practical reasons, and on the basis of experience, operational, instruction, and simulation know-how, often iterations among initial and final steps will have to be made.

#### 4.1.1. Mission Analysis

As a first global step, the systems to be simulated have to be described as linked to missions, missions to system functions, functions to tasks, and tasks to skills. Mission analysis involves the system in its context: a systematic description of the goals of the system and how these goals should be achieved, the required functionalities of the system (system functions), and the relevant circumstances or environmental conditions (physical and tactical aspects) that may be encountered. An example of a mission of a system is to take control over an area or to protect civilians of a city against revolting forces. The analysis of such system missions should include the complete scope of the systems activities and goals with minimal overlap among missions. The missions can be analysed at different aggregation levels. At the highest level, five types of missions can be discerned:

- Offensive,
- Defensive,
- Transport,
- Peace keeping / peace enforcement,
- Reconnaissance.

These missions can be described in three aspects: *system functions*, *environmental conditions*, and *system deployment* which concerns the interaction between both.

*System functions* are not always active; they depend on the type of mission. At the highest level, 8 system functions are most commonly encountered: i.e., a weapon system may include one or several of the following system functions:

- Mobility (manoeuvring),
- Navigation,
- Intelligence,
- Target acquisition,
- Weapon delivery,
- Combat service support,
- Command and Control ($C^2$),
- Provision of mobility and survivability.

These are the system's functions at the highest level and they can be split into sub-functions. These main system functions also provides the basic structure of the military task taxonomy used for the selection of promising domains for low-cost simulation research (see chapter 7). For the present purposes, these 8 main functions will suffice. A given system can be able to perform several missions, each of which may involve a different set of system functions.

The description of the *environmental conditions* consists of tactical and physical characteristics. Tactical characteristics involve the individual qualities (features) as well as those of the enemy in terms of the physical basis (ground, sea surface, sea subsurface, air) and kinds of threat (anti-tank weapons) and system level (individually operating system vs. group component). Physical characteristics involve geographical area, time, and weather (visibility) conditions. These are important for the assessment of military task domains with respect to low-cost simulation fitness because these characteristics will substantially determine the functionalities of the training system.

*System deployment* is also crucial for the definition of simulator requirements. This describes the combination of the system functions and the environmental conditions. This combination provides the requirements (norms) that have to be fulfilled under critical conditions, i.e., what should the system be capable of? (e.g., landing on a frigate at night).

### 4.1.2. Task analysis

For all the described system functions, tasks can be described. A task is a (part of a) system function allocated to a person. In other words: it is a goal-directed sequence of activities which can be described at various levels. In general, task descriptions are more specific than system functions. For the weapon delivery function, for example, several sub-tasks can be identified, such as: achieve position, determine target destination, select weapon, aim, deliver.

Tasks can be described at a global level by:

- an input (map, display, instruments, environment),
- an operation (a skill such as scanning, detection, identification, matching, assessment, decision making, planning, steering, comparing, etc.),
- and an output (route plan, smooth braking, straight driving, smooth declining, stable hovering, deployment of personnel, etc.).

The skills that are necessary to perform the task and sub-tasks are most commonly divided into the five previously described main categories, i.e., perceptual-motor skills, procedural skills, cognitive skills, time-sharing skills, and team or task sharing skills. Generally, simulators for perceptual motor tasks require dynamic interactions with a natural environment whereas procedural and cognitive tasks have more artificial and static attributes. This makes the simulation of the task information from the operational environment usually more simple for procedural and cognitive tasks (see chapter 3).

For simulation purposes, the task in relation to the environment and the system deployment is crucial for the description of the requirements of the training system to be designed. This defines the input from the system or the environment to the subject, the output of the subject to the system and the requirements that are to be attained by the man-machine system as a whole.

### 4.1.3. Cost-effectiveness analysis and training programme development

Low-cost simulation methodology involves the explicit incorporation of the trade-off between costs (see chapter 6) on the one hand and training value on the other hand. The most prominent consequence of this starting point is that full fidelity of a simulator is, in most cases, not required. (see Fig 1). It may even be the case that deviations from full fidelity are more fruitful, not only because of reducing technical costs, but because of the potential enhancement of transfer of training. Also part-task training, selectively focusing on the task variables that can be trained with high training effectiveness will often be crucial for successful low-cost simulations.

This latter point implies that implementation of the simulation system into an existing training program, usually will require an adaptation of this program taking into consideration the possibilities and limitations of the new training system. Possibilities may involve: better feedback, automatic performance measurement, quick change of training scenario's etc., whereas more conventional training methods and techniques will be required to train those task aspects that cannot be trained effectively (or cost-effectively) on the simulator.

## 4.2. Cue dominance and critical cues

Despite all efforts, concepts such as similarity and fidelity remain indistinct. Or as Lintern phrases it: "The challenge remains for skill acquisition research to characterise the similarity criterion with sufficient clarity for development of theory and design of training programs and equipment" (Lintern et al., 1989). In practice this means that it has to be investigated which task elements have to be presented for efficient transfer. An interesting approach, especially relevant to perceptual-motor tasks, is that of cue dominance and critical cues (Warren & Riccio, 1985). Fundamental to this approach is the idea that some cues are more relevant to task performance than others, even if they represent the same information. The cues that are most relevant to performance are called critical cues. These can be arranged according to a so called cue dominance hierarchy. The experimental results from this study indicate that superior cues prevent the use of weaker cues when both type of cues are presented simultaneously. In other words, this suggests that training the full range of cues is sub-optimal because only the dominant cues handled (Korteling, 1991). Critical cues can be identified by means of task analysis and psychological research.

Similar to the notion of critical cues is the concept of the environmental invariant (e.g.

Lintern et al., 1989). The invariant specifies unchanging relations between perceptual elements in the environment such as for example the relation between the position of a light source and the direction and size of the cast shadow from an illuminated object. Because invariant relations are a major source of information for the control of action, they are thought to be necessary for the learning of (complex) tasks. Simulator training should therefore incorporate these invariants in order to achieve high transfer.

The implication of these notions is relevant to low-cost simulation: training aimed at action control by critical cues, (instead of the full range of cues) leads to a reduction of computational costs of simulation and to a reduction of physical fidelity. As a consequence, training efficiency (TER) is supposed to improve, even though the percentage of transfer (%T) may be reduced (Warren & Riccio, 1985). For this reason, the collection and representation of critical cues is a promising subject for low-cost simulation research.

Although the relation between fidelity and transfer cannot be seen independently from other factors such as "type of task" and "trainee level", there is general agreement on the idea that this relation is monotonously positive. So it can be assumed that an increase in fidelity will also result in higher transfer (this relation does not reckon with transfer efficiency). As follows from the CER, the costs involved in achieving extra fidelity should not exceed the benefit of higher transfer efficiency as this would be cost-inefficient and completeness. In order to be cost-efficient, efforts should not aim at high-fidelity simulation of (sub) tasks that are difficult to simulate (i.e., expensive), but at tasks that can be simulated against low-cost with existing technologies.

Since there is no easy way to assess transfer of training, the low-cost simulation approach involves the selection of suitable tasks for low-cost simulation, the aggregation of sub-tasks and critical cues within these tasks that can easily be simulated with high-fidelity, the elimination of the tasks that are difficult to simulate, and the adaptation of the training program optimally to this outcome, for example by providing performance measurement and feedback, part-task training, or elements of computer based training.

## 4.3. Performance measurement and feedback

Compared to traditional instruction, the simulator offers additional didactic options. It is relatively easy, for example, to measure and store all kinds of system parameters. This allows for provision of automatic and objective measurement and detailed feedback concerning task performance, both in relation to performance criteria. Automatic and objective performance measurement may decrease the amount of time to be invested by instructors and may at the same time enhance the quality of performance judgement and feedback by instructors. The frequency and the detail with which feedback is supplied are strong determinants for training quality and therefore relevant to training efficiency (Boer, 1991). Feedback can be provided in two forms: as knowledge of results (extrinsic), in the form of guidance or augmented cueing (intrinsic), or as a combination of both (Patrick, 1992).

### 4.3.1. Knowledge of results

Storage of system parameters during a training session enables conscientious investigation of changes in performance. This way the trainee can receive detailed knowledge of results (KR) in a way that is not possible in the real world. KR can be used as a means to motivate the student and assist him/her in the process of correcting flaws in cognition and action, thereby improving performance (Boer, 1991; Wickens, 1992).

There is some controversy about the necessary level of detail to optimise KR. According to Boer (1991) elaborate and detailed KR can initially affect performance negatively but in the end it will lead to superior task performance and understanding. It is, nonetheless, not the amount of feedback that determines the effectiveness of KR but rather the relevance of the selected system parameters for feedback. Specific guidelines have to result from task analysis and will differ for each task. Korteling & Van den Bosch (1994), for instance, present global guidelines for designing performance measurement and feedback (PMF) systems based on evaluation of such a system for a tank driving simulator.

### 4.3.2. Augmented cueing

Intrinsic feedback can be provided by means of augmented cueing. In that case, information that is not available in the real world is presented to the trainee during training. The cues could designate, for example, an optimal runway approach for a simulated aircraft. The deviations from the optimal path are made visible and enable the pilot to immediately adjust his own steering inputs to match the optimal track. Wickens (1992) refers to this as a "training wheels" method. The availability of the supplemental information should help the trainee to learn what appropriate behavioural adjustments to make. After the desired behaviour is mastered, the training wheels will be removed.

The costs associated with augmented cueing usually are very low. According to Lintern, Roscoe, & Sivier (1990): "*its implementation in a computer-based simulation (...) requires relatively trivial modifications to software*" and "*it has potential to enhance training effectiveness at little additional cost.*"

The effects of augmented cueing on performance seem to be complex. Based on the available literature it can be stated that augmented feedback can be a potent instructional variable provided that no cue-dependency is developed. Its largest benefits are to be expected in the early stages of training (Boer, 1991; Lintern et al. 1987; Lintern, Roscoe & Sivier,1990; Lintern, Roscoe, Koonce & Segal, 1990).

*Off-target feedback*

One important drawback of augmented cueing is that transfer may be poor as a consequence of the trainee becoming dependent on the feedback (Lintern et al. 1987; Lintern, Roscoe & Sivier, 1990; Wickens, 1992). To overcome this problem, it is suggested to provide feedback only when the trainee exceeds pre-set error limits. This is called off-target feedback (Lintern et al. 1987). Off-target feedback prevents excessive errors during training whereas the trainee cannot depend on it to perform the task without errors.

*Fading*

Another way of preventing cue-dependency is fading. By slowly diminishing the augmented information, the simulated task environment gradually becomes more similar to the real task environment. This way the trainee is forced to become independent of the enhanced feedback.

## 4.4. Part-task training

Most complex tasks are composed of smaller sub-tasks that have to be performed sequentially or simultaneously. For a beginning student the complexity of a task might seem overwhelming. Part-task training is a way of providing the trainee with smaller bits of information which he can handle. Another reason to employ part-task training might be that some sub-tasks can be simulated better than others. Two types of part-task training are generally distinguished: Segmentation and Fractionisation.

### 4.4.1. Segmentation

In segmentation, a task is subdivided in temporal units that can be trained in any pre-specified order. After initial training is completed, the segments have to be integrated to perform the complete task. This can be done in different ways:

- The simplest form is part training. Each part of a task is trained separately. After all parts have been trained they are combined into the whole task.
- A slightly different approach is followed in progressive part training. Here, each segment is integrated with the previously trained segment(s) before the next segment is trained.
- In backward chaining (e.g. Wightman & Sistrunk, 1987) the final segment of a task is trained first followed by the penultimate segment until finally the first part can be trained. This approach is based on the idea that activity between action and knowledge of results interferes with the progress of learning. When starting with the final segment, knowledge of results is obtained immediately and once well learned, each segment becomes the source of information feedback for the earlier segments.

### 4.4.2. Fractionisation

Fractionisation is the subdivision of a task in several units that are normally performed simultaneously. The classic example of fractionisation is the piano player that separately trains the left hand (chords) and right hand (melody) of a piece of music. Wickens (1992) comments that although fractionisation might result in efficient learning of the sub-tasks, the development of so called time-sharing skills which might be necessary for co-ordinated performance of both tasks together will be prevented. To avoid this problem, he suggests a form of training called varied priority training, i.e., systematically emphasising one task component and de-emphasising another, in order to maintain the integrity of the task.

## 4.5. Desktop simulation

The utilisation of (personal) computer for purposes of instruction and training is known under the name Computer Based Training (CBT). CBT has traditionally been in the form of tutorials. The objective of these tutorials is to teach students prerequisite, theoretical knowledge for task performance. Now that personal computers have become more powerful, it is possible to run simulation models of systems, devices and processes for instructional and training purposes. The student interacts in real-time with a model of the system via the interfaces of the computer, i.e. keyboard, touch screen, mouse. This is usually called "desktop simulation".

Because desktop simulation makes use of a personal computer ("PC") configuration, it is usually not possible to model the physical (appearance) aspects of the operational system in a true-to-life fashion (except, of course, when the simulated system itself is a PC-run system). Instead, the essential functionalities of the task environment are represented symbolically in the desktop simulation.

Recently, there is a growing interest of combining the virtues of traditional CBT and desktop simulation for optimising training efficiency. Recent desktop simulation programs consist therefore of three main components (Reigeluth & Schwarz, 1989):

a) a model of the system,
b) task scenario's,
c) instructional facilities.

The system model is a mathematical description of input-output relations governing the system's behaviour. Task scenario's refer to the way the task is performed in the real world (including common errors). Instructional facilities are added to the program and are designed to facilitate learning (e.g. providing augmented feedback, opportunity for students to ask for guidance, (automatic) performance measurement, etc.). Thus, the central learning opportunity is that the student executes the task in a (symbolical) simulation of the task environment. However, the desktop simulation program enhances the value of this learning experience by adding more traditional CBT facilities.

An important question is to what functional level the system should be simulated. The required level of modelling is defined by the inputs of the task performer to which the simulation should produce a functionally valid output (response). This is ultimately determined by the task scenario's that the model should be able to run. A thorough task analysis is therefore the basis for developing a simulation model providing students with valid responses to (sequences of) actions.

Van den Bosch (1995) asserts that desktop simulation has potential to train practical skills needed in processes and procedures because it relates to both practical and theoretical training needs with a high level of flexibility.

Summarising then, there are three principal requirements for using desktop simulation for training purposes (de Jong, 1991):

- Firstly, the simulation should include a formal, mathematical model, allowing for real-time interaction between student and the simulated system.
- Secondly, the desktop simulation should be used to achieve pre-defined learning objectives in the context of representative task scenario's.
- Thirdly, the desktop simulation should include facilities to induce learning processes.

# Chapter 5

## 5. INSTRUCTIONAL SYSTEMS DEVELOPMENT FOR LOW-COST SIMULATORS

In this chapter a review of the literature regarding instructional systems development for simulator-based training systems is presented. Although no models are specifically aimed at low-cost simulators, some aspects of the distinctive models are important.

After a brief introduction (§ 5.1), four models for Instructional Systems Development are discussed (§ 5.2). The conclusions are presented in the final section (§ 5.3).

## 5.1. Introduction

The objective of training systems is to change the behaviour of the trainees (the personnel) so that they can perform required tasks more effectively and efficiently (Gaines-Robinson & Robinson, 1989). Since the second World War system analysis made its entrance in training development, and this resulted in the Instructional Systems Development (ISD) approach. Systems analysis is a powerful problem-solving approach due to three main features (Hays, 1992, p.260):

- it uses an interdisciplinary team of experts to bring as much relevant information to a problem as possible,
- it uses models (or simplifications) to reduce complex problems to analysable proportions,
- it uses systematic, yet dynamic problem-solving methods that can be modified by the team of experts at any point during the analysis to better handle the specific problem.

Schiffman (1986) distinguishes five views to instructional design:

- the media view,
- the embryonic systems view,
- the narrow systems view,
- the standard systems view,
- the instructional systems design view.

This is a hierarchical classification, in that the ISD-view encompasses all the other views. Figure 2 shows the *instructional systems design view* (Schiffman, 1986, p.17) which is the most encompassing view. Instructional systems design is a synthesis of theory and research related to:

a) how humans perceive and give meaning to the stimuli in their environment;
b) the nature of information and how it is composed and transmitted;
c) the concept of systems and interrelationships among factors promoting or deterring efficient and effective accomplishment of the desired outcomes;
d) the diffusion of the (instructional) solution;
e) the consulting or managerial skills necessary to melt points ‘a’ to ‘d’ into a coherent whole.

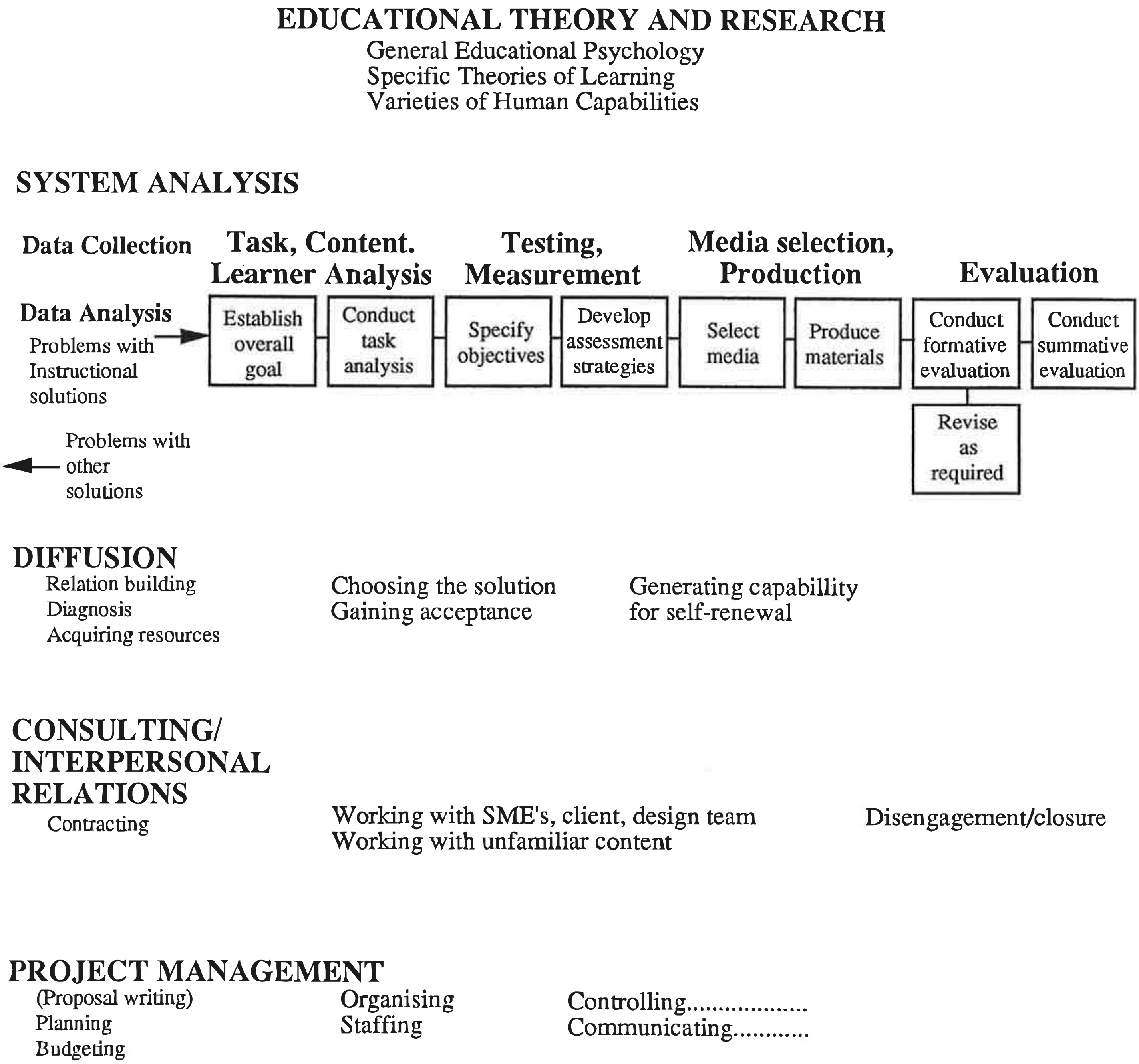


*Figure 2: The instructional systems design view*

The instructional systems design view as presented in Figure 2 incorporates all necessary elements that should be part of a methodology that guides the process of designing, developing and evaluating instructional systems.

A single designer is not expected to have all of the knowledge and skills, therefore a design team of experts is desirable. Whenever instruction is being designed, an appeal must be made on the disciplines of educational theory and research, system analysis, diffusion, consulting/interpersonal relations, and project management. In this view the development of training and instruction systems is a continuous and iterative process. During the whole process of analysis, design, implementation and evaluation the instructional designer (or design team) must check if one is on the right track. Especially the matter of dissemination is of great importance.

Based on these views many different models for instructional systems development have been developed. More extensive reviews of ISD models are described elsewhere (e.g. Andrews & Goodson, 1980; Gustafson, 1991; Van Berlo, 1996). In the following section, however, only the models that are of interest for designing and developing simulators will be discussed.

## 5.2. Models for instructional systems development

Many factors affect the cost-effectiveness of training programs and/or training devices. One of these factors is the efficiency of the methodology that is applied in the process of designing and developing an instructional system. A well-defined methodology with clear guidelines specifically aimed at the ultimate goal of the ISD-process (e.g. design and application of low-cost training simulators) will be more effective and efficient compared to a methodology that leaves too much room for alternative interpretations by different instructional designers. In this section four ISD models will be discussed containing components that could be of use for designing low-cost simulator-based instructional systems:

- the Instructional Development Institute (IDI) model (§ 5.2.1),
- the Interservices Procedures for Instructional Systems Development (IPISD) model (§ 5.2.2),
- the Briggs and Wager model (§ 5.2.3),
- ROPES (§ 5.2.4).

### 5.2.1. IDI-model

The Instructional Development Institute model was originally designed for public school personnel to tackle large-scale instructional problems (National Special Media Institute, 1971) and is taught in many professional preparation programs. It is developed by the University Consortium for Instructional Development and Technology and extensively tested and revised by the co-operating universities (Indiana University, Michigan State University, Syracuse University, University of Southern California and the U.S. International University). The IDI model is problem oriented, specifies team development, and assumes distribution or dissemination of the results of the effort. The model has three stages, each containing three steps with every single step subdivided in elements. It has a proceduralised character and is essentially linear in its approach, although you can start the process at every step dependent to the situation.

The three stages of the IDI model are:

1. define,
2. develop,
3. evaluate.

'Define' has three steps, viz. identify the problem, analyse the setting, organise the management:

- The first step, identifying the problem, is of crucial interest due to a system approach and requires conducting a needs assessment, establishing priorities among various and conflicting needs, and stating one or more problems to be addressed. The stating of problems in measurable terms is important for later assessment of progress.
- Step two, analyse the setting, specifies additional data collection concerning audience (e.g. opinion leaders), conditions under which development must occur, and what (human) resources are available for developing and delivering the solution.
- Organise management includes stating all major tasks and assigning responsibility for those tasks to team members, and establishing time-lines for their completion. This third step is explicitly described in the IDI model because of the belief that poor management leads to failure of development efforts.

The second stage (Develop) contains the following steps: identify objectives, specify methods, and construct a prototype. Objectives must include an audience, a description of the behaviour, the condition under which it has to be performed and a degree of performance. When the objectives are stated, the next step is to select strategies and media based on the type of objective. After that, prototypes, testable drafts of all the materials, are built.

In the third stage (Evaluate) the prototype is being tested under conditions as similar as possible to its eventual use (also called 'formative evaluation'). The data are analysed with respect to the objectives, methods and evaluation techniques. Finally, the instruction is revised and implemented.

The strength of the IDI model is its three levels of detail, that makes it practicable for both beginning and expert instructional developers. Its basic limitation is the implication of a linear step-by-step development process. Any scientific validation is unknown to the authors. With regards to simulator-based training the steps of the organisation of management, and the construction and testing of prototypes are worth mentioning.

### 5.2.2. IPISD-model

The Interservices Procedures for Instructional Systems Development was developed in the context of US military training and was a joint effort of the Army, Navy, Marines, and Air Force. It is one of the most detailed models of instructional development available and published as a four volume set (Branson, et al., 1975). Later, slightly adjusted models were developed (e.g. Cantor, 1985-86) but basically these are the same. The IPISD model divides the development of instruction into five stages: analyse, design, develop, implement, and control, each consisting of several steps.

- In phase one (Analyse) an inventory of tasks is compiled, and tasks requiring instruction are selected. Performance standards and evaluation procedures are specified, and existing courses are examined to determine if any of the identified tasks are included. The final analysis step is to select the most appropriate instructional setting for each task.

- The Design-phase begins with the conversion of each task into instructional outcomes, i.e. the objectives. Tests are designed and validated to match the objectives. Next, the entry behaviour is determined and compared to the level of learning analysis, followed by the design of the sequence and structure for the objectives.
- The first step in the phase of 'Development' is to classify the objectives by learning category to identify learning events and activities necessary for optimum learning to take place. Media are then selected and a management plan developed. After reviewing existing materials for their relevance, and, if necessary, production of new materials, the entire instruction package is field tested and revised.
- In phase four (Implement) staff training is required for course managers in the utilisation of the package, content training of subject matter personnel, and distribution of all the materials to the selected sites. Instruction is conducted and evaluation data are collected on both learner and system performance.
- The last phase of IPISD is 'Control'. Internal evaluation is the analysis of learner performance in the course to determine instances of deficient or irrelevant instruction. In the external evaluation, personnel assess job-task performance on-the-job to determine the actual performance of the trainees. All collected data can be used as quality control on instruction and as input to any phase of the system for revision.

More or less deduced of the IPISD-model is the *Optimisation of Simulation-Based Training Systems (OSBATS)*, a software tool developed for use within the U.S. Army. OSBATS consists of five modelling components (Sticha, et al., 1990):

- Simulation Configuration Module: a tool that clusters tasks into the categories of part-mission training devices, full-mission simulators, and actual equipment.
- Instructional Feature Selection Module: a tool that analyses the instructional features needed for a task cluster and specifies the optimal order for selection of instructional features.
- Fidelity Optimisation Module: a tool that analyses the set of fidelity dimensions and levels for a task cluster and specifies the optimal order for incorporation of advanced levels of these dimensions.
- Training Device Selection Module: a tool that aids in determining the most efficient family of training devices for the entire task group, given the training device fidelity and instructional feature specifications developed in the previous modules.
- Resource Allocation Module: a tool that aids in determining the optimal allocation of training time and number of training devices needed in the recommended family of training devices.

These modules can be used iteratively. Both the subset of tools that are used and the order in which they are used, may vary depending on the requirements of the problem and the preferences of the user.

The IPISD model is designed specifically for military training in the skills/job area. Its strength is the extremely detailed level of specification of the procedures to follow during the ISD process. On the other hand, this level of detail lacks generalisability to other environments. Another limitation is the linear approach to ISD. The level of analysis and prescription this model specifies can be done only by a heavily staffed and highly financed organisation (e.g. the military). It requires a commitment of substantial resources on a long term basis. However, the high level of detail could be an advantage with regards to simulator-based training. Any scientific validation of the model is unknown to the authors.

### 5.2.3. The Briggs and Wager model

The model for instructional development that was presented by Briggs and Wager (1981) is used mostly in classroom teaching. Nevertheless it can be of use for developing instruction in other learning environments as well. The model consists of 15 stages. Although the first stage (needs assessment) is characteristic of systems models, the Briggs and Wager model primarily focuses on product development. All steps are listed in the order in which they should be performed, although the authors noted that this will be an iterative sequence as materials are being developed, tested and finalised. The model consists of the following stages:

1) Assessment of needs, goals and priorities;
2) Assessment of resources, constraints and selection of a delivery system (this can be compared with a learning environment);
3) Identification of curriculum and course scope and sequence;
4) Determination of gross sequence of courses;
5) Determination of sequence of unit and specific objectives;
6) Definition of performance objectives;
7) Analysis of objectives for sequencing of enabling objectives;
8) Preparation of means of assessment of learner materials;
9) Designing lessons and materials. A strong emphasis in this phase is on the so-called 'learning events';
10) Development of media, materials and activities;
11) Formative evaluation, involving pilot testing of the materials which may lead to modifications in the previous stages;
12) Field test and revision;
13) Instructor training;
14) Summative evaluation;
15) Diffusion and operational installation (i.e. implementation).

The most important activity in this model is the designing of the instructional events (Gagné and Briggs, 1979). According to this point of view, instruction is considered as a set of events external to the learner which are designed to support the internal processes of learning. Further, media are selected and prescriptions are drawn up concerning utilising appropriate conditions of learning.

The model of Briggs and Wager has many similarities with the IPISD model. Both models proceed from an assessment of training needs at the system level to a specification of objectives and subsequent design and/or development of training materials. They also emphasise the evaluation of training materials both prior and after the instructional program. The model has been (and is still) extensively used by many instructional developers, primarily in classroom settings. Lately, it also serves as a basis for the development of computer-based instruction. A scientific validation is not known to the authors. With regards to simulator-based training the selection of the delivery system, the definition of the learning events, the field testing of the instructional material, and the instructor training are worth mentioning.

### 5.2.4. ROPES

Hooper & Hannafin (1988) present guidelines for the design of instruction using interactive technologies. According to this model, there are five distinct instructional phases: retrieval, orientation, presentation, encoding, and sequence (ROPES). In each phase design guidelines are presented that are based on psychological rather than technological theory and research.

Design guidelines should be considered within the context of how they relate to retrieval of information. To retrieve information from the long term memory (LTM), some cueing mechanism is required. The generation of cues can be enhanced by embedding strategies that facilitate meaningful learning, and relating instructional content to trainees' prior experience. Orienting activities help to prepare the learners for instruction by retrieving relevant information from LTM to be encoded with new information. Orientation design decisions must be based upon intended cognitive outcomes and motivational issues. Technological innovations provide a broad range of media to be employed by the instructional designers. These presentation modes, however, should be used judiciously. Different modes of presentation should be varied systematically, depending on the specific learning task. Encoding requires new information to be organised within an existing cognitive structure. This can be attained by, for instance, incorporating prompts that facilitate comprehension monitoring, and providing feedback that identifies the steps involved in the correct situation. The primary issue concerning lesson sequencing, according to Hooper and Hannafin (1988), is not of how much autonomy should be given to the learner, but rather what type of control students are given. Obviously, this depends on the characteristics of the target group.

A major point of ROPES is that, when designing instruction using interactive technologies, one should not be guided by the technological possibilities and the features of the media. On the contrary, the objectives of instruction are the starting point. Also valuable in designing simulator-based training is that different media should be varied systematically, and that characteristics of the target group should be taken into account. This model is based on psychological theory and research; yet a scientific validation of the model as a whole is not known to the authors.

## 5.3. Conclusions

In this chapter four models for instructional systems development were described. The models are being applied within civilian and military settings. Although there is (more or less) experience with the application of the models, no scientific validation of any model is known to the authors.

Some models focus on the design and use of interactive media during instruction, but only in one case the primary focus is on simulator-based training in particular (OSBATS). Nevertheless, some aspects of the distinctive models are relevant for designing low-cost training simulators. These aspects are:

- A dynamic, iterative approach to ISD should be followed. The development of training systems is a cyclical, rather than a linear process. Therefore it is necessary to distinguish different levels of analysis (e.g. system level, team/crew level, individual level) and design (e.g. by means of prototyping).
- The procedures to follow during the ISD process must be specified in detail.
- The starting point of the ISD process is analysing the system in which the operator(s) has (have) to perform the actual tasks.
- Prototypes must be constructed and tested (in the field).
- Instructional development is a team effort, so the tasks and responsibilities of every team member should be described and co-ordinated with each other.
- The notion of different kinds of instructional objectives and the specific means of achieving these objectives. A (psychological) task analysis should be conducted to identify the cognitive, and perceptual-motor processes which underlie task

performance.

- The technological possibilities and features of the media, and a systematic variation of the media used during instruction must be critically assessed.
- Validated and reliable tests must be developed.
- The characteristics of the target group (including the trainee's motivation) must be taken into account.
- The instructor must be trained.

In addition, the need for cost effectiveness analysis should be stressed. This subject, however, is dealt with in chapter 6.

# Chapter 6

## 6. COST EFFECTIVENESS ANALYSIS

### 6.1. Introduction

Training is a process in which large amounts of resources such as personnel, capital assets, and materials are being used. In these times of decreasing defence budgets, downsizing and new defence postures, detailed information on the costs of training and instruction must be made available to ensure cost-effective training. This is especially the case when training devices are used that are relatively expensive to design and produce, such as training simulators. Although a large number of studies illustrate the (cost) effectiveness of these training devices, there are few studies that explicitly follow a systematic methodology to guide this process. A related problem in estimating the cost effectiveness of a program (or training device) is the difficulty of clearly defining the precise effects or benefits (Blomberg, 1989).

A cost effectiveness analysis (CEA) gives insight in the amount to which a training device enables the student to achieve the goals of instruction, in relation with the costs that can be identified. These costs are related to, for instance, the actual development of the training system, the costs during the training (instructor costs, lost production, total training time), the maintenance and updating of the training system, the effort to formulate the (technical and functional) specifications of the training system. But also the effectiveness of the training system to make the trainees achieve the instructional goals as compared to alternative systems (or in case of simulators, as compared to the actual equipment), has to be taken into account when conducting a cost effectiveness analysis.

A cost effectiveness analysis should be an integral part of the instructional systems development (ISD) process. It can be carried out at the beginning of the ISD process, as well as at the end. A CEA at the beginning of the ISD process is being conducted within a feasibility study (ex ante evaluation). The purpose of the feasibility study is to determine if a proposed solution to a training problem is a suitable one, e.g. the development of a part-task simulator, or full mission simulator.

In the following section

- a general introduction into the more recent literature on CEA
- and a specific summary of the CEA approaches, especially the cost-utility analysis

are given.

The specific summary aims at giving the methodological background, which is the framework of NUKAM, the "Nutzen-Kosten-Analyse für Ausbildungsmittel", used by the German Armed Forces.

## 6.2. General introduction into the more recent literature on CEA

Kearsley (1983) presents an overview of 12 major steps in conducting a CBT feasibility study. He also developed four checklists to help the instructional designer in conducting a feasibility study. These checklist regard the instructional, the organisational, the technical, and the economical feasibility. A CEA at the end of the ISD process is used as a means of evaluating the adequacy of the solution of the training problem.

At the Ohio State University a program was developed for CEA (Ruth, 1985). This analysis to determine the cost effectiveness is a part of the training system design. The complete training system design model includes the following steps:

1. needs identification / forecasting;
2. needs analysis;
3. anticipated cost-benefit evaluation;
4. performance objectives and savings base design;
5. data gathering;
6. course design;
7. implementation of training;
8. data gathering;
9. on-the-floor follow-up;
10. actual return-on-investment calculation
11. retraining/revision.

Although these steps are listed chronologically, they are often performed simultaneously.

Kearsley (1982) developed four models for conducting CEA. These models relate to four different problems. The resource requirements model is concerned with the relation between analysis, design, development, implementation and evaluation of the training on the one side, and personnel, equipment, lodging and materials on the other side. The life cycle model is concerned with the research and development of, and the phases of introducing, maintaining and replacing the training system. The benefits analysis model is concerned with the effects of the training system itself. It focuses on the analysis of the characteristics of the instructional system, the instructional results, and finally the operational results. The productivity model is concerned with the relationship between the requirements for the training (the costs needed) and the training results in order to determine the point of declining profits of the training system. Kearsley (1982) offers guidelines to choose the most appropriate model. This depends largely on the kind of problem to be tackled, and on the amount of time and money available to conduct CEA. When no model is appropriate an 'ad hoc model' can be employed. An ad hoc model is a conceptual framework focused on a specific problem and usually contains elements of the previously mentioned models.

A technique for conducting a CEA when assessing future investments for training systems design, is the Investment Appraisal (Bond, Worthington, & Hornem, 1989). It is a systematic approach to expenditure decisions and should begin, at least on a preliminary basis, early in the ISD process. The Investment Appraisal consists of eight main steps.

1. First the objectives are defined to make clear what scores as a benefit or

otherwise.

2. Next, the main alternative ways of meeting the objectives should be listed.
3. For each option, the costs, benefits, timing and uncertainties must be identified.
4. The costs and benefits which can be valued in money terms should be discounted.
5. In step five, the uncertainties should be weighted up to take account of possible errors in the estimates of costs and benefits.
6. The choice between options often needs to consider factors which cannot usefully be valued in money terms. These may include political implications, planning feasibility or environmental factors.
7. The seventh step is presenting the results. It is often useful to set out:
   a) the objectives,
   b) the options,
   c) the capital costs,
   d) other large costs of benefits,
   e) any marked pattern in the timing of costs,
   f) net present value,
   g) important uncertainties and sensitivities,
   h) each factor which cannot be valued in money terms,
   i) the option which is judged to give the best value for money,
   j) how this option compares with alternatives.
8. The last step of the Investment Appraisal, monitoring, is checking the progress of the chosen option against the estimate. This serves both as a control function and as a source of learning to assist future planning.

## 6.3. Approach to CEA with NUKAM

This paragraph recapitulates a CEA methodology, which was developed for the German Armed Forces early in the 1980ies and is the methodological background of NUKAM (Nutzen-Kosten-Analyse für Ausbildungsmittel). It was proposed to use NUKAM as a method in ELSTAR. (Cf., Von Baeyer, 1985a,b; Braby, et al., 1975; Carpenter, 1970; Knapp & Orlansky, without year; Orlansky, String & Chatelier, 1982; Rehm, 1980; Weiss, 1982; Wienclaw & Orlansky, 1983).

There are three methods of cost/effectiveness analyses (CEA) available. All of them are different ways to compare data derived from effectiveness studies to data stemming from cost analyses (actual cost data or planning cost estimates). In principle all three methods are applicable to training. In reality some of them are better for ex ante (feasibility studies) or ex post evaluations (field studies). In the following paragraphs the applicability of the methods is typified and defined by distinctions, which allocate domains for each method. Of course, there are fuzzy fringes between the methods and their domains. For the sake of clarity these are neglected.

The three methods are:

- cost/benefit analysis for the assessment of money, which might be saved, when training time can be reduced or the weapon system is replaced by a training device; it may also be applied, when the general effectiveness of a training course or even the "military value of training" should be stated in comparison to other military areas, like "maintenance".
- cost/effectiveness analysis (in the physical/technical sense of this term) for the measurement of student performance and the identification of cost drivers, when the technical capabilities of a simulator have to be evaluated

- cost/utility analysis for the assessment of the didactic qualities of training and training devices and for the assessment of its overall usefulness.

Which method can be applied is a matter of:

- available data,
- purpose of the study (*ex ante* / *ex post* evaluation, interest more in the student performance or the choice between alternatives or the cost),
- scientific approach (qualitative or quantitative approach, empirical or operations research methodology),
- organisational circumstances.

### 6.3.1. Cost / benefit analysis

The cost/benefit analysis of training may be done as:

- an *ex ante* evaluation, in order to predict the economic value of new training programmes,
- or an *ex post* evaluation, in order to prove the savings in money as a result of choosing a particular training alternative.

It may be applied in the following situations:

- decision whether a course shall be delivered by military personnel or by contractor personnel and what will be more effective,
- decision whether the use of a highly complex simulator will be cheaper than the use of the weapon system to achieve defined training objectives,
- decision whether the prolongation or shortening of courses will ultimately be more or less economic.

The cost/benefit analysis starts with an analysis of actual or planning cost for all life cycle cost (LCC) categories. It then defines and measures the "benefit" of training by working out either what it would cost, not to have the training program or what the training program is directly worth in money. Alternatives are treated likewise. Alternatives are treated likewise.

The cost/benefit analysis is an economic evaluation, which tries to "monetarise" the usefulness of a training program. It is a valid method, if the aim is purely economic. It has the following pitfalls:

- Military training courses are no market goods and as such have no a market price. Therefore, the usefulness as such cannot be measured in terms of money. Only, the savings of money, when allocating resources differently, can be determined.
- The usefulness or effectiveness of training is either assumed or estimated by "shadow prices".
- Since didactic "usefulness" of training is not considered, this means that it is held constant in all alternatives.

### 6.3.2. Cost / effectiveness analysis (in a purely technical sense of the word)

The cost/effectiveness analysis (in strict sense) of training should be done only as an *ex post* evaluation.

It may be applied in the following situations:

- assessment of the technical capabilities of training devices (or prototypes) and their relation to the costs, transfer of training studies, if (and only if) the training

effectiveness is defined in terms of observable and (rather) exactly measurable behaviour by means of experimental or at least quasi-experimental designs;
- identification of cost drivers which are associated with technical features of training devices.

The cost/effectiveness analysis (in strict sense) is an exact method. This is why it will probably not be the standard for training. As it appears, technical questions in training or well designed and controlled transfer-of-training experiments will demand for this method.

### 6.3.3. Cost/utility analysis

The cost/utility analysis can be done as:
- an *ex ante* evaluation to predict the usefulness of alternative training programmes, when no measurable data are available,
- or an *ex post* evaluation, when it is too difficult to collect data for a cost/benefit or a cost/effectiveness analysis.

The cost/utility analysis may be applied in the following situations:
- choosing between alternative training programmes within the Instructional System Design procedure (ISD, see chapter 5),
- choosing alternative training devices early in the systems development cycle,
- evaluating whole training programmes with all cost and effectiveness implications.

As it appears, the cost/utility analysis will be the method of choice for training. Because it is not based upon exact data, it never loses its particular subjective connotations. However, the cost/utility analysis is a scientific method. It consists of a set-up of systematic criteria and expert ratings with the following working steps:
- systematic development of the decision problem in terms of a break down structure of criteria
- evaluation of the criteria by weighing each criterion according to its relevance to the decision problem, and by scoring each alternative program for each weighted criterion.
- computation of the overall utility value of each alternative and formation of a rank order of all alternatives
- LCC analysis of each alternative program (actual or standard cost)
- comparison of each alternative program as to the relevant criteria, utility value, and the costs.

## 6.4. Problems of the practical performance of CEA

The theory of CEA has become relatively well structured and may lead to the hope that the practice will be easy. This is not the case. The practical problems are obvious:
- Definition of the decision goal; the user and the procurer may have different interests.
- The systematic context of the decision; the evaluation may be set off irrespective of relevant circumstances, such as weapon system development or curriculum changes
- The available data and experts; data and experts may exist but are not known to the evaluating agency
- The organisation of a CEA including the role of CEA in the systems development

cycle which emphasises the character of the CEA as a management tool in the hand of the planning authorities.

The sections below will deal with the aforementioned practical problems in more detail.

### 6.4.1. The definition of the decision goal

In theory again, the decision goal is clear: to find the most cost-effective training programme given the available resources. But this goal entails ambiguities, still:

- Do the costs have to be optimised on the basis of a given effectiveness, or vice versa?
- Is the training effectiveness the only measure of effectiveness, or are there other, e.g. organisational and technical, measures prevailing ?
- Do the evaluators or the experts have certain solutions in mind, which they want to prove by a scientific study ?

Therefore, the decision goal is always the total training programme or training system. The optimisation must work in either direction; cost and effectiveness must be traded off both being the dependent variables. The CEA cannot be done with a personal bias of the evaluators and experts, be it open or concealed.

### 6.4.2. The systematic context of the decision

The context of the decision is defined by time and organisation. CEA may not be synchronised with the technical, tactical and logistic planning of a new weapon system, or may not be aware of the changes in a training curriculum. Research data may not be known. And last, but not least the evaluator may be tied to an organisational context, which has an effect on his results. Therefore, CEA should have a defined place in the weapon systems development and in the systems approach to training. It should be a milestone in every planning of training and should be done by an independent organisation.

### 6.4.3. The available data and experts

Data on cost and effectiveness of training are not always available. But often they must not be generated by research. They are in the minds of experts, who have to be found and questioned.

All data on subject matters should be stored in a training data bank for the purpose of analysis and evaluation.

### 6.4.4. The organisation of a CEA

Cost/effectiveness analyses of training must be undertaken as a team work of a specially tasked working group. This may consist of experts of the following fields:

- General didactics and training methodology
- Training subject including special didactics and methodology
- Training Technology (if applicable)
- Personnel and Manpower (if applicable)

- Instructional Systems Development of the training subject
- Empirical research on training
- Cost analysis.

The working group must be given a clearly structured goal, including a time frame for its work.

Cost/effectiveness analyses of training devices in the framework of the weapon systems development cycle should be a matter of routine. They have a threefold function:

- establishment of alternative technology options, when little is known about tactics and logistics of the weapon system and yet cost for (e.g.) simulators or embedded training must be considered
- detailed effectiveness studies and cost estimates (with or without prototypes), when more is known about the weapon system and the development and procurement of (e.g.) simulators or embedded training must be decided upon
- post fielding analysis, to collect historic data.

It is hardly possible to give numeric examples for the three methods. For, every CEA method is too complex and can only be fully worked out in a given decision context. To describe the decision context would demand, however, a lengthy elaboration and would therefore be beyond the scope of this report. Work Package 1.c of this project will produce a task and cost-utility analysis and can serve as an excellent example.

# Chapter 7

# 7. DOMAIN SELECTION

## 7.1. Introduction

This chapter presents the methodology for a first selection of military task domains that are suitable for application of low-cost simulator training, and that are challenging because research will generate technological and conceptual knowledge on low-cost simulator training solutions.

The following activities are reported:

- analysing military missions and constructing the ELSTAR taxonomy of military task domains (see 7.2)
- defining a set of criteria for judging whether a task domain is suitable for low-cost simulator training and knowledge generation (see 7.3)
- the method and procedure for scoring the identified task domains for each of the defined criteria (see 7.4)
- selection of military task domains (see 7.5)

## 7.2. ELSTAR taxonomy of military task domains

In order to select military task domains appropriate for research into low-cost simulator training, a comprehensive taxonomy of military tasks was needed. A search in the "Cognitive Ergonomics" database was conducted to see whether suitable taxonomies already existed (the "Cognitive Ergonomics" database includes the important military journals, reports, conference proceedings and books). The following keywords were employed:

"taxonomy & task*" 49 hits,
"military tasks" 94 hits.

However, this produced no references containing taxonomies directly applicable for ELSTAR. The "Universal Joint Task List" (version 2.1; 1995), produced by the Joint Chiefs of Staff (of the US armed forces) proved to be the most appropriate. It was decided to use this list as a basic source. With the military expertise available within the consortium and with the help of military contacts, this task list was used for constructing the ELSTAR taxonomy (see Appendix A3).

The ELSTAR taxonomy is structured according to six main military functions:

- MANOEUVRING,
- INTELLIGENCE (target information, tactical reconnaissance, and surveillance),
- TARGET ACQUISITION AND WEAPON DELIVERY,
- COMBAT SERVICE SUPPORT,
- COMMAND & CONTROL,
- MAINTAINING MOBILITY & SURVIVABILITY.

Each of these is specified into one or more sub-functions (e.g. sub-functions of MANOEUVRING are 'to move', and 'to navigate').

In many cases, the execution of a function is affected by;

- *organisational level*, e.g. warrior *vs*. staff level,
- *level of threat*, e.g. manoeuvring in a low-threat environment is performed differently than in high-threat environments,
- and by *task- and environmental conditions*, e.g. navigating in a directly-perceived environment differs essentially from navigating in an instrumentally-perceived environment.

Where appropriate, the military (sub)functions are broken down according to such distinctive features.

This structure allowed us to identify the military task domains relevant for the purpose of examining low-cost simulation solutions (military task domains are printed in bold small capitals). For some task domains it is necessary to specify the equipment that is used (e.g. monitoring of manoeuvring through using radar equipment). Where appropriate, this has been specified in the taxonomy.

## 7.3. Definition of the selection criteria

One major objective of Work Package 1.a is to accomplish a preliminary selection of appropriate military task domains. In order to do this, four main selection criteria were formulated:

- training need,
- simulation need,
- generation of knowledge,
- simulation simplicity.

These are discussed in more detail below.

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 (on the basis of present technological and strategic trends)

The training need for each task domain specified in the ELSTAR taxonomy refers to the number of trainees, the intensity of a typical training program (time to acquisition and refresher-training demands), and the domain's military strategic significance, now and in the future. For instance, task domains involving systems or technologies soon to be replaced should be assigned low future significance. Similarly, high future significance should be assigned to those task domains of which military experts predict increasing significance. In general, task domains relevant for peace keeping and humanitarian operations in unfamiliar areas were considered important.

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 (added value) expected.

The simulation need criterion was aimed at the selection of task domains that are unsafe to train without simulators, that could be trained more efficiently with simulators, or that are likely to be trained more effectively by simulator training. In order to evaluate these criteria for a particular task domain, the following potential advantages of simulator training were considered:

- easy and flexible training scenario generation (systematically varied with an increasing difficulty level)
- added training value by augmented feedback possibilities
- added training value by automated and objective performance measurement and feedback
- release of environmental burden, pollution, etc.

*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)
[3.3 High costs of conventional training]

This criterion was used to examine what kind of knowledge is necessary to develop a low-cost training simulator for a task domain. It is the goal of the ELSTAR project to produce generic knowledge. Therefore topics associated with developing low-cost simulation should not be restricted to few task domains or skill dimensions, and should be conceptually and technologically challenging. This *'generation of knowledge'* criterion contained three sub-criteria, i.e.: no satisfying solutions available, non-trivial simulation questions, and costs of conventional training.

- The first of these investigated whether or not training equipment is already available to train the (sub)tasks of a task domain satisfactorily. "Satisfying" in this sense means: cost-effective and with sufficient transfer of training.
- The second *'non-triviality'* sub-criterion demanded that the selected most suitable domains should not be so fit for low-cost simulation that there remain no real questions to be answered.
- Finally, *'costs of conventional training'* (equipment, training personnel, logistic requirements) was not regarded a 'hard' sub-criterion. Whereas simulation can be regarded more attractive with high conventional training costs, *low-cost* simulation is mandatory when conventional training costs are low. Therefore, information concerning this criterion was collected only for the sake of knowledge accumulation, not for the selection of task domains.

*4. Simulation simplicity*

4.1 Requiring a (relatively) simple mathematical model
4.2 Requiring simple visual information (man-made/static *vs*. natural/dynamic and simple *vs*. complex environment)
4.3 Minor mechanical motion requirements (number of degrees of freedom, amplitudes, frequencies, payload requirements)
4.4 Minor requirements concerning other perceptual information (acoustics, smell)
4.5 Minor MMI requirements (console with controls and displays)
4.6 Minor communication and co-ordination requirements, e.g., individual training (stand-alone simulators, no/minor requirements for distributed interactive

simulation for team training purposes)

Simulation simplicity referred to the technological investments that are supposed to be necessary in order to simulate a task domain. This is not a very hard criterion that in itself could be used to select or eliminate domains from the list. For some domains it may be very difficult to simulate the required control systems and information displays (e.g. infrared displays, aircraft flight)but if the simulation need is high (e.g. safety, efficiency, potential advantages) then the benefits obtained may outweigh the costs of investments of technological solutions required for a training simulator. On the other hand, if a system is relatively easy to simulate then it is likely that satisfying simulator training facilities for the particular task domain have already been developed. Therefore, the simplicity criteria may be in conflict with sub-criterion 3.1 (satisfying solutions already present). In conclusion, this main criterion was used in an explorative manner; the scores on this criterion reflect for each domain the kinds of technical problems that will be encountered in the remainder of the ELSTAR project.

## 7.4. Scoring the task domains

All task domains of the ELSTAR taxonomy were scored by consulting military and simulator experts with respect to the 15 criteria described above. Criteria involving 'military training need', 'simulation need', and sub-criteria 3.1. and 3.3 of 'knowledge generation' were scored on the basis of results on a questionnaire, personally administered to military field experts of each service (Army, Air force and Navy) of the Dutch armed forces. The results were extrapolated to the situation for the other participating countries by using a global inventory of the number of military systems available to each country. Given the number of military task domains, it is obvious that scoring could only be performed at a global level. The remaining (sub)criteria were scored by simulator experts. The experts assigned each task domain a minus (-), a zero (0) or a plus (+) for each criterion, where a + indicates good opportunities for low-cost simulation. For those task domains were low-simulator training seemed extremely promising, a (++) was assigned.

## 7.5. Selecting the task domains

If a satisfying training solution was already available (see criterion 3.1), then the task domain was intended to be eliminated from the list. Unfortunately, there is much disagreement among (military) experts whether or not a training solution is really satisfying, and there is seldom any hard evidence available on the transfer of training (see § 3.4). Therefore it was often not possible to use this criterion in the intended resolute way. This criterion will be studied in more detail in subsequent parts of Work Package 1.

Task domains potentially suitable for low-cost simulator training were required to have substantial or high training need (1.1 - 1.3) and simulation need (2.1 - 2.3). Furthermore, satisfying simulator solutions should presently be lacking, and developing such solutions should involve non-trivial problems to be solved (3.1 - 3.2). Applying these restrictions reduced the number of task domains substantially. A final selection was made from the remaining task domains in such a fashion that the selection covered a broad range of military main functions (e.g., manoeuvring, intelligence, etc.), tasks (e.g. perceptual-motor, cognitive), and that there was a more or less equal distribution over the three armed forces.

# *Chapter 8*

# 8. RESULTS

## 8.1. Task domains

Table 8.1 shows the task domains of the ELSTAR taxonomy that, on the basis of the scores on the 15 (sub)criteria, appeared appropriate for further study.

| MAIN FUNCTION | SELECTION |
|---|---|
| **Manoeuvring** | 1.1.1.1.1<br>1.1.1.1.2<br>1.1.2.3.1<br>1.2.1.1.2<br>1.2.1.2.4.1<br>1.2.2.1.2<br>1.2.2.2.1.1<br>1.2.2.2.1.2<br>1.2.2.2.2.1<br>1.2.2.2.2.2<br>1.2.2.2.4.1<br>1.2.2.2.4.2<br>1.2.2.2.4.3 |
| **Intelligence** | 2.1.2.1.2<br>2.1.2.1.5 |
| **Target acquisition & weapon delivery** | 3.1.1.1.1<br>3.1.1.1.2<br>3.1.1.2.2<br>3.1.2.1.1<br>3.2.2.1.1 |
| **Combat service support** | 4.1.1<br>4.1.2<br>4.1.3 |
| **Command & Control** | 5.1.1<br>5.1.2<br>5.1.3<br>5.2.1<br>5.2.2<br>5.3.3 |
| **Providing mobility and survivability** | - |

***Table 8.1:*** *Selected task domains*

As can be seen, the task domains in the list are not very well-distributed over the military main functions, i.e., manoeuvring is over-represented. This is mainly caused by the relatively high number of task domains concerning the use of image intensifiers and infrared equipment.

It is clear that from the total number of 100 task domains, still a rather high proportion (29 domains, i.e., 29 %) is considered appropriate for research, development, and application of low-cost simulation technology. Because it was not considered feasible to perform task- and cost utility analyses on this large portion of the entire military training field, redundant task domains were eliminated from this list (e.g., one of the two "vehicle driving" domains and two of the three "fault diagnosis" domains). This resulted in a sub-set of 15 domains that formed a more concise, but still representative, selection.

Table 8.2 contains a more elaborate presentation of this selection including the scores assigned to each (sub)criterion.

| Task domain (see Appendix A3) | | Selection criterion (see 7.3) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1.1 | 1.2 | 1.3 | 2.1 | 2.2 | 2.3 | 3.1 | 3.2 | 3.3 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 |
| 1.1.1.1.1 | To move wheeled vehicles (in low/high-threat environments) | + | ++ | 0 | 0 | + | + | + | + | + | - | - | 0 | + | + | + |
| 1.1.2.3.1 | To move an unmanned platform using video images | + | 0 | ++ | - | + | + | + | + | + | 0 | + | + | + | + | + |
| 1.2.1.1.2 | To navigate an air platform in directly perceived low-threat environments | + | + | + | - | + | + | 0 | 0 | + | + | 0 | + | + | + | 0 |
| 1.2.1.2.4.1 | To navigate an unmanned platform using video images in low-threat environments | + | 0 | ++ | - | + | + | + | + | + | + | - | + | + | + | + |
| 1.2.2.1.2 | To navigate an air platform in directly perceived high-threat environments (low-level flight) | ++ | + | + | + | + | + | 0 | + | + | + | - | 0 | + | + | - |
| 1.2.2.2.1.1 | To navigate a land platform using image intensifiers in high threat environments | + | + | + | 0 | + | + | + | 0 | + | + | - | + | + | + | - |
| 1.2.2.2.1.2 | To navigate a land platform using infrared equipment in high threat environments | + | + | + | 0 | + | + | + | + | + | - | - | + | + | + | - |
| 1.2.2.2.4.1 | To navigate an unmanned platform using video images in high-threat environments | + | 0 | ++ | - | + | + | + | + | + | + | - | + | + | + | 0 |
| 2.1.2.1.2 | To collect information using infrared equipment | + | ? | ++ | - | + | + | + | + | + | - | - | + | + | + | 0 |
| 2.1.2.1.5 | To collect information using video image equipment in unmanned vehicles | + | 0 | ++ | - | + | + | + | + | + | + | - | + | + | + | + |
| 3.1.1.1.1 | To operate a Line-of-sight, guided, 'fire & forget', single-unit operation, weapon system | + | ++ | 0 | + | + | + | + | + | + | + | - | 0 | 0 | + | 0 |
| 3.1.1.1.2 | To operate a Line-of-sight, guided, 'fire & forget', co-ordinated unit operation , weapon system | + | + | 0 | - | + | + | + | + | + | + | - | + | + | + | - |
| 3.2.2.1.1 | To operate a Non-Line-of-sight, non-guided, 'fire & forget', single-unit operation, weapon system | + | + | 0 | + | + | + | + | + | + | - | + | + | + | - | 0 |
| 4.1.3 | Maintenance, fault diagnostics & repair of equipment of complex, composite systems of the Navy | + | ++ | 0 | - | 0 | + | + | + | + | - | - | + | - | 0 | 0 |
| 5.1.3<br>5.2.3 | Mission planning and implementation at the warrior levelat the staff level or in the Navy | ++<br>++ | +<br>+ | +<br>0 | -<br>- | -<br>- | +<br>+ | +<br>0 | +<br>+ | +<br>+ | -<br>- | -<br>+ | +<br>+ | +<br>+ | +<br>+ | -<br>- |

*Table 8.2: Scores on (sub)criteria assigned to task domains selected from the ELSTAR taxonomy*

The task domains under the main function "Providing mobility and survivability" appeared to be less suitable for further research. The reason for this is that on one hand, the search- and identification tasks, primarily involves perceptual skills (interpretation of perceptual information such as visual- or infrared images or sonar patterns) without the need for real-time *interaction* with a system or an environment. In addition, other tasks may be procedural and easy to be simulated such that satisfying solutions are already available. Finally, these kinds of tasks may require direct interaction with the real environment (e.g., detonating mines, or removing obstacles). It is very unlikely that these tasks can be simulated with the present and near-future state of technology.

The scores on the six "simulation simplicity" criteria show that technical problems to be solved mostly concern visual information presentation, mathematical modelling, and communication. In addition, least problematic are the domains involving the manoeuvring of unmanned platforms and air platform navigation in low-threat conditions, whereas simulation of high-threat land platform navigation with infrared equipment and maintenance of complex systems appears most complicated.

## 8.2. Relevant training areas

The selected task domains do not always match in a one-to-one fashion with the often complex and distributed structure of military training practice. It appeared that some domains presumably would be involved in the same actual training program. Therefore, in order to further investigate the opportunities for low-cost simulation in the next phases of this work-package, 9 military "training areas", covering the 15 task domains selected from the taxonomy, were defined. A survey is presented below, describing these areas.

**Military training areas**, including:

- the relevant main functions,
- the selected task domains and military forces that are directly investigated,
- the Industrial Partner to which the domain is allocated.

---

**1 Training of wheeled vehicle control ("to move") in low- and high-threat environments (excluding the use of image intensifier and infrared equipment)**

military main function: Manoeuvring
selected task domain: 1.1.1.1.1
relevant military force: Army
allocated to, and responsibility of: TNO

**2 Training of air platform navigation in directly perceived low- and high-threat (low-level flight) environments, excluding the use of image intensifier and infrared equipment**

military main function: Manoeuvring
selected task domains: 1.2.1.1.2; 1.2.2.1.2
relevant military force: Air force
allocated to, and responsibility of: STN/IABG

**3 Training the use of (head-mounted) infrared equipment and image intensifier equipment for land platform navigation and information acquisition in high-threat environments**

military main function: Manoeuvring & intelligence
selected task domains: 1.2.2.2.1.1; 1.2.2.2.1.2; 2.1.2.1.2
relevant military force: Army
allocated to, and responsibility of: ECON

4 **Training the manoeuvring of unmanned platforms with video payload in low- and high-threat environments**

| | |
|---|---|
| military main function: | Manoeuvring & intelligence |
| selected task domains: | 1.1.2.3.1; 1.2.1.2.4.1; 1.2.2.2.4.1; 2.1.2.1.5 |
| relevant military force: | Army |
| allocated to, and responsibility of: | TNO |

5 **Training operators of Line-of-sight, guided, 'fire-and-forget', single-unit operated weapon systems**

| | |
|---|---|
| military main function: | Target acquisition and weapon delivery |
| selected task domains: | 3.1.1.1.1 |
| relevant military force: | Air force |
| allocated to, and responsibility of: | STN/IABG |

6 **Training operators of Line-of-sight, guided, 'fire-and-forget', co-ordinated-unit operated weapon systems**

| | |
|---|---|
| military main function: | Target acquisition and weapon delivery |
| selected task domains: | 3.1.1.1.2 |
| relevant military force: | Air force |
| allocated to, and responsibility of: | CORYS |

7 **Training operators of Non line-of-sight, non-guided, 'fire-and-forget', single-unit operated weapon systems**

| | |
|---|---|
| military main function: | Target acquisition and weapon delivery |
| selected task domains: | 3.2.2.1.1 |
| relevant military force: | Navy |
| allocated to, and responsibility of: | TEE/LB |

8 **Training in fault diagnostics and maintenance of complex, composite systems military main function**

| | |
|---|---|
| military main function: | Combat service support |
| selected task domains: | 4.1.3 |
| relevant military force: | Navy |
| allocated to, and responsibility of: | CORYS |

9 **Mission planning and implementation at the warrior or at the staff level**

| | |
|---|---|
| military main function: | Command & Control |
| selected task domains: | 5.1.3 or 5.2.3 |
| relevant military force: | Navy |
| allocated to, and responsibility of: | TEE/LB |

These training area's provide a basis for investigating the selected task domains. As can be seen, in this list each military force is represented 3 times.

The selection of unmanned platforms is also relevant for some domains of the main function "Providing mobility and survivability", that, thus far, were not represented in the selection (see table 8.2). These additional task domains are shown in Table 8.3, including the scores assigned to each of these additional task domains for each (sub)criterion. (A +/- means that in some cases it is easy (procedural tasks) and in some cases (direct contact with the environment) it is very difficult to technically accomplish an appropriate simulation.)

| **Task domain** (see Appendix A3) | | **Selection criterion** (see 7.3) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1.1 | 1.2 | 1.3 | 2.1 | 2.2 | 2.3 | 3.1 | 3.2 | 3.3 | 4.1 | 4.2 | 4.3 | 4.4 | 4.5 | 4.6 |
| 6.1.2.1 | Searching and identifying mines at land | + | 0 | ++ | - | ++ | + | ? | 0 | + | + | 0 | + | + | + | 0 |
| 6.1.2.2 | Searching and identifying mines at sea | + | 0 | ++ | - | ++ | + | - | - | + | + | 0 | + | + | + | 0 |
| 6.1.3.1 | Removing mines at land | + | + | ++ | - | ++ | - | ? | ? | +/- | +/- | 0 | +/- | + | +/- | 0 |
| 6.1.3.2 | Removing mines at sea | + | 0 | ++ | - | ++ | - | - | - | + | + | + | + | + | + | + |

***Table 8.3:*** *Scores on (sub)criteria assigned to additional task domains*

## 8.3. Distribution over forces, main functions and psychological skills

Table 8.4 shows the distribution of training areas over military forces, over military main functions, and over psychological skill type (Pr = procedural, Pm = perceptual-motor or perceptual, C = cognitive including psycho-social skills). The numbers in the cells refer to the training areas identified in section 8.2.

| | **Manoeuvring** | | | **Intelligence** | | | **Target Acquisition & Weapon Delivery** | | | **Combat Service Support** | | | **Command & Control** | | | **Providing mobility and survivability** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pr | Pm | C | Pr | Pm | C | Pr | Pm | C | Pr | Pm | C | Pr | Pm | C | Pr | Pm | C |
| **ARMY** | 1,4 | 1,3,4 | 4 | | 3,4 | | 5 | 5 | | (8) | | (8) | | | (9) | (4) | (4) | (4) |
| **NAVY** | (4) | (4) | (4) | | (4) | | 7 | | | 8 | | 8 | | | 9 | (4) | (4) | (4) |
| **AIR FORCE** | | 2,(3) | 2 | | (3) | | | 6 | 6 | (8) | | (8) | | | (9) | | | |

***Table 8.4:*** *The distribution of the training areas that have been defined for further study over military forces, over military main functions, and over psychological skill types*

The numbers of the training areas that are printed in parentheses denote military main functions, and military forces that will not be directly investigated in the study (e.g., $C^2$ at the staff level for the Army or Air force). It may be expected, however, that the knowledge that will be acquired will also be very relevant to the domains that apply to these combinations of functions and forces. This implies that the subsequent study will be relevant to all domains mentioned in table 8.1 and to the additional domains of 8.4 as well. The table shows that for each military force all main functions and all three skill types will be studied.

Training area # 4 (unmanned platform control) is rather over-represented in this list because this task applies to all military forces, three main functions, and three skill types.

# Chapter 9

## 9. CONCLUSIONS AND DISCUSSION

Because the purpose of training simulators is to teach practical skills, transfer of training is *the* critical and conclusive issue in research, development, and application of simulator systems. On a theoretical level, the factors determining transfer of training are well documented e.g. the (perceived) similarity between training and actual task, increasing variability in training, decreasing feedback during training but there are no specific and firm guidelines telling us how to use this knowledge for a particular (simulator) training program. In this respect, the literature shows few solid field studies into the transfer-of-training of (military) simulator training programs. Instructors usually tend to be positive about their training devices but hard evidence is often lacking. Conducting systematic and controlled field studies into transfer of training (utilising longitudinal forward transfer paradigms) is costly in terms of money, amount of work, organisational efforts, etc. It is therefore not surprising that these studies are scarcely conducted. However, the evaluation of training programs using more simple evaluation methods (e.g. backward transfer paradigms) should certainly become more common practice.

There are models for instructional systems development available trying to accommodate for the design of simulator based training, but no scientific validation of these prescriptive systems is known to the authors. Since many interacting variables determine simulator validity in real training programs, it is still difficult to formulate hard predictions.

Thus, there still exist many questions involved in the specification, procurement, and implementation of (low-cost) simulators into new or existing training programs. Presently RTP 11.1 (MASTER) works on the definition of training system concepts for simulator-based training. The goal of the RTP 11.8 (ELSTAR) project is to acquire knowledge on, and to formulate guidelines for, the specification (development, application) of low-cost training simulators.

Specifying the functionalities of a simulator in order to obtain good transfer-of-training is a complex process, requiring expertise on:

- military missions, tasks, and skills to be trained;
- training and instruction methodology;
- available simulation technology;
- etc.

One approach is to try to accomplish the best possible fit between the training and the task environment (pursuing high physical fidelity). This method, however, often involves high costs, even though an expensive simulator does not guarantee good performance. The key factor of success is whether the simulator represents the critical task elements in a psychologically valid way.

The ELSTAR approach for developing low-cost training simulators is to identify the critical task elements and to select those that can be easily simulated with high fidelity. This approach calls for:

1) selection of military task domains that are suitable for cost-effective simulator training,
2) aggregation of (sub)tasks and critical cues that can easily be simulated with high-fidelity in combination with the elimination of the (sub)tasks that are difficult to simulate,
3) careful integration of simulator training into the curriculum, taking into account the opportunities and limitations of the low-cost training simulator.

In general, costs involved in achieving higher fidelity and completeness of simulation shall not exceed the benefits of higher transfer of training. Thus, the ELSTAR approach will often lead to part-task simulator training, rather than a full-mission training device. The prospect of this approach is that recognised advantages of simulator training (better feedback, automatic performance measurement, part-task training, cue augmentation, fading, quick manipulation of training scenario's etc.) are available for those sub-tasks that can be efficiently simulated, whereas more conventional training methods and techniques will be applied to train those part-tasks that can not be trained (cost-)effectively on a low-cost training simulator.

One major goal of the first work-package of the ELSTAR project is to make a preliminary selection of military task domains that are suitable for application of low-cost simulator training, and that are challenging because research will generate technological and conceptual knowledge on low-cost simulator training solutions. The global approach was the following:

1) construct an appropriate taxonomy of military task domains;
2) define a list of criteria for establishing whether a particular task domain is apt for further research;
3) pre-select task domains, by using the criteria, for which further research seems promising;
4) select from the resulting list a heuristic set of task domains and training areas for further research.

These stages are discussed in more detail below.

### 1. *The ELSTAR taxonomy of military task domains*

The field of military training consists of an enormous number of different training programs, often characterised by a rather complicated relationship to military missions, functions and operational systems. Searches in literature databases revealed that there is no comprehensive taxonomy of military tasks fitting the purposes of low-cost simulation research. Therefore, we had to construct one ourselves. For that purpose the "Universal Joint Task List" (Kross, 1995) was used as a global basis. With the help of military experts the ELSTAR taxonomy of military task domains was constructed (version 1.0). This taxonomy consists of about 100 task domains.

It is not an easy undertaking to represent the elaborate and scattered field of military training in a structured and consistent way. Problems encountered were that the information concerning the training programs is often distributed over many different centres, that training centres are frequently ignorant of each others services, and that sometimes essential information is difficult to obtain. The development of the taxonomy was therefore a re-iterative rather than a single-step process. The process of fine-tuning the taxonomy is still continuing. Principal changes, however, are not expected.

2. *Selection criteria*

The criteria for establishing whether or not a task domain is suitable for further research into low-cost simulator training were defined by consulting the literature, and by consulting training and simulator experts. Four groups of selection criteria were formulated:

- training need (3 x),
- simulation need (3 x),
- generation of knowledge (3 x),
- simulation simplicity (6 x).

3. *Selection of suitable task domain*

The ELSTAR taxonomy and the set of criteria proved to be effective in obtaining information from military-, training- and simulator experts. The taxonomy matched, by and large, with the way military training specialists understand their field, and the task domains could easily be translated into concrete military activities, functions and tasks. This facilitated the communication between military experts and simulator experts considerably. Furthermore, the taxonomy provided simulation experts with a comprehensive overview of the relevant dimensions of the operational tasks. Thus, in general, the task domains could readily be assigned a score for each selection criterion.

In order to select a task domain as potentially suitable for low-cost simulator training, it was required to have a high training need and a high simulation need. Furthermore, satisfying simulator solutions should presently be lacking, and developing such solutions should involve non-trivial problems to be solved. The selection of task domains was made in such a fashion that the selection covered a broad range of tasks, and that there was a more or less equal distribution over the three armed forces.

The 29 domains that were pre-selected for further research still cover large areas of military training, which signify their potential value for (low-cost) training simulation. Critical criteria for selection in this respect were *training need* and *knowledge generation*. "Driving a (wheeled) vehicle", for example, is a task domain with a very high number of trainees. Moreover, developing low-cost simulator solutions for cost-effective driver training requires significant research. "Controlling unmanned platforms" is a task domain that is selected primarily because of its rapidly increasing significance, i.e., for data registration and communication (e.g., AGARD 1996). Furthermore, this domain has good prospects for the application of low-cost simulators. The *simulation need* criteria failed to substantially discriminate among the various domains; almost all domains would benefit from the potential advantages of training simulation. The *simulation simplicity* criteria and the sub-criterion concerning *costs of conventional training* do not lead in itself to conclusions about the necessity for low-cost simulation research, but they provided information that will be relevant in subsequent phases of this study.

All domains pertaining to Command and Control were pre-selected. Task domains appearing less appropriate for further investigation pertain to the main function 'Providing mobility and survivability'. The reason for this is that on one hand, the search- and identification tasks, primarily involve perceptual skills (interpretation of perceptual information such as visual- or infrared images or sonar patterns) without the need for real-time *interaction* with a system or an environment. In addition, other tasks may be procedural and thus rather easy to simulate such that satisfying solutions are already available. Finally, these kinds of tasks also may require direct interaction with the real environment (e.g., detonating mines, or removing obstacles). It is very unlikely that these tasks can be simulated with the present and near-future state of technology. However, planned studies into the control of unmanned platforms will be related to missions involving mine searching, identification, and removing. It is therefore expected that results of these studies will provide a spin-off for task domains of this military main function.

Notice that few procedural task domains have been selected for further study, presumably because these tasks present relatively minor problems with regard to low-cost simulation. Tasks demanding cognitive/social- and perceptual-motor skills form the majority of the selection. The development of appropriate low-cost simulators for these tasks require vital, and challenging problems to overcome.

The scores on the 6 "simulation simplicity" criteria showed that technical problems, to be solved mostly concerned visual information presentation, mathematical modelling, and communication. In addition, least problematic were the domains involving the manoeuvring of unmanned platforms and air platform navigation in low-threat conditions, whereas simulation of high-threat land platform navigation with infrared equipment and maintenance of complex systems appeared most complicated.

## 4. *Definition of heuristic task domains and training areas for further research*

In order to investigate the opportunities for low-cost simulation, a representative and more concise sub-set of 15 task domains was formed by elimination of some redundant domains (e.g., one of the two "vehicle driving" domains and two of the three "fault diagnosis" domains). These selected task domains, however, still do not exactly match in a one-to-one fashion with the often complex and distributed structure of military training practice. Actually, some domains would be involved in the same, or very similar, real training programme.

Therefore, 9 military training areas were defined that covered these 15 selected task domains. In brief, the areas involved are:

1) wheeled vehicle control,
2) air platform navigation,
3) infrared and image intensifier equipment,
4) control of unmanned vehicles,
5) line-of-sight/guided/fire-and-forget/single-unit weapon systems,
6) line-of-sight/guided/fire-and-forget/coordinated-unit weapon systems,
7) non line-of-sight/non-guided/fire-and-forget/single-unit weapon systems,
8) fault diagnosis in complex systems,
9) command and control on warrior'- or staff- level.

The remainder of the present work-package consists of three steps:

- For each military training programme/area, more detailed data will be acquired with respect to task- and cost-utility information.
- Subsequently, the results will be used to verify whether, and to what degree, the selected task domains are indeed interesting for low-cost simulator development and application.
- Finally, a set of 3-5 task domains will be selected for further research, which ultimately (after 4 subsequent work-packages) aims at a handbook comprising guidelines for low-cost simulator development, acquisition, and its application.

# Appendices

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# A2 GLOSSARY

| | |
|---|---|
| $C^2$ | Command & Control |
| **CBT** | Computer Based Training |
| **CEA** | Cost Effectiveness Analysis |
| **CER** | Cost Effectiveness Ratio |
| **Chunking** | The grouping of smaller units of information into a larger, in itself meaningful, whole. |
| **Cognitive skills** | Tasks that depend on the use of problem solving heuristics and decision making strategies |
| **Cost-utility** | Estimation of the overall efficiency of alternative training and simulation concepts by means of a structured weighing process |
| **Cue** | That aspect of a stimulus pattern that acts as a signal in guiding the trainee's behaviour |
| **Desktop simulation** | Each form of workstation-based simulation that integrates the instructional aspects of CBT with the dynamic training possibilities of simulation |
| **Face validity** | Validity, estimated on the basis of superficial, apparently relevant characteristics |
| **Full mission simulator** | Top level training device which provides sufficient cues and facilities necessary for training complete missions of a specific system |
| **Functional fidelity** | The similarity between the trainee's behaviour in the simulated task (perceptual, motor and cognitive processes) and in the operational task under similar conditions |
| **ISD** | Instructional Systems Design |
| **LCC** | Life Cycle Cost |
| **MMI** | Man Machine Interface |
| **NUKAM** | Nützen Kosten Analyse für AusbildungsMittel |
| **Part-task trainer** | A device which provides an individual or a group with the ability to learn only portions of the total task |
| **Perceptual motor tasks** | Tasks that mainly require perceptual inputs on which motor outputs have to be based |
| **Physical fidelity** | The extent to which the simulator mimics the real equipment in terms of information perception and control characteristics |

| | |
|---|---|
| **Procedural tasks** | Tasks in which the primary activity to be performed involves the execution of an algorithmic sequence of discrete actions |
| **Recurrence training** | Type of training to refresh knowledge from previous training |
| **Retention** | The degree to which performance is maintained in the absence of training and experience relative to the performance at the end of training (complementary to decay) |
| **Scenario** | A description of initial conditions and a possible sequence of events and circumstances imposed on the trainees (or systems) to achieve exercise objectives |
| **TER** | Transfer Effectiveness Ratio |
| **TCR** | Training Cost Ratio |
| **ToT** | Transfer of training |
| **Validity** | The extent to which skills acquired in the simulator transfer to the operational equipment |

## A3 ELSTAR TAXONOMY OF MILITARY TASK DOMAINS

- Document ELS-DEL/1-TAXO, ind. 1 (revision of the document formerly referenced as ELS-AVT/1-A).

CORYS
I.A.B.G.
TNO HFRI
STN ATLAS
TRACTEBEL
ECON Electronics
LEENTJENS BOËS

# ELSTAR

European Low-cost Simulators for the Training of Armed forces

| | | |
|---|---|---|
| Title | : | **TECHNICAL REPORT**<br>**Taxonomy of military task domains** |
| Work Package | : | 1 (Analysis of military training) |
| Activity | : | **1.a** (Literature Review and preliminary selection of military fields) |
| Work Package Leader | : | TNO / HFRI |
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# EUCLID RTP 11.8

European Co-operation for the Long term In Defence
CEPA 11 RTP 11.8

## Low-cost simulators

# TABLE OF CONTENTS

# 0. INTRODUCTION

The goal of Work Package 1.a of the EUCLID - ELSTAR project is to identify those military task domains that are most fruitful for low-cost simulator training. In order to this, a comprehensive taxonomy of military tasks was made. Of the available taxonomies of military tasks in the literature, the "Universal Joint Task List" (version 2.1; 1995) proved to be most appropriate. However, that task list proved not directly applicable, and was therefore reconstructed and modified in the following way.

The ELSTAR taxonomy is structured according to six main military functions:

- MANOEUVRING,
- INTELLIGENCE (target information, tactical reconnaissance, and surveillance),
- TARGET ACQUISITION AND WEAPON DELIVERY,
- COMBAT SERVICE SUPPORT,
- COMMAND & CONTROL,
- MAINTAINING MOBILITY & SURVIVABILITY.

Each of these is specified into one or more sub-functions (*e.g.* sub-functions of MANOEUVRING are 'to move', and 'to navigate').

In many cases, the execution of a function is affected by;

- *organisational level*, *e.g.* warrior *vs.* staff level,
- *level of threat*, *e.g.* manoeuvring in a low-threat environment is performed differently than in high-threat environments,
- and by *task- and environmental conditions*, *e.g.* navigating in a directly-perceived environment differs essentially from navigating in an instrumentally-perceived environment.

Where appropriate, the military (sub)functions are broken down according to such distinctive features.

This structure allows to identify the military task domains relevant for the purpose of examining (low-cost) simulation solutions (military task domains are described at the lowest level of the branches). For some task domains it is necessary to specify the equipment that is used (*e.g.* monitoring of manoeuvring through with radar equipment).

# 1. MANOEUVRING

1.1. *To move a platform in low- and high-threat environment*
This is the transport function. It refers to platform control; the technical skill of handling the platform.

1.1.1 *in a directly perceived environment, without optical equipment*

1.1.1.1 **LAND PLATFORM CONTROL**
*e.g.* driver Main Battle Tank

1.1.1.1.1. Wheeled vehicles (*e.g.* driver trucks)

1.1.1.1.2. Tracked vehicles (*e.g.* driver Main Battle Tank)

1.1.1.2 **FIXED-WING AIRCRAFT CONTROL (NAVY)**
*e.g.* pilot of fighter or bomber

1.1.1.3 **FIXED-WING AIRCRAFT CONTROL (AIR FORCE)**
*e.g.* pilot of fighter or bomber

1.1.1.4 **ROTARY-WING AIRCRAFT CONTROL (NAVY)**
*e.g.* pilot of helicopter

1.1.1.5 **ROTARY-WING AIRCRAFT CONTROL (AIR FORCE)**
*e.g.* pilot of helicopter

1.1.1.6 **SEA PLATFORM CONTROL**
*e.g.* helmsman frigate

1.1.2 *in a directly perceived environment using optical equipment*
*e.g.* infrared, image intensifiers.

1.1.2.1 **LAND PLATFORM CONTROL**

1.1.2.1.1. Wheeled vehicles using image intensifier

1.1.2.1.2. Wheeled vehicles using infrared equipment

1.1.2.1.3. Tracked vehicles using image intensifiers

1.1.2.1.4. Tracked vehicles using infrared equipment

1.1.2.2 **ROTARY-WING AIRCRAFT CONTROL**
*e.g.* pilot of helicopter

1.1.2.2.1. using image intensifiers

1.1.2.2.2. using infrared equipment

1.1.2.3 **UNMANNED PLATFORM CONTROL**
*e.g.* operator using the controls to lead the unmanned air-, sea-, or land-platform in a desired direction

1.1.2.3.1. using video equipment

1.1.2.3.2. using image intensifiers

1.1.2.3.3. using infrared equipment

1.2 *To navigate*
This refers to the planning, monitoring and correcting of manoeuvring according to a pre-specified route and plan, taking into account the constraints of the physical and

operational environment.

1.2.1. *To navigate in a low-threat environment*
This refers to the planning, monitoring and correcting of manoeuvring according to a pre-specified route.

1.2.1.1. *in a directly perceived environment, without optical equipment*

1.2.1.1.1. **A LAND PLATFORM**
*e.g.* reading and interpreting maps in a fixed or moving vehicle (*e.g.* commander Main Battle Tank)

1.2.1.1.2. **AN AIR PLATFORM**
*e.g.* navigating by direct vision (*e.g.* helicopter, non flying, pilot)

1.2.1.1.3. **A SEA PLATFORM**
*e.g.* sailing on beacons, or mooring a ship (team of bridge officer, navigation officer and officer of the watch on a frigate)

1.2.1.2. *in a directly perceived environment, using optical equipment*

1.2.1.2.1. **A LAND PLATFORM**
*e.g.* commander Main Battle Tank
1.2.1.2.1.1. using image intensifiers
1.2.1.2.1.2. using infrared equipment

1.2.1.2.2. **AN AIR PLATFORM**
*e.g.* navigating a helicopter
1.2.1.2.2.1. using image intensifiers
1.2.1.2.2.2. using infrared equipment

1.2.1.2.3. **A SEA PLATFORM**
*e.g.* binoculars

1.2.1.2.4. **AN UNMANNED PLATFORM**
*e.g.* navigating an unmanned (undersea or surface level) minesweeper (*e.g.* PAPS or TROIKA)
1.2.1.2.4.1. using video equipment
1.2.1.2.4.1. using image intensifiers
1.2.1.2.4.2. using infrared equipment

1.2.1.3. *in an instrumentally perceived environment*
*e.g.* navigating a ship by GPS, SATCOM, or DECCA (bridge officer frigate); flying on navigation equipment (*e.g.* fixed and rotary wing, non-flying, pilots)

1.2.1.3.1. **AN AIR PLATFORM** using platform control instruments
*e.g.* radar, Doppler, Inertial Navigation System (INS), Instrumented Landing Systems (ILS), TAKAN, SATCOM, or GPS

1.2.1.3.2. **A SEA PLATFORM** using platform control instruments
*e.g.* radar, SATCOM, GPS

1.2.1.3.3. **A UNDERWATER PLATFORM** using platform control instruments
*e.g.* radar, GPS

1.2.1.3.4. **AN UNMANNED PLATFORM** using platform control instruments
*e.g.* radar, GPS

1.2.2. *To navigate in a high-threat environment*
This refers to the planning, monitoring and correcting of manoeuvring according to a pre-specified plan, taking into account the constraints of the physical and operational environment. This is the function of tactical manoeuvring which includes 'movement',

'navigation', and 'co-ordination with fire-power support'. Training this type of manoeuvring is generally performed in a team. This task domain is appropriate for crew- and unit commanders.

1.2.2.1. *in a directly perceived environment, without optical equipment*

1.2.2.1.1. **A LAND PLATFORM**
*e.g.* dismounted infantry or marines, carrying out formation movement of tank platoons (*e.g.* commander Main Battle Tank, or tank platoon commander)

1.2.2.1.2. **AN AIR PLATFORM**
*e.g.* low-level flight in close-air support missions (*e.g.* helicopter, non flying, pilot)

1.2.2.1.3. **A SEA PLATFORM**
*e.g.* sailing in formation in response to (air) attacks (team of bridge officer, navigation officer and officer of the watch on a frigate)

1.2.2.2. *in a directly perceived environment, using optical equipment*
*e.g.* dismounted infantry or marines, carrying out formation movement of tank platoons in the dark (*e.g.* commander Main Battle Tank, or tank platoon commander); low-flying using optical equipment in close-air support missions (*e.g.* helicopter, non-flying, pilot )

1.2.2.2.1. **A LAND PLATFORM**
*e.g.* navigating a land platform in tactical missions (*e.g.* commander Main Battle Tank)
1.2.2.2.1.1. using image intensifiers
1.2.2.2.1.2. using infrared equipment

1.2.2.2.2. **AN AIR PLATFORM**
*e.g.* navigating a helicopter in tactical missions (*e.g.* low-flying) utilising image intensifier or infrared equipment
1.2.2.2.2.1. using image intensifiers
1.2.2.2.2.2. using infrared equipment

1.2.2.2.3. **A SEA PLATFORM**
*e.g.* binoculars

1.2.2.2.4. **AN UNMANNED PLATFORM**
*e.g.* navigating an UAV; navigating an unmanned (undersea or surface level) minesweeper (*e.g.* PAPS or TROIKA)
1.2.2.2.4.1. using video equipment
1.2.2.2.4.2. using image intensifiers
1.2.2.2.4.3. using infrared equipment

1.2.2.3. *in an instrumentally perceived environment*

1.2.2.3.1 **AN AIR PLATFORM** using platform control instruments
*e.g.* performing air-bombardments with target identification through radar images (*e.g.* pilot non flying of bomber aircraft)

1.2.2.3.2 **A SEA PLATFORM** using platform control instruments
*e.g.* sailing in convoys in the mist (*e.g.* bridge officer frigate)

1.2.2.3.3 **AN UNDERWATER PLATFORM** using platform control instruments
*e.g.* approaching sea-level targets without being detected (*e.g.* commander submarine)

1.2.2.3.4 **AN UNMANNED PLATFORM** using platform control instruments *e.g.* in target-acquisition missions, battle-damage assessment, NBC-detection, etc.

1.2.3 *To co-ordinate platform manoeuvres to maximise a unit's firepower*
This refers to the use of fire, to the request / adjustment of fire, and to the threat of such fire to prevent the enemy from occupying the area. This is essentially a command & control function, but focused on co-ordinated manoeuvring, see 5.1.

# 2. INTELLIGENCE: TARGET INFORMATION, TACTICAL RECONNAISSANCE, AND SURVEILLANCE

2.1 *At the warrior level*
'Combat-unit' level and below. Units that operate in the battlefield, thus (partly) requiring information from the natural task environment.

2.1.1 *in a directly perceived environment*
Either visually or using equipment, like binoculars, image intensifiers, laser distance measuring device, etc.

2.1.1.1 **SEARCHING, DETECTING, LOCATING, AND IDENTIFYING TARGETS**

2.1.1.1.1 at land

2.1.1.1.2 at sea

2.1.1.1.3 in the air

2.1.1.2 **COLLECTING ENVIRONMENTAL INFORMATION ON THE AREA OF OPERATION**

2.1.1.2.1 at land

2.1.1.2.2 at sea

2.1.1.2.3 in the air

2.1.1.3 **CONDUCTING POST-ATTACK BATTLE DAMAGE ASSESSMENT (BDA)**

2.1.2 *in an instrumentally perceived environment*

2.1.2.1 **COLLECTING ENVIRONMENTAL AND ENEMY INFORMATION AND BDA**
(see 2.1.1.2) through:

2.1.2.1.1 radar equipment operation (AWACS)

2.1.2.1.2 infrared equipment operation

2.1.2.1.3 sonar equipment operation

2.1.2.1.4 radio signals tracking equipment operation

2.1.2.1.5 (RPV) video image equipment operation

2.2 *At the staff level*
Company, battalion & brigade-level. Units that do not operate directly in the battlefield, requiring symbolic information for task performance, acquired verbally or by (electronic) data links.

2.2.1 *in a symbolic representation of the environment*

2.2.1.1 **ASSESSING ENVIRONMENTAL AND ENEMY CONDITIONS**
This heavily parallels one function of command & control, focused on information collection. See 5.2.

# 3. TARGET ACQUISITION AND WEAPON DELIVERY

## 3.1 *Line-of-sight weapon systems*

### 3.1.1 *guided*

#### 3.1.1.1 *'fire & forget' systems*

After launching the guided missile automatically keeps on track; no further input of the operator is needed.

**3.1.1.1.1 SINGLE-UNIT OPERATION**

*e.g.* launching a Stinger (which is operated by a single soldier, and the missile keeps on track to the air target through a heat-detection system).

**3.1.1.1.2 CO-ORDINATED UNIT OPERATION**

*e.g.* performing precision bombardments through close-air support (in which the forward air controller (FAC) guides the pilot verbally (through radio communication) to the target).

#### 3.1.1.2 *continuous manual control systems*

In contrast to 'fire-and-forget' weapon systems, the operator needs to keep the missile on its track onto the target (for instance by means of a viewfinder) until missile impacts.

**3.1.1.2.1 SINGLE-UNIT OPERATION**

*e.g.*:

- operating a FOG-W (in which the course of a missile is tele-controlled by an operator receiving input from a video camera mounted at the missile's head; see also 2.1.2.1.5;
- launching 'hell-fire' from an Apache helicopter (in which an operator identifies a (ground) target using a laser beam, and the weapon delivery system automatically calculates and implements the missile's course required to approach the target vertically);
- launching a TOW (Tracked Optical Wire) (an anti-tank weapon, delivered from a unit mounted (or dismounted) on a jeep);
- operating a Dragon (the portable anti-tank Dragon is launched from the shoulder. The operator keeps the viewfinder on the target upon missile impact. The position of the missile is communicated to the launching base by an infrared signal; deviations from the correct path are detected and the launch base sends back, by a copper wire, signals to the missile to correct its course).

**3.1.1.2.2 CO-ORDINATED UNIT OPERATION**

*e.g.* performing precision bombardments through close-air support (in which the forward air controller (FAC) uses laser equipment to 'acquire' the target, the laser equipment transmits this information to the weapon delivery system of the bombing aircraft. The FAC needs to maintain the laser beam directed upon the target until impact).

### 3.1.2 *non-guided*

#### 3.1.2.1 *'fire & forget' systems*

All non-guided weapon systems are 'fire & forget' systems.

**3.1.2.1.1 SINGLE-UNIT OPERATION (ARMY)**

*e.g.* shooting a rifle, throwing grenades, tank gunnery, mounted or dismounted large-calibre weapons.

3.1.2.1.2 **SINGLE-UNIT OPERATION (AIR FORCE)**

3.1.2.1.3 **SINGLE-UNIT OPERATION (NAVY)**
*e.g.* shooting a 20 mm canon.

3.1.2.1.4 **CO-ORDINATED UNIT OPERATION**
Co-ordinated tactical firing of a platoon, but the focus here is more on "command and control" than on "weapon delivery"; see therefore 5.1.

3.2 *Non Line-of-sight weapon systems*

3.2.1 *guided*

3.2.1.1 *'fire & forget' systems*

3.2.1.1.1 **SINGLE-UNIT OPERATION (ARMY)**
*e.g.* operating a Patriot or a Hawk (which is operated by a single unit, and the missile keeps on track to the air target through automatic detection system).

3.2.1.1.2 **SINGLE-UNIT OPERATION (AIR FORCE)**
*e.g.* operating a Patriot or a Hawk (which is operated by a single unit, and the missile keeps on track to the air target through automatic detection system).

3.2.1.1.3 **SINGLE-UNIT OPERATION (NAVY)**
*e.g.* operating a Sea Sparrow, harpoon, etc.

3.2.2 *non-guided*

3.2.2.1 *'fire & forget' systems*
All non-guided weapon systems are 'fire & forget' systems.

3.2.2.1.1 **SINGLE-UNIT OPERATION**
*e.g.* launching grenades against air targets from armoured vehicles, operating a 40 long 70 large calibre canon.

3.2.2.1.2 **CO-ORDINATED UNIT OPERATION**
*e.g.* operating mortars, artillery, Multiple Launched Rockets System (MLRS) with forward ground control.

3.3 *Electronic warfare*
Non-lethal engagement to impair the performance of enemy equipment.

3.3.1 **OPERATING WEAPONS USING ELECTROMAGNETIC OR DIRECTED ENERGY (ARMY)**
*e.g.* radio wave and radar wave disturbance systems.

3.3.2 **OPERATING WEAPONS USING ELECTROMAGNETIC OR DIRECTED ENERGY (AIR FORCE)**
*e.g.* chaff, radio wave and radar wave disturbance systems.

3.3.3 **OPERATING WEAPONS USING ELECTROMAGNETIC OR DIRECTED ENERGY (NAVY)**
*e.g.* chaff, radio wave and radar wave disturbance systems.

# 4. COMBAT SERVICE SUPPORT

## 4.1 MAINTENANCE, FAULT DIAGNOSTICS & REPAIR OF EQUIPMENT

4.1.1 of complex, composite systems (Army)
*e.g.* including mechanical, hydraulic, and electronic components.

4.1.2 of complex, composite systems (Air Force)
*e.g.* including mechanical, hydraulic, and electronic components.

4.1.3 of complex, composite systems (Navy)
*e.g.* including mechanical, hydraulic, and electronic components.

## 4.2 EXECUTING DIRECT EMERGENCY PROCEDURES IN CASE OF SYSTEM FAILURES

The task performer operates directly in the environment, *e.g.* executing an evacuation plan, ducking for cover, etc.

## 4.3 EXECUTING INDIRECT EMERGENCY PROCEDURES IN CASE OF SYSTEM FAILURES

The task performer operates by means of an interface, *e.g.* switching off a power plant, etc.

## 4.4 *Protection of humans*

### 4.4.1 SEARCH AND RESCUE PROCEDURES

This is primarily a "command & control" task; see therefore 5.1.

4.4.1.1 at land

4.4.1.2 at sea

### 4.4.2 HUMAN CARE

*e.g.* food supply.

### 4.4.3 MEDICAL CARE

### 4.4.4 HUMAN PROTECTION

*e.g.* NBC (personal and system), fire, camouflage, shelter.

4.4.4.1 at 'combat-unit' level and below
Units that operate in the battlefield, thus (partly) requiring information from the natural task environment. This usually involves the execution of relatively simple procedures.

4.4.4.2 at the staff level
Company, battalion & brigade-level. Units that do not operate directly in the battlefield, requiring symbolic information for task performance, acquired verbally or by (electronic) data links). This is primarily a "command & control" task, see therefore 5.1.

## 4.5 *Logistics and administration*

### 4.5.1 ORDERING, RECEPTION AND REGISTRATION OF SUPPLIES

*e.g.* fuel, water, oil, spare parts, etc. This is primarily a "command & control" task, see therefore 5.1.

# 5. COMMAND & CONTROL

5.1 *At the warrior level*
'Combat-unit' level and below. Units that operate in the battlefield, thus (partly) requiring information from the natural task environment.

5.1.1 ARMY: MISSION PLANNING, PREPARATION, AND IMPLEMENTATION
- **planning**: assessing personnel deployment; assessing environmental and enemy conditions; co-ordinating the mission's co-operating sections and establishing communication procedures; co-ordinating transportation, supplies, and human resources;
- **preparation**: verifying environmental and enemy conditions; ordering necessary precautions against threats (*e.g.* NBC); and briefing the units involved;
- **implementation**: plan implementation (plan execution, plan adjustment); situation assessment (monitoring, diagnosis); and communicating and reporting (to lower control, to higher control).

5.1.2 AIR FORCE: MISSION PLANNING, PREPARATION, AND IMPLEMENTATION
- **planning**: assessing personnel deployment; assessing environmental and enemy conditions; co-ordinating the mission's co-operating sections and establishing communication procedures; co-ordinating transportation, supplies, and human resources;
- **preparation**: verifying environmental and enemy conditions; ordering necessary precautions against threats (*e.g.* NBC); and briefing the units involved;
- **implementation**: plan implementation (plan execution, plan adjustment); situation assessment (monitoring, diagnosis); and communicating and reporting (to lower control, to higher control).

5.1.3 NAVY: MISSION PLANNING, PREPARATION, AND IMPLEMENTATION
- **planning**: assessing personnel deployment; assessing environmental and enemy conditions; co-ordinating the mission's co-operating sections and establishing communication procedures; co-ordinating transportation, supplies, and human resources;
- **preparation**: verifying environmental and enemy conditions; ordering necessary precautions against threats (*e.g.* NBC); and briefing the units involved;
- **implementation**: plan implementation (plan execution, plan adjustment); situation assessment (monitoring, diagnosis); and communicating and reporting (to lower control, to higher control).

5.2 *At the staff level*
Company, battalion & brigade-level. Units that do not operate directly in the battlefield, requiring symbolic information for task performance, acquired verbally or by (electronic) data links.

5.2.1 ARMY: MISSION PLANNING AND IMPLEMENTATION
- **planning**: assessing personnel deployment; assessing environmental and enemy conditions; co-ordinating the mission's co-operating sections and establishing communication procedures; co-ordinating transportation, supplies, and human resources;
- **implementation**: plan implementation (plan execution, plan adjustment); situation assessment (monitoring, diagnosis); and communicating and reporting (to lower control, to higher control).

5.2.2 AIR FORCE: MISSION PLANNING AND IMPLEMENTATION
- **planning**: assessing personnel deployment; assessing environmental and enemy conditions; co-ordinating the mission's co-operating sections and establishing communication procedures; co-ordinating transportation, supplies, and human

resources;
- **implementation**: plan implementation (plan execution, plan adjustment); situation assessment (monitoring, diagnosis); and communicating and reporting (to lower control, to higher control).

#### 5.2.3 NAVY: MISSION PLANNING AND IMPLEMENTATION

- **planning**: assessing personnel deployment; assessing environmental and enemy conditions; co-ordinating the mission's co-operating sections and establishing communication procedures; co-ordinating transportation, supplies, and human resources;
- **implementation**: plan implementation (plan execution, plan adjustment); situation assessment (monitoring, diagnosis); and communicating and reporting (to lower control, to higher control).

## 6. MAINTAINING MOBILITY & SURVIVABILITY

### 6.1 *Maintain mobility*

To maintain freedom of movement for personnel and equipment in the battlespace without delay.

#### 6.1.1 REMOVING NATURAL AND MAN-MADE OBSTACLES

6.1.1.1 at land (*e.g.* engineering service)

#### 6.1.2 SEARCHING AND IDENTIFYING MINES

6.1.2.1 at land

6.1.2.2 at sea

- below sea level: PAP;
- at sea level: sonar operator from helicopter or aircraft, see 2 (for what regards the Navy).

#### 6.1.3 REMOVING MINES

6.1.3.1 at land

6.1.3.2 at sea

#### 6.1.4 ENHANCE MOVEMENT

*e.g.* construction and repair of roads, trails, forward airfields, etc.

### 6.2 *Conduct countermobility*

#### 6.2.1 LOCATION SELECTION AND EMPLACEMENT OF OBSTACLES AND MINES

*e.g.* demolishing a road segment constructing a log crib and emplacing mines.

6.2.1.1 at land

6.2.1.2 at sea

#### 6.2.2 DETONATE MINES OR EXPLOSIVES

With the objective to prevent enemy mobility through deterrence with destruction of enemy personnel, vehicles, etc.

Toelichting

*ELSTAR*

**European Low-cost Simulators for the Training of Armed forces**

| | |
|---|---|
| Document: | Deliverable 1a |
| Title: | Analysis of military training: Literature review and preliminary selection of military fields |
| Authors: | J.E. Korteling, M.L. van Emmerik, M. Van Berlo, A. Von Baeyer |
| WP Leader: | TNO Human Factors Research Institute (Korteling) |
| Reference: | ELS-DEL/1-a, index 3 |
| | ELS-DEL/1-TAXO, index 1 (vd Bosch) |

Toelichting:

TNO-TM is projectleider van het eerste werkpakket van het EUCLID RTP11.8 project (ELSTAR) over low cost simulatoren. Dat eerste werkpakket is getiteld "Analysis of military training" en heeft als doel militaire trainingsdomeinen te identificeren die zich goed lenen voor low-cost simulatie en voor research op dat gebied. Voorts zullen, o.b.v. onder andere kosten-baten analyse, taak- en trainingsanalyse, domeinkennis en simulator-technische kennis voor een selectie van deze domeinen functionele specs worden geleverd voor generieke low-cost simulatoren.

Het werkpakket bestaat uit vier onderdelen. De resultaten van elk onderdeel worden vastgelegd in een "deliverable". De bijgaande publikatie betreft de het deliverable van het eerste onderdeel: literatuurinventarisatie, taaktaxonomie en domeinselectie. Het TM gedeelte hiervan is al rondgeweest en als TM rapport (TM-97-A035) uitgebracht.

TNO-TM is verantwoordelijk voor vrijwel het gehele stuk. Alleen hoofdstuk 6 is het werk van IABG (in de persoon van Alexander von Baeyer).

CORYS (Frankrijk) is prime contractor van het EUCLID RTP11.8 project, en heeft dit deliverable afgewerkt en naar de Management Group van de deelnemende landen gestuurd. Deze heeft het stuk inmiddels goedgekeurd.

Opmerking: Appendix 1 en 2, dat zijn de militaire taaktaxonomie en de scores hierop, liggen nog bij CORYS. Daarom heb ik hiervan een copie uit het TM rapport (met alleen een andere opmaak) bijgevoegd.