Proceedings of the joint *14th Triennial Congress of the International Ergonomics Association/44th Annual Meeting of the Human Factors and Ergonomics Society (HFES/IEA 2000)*. San Diego, CA. 30 July – 4 August, 2000.

The Use of Work Domain Analysis for the Design of Training Systems

Gavan Lintern & Neelam Naikar
Defence Science and Technology Organisation
PO Box 4331, Melbourne, Vic 3001
gavan.lintern@dsto.defence.gov.au neelam.naikar@dsto.defence.gov.au

ABSTRACT

In this paper we argue that specifications for training equipment must be based on statements of mission-system functionality. To develop a good description of functionality is a difficult technical challenge, and the methodology of Work Domain Analysis has been developed for that purpose. However, a Work Domain Analysis does not fully specify the devices that are needed for training. Other forms of analysis and inference are needed to resolve issues of crititicality, instructional functions, implementation of functions in a training device, and fidelity of training device features. In this paper we explain the means of moving from functional requirements as developed by a Work Domain Analysis to specifications for training equipment.

INTRODUCTION

The increasing complexity of combat systems is encouraging the Australian Defence Forces to focus more attention on training. For systems that are in procurement or are to be upgraded, the desire is to have a training system available at the time the combat system becomes operational. However, the training requirements for such a system cannot be fully anticipated. In complex military systems, subject matter experts will develop new patterns of use as they acquire expertise with the system. Furthermore, patterns of use will be influenced by the capabilities of future enemy systems, which also cannot be fully anticipated. It is of particular concern that expensive training devices such as simulators and part trainers might need to be acquired before all training requirements are known.

At the Defence Science and Technology Organisation, the solution we have proposed to this dilemma is to develop specifications for training equipment by reference to the functional capabilities of the combat system. Our approach relies heavily on a Work Domain Analysis, although as far as possible, we undertake other elements of a full Cognitive Work Analysis in order to develop supporting information. In previous reports of that work we identified specific types of functional requirements for training equipment as they relate to different levels of functional capabilities identified in the means-end hierarchy of the work domain (Lintern & Naikar, 1999; Naikar & Sanderson, 1999; Naikar, Sanderson & Lintern, 1999). We have, however, not yet fully reported all implications of a Work Domain Analysis for the design of training equipment.

In this paper we develop and explain the links between functional requirements (as identified by a Work Domain Analysis) and specifications for training equipment. We address three issues; the rationale for the application of Work Domain Analysis to this problem, the relevance of Work Domain Analysis to training system design, and requirements beyond Work Domain Analysis to complete the specifications for training equipment.

A RATIONALE FOR WORK DOMAIN ANALYSIS

Work Domain analysis is a framework for identifying and representing the functional properties of a work system. It identifies functional properties at different levels of abstraction and represents them in a means-end hierarchy to show the relationships between functions at different levels of abstraction. Cognitive Work Analysis and the contribution of Work Domain Analysis to it are described fully by Vicente (1999). The use of the means-end hierarchy as a representational tool is further explained by Naikar and Sanderson (1999), who have promoted Work Domain Analysis as a means of ascertaining the functional requirements for a training system.

A fragment of an abstraction hierarchy taken from the analysis of a combat aircraft (Naikar and Sanderson, 1999) is shown in figure 1. Each of the functions in the figure may be decomposed into smaller parts. For example, the Purpose-Related Function, *To communicate and coordinate with relevant entities*, may be decomposed into *tactical* and *domestic* elements. The *tactical* element may be further decomposed into *communication and coordination with wingman, with air controllers and with other forces*, and the *domestic* element may be further decomposed into *communication and coordination with maintenance personnel, with operations personnel and with civil air traffic controllers*.

Event Independence

The emphasis in Work Domain Analysis is on functional structure, which includes both intentional and physical constraints. The analysis typically starts with a review of relevant documents and proceeds through a verification phase with subject-matter experts. The process of Work Domain Analysis for definition of training systems as outlined by Naikar & Sanderson (1999) is essentially similar to Work Domain Analysis for any other purpose.

Training systems are usually developed from specifications based on current operational or training

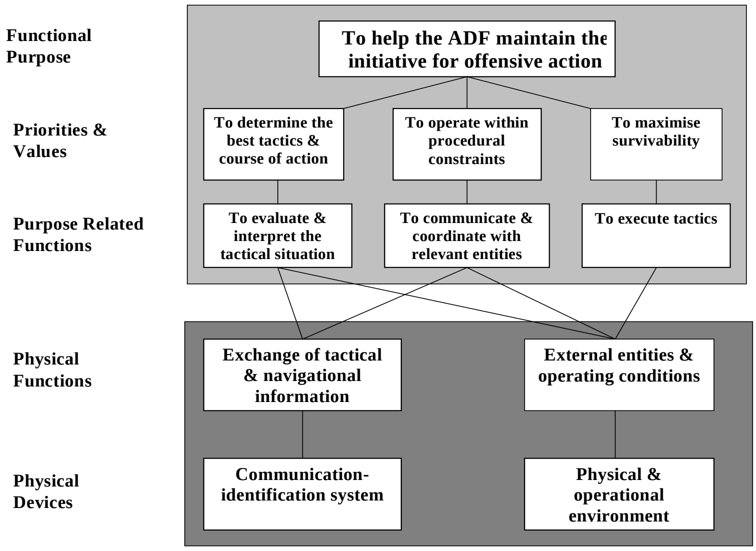

Figure 1. A fragment of an Abstraction Hierarchy for a combat aircraft with means-end links shown. As is typical in a complex information system, intentional constraints dominate at the higher levels and physical constraints dominate at the lower levels. (ADF: Australian Defence Forces)

practice. Most analyses of training requirements start with typical events or scenarios. In Vicente's (1999) terms, these are event-based analyses, which do not inform design for patterns of use that cannot be anticipated. Work Domain Analysis, by its emphasis on functional structure, is event independent. Its event-independent nature is one primary reason for using it in preference to other types of analyses, especially to specify training devices for combat systems that are not yet operational.

Functional Structure

The specification of training devices for complex military systems has typically been a mix of physical and functional statements, with the functional statements generally at the lower levels of abstraction. It is now apparent that physical specifications will often constrain suppliers to sub optimum design solutions and so the trend in specifying military equipment is towards functional specification (McDaniel, 1996). Thus, any form of training requirements analysis undertaken for the purpose of specifying training equipment should converge on a statement of functional requirements.

Event-based analyses typically converge on physical descriptions of interfaces and devices needed for instruction of each task. At some point it is necessary to consider the functional properties of the devices that are to be simulated. However, the step of moving from a description of events (i.e. tasks or scenarios) to functional requirements is most often done informally and event by event. In contrast, Work Domain Analysis derives the functional specifications for training devices from the functional specifications of the system itself. This is a more direct, more systematic, and more efficient way of proceeding towards a listing of essential functional requirements.

Critical functional elements are often neglected even in the development of high-fidelity flight training devices (Galanis, 2000). A systematic and thorough analysis of the right form is essential if deficiencies of the sort noted by Galanis are to be reduced. Work Domain Analysis is presented here as a form of analysis that seeks to identify all functional properties of the mission system that impact how human activity might unfold within a mission. However, there are practical limits on the analysis. They reside in the coverage of documents and the insights of the subject matter experts that provide the information for the analysis, and also on the ability of the analysts to uncover the relevant information. The development of a complete description of functionality remains a difficult technical challenge even with the best of analytic tools.

The emphasis on Work Domain Analysis should not be taken to imply that standard forms of task analysis and instructional system design are never useful. Issues of curriculum design, syllabus development and training course design may need information not available from Work Domain Analysis. However, in the development of training systems, it is the functional requirements that must be identified. Work Domain Analysis is tailored for that job.

RELEVANCE TO TRAINING SYSTEM DESIGN

Functional Requirements for Whole and Part Training

A means-end hierarchy displays mission functions that might be implemented in a suite of training devices. In addition, because it displays the relationships between functions at different levels of abstraction, it also reveals how the failure to implement a specific function will compromise training in relation to functions at higher levels. What functions must be implemented in either whole or part trainers should be evident from inspection of the means-end hierarchy.

Where whole training is the requirement, the goal should be to simulate all mission functions at the highest useable level of detail. Where part training is the requirement, the goal should be to simulate the mission functions specific to the part task to be trained plus all other supporting mission functions, to a level of detail consistent with the skills that are to be learned. For example, to satisfy a part training need for tactical communication and coordination, it would be necessary to simulate functions related to *communication and coordination with wingman, air controllers and other forces* but not *with maintenance personnel, operations personnel or civil air traffic controllers.* As is evident in figure 1, it would also be necessary to simulate the relevant *external entities and operating conditions*.

A function is a potential capability that must be exercised by some form of activity to realise that potential. The four upper levels of the means-end hierarchy display functions that are realised through skilful human activity. In that the purpose of training is to develop the essential human skill, these functional statements imply the nature of the scenarios that must be used in training. For example, a decomposition of the function *communicate and coordinate with relevant entities* will specify the essential kinds of communication and coordination (e.g. tactical or domestic) and entities with which communication and coordination occurs. A scenario for teaching *communication and coordination* should therefore incorporate the relevant types of activities and entities and should be designed to exercise all elements of the means-end hierarchy that are linked to the targeted function.

Measures of Merit

The means-end hierarchy may be used to identify the dimensions that should be measured to assess human competency. At each level, functions imply the measures of merit that will indicate whether that functional potential has been realised, with the higher levels implying measures that are more abstract. At the level of physical function the measures will be related to performance of equipment and are not relevant to operator competency. However functions at the higher levels require some form of activity from one or more humans in the system, and the dimension on which performance (of the human-machine element) might be assessed is implicit in the functional definition. In contrast to the use of Work Domain Analysis for interface design, poor performance as shown by measures of merit in relation to a specific function is viewed as a training problem rather than as a design problem.

Training Scenarios

Scenarios should permit students to exercise all possible means by which targeted functions may be realized. The goal is to teach flexible use of multiple means to achieve goals. Scenarios should also reveal to students the complex and sometimes conflicting effects that means exercised at one level can have on functions at higher levels. For example, a combat pilot may communicate a new rule of engagement and a consequent change in a plan of attack to a wingman via radio channels, thereby preserving the priority *to operate within procedural constraints*. However, radio transmission may be noticed by an enemy pilot and thereby compromise the priority *to maximize survivability.*

ADDITIONAL REQUIREMENTS

An underlying assumption of our work is that there is a close correspondence between functional properties of a mission system and the functional requirements for an effective training system. However, a Work Domain Analysis cannot completely specify training equipment requirements. Training devices do not have to simulate all functional properties of a mission system and some functions required of training devices are not generally found in the mission system. In addition, the manner in which functions should be implemented and the fidelity of implementation are not specified in the means-end hierarchy.

Critical Training Areas

Work Domain Analysis results in a comprehensive representation of functional mission requirements but does not offer any guide to relative importance or criticality. Certain areas of expertise are relatively more difficult to acquire, and some are more central to effective performance of the human operators. Those that are more difficult to acquire or more central should be emphasised at the expense of areas that are easy to acquire and peripheral to effective performance. Other procedures of Cognitive Work Analysis (Vicente, 1999) or of Applied Cognitive Task Analysis (Crandall, Klein, Militello, & Wolf, 1994) can supplement the Work Domain Analysis to identify areas that should be emphasised. These procedures are necessarily based on interviews with subject matter experts but, to accommodate new patterns of use, the analyses should emphasise generic rather than specific events.

Instructional Functions

Analysis of a mission system will not identify functions specific to the instructional process. Information on instructional strategies (such as feedback, task segmentation and mid-flight freeze) must be derived from other sources. Interviews with subject matter experts can identify classes of instructional functions that have been found useful in similar systems and a review of instructional research literature can identify new possibilities for enhancing instruction.

Implementation of Functions

The form in which a functional requirement may be implemented within a training device is not specified within a means-end hierarchy. The step from functional specification to design of an implementation requires an inference. That will typically rely on the expertise of training system designers who must develop an implementation that satisfies the implications of the functional requirement. For example, the function *communicate and coordinate with relevant entities* implies a need for distributed training with multiple agents.

Either constructive or human agents might replace operators who are not the target of the training. Whether human or constructive, those agents should offer a level and style of challenge most required by trainees for their development.

Training Device Fidelity

There is nothing in Work Domain Analysis that identifies an appropriate level or type of fidelity for a training device. The primary need is to develop training devices that promote transfer of skill to the mission system. It is evident from the research in this area that judgements of subject matter experts regarding levels and types of fidelity needed for transfer are unsound. For example, many experienced pilots believe that high-fidelity motion systems are essential for flight training simulators but the research evidence indicates that it is not (Lintern, 1987). There is even some evidence that the use of a motion system in a flight training simulator can interfere with transfer to real flight (Lintern & McMillan, 1993).

The only trustworthy means of resolving fidelity issues is to rely on transfer relationships that have been demonstrated in scientific research. Although the evidence is incomplete, many important relationships have been tested. For example, layout of instruments and controls must correspond closely to the layout found in the mission system. Information must have the same format and should correspond in legibility to that found in the mission system. In contrast, the physical implementation of devices (eg. displays and controls) need not be of high fidelity. As a general rule, information that supports operator decision, judgement and response must be accurate but there is no need to mimic characteristics of the mission system that are not informative within the operator's perception-cognition-action cycle. In addition, implementations of functional requirements should not offer information that encourages an inappropriate control strategy[1].

SUMMARY

The complexity of modern weapons platforms requires that the specification of training equipment to be based on a systematic and comprehensive analysis. We have argued that mission system functionality is the primary basis for design of training equipment. Most forms of training requirements analysis converge on a description of mission system functionality but do so indirectly via descriptions of tasks or scenarios. In contrast, Work Domain Analysis is a direct method of identifying system functionality.

Functional statements of mission systems can be used to guide design of training equipment, design of whole and part training, development of the form of assessment, and the development of training scenarios. There are, however, several issues that an analysis of mission functions cannot resolve. There are needs to identify critical areas that should be emphasised in training, to identify instructional functions not found in the mission system, and to decide how functions should be implemented in a training device. There is also the issue of training device fidelity, which cannot be determined from functional mission statements. Training device fidelity must be established primarily through reference to transfer relationships that are documented in the scientific literature.

The argument we have developed here highlights the need for extension of Cognitive Work Analysis to complete the design process. In contrast, Sanderson and Naikar (2000) have noted the need for further development within the system of Cognitive Work Analysis. Nevertheless, even in its current state of development, Cognitive Work Analysis provides information for design that is not readily derived from any other form of analysis.

[1] Much of the information provided in flight simulators by motion systems is not specific to the pilot's perception-cognition-action cycle and does not facilitate transfer to real flight. Roll and pitch motions can be informative, but pilots are taught to ignore them in real flight because they can be misinterpreted. In addition, motion systems inevitably offer some false information. Despite a long-standing interest in motion fidelity, it remains unclear what information a motion system offers that is useful for the control of an aircraft.

REFERENCES

Crandall, B., Klein, G., Militello, L. G., & Wolf S.P. (1994). *Tools for applied cognitive task analysis*. Fairborn, OH: Klein Associates Inc.

Galanis, G. (2000). The Blind Drunk Pilot: A Case Study. *Proceedings of SIMTECT 00, February 28-March 2, 2000, Sydney, Australia*. The SimTecT 2000 Organising and Technical Committee.

Lintern, G. (1987). Flight simulation motion systems revisited. *Human Factors Society Bulletin, 30* (12), 1-3.

Lintern, G., & McMillan, G. (1993). Transfer for flight simulation. In R. Telfer (Ed.), *Aviation instruction and training* (pp. 130-162). Aldershot, United Kingdom: Ashgate.

Lintern, G., & Naikar, N. (1999). Specification of training simulators by Cognitive Work Analysis. *Proceedings of the Tenth International Symposium on Aviation Psychology, May3 – 6, 1999, Columbus, Ohio*.

McDaniel, J. (1996). The demise of military standards may affect ergonomics. *International Journal of Industrial Ergonomics, 18,* 339-348.

Naikar, N. & Sanderson, P. M. (1999). Work Domain Analysis for training system acquisition. T*he International Journal of Aviation Psychology, 9,* 271-290.

Naikar, N.; Sanderson, P & Lintern, G. (1999). Work Domain Analysis for training system design. *Proceedings of SIMTECT 99, March 29-April 1, 1999, Melbourne, Australia*. The SimTecT 99 Organising and Technical Committee, pp 65-68.

Sanderson, P. M. & Naikar, N. (2000). Temporal coordination control task analysis for analysing human-system integration. *Proceedings of the 44th Annual Meeting of the Human Factors and Ergonomics Society.*

Vicente, K. J. (1999). *Cognitive Work Analysis: Towards safe, productive, and healthy computer-based work*. Mahweh, NJ: Lawrence Erlbaum & Associates.