M. Grootjen, E.P.B. Bierman, M.A. Neerincx, "Optimizing cognitive task load in naval ship control centres: Design of an adaptive interface", IEA 2006: 16th World Congress on Ergonomics, 2006.

Optimizing cognitive task load in naval ship control centres: Design of an adaptive interface.

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Abstract

In the last 2 decades, major changes in information technology have taken place. In process control, the ongoing automation and the application of new technologies caused a radical change in the position of the operator. Combined with manning constraints, and the ever increasing pressure to maximize the operational capability, navies stand for a huge challenge. Because of this new situation, operators need personalized support which can differ in time: the system should accommodate the user with the right task support at the right time.
This paper presents the design and first user evaluation of an adaptive interface. A method for cognitive task analysis and 4 support concepts, which were validated for static function allocation and interface design, were taken as starting point. Specific instances of the resulting adaptive interface are the possibility to redirect the alarm (system or operator initiated), and the changing functional layout (e.g. buttons, alarm categories). A first user evaluation of the interface with 64 navy students shows promising results. The method for cognitive task analysis and the 4 support concepts prove to be useable for adaptive support as well. Evaluation shows very positive results on the support system, specifically on the task allocation functions.

Keywords: human-computer interaction, adaptive interface, mental load, cognitive engineering, dynamic task allocation, ship control centre.

1. Introduction

In the last 2 decades, major changes in information technology have taken place. In process control, the ongoing automation and the application of new technologies caused a radical change in the position of the operator. This position shifted from monitoring and control to supervision. However, the development of new support systems couldn't keep up with this changing situation. This section first summarizes the problems in process control, then solutions how to deal with these problems will be give. Section 2 shows the design of an adaptive support system, which is tested and evaluated in Section 3. Finally, section 4 discusses some problems and presents the conclusions.

1.1 Problems

Analyzing the problems in process control during multiple seminars and projects, we identified some main topics:

- Information type. The type of information an operator has to handle changed. For example from analogue to digital, and from sensor value to information on a 'higher level'. Especially when different types of information are used together, problems can arise.
- Information volume. The number of used sensors, and the accuracy of the sensors has increased enormously in the last decades. Because of this,

the information volume offered to the user has grown exponentially.

- Information volume fluctuation. Nowadays, highly dynamic systems cause extreme fluctuations in the volume of information produced.
- Task integration. The integration of tasks from different domains (e.g. navigation and propulsion) increases, demanding more flexibility of human operator and system.
- Increasing autonomy. Autonomous systems may cause 'out of the loop' problems for an operator.
- Increasing complexity. Systems and their dependencies become more and more complex. Consequently the problems the operator has to solve increase in complexity.
- Low personnel costs. The pressure to work with the lowest possible costs and the highest possible efficiency of the overall man-machine system after implementation asks for an optimal distribution of personnel.
- Low training costs. The minimization of the training costs asks for intuitive systems.
- Increasing legislative constraints. The increasing number of laws (e.g. to protect the environment & employees [1], in combination with the pressure to maintain maximum operational capability, put extra constraints on the system design.

To deal with the mentioned problems, we think the operator needs specifically personalized support which can differ in time [2]. A strong need for an innovative framework, which can be used to design adaptive user friendly systems from the operators point of view, urges [2,3]. Such a system should accommodate the operator with the right task support at the right time. This paper is part of a Ph.D. research, called "Adaptive Interfaces for Operational Support", with as main goal the development and testing of such a framework in the maritime domain.

1.2 Research focus

Recently, a method for the design of user friendly support systems has been developed [4,5]. The method results in an interface concept which is of great value and increases efficiency and effectiveness. This cognitive support was specifically designed to optimize the Cognitive Task Load (CTL) of the user. Until now, it was evaluated for static function allocation and interface design. Static function allocation refers to the process of distibuting tasks and functions at design time, by analyzing both system and operator competences. However, CTL is a dynamic variable which varies enormously over time. If we want to keep the CTL at an optimum at all time, we need a real time tool to influence CTL. In other words, we want to develop a new adaptive support application, which uses *dynamic task allocation*. With dynamic task allocation a task, or part of a task, can be transferred to another actor (i.e. automated component or operator). Obviously, this has consequences for the interface, which is dynamically altered as well.
This paper describes the first design and usability testing in the navy domain of the mentioned dynamic interface support.

2. Design of adaptive support

Oppermann [6] states that the user interface is the part of a system responsible for getting input from the user and for presenting system output to the user. A system that adapts either of these functions to the user's task or to the characteristics or preferences of the user, is an adaptive interface. This section shows the design of an adaptive interface in naval ship control.

2.1 Model for Cognitive Task Load

Starting point in the design of our adaptive interface is the CTL model of Neerincx [5]. Neerincx developed a CTL model (Fig. 1) which distinguishes three load factors that have a substantial effect on task performance and mental effort. The first load factor is the classical factor percentage time occupied (%TO). The second load factor is the level of information processing (LIP) (cf. the skill-rule-knowledge framework of Rasmussen [7]).

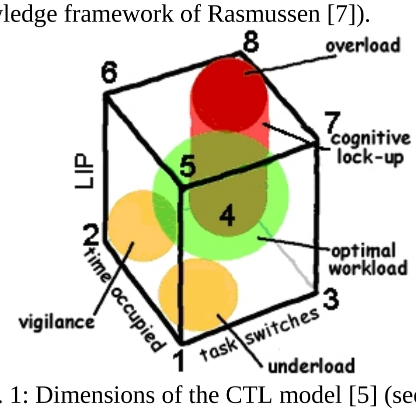

Fig. 1: Dimensions of the CTL model [5] (see text for explanation).

To address the demands of attention shifts, the cognitive load model distinguishes task-set switching (TSS) as a third load factor. Fig. 1 presents a 3-dimensional 'load' space in which human activities can be projected with regions indicating the cognitive demands that the activity imposes on the operator. In the middle area, CTL matches the operator's mental capacity. At angular point 8 CTL is high and an overload situation occurs. Angular point 1 represents the area in which CTL is not optimal due to underload. When TO is high, and LIP and TSS are low, vigilance problems can appear (angular point 2) [8]. When TO and TSS are high, lock-up can appear [9].

2.2 Support functions and concepts

After validation of the CTL model, Neerincx & Lindenberg [10] developed four support functions (Table 1) and an interface (Fig. 2) that influence CTL specifically on the three load factors.

Table 1.
4 support functions with accompanying load factor

Support function	Supports on
1. Information handler	TO
2. Rule Provider	LIP
3. Diagnosis Guide	LIP
4. Task Scheduler	TSS

For each support function a support concept (numbered 1 to 4 below, according to the numbers in Table 1) with several instances can be distinguished:

1. Combining and structuring information
    - Ordering alarms in categories
    - Process-based (automatic) presentation of required interface component
    - Hyperlinks within and between the components
2. Providing normative procedures
    - Context specific procedural information
    - Spatial advice
3. Guidance of diagnostic processes
    - Help with diagnostic process
4. Providing an overall work plan
    - Task overview
    - Check mark ability (process state)
    - Prioritising alarms

2.3 The adaptive interface

Until now, these concepts and instances were extensively tested [11,12] without application of dynamic support. However, they served as fundaments for the current research. Following the design principles for adaptive interfaces [13], a new adaptive support interface was developed shown in Fig. 2. In addition to the 4 support functions the adaptive user interface:

- Shows only the categories with active alarms (Fig. 2: A). 'Empty' categories disappear from the interface. The alarms in the top part of the category are own alarms, the alarms on the bottom are of other operators.
- Contains only the buttons that are relevant for the alarms the operator handles (Fig. 2: B).
- Provides the operator with the possibility to redirect the alarm, or an entire category, to another operator by pressing the  icon (Fig. 2: C).

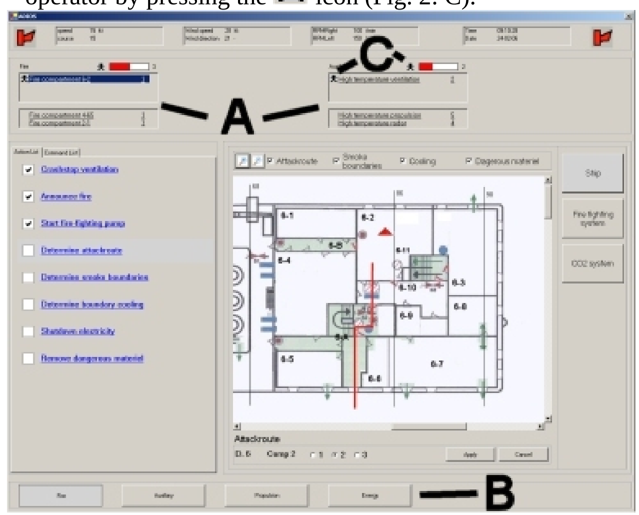

Fig. 2 : The adaptive interface. The operator is working on fire alarm in compartment 6-2.

In Fig. 2 the operator is working on the alarm 'fire in compartment 6-2'. Clicking on the alarm shows the accompanying procedure list on the left. The active (4th) step is highlighted and the required information is presented in the middle of the interface.

3. Evaluation of adaptive support

3.1 Method

For the experiment participants with a maritime background were needed. 64 participants, 56 males and 8 females between 18 and 27 years of age (mean 19.5, SD 1.63), of the Royal Netherlands Navy College were selected. To achieve a homogeneous group only first and second year cadets were allowed to participate. The participants were obligated to participate, 3 couples with the highest performance were rewarded with a bonus of 100 euros. The participants had to perform a computer task using the adaptive interface described in section 2. Their goal was to solve the problems together, as good and fast as possible. Every couple had to deal with 4 fire alarms, a low pressure alarm of the fire-fighting system, 3 alarms concerning the cooling system of the ship, one bilge water alarm and a high temperature diesel engine alarm. How to deal with these alarms was described in a predefined procedure. Depending on the performance of the couples, the scenario took about 20 minutes. Before starting the scenario an instruction was given (60 minutes) and the participants used the system during a training scenario (20 minutes). Fig. 3 shows a couple during the experiment. They were allowed to talk to each other about everything, it was forbidden to look on each others screen.

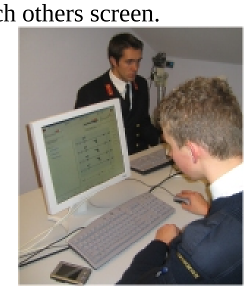

Fig. 3 : Couple performing the experiment, communication was allowed.

The experiment consists of three conditions with a between subjects factor 'task-allocation (TA) support' as independent variable:

1. No task allocation support, only participants together determine task-allocation
2. System provides advice for task allocation.
3. System reallocates tasks, the operator will be informed.

In addition to the role of the system in conditions 2 and 3, the operators were still able to reallocate tasks themselves. Timing of advice messages and automatic TA were the same and determined in advance using the CTL method [5]. Table 2 shows the experimental design.

Table 2
Experimental design

	No TA support	TA advice	TA auto
# couples	11	10	11

3.2 Results

This paper only presents subjective measures, objective measures will be published in the second half of 2006. After the experiment, participants had to answer 15 questions on a 5 point scale (1=not true, 5=true). Table 3 presents the results.

Table 3:
Results 5 point scale questionnaire (1=not true, 5=true).
Q=Question, M=Mean, SD=Standard Deviation.

Q	No TA support		TA advice		TA auto		Total	
	M	SD	M	SD	M	SD	M	SD
1	1.5	0.1	1.3	0.1	1.0	0.1	1.2	0.6
2	4.0	0.2	3.8	0.2	4.0	0.2	4.0	0.9
3	4.7	0.2	4.7	0.2	4.3	0.2	4.4	0.8
4	4.6	0.1	4.9	0.1	4.9	0.1	4.8	0.4
5	1.3	0.1	1.3	0.1	1.0	0.1	1.2	0.4
6	1.5	0.2	1.7	0.2	1.9	0.2	1.6	0.8
7	1.8	0.2	1.9	0.2	1.7	0.2	1.8	1.0
8	3.3	0.2	3.5	0.2	3.6	0.2	3.5	0.9
9	2.2	0.2	1.7	0.3	1.5	0.2	1.8	1.2
10	3.9	0.2	3.8	0.2	3.9	0.2	3.9	1.0
11	1.4	0.2	1.7	0.2	1.6	0.2	1.6	0.8
12	-	-	-	-	3.4	1.1	3.4	1.1
13	-	-	-	-	3.8	1.1	3.8	1.1
14	-	-	3.1	1.1	-	-	3.1	1.1
15	-	-	2.1	1.0	-	-	2.1	1.0

1. The TA function was difficult to use.
2. The TA function was pleasant to use.
3. The TA function was useful to use.
4. The TA function allows us to solve problems faster and better.
5. It takes a lot of effort to reallocate alarms.
6. I receive alarms of my colleague with which I don't know what to do.
7. I think the appearing and disappearing of alarm categories is confusing.
8. The system always acts as I expect it.
9. I sometimes miss buttons on the bottom of the screen.
10. I feel like I am in control of the system.
11. I receive alarms of my colleague when I don't want it.
12. Automatic TA of alarms disturbs my normal way of working.
13. Automatic TA of alarms, without being able to influence it, is annoying.
14. When I am advised to reallocate an alarm, I

fully trust the advise and accept it.
15. TA advices disturb my normal way of working.

3.3. Interpretation of results

The first 5 questions of Table 3 concern the TA function (i.e. all three possibilities of TA: by own choice, advice or automatically). In general, the participants were very positive about the TA function. Question 4 (‘the TA function allows us to solve problems faster and better’) scores 4,8 points (SD 0.4). Questions 6 to 8 are on situational awareness. Only the results on question 8 (‘the system always acts as I expect it’) were not very obvious (M 3.5, SD 0.9). The other 2 questions show no negative effects on situational awareness. Questions 10 and 11 show the participants have the feeling they are in control of the system. Questions 12 and 13 show that the participants are not very positive about the automatic TA function. Especially the answer to question 13 (‘the automatic TA function, without being able to influence it, is annoying’) shows this (M 3.8, SD 1.1). Questions 14 and 15 show a preference for the advice TA function, however the effect on trust could be improved.

4. Conclusion and discussion

The increase in automation in process control emerged a strong need for dynamic adaptation tools. This paper shows the design and evaluation of one part of such a dynamic adaptation tool: the adaptive interface. Three main conclusions can be made:

1. The CTL method can be used in the design of adaptive support
2. Support concepts which were initially designed for static task allocation prove to be useable in the adaptive interface design as well.
3. Evaluation shows very positive results on the support system, specifically on the TA functions. Participants prefer the advice TA function. However improvements to take away negative effects on trust have to be made.

In consideration of this paper, some important points should be taken into account:

<u>Adaptation versus Self-Adaptation.</u> Who should make the decision for dynamic task allocation is an important question, which is part of our project but out of the scope of this paper. The decision can be made by automation, the operator or by a mix of both. Even another operator (e.g. a superior) can be involved and make the decision. Schneider-Hufschmidt et. al [14] describes 4 different tasks that have to be performed in the adaptation process from the user’s point of view. Each task can be performed by the system, or by a user, so 8 different configurations arise. The configuration where the computer takes all actions is defined as ‘self-adaptation’, the one where the operator takes all actions is called ‘adaptation’. van der Kruit [15] defines only two categories, ‘adaptable’ and ‘adaptive’ automation.

<u>Framework for adaptive support.</u> To evaluate the adaptive interface, it was sufficient to determine the moments of advice and automatic TA in advance. However, in the development of a full scale adaptive system, the right moment of support is of utmost importance. Parallel to the interface evaluation described in this paper, a framework to measure and influence task load is being developed. Goal of this framework is the real time generation of a work plan which tells us when to adapt support.

<u>Statistical analysis.</u> A statistical analysis of the data is out of the scope of this paper. However, a large amount of data was collected. For example: (team)performance (# correct actions & time used), mental effort [16], variables of the CTL model (TO, TSS, LIP), type of communication (about TA or problem solving), spatial ability and physiological data.

<u>TA between computer and operator.</u> Next step in the development of the adaptive interface is the possibility for the operator to accept the alarm and choose a certain level of task allocation between the operator, computer and/or other operators. This level is represented by the icon behind each alarm (see also [17]). In Fig. 4, the operator gets an alarm ‘Sitrep 1’. This means it is time to give his first Situational Report, and inform the crew about the status of the calamities. For this alarm five levels of task allocation are available:

1. Manual. A procedure is presented in the procedure presentation area (left). Clicking on a procedure step shows the accompanying information in the middle of the interface. From here information can be selected and put into the sitrep (right). No further advise is given.
2. Critiqued. See manual mode, but now the system criticizes the operator in case of faults.
3. Supervised. The tasks are executed as in the manual mode, but a human supervisor checks the operator.

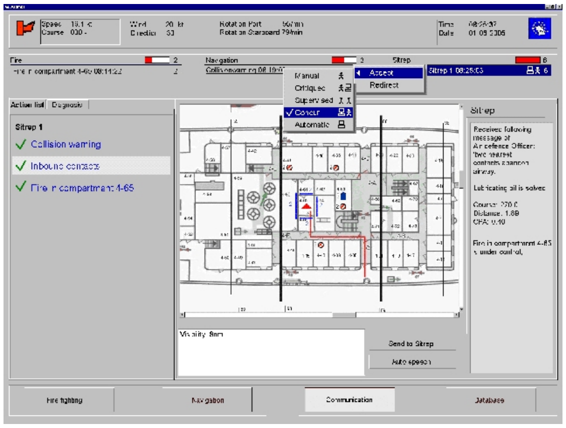

Fig. 4: The adaptive interface with 5 levels of TA: The operator accepts the alarm in concur mode.

4. Concur (shown in Fig. 4), See critiqued, and in this mode all information will be selected by the system. The operator is still able to change the selected information.
5. Automatic. this highest automation mode, returning to the procedure steps is not possible anymore.

Experiments on trust, situational awareness and performance with this interface will be conducted at the end of 2006.

Acknowledgements

We would like to thank J.C.M. van Weert, K.D. Stolk and especially M. Marckelbach for their enthusiasm and assistance during the experiments.

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