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How to Manage Cognitive Task Load During Supervision and Damage Control in an All-Electric Ship

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Abstract: On one hand, an all-electric ship may take over and support operator tasks in order to improve the operational effectiveness and efficiency on board of a ship. At the other hand, information processing demands seem to increase substantially for the operators in such a ship. Recently, a Cognitive Task Load analysis method was developed for the design of operator tasks and computer support, aiming at optimal load distributions during high-demand situations in current and future naval ships. This paper gives a brief overview of the method, presents results of a task load study in the Multi-purpose frigate of the Royal Netherlands Navy, and summarises current user interface concepts that provide an "integrated view" for supervision and damage control activities in an all-electric ship.

Key-Words: Workload, supervision, human-computer interaction, cognitive engineering, task analysis, navy, ship control centre.

1 Introduction

Due to automation in all-electric ships, fewer personnel will have to manage high-demand situations and supervise complex automated systems. Reduced manning concepts appear based on the notion that the information and communication technology can take over and support operator tasks. However, information processing demands seem to increase substantially for the operators due to the availability of more-and-more information that has to be processed, the increased scope of actions and the ever increasing costs of errors in an environment with possibly ambiguous and insecure information. The Royal Netherlands Navy (RNlN) is maintaining and developing various classes of frigates, starting with the Standard frigate, succeeded by the Multi-purpose frigate, to the new Air Defence and Command Frigate that is currently in its test programme. An important question is how to systematically address Human Factors in the development and maintenance processes of such complex and dynamic human-machine systems in order to realise an optimal operational effectiveness and efficiency.

The naval frigates have a Ship Control Centre (SCC) to supervise platform systems, and plan and co-ordinate damage control activities. The number of activities will be small when the systems function well and damage is absent. When damage or disturbances appear, the—possibly cumulating—problems have to be solved as fast as possible. Task load can thus vary enormously from one extreme to the other and will as such be an important factor for the effectiveness of the human problem-solving process. To deal with this problem for example, the Royal Netherlands Navy considers to add platform supervision tasks to the navigation tasks on the bridge of an amphibious transport ship, so that the ship control centre can be unmanned under non-critical situations.

TNO Human Factors has been developing a method for Cognitive Task Load (CTL) analysis to guide such human-machine development processes in order to realise acceptable levels of task load for the operators in the control centre and on the bridge [1]. A first test application of this method for the Air Defence and Command Frigate showed its possible contributions for improved task allocation [2], while a second application provided a promising concept for user interface support [3]. The method for CTL-analysis is being developed in an iterative way by incorporating the results of empirical research incrementally. This paper gives a brief overview of the method, presents results of a task load study in the Multi-purpose frigate of the Royal Netherlands Navy to extend its empirical foundation, and summarises current user interface concepts that provide an "integrated view" for supervision and damage control activities in an all-electric ship.

2 The CTL Analysis Method

2.1 The CTL Model

The "core" of the CTL-analysisis is a model of cognitive task load, predicting whether future task demands are attuned to the limited human information-processing capacities. This model, distinguishes three load factors that have a substantial effect on task performance and mental effort. The first classical load factor, percentage time occupied, has been used to assess workload in practice for time-line assessments. Such assessments are often based on the notion that people should not be occupied more than 70 to 80 percent of the total time available. To address the cognitive task demands, the cognitive load model incorporates the Skill-Rule-Knowledge framework of Rasmussen [2] as an indication of the level of information processing. At the skill-based level, information is processed automatically resulting into actions that are hardly cognitively demanding. At the rule-based level, input information triggers routine solutions (i.e. procedures with rules of the type 'if <event/state> then <action>') resulting into efficient problem solving in terms of required cognitive capacities. At the knowledge-based level, the problem is analysed and solution(s) are planned, in particular to deal with new situations. This type of information processing can involve a high load on the limited capacity of working memory. To address the demands of attention shifts, the cognitive load model distinguishes task-set switching as a third load factor. Complex task situations consist of several different tasks, with different goals. These tasks appeal to different sources of human knowledge and capacities and refer to different objects in the environment. We use the term task set to denote the human resources and environmental objects with the momentary states, which are involved in the task performance.

The combination of the three load factors determines the cognitive task load: the load is high when the percentage time occupied, the level of information processing and the number of task-set switches are high. Figure 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, task load matches the operator's mental capacity. At angular point 8, task load is most high. Angular point 1 represents the area in which performance is not optimal due to underload. When the time occupied is high, and level of information processing and number of task-set switches are low, vigilance problems can appear (angular point 2). When the time occupied and the number of task-set switches are high, cognitive lock-up can appear (i.e., the tendency of people to focus on single faults, ignoring the other subsystems to be controlled; line 4-8).

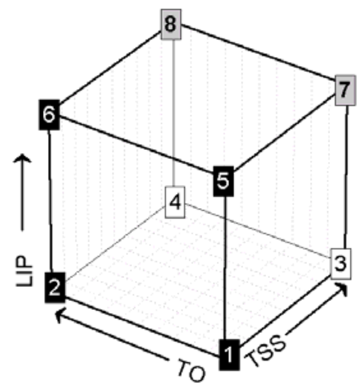

Fig.1 Dimensions of the Cognitive Task Load model: Time occupied (TO), Task Set Switches (TSS) and Level of Information Processing (LIP).

2.2 Example CTL Analysis

Cognitive task load can only be analysed for specific, concrete task contexts. An effective method to create such a context is the use of scenarios [4]. Scenarios presuppose a certain setting. Within the setting, roles are played by actors. In complex scenarios different actors can be involved, possible interacting with each other. Actors have specific goals or tasks. To achieve this goal actions have to be taken. Neerincx et al. [2] provide a method and description format to systematically create and assess normal and critical situations with their corresponding action sequences. Such an action sequence displays actions of different actors on a time-line, including the interaction with support systems. The actions can be triggered by events, and are grouped according to their higher-level task (goal). Van Veenendaal [5] assessed the action sequences for alternative designs of the naval ship's bridge, comprising different task allocations and support functions for navigation and platform supervision. Normal and critical scenarios were specified with domain experts. Furthermore, for every scenario, support functions were specified and included in the action sequence specifications (i.e. information handler, rule provider, diagnosis guide and task scheduler). The action sequences were validated with domain experts. The cognitive load model was used to assess these action sequences, each sequence with and without the four support functions. First, the three load factors were calculated per 6 minutes task performance, showing the dynamic load fluctuations in the 3-dimensional load cube of figure 1. Subsequently, via questionnaires experts assessed the action sequences to acquire subjective load measures and estimations of the support effects.

The analysis showed that the task of the Officer of the Watch could be extended with platform control tasks under normal conditions. The support functions will complement the knowledge and experience of the bridge crew to realise an adequate performance level. In critical situations however, extra, technical personnel has to be called up. This study provided the first indicators for implementing such a dynamic task allocation

3 Experiment "SCC trainer task"

The CTL-model is derived from cognitive research of different task domains and requires further empirical foundation to assess its validity for the domain of complex damage control tasks. Our research approach is to conduct experiments in controlled laboratory settings and in more complex, realistic settings to systematically test the theoretical foundation and investigate its application in the "real world".. In this approach, the test environment subsequently increases in complexity and decreases, therefore, in controllability. This way we can test and refine the theory, and achieve a good understanding of its applicability in practice. The first experiment used a simple laboratory task, called "alarm 112 task" [6], while the second used a test-environment with computer tasks that exhibit important features from damage control on ships explicitly, called "SCC computer task" [7]. Both lab experiments showed that "level of information processing" and "task-set switching" can affect operator performance and mental effort substantially, in addition to the classical load measure "time-occupied". Furthermore, the negative effects of the load factors prove to reinforce each other in the lab experiments. This paper presents the third experiment that has been conducted in a realistic SCC simulator of the Multi-purpose frigate, called "SCC trainer task".

3.1 Research questions

This experiment should improve the empirical foundation of the CTL model and method, and provide a first estimation of the critical load values for the SCC. We distinguish two hypotheses:

1. Application of the CTL-method results in CTL-specifications per crew member that predict the actual CTL of a crew member adequately. In other words, we expect that the method provides good predictions of the task load that will actually appear in the SCC trainer.
2. The three load factors affect task performance and mental effort substantially, and can be used to identify under- and overload situations. Corresponding to the lab experiments, we expect an increased mental effort and reduced performance of "level of information processing", "task-set switching" and "time occupied".

3.2 Scenarios

The SCC occupation depends on the so-called Readiness State, consisting of one to six persons. In the experiment, we will record the task performance and subjective effort of two crewmembers, an operator and a manager, to acquire the task load indicators for these two different types of operators. For the extremes of each of the three load factors, we specified a scenario and the corresponding action sequences of the operator and the manager in co-operation with the RNlN Technical Education School, resulting in (2x2x2=) 8 action sequences (the corners of the load cube). Subsequently, the scenario was implemented in the SCC-trainer and the instruction for the "simulation controllers". An expert operator and manager, who had ready knowledge of the scenario and the normative procedures to handle this scenario, provided the baseline task performance for each scenario.

3.3 Participants

Thirteen teams participated in the experiment. The selected teams were active teams onboard of the M-frigates that were in harbour at the time of the experiment. Each team consisted of an operator and a manager. However, some teams consisted of more team members to make the scenario's more realistic (e.g. more realistic for the specific operator and manager that were evaluated). The actions of the extra team members were not used in the evaluation of this research.

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Table 1 The eight conditions (see corners in figure 1) in the experiment.

Con-dition	*CTL factor* *TO*	*TSS*	*LIP*	*Scenario types*	*Operator & Manager*	*Number of teams*
1	low	low	low	MBD's	Officer o/t watch Additional officer	5
2	high	low	low	MBD's	Officer o/t watch Additional officer	5
3	low	high	low	Fire at sea	DC-officer NBCD operator	4
4	high	high	low	Fire at sea	DC-officer NBCD operator	4
5	low	low	high	MBD's	Officer o/t watch Additional officer	5
6	high	low	high	MBD's	Officer o/t watch Additional officer	5
7	low	high	high	battlestations	M-officer Engine operator	4
8	high	high	high	battlestations	M-officer Engine operator	4

3.4 Experimental Design

The CTL model distinguishes 3 variables, resulting in eight different conditions (see Table 1). For each condition, a separate scenario had to be developed. Because it seemed not possible to use the same scenario type (e.g. MBDs) for all conditions, three different scenario's were used for combinations of the conditions (see Fig. 1 and Table 1). One scenario was used for the conditions 1, 2, 5 and 6, one scenario for the conditions 3 and 4 and one scenario for the conditions 7 and 8.

3.5 Procedure

All experimental sessions were recorded on video tape. This tape was replayed after each session, during which the operators and managers had to indicate when they started and stopped an action. A software tool was used for this analysis that was originally developed for a workload analysis of the Lynx helicopter crew [8]. This tool differentiated between 'task sets' and 'actions'.. The participants had to give a score on two rating scales: 1) mental effort and 2) task complexity. These rating scales appeared successively on the computer screen every minute. The participants were instructed to evaluate the previous minute for these ratings. The range of the rating scales was between 0 and 10 with steps of 0.25 points. A rating could be given by moving a pointer with the arrow keys and pressing the 'enter' key when the pointer indicated the proper rating. At the first appearance of the scale, the arrow pointed to the value '5' and all successive times, the arrow pointed to the last rating. So, when the effort or complexity was not changed during the last minute, the participant could simply indicate this by pressing the enter key.

In order to get the start of a new task set and the beginnings end endings of all actions properly, all video tapes were analysed by an expert. Each tape was replayed twice: once to score the task sets and actions of the operator and once to do the same for the manager. The advantage of this procedure was that the same criteria for an action was used in all sessions.

Fig. 2 Ship Control Center (SCC) during the experiment. Camera's for video recording of the session were attached to the ceiling.

One operator and one manager formed a team in the present study. 13 teams participated in the experiment (10 teams from the ships and 3 teams to determine the base line times). For practical reasons, it was not possible to fill all conditions with the same teams. Four teams performed conditions 1, 2, 5 and 6 (see Fig. 1). Three teams performed conditions 3 and 4 (see Fig. 1) and the other three teams performed conditions 7 and 8 (see Fig. 1).

3.6 Results

The results of the experiment can be summarised as follows:

- The task load factor ‘level of information processing’ had the largest impact on the subjective effort ratings, especially for the operators (corresponding to the previous lab experiments).
- The experiment showed also interaction effects: the load proved be high, in particular when the more than one factor was high (i.e. the loading effects reinforce each other).
- The participants needed more time to complete the scenario’s and to perform the tasks than the experts. For the high-LIP conditions a substantial additional increase was found. Furthermore, it seemed that the participants did not work efficiently compared to the experts in the low-TO and low-TSS conditions.
- A small reduction in performance was found for the high-TSS and high-LIP conditions. Higher task load does not automatically result in a reduced level of performance. Effects of increased task load can be counteracted by an increase in mental effort. Thus, the performance effects must be related to the effort scores. Time occupied hardly affected the effort and performance and thus, did hardly affect task load. High levels of TSS and LIP resulted in a reduced performance and increased effort and thus, increased the task load

4 User Interface Support

The “SCC trainer task” experiment showed situations in which task load can cause reduced operational effectiveness and efficiency. Based on the CTL model and method for cognitive task analysis, we developed 4 support concepts to prevent such load problems, and for each concept high-level design principles [1]:

The *Information Handler* filters and integrates information to improve situation awareness, i.e. knowledge of the state of the system and its environment, and reduces the time occupied. Due to the increasing availability of information, situation awareness can deteriorate without support. Correct information should be presented at the right time, at the right abstraction level, and compatible with the human cognitive processing capacity.

The *Rule Provider* provides normative procedures for solving (a part of) the current problem and affects the level of information processing. Due to training and experience, people develop and retain procedures for efficient task performance. Performance deficiencies may arise when the task is performed rarely so that procedures will not be learned or will be forgotten, or when the information does not trigger the corresponding procedure in human memory. For these situations, rule provision aims at supplementing human procedural knowledge.

The *Diagnosis Guide* affects the level of information processing. The level of information processing increases when no complete (executable) procedure is available to deal with the current alarms and situation. This support function guides the operator during the diagnosis resulting in an adequate problem-solving strategy for a specific task.

The *Scheduler* affects the number of task-set switches by providing an overall work plan for emergency handling. Task priorities are dynamically set and shown in a task-overview to the operator resulting in effective and efficient switches.

Grootjen et al. [2] show how these support functions can be integrated into the user interfaces on board an all-electric ship. Furthermore, the support functions proved to be very effective in an evaluation of a prototype system. Current research focuses on establishing dynamic task allocation by a context-aware system, implemented as an adaptive user interface. The adaptive interface personalises and instantiates the four support functions and attunes them to the specific environmental conditions.

5 Conclusion

In an all-electric ship, operator tasks will be more and more focused on handling non-routine situations supported by information technology. Cognitive task analyses are needed to realise an adequate human resource deployment by training, selection, task allocation and cognitive support systems. To enable well-founded analyses in such task environments, we have been developing a CTL model and method in an iterative process building on established Human Factors approaches [e.g. 9, 10].

This paper presented an overview of the method and a summary of one of the experiments that should add on the empirical foundation. Referring to the two research questions of section 3.1, we can derive the following conclusions from the experiment:

1. The CTL method provides useful predictions on the relative value for each of the three load factors.
2. Corresponding to previous lab studiess, the experiment showed substantial effects of the load factors on performance and mental effort.

It should be noted that the CTL method provides a meso-level analysis, so that it can be used in early system design stages. In addition to the assessment of design alternatives, the method can also aid with deriving user requirements for support systems. Such requirement might be stated in a form as: "System component X should provide task support for Y scenarios, so that the performance and cognitive task load of Z operators will not exceed the following measures…".. In general, the CTL method fits well with current Cognitive Systems Engineering approaches [11]. As such it will contribute to the development and implementation of user-interfaces, which provide integrated and context-dependent support for supervision and damage control activities in an all-electric ship.

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