Grootjen, M.; Neerincx, M.A.; Passenier, P.O., "Cognitive support for ship Damage Control - Design and evaluation of a prototype user interface", *INEC Proceedings*, 2002.

Cognitive support for ship Damage Control

Design and evaluation of a prototype user interface

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Abstract

Recently, four cognitive support concepts were developed, that should help to handle high-demand situations. These concepts are based on a cognitive task load model and can be realised with a specific method for cognitive task load analysis. The model and method describe task load in terms of three behavioural factors: *the percentage time occupied*, *the level of information processing* and *the number of task-set switches*. This paper shows the design and evaluation of a prototype user interface providing the proposed support concepts. Application of the design method proved to be possible for the chosen maritime domain (the bridge of an icebreaker) and resulted in an interface that contains *an information handler*, *a task scheduler*, *a diagnosis guide* and *a rule provider.* The resulting prototype user interface was evaluated with navy cadets, to study the effects of cognitive support, under high and low task load, on task performance, mental effort and out of the loop effects.

The use of support functions leaded to a substantial increase in performance, especially at high task load. Costs on out of the loop effects, like the not reacting on an implemented wrong advice and a decrease in understanding of performed actions, could not be found.

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1 Introduction

In different work domains, such as defence and process control, the need for improved deployment of human knowledge and capacities is increasing. In addition to selection and training, adequate task allocation and computer support can help to realise such improvement. The research reported here has been partly funded by the EU project ATOMOS IV (Advanced Technology to Optimise Maritime Operational Safety, Intelligent Vessel), and as such is a continuation of earlier work aimed at the development and demonstration of decision-support concepts in the maritime domain (a.o. DISC II: Demonstrator Integrated Ship Control).

We developed a method for cognitive task analysis (Neerincx et al, 2000), which includes a model of cognitive task load that comprises the effects of task characteristics on performance and mental effort. This model describes task load in terms of three behavioural factors: *the percentage time occupied*, *the level of information processing* and *the number of task-set switches*. The first factor is the classical load factor, *percentage time occupied*, which has been used to assess workload for time-line assessments.
To address the cognitive task demands, the new load model incorporates the Skill-Rule-Knowledge framework of Rasmussen (1986) 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 <actions>’) resulting into efficient problem solving in terms of required cognitive capacities. At the knowledge-based level, based on input information the problem is analysed and solution(s) are planned, in particular to deal with new situations. This type of information processing can involve a heavy load on the limited capacity of working memory.
To address the demands of attentional shifts, the model distinguishes *task-set switching* as a third load factor in the performance of process control tasks. 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. Switching entails a change of applicable task knowledge on the operating and environment level.
The combination of the three load factors determines the cognitive task load (Figure 1). It should be notified that specific regions in the cube of Figure 1 will hardly appear in practice. In practice, there is a 3-dimensional ‘load’ space in which human activities can be projected with regions indicating under- and overload.

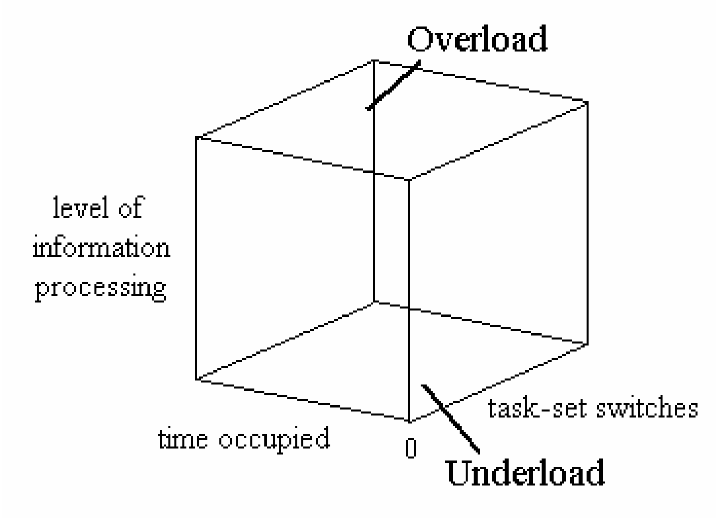

Figure 1: The three dimensional model of cognitive task load

Experiments showed that the model and method are of use for task allocation in experimental (Neerincx & van Besouw, 2001) and complex environments (Neerincx et al, in press).
In Neerincx & Lindenberg (2000) the method for cognitive task analysis has been applied resulting in an interface that contains four support functions affecting mental load: *an information handler*, *a task scheduler*, *a diagnosis guide* and *a rule provider*. An overview of the load factors, support concepts and support functions is given in Table 1.

Table 1: The load factors with accompanying support concepts and functions that reduce the negative effects of each load factor.

Load factor	Support concept	Support function
Time occupied	Combining and structuring information	Information handler
Level of information processing	Providing normative procedures	Rule Provider
	Guidance of diagnostic processes	Diagnosis Guide
Task-set switching	Providing an overall work plan	Emergency Scheduler

Information handler
This type of support filters and combines information to improve situation awareness, i.e. knowledge of the state of the system and its environment (Endsley, 1995) and is of influence on the load factor time occupied. Due to the increasing availability of information, situation awareness can deteriorate without support. Correct information should be presented on the right moment, in such a way that the costs on the cognitive capacity of the operator, when interpreting the information, are as low as possible.

Rule Provider
The Rule Provision function provides the normative procedure 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.

Diagnosis Guide
The diagnosis guide affects the task load factor 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. The diagnostic guide supports the operator by giving guidance in his diagnostic process.

Scheduler
The scheduler affects the cognitive load factor number of task-set switches by providing an overall work plan for emergency handling.

In this paper we focus on the effects of the support functions under high and low task load on task performance, mental effort and out of the loop effects. We will apply the method for cognitive task analysis (Neerincx et al, 2000) for the domain of an icebreaker, with a fire emergency as test scenario. For this scenario, based on the four support functions, an interface is designed. With the task analysis and the interface two experimental prototypes are developed: one with support functions, and one without. These prototypes are tested with students of the Royal Netherlands Navy Institute.
For a complete documentation of this research, see Grootjen et al (2002).

2 Design of user interface

Section 1 distinguished three load factors and a set of support functions that can reduce the negative effects of each factor on task performance and mental effort. This chapter will present the interface with the four support functions for an integrated ship's bridge.

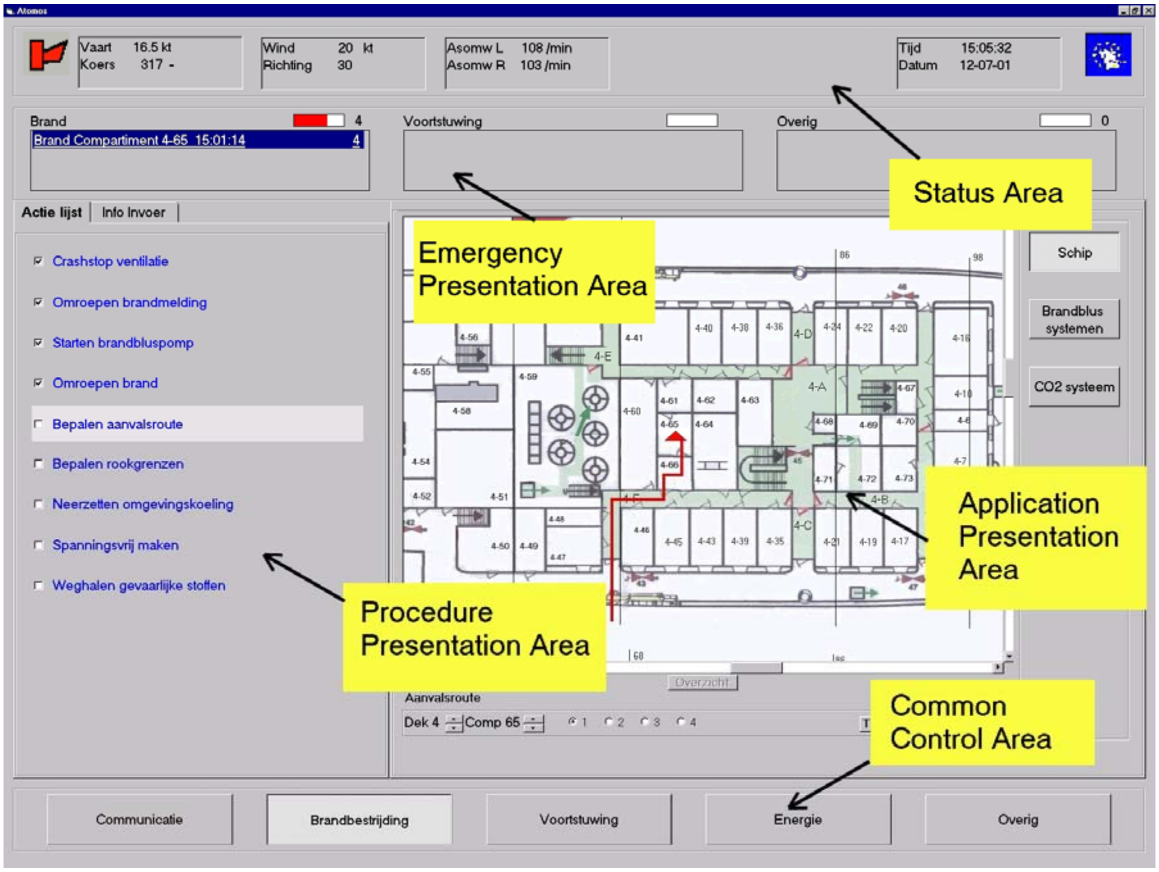

Figure 2: The interface with five different area's during a fire emergency (interface based on Neerincx & Lindenberg, 2000).

Figure 2 shows an example of the user interface during a fire emergency. In this interface five different areas can be distinguished:

1. The status area is shown on the top part of the screen. In this area real-time information is presented and an alarm bell is used to indicate the alarm status.
2. The emergency presentation area shows the emergencies with their time of occurrence.
   - The alarms are categorised into groups (Fire, Propulsion and Others).
   - Each emergency is presented as a hyperlink that 'loads' the corresponding procedure in the procedure presentation area. Selection of an emergency is indicated by 'inverted' video (blue background in Figure 2).
   - Next to each emergency a number is given to indicate the priority of that particular emergency.
   - Next to the group name a priority indicator (horizontal bar) and a corresponding number are given, showing the highest priority of that group.
3. The procedure presentation area provides web-browsing functionality and consists of two tabs, the 'action' and 'relation' tab:

- The action tab presents a list of all actions that must be performed to deal with the selected emergency.
- Checkmarks can be placed in the appropriate checkboxes to indicate that a specific step in the procedure was completed. The background of the following step in the procedure is highlighted while the background of the other actions is grey (i.e. the first not check-marked step is highlighted).
- The relevant application for the current (i.e. highlighted) step is activated and presented automatically in the application presentation area.
- Explanation or definitions about the actions in the procedure can be consulted by a right mouse-click on the action.
- Unlike the action tab, which is always available, the relation tab is not available most of the time (indicated by being dim). It becomes available whenever the system manager discovers one or more hypotheses about the system's state and relations between alarms (emergencies); the tab presents them to the operator.
- A toggle switch is presented before each hypothesis to indicate whether the hypothesis is true (Y), not true (N) or still open (no button pushed). Each diagnosis of the relations ends with a 'Finished' checkbox.
- After the operator finishes the diagnosis, the system manager will indicate and explain whether the choices are consistent in a dialogue box. When the choices are consistent, the dialogue box proposes changes in the context model that correspond to the hypotheses assessment. The operator can choose whether or not he wants to approve to the changes. When the operator approves, the changes are made and immediately used to dynamically improve the procedures and the operator returns to the 'Action List' tab that contains the improved procedure. When he disapproves, no changes are made and he is also returned to the 'Action' tab. The operator can do the diagnosis again by clicking the relation tab.

4. The <u>application presentation area</u> in the middle of the screen is used to present the active application. The buttons on the right side of the screen are used to switch between sub-applications.
    - Procedure actions concerning a damage control action in the ships plot contain a spatial advice, given by the system manager in the application area. For example for the action 'determine attack route', the correct attack route, following standard procedures for the current situation, is shown by the system manager (the red line in Figure 2).
5. The <u>common control area</u> contains five buttons, which can be used to switch from one application to another.

Table 2 gives an overview of all support instantiations and their connection with the support functions.

Table 2: All support instantiations and their connection with the support functions.

Support function	**Support instantiation**
Information Handler	Ordering alarms in categories Process-based (automatic) presentation of required interface component Hyperlinks within and between the components
Rule Provider	Context specific procedural information Spatial advice (graphical presentation of 'routing rules')
Diagnostic Guide	Help with diagnostic process
Task Scheduler	Task overview Check mark ability (process state) Prioritising alarms

3 Evaluation of the user interface

The preceding Section described the user interface. With this interface a prototype was implemented which was used in an experiment to determine the effects of the support under high and low task load.

Method

In the experiment 57 student, 47 males and 10 females between 18 and 24 years of age (mean 20.1 SD 1.5), of the Royal Netherlands Navy College participated. The participants had to perform a computer task in which they had to deal with different alarms. The main alarms every participant had to deal with were: 'fire in compartment 4-65' and 'low-pressure alarm in the fire fighting system', 27 of the participants also had to deal with the alarms: 'malfunction of a ventilation valve', 'high temperature of a diesel cylinder' and 'network failure'. These three alarms were easier to solve in a shorter period of time. All participants had to give a sitrep (situation report for the crew) every five minutes to keep their personnel in the ship informed. Depending on the performance of the participant, the scenario took about 20 minutes.

Variables

Support mode

The first independent variable is the between subjects factor support. To assess the effects of support, both scenarios I and II (Figure 3) were performed with and without support.

Task-Set Switching (TSS)

The second independent variable was also varied between subjects. The example in Figure 3 shows the actions of two scenarios, both scenarios consisting of the same main tasks-sets (i.e. alarms, A and B). To achieve a low and high condition for the number of task-set switches, three task-sets were added in scenario II (in the example of Figure 3 only one task-set: C).

Level of Information Processing (LIP)

The third independent variable was varied within subjects. One session with a participant consisted of two parts (Figure 3). After performing the first part, the participant received an extra instruction. In this instruction the problems of part 1 were explained, by showing the scenario on a computer. In part 2 of the scenario, the same actions had to be performed. In this way a lower level of information processing was realised compared to part 1. To prevent the ability to predict the events in part 2, the time in the scenario when the additional task-sets were activated (i.e. the appearance of alarms) was altered.

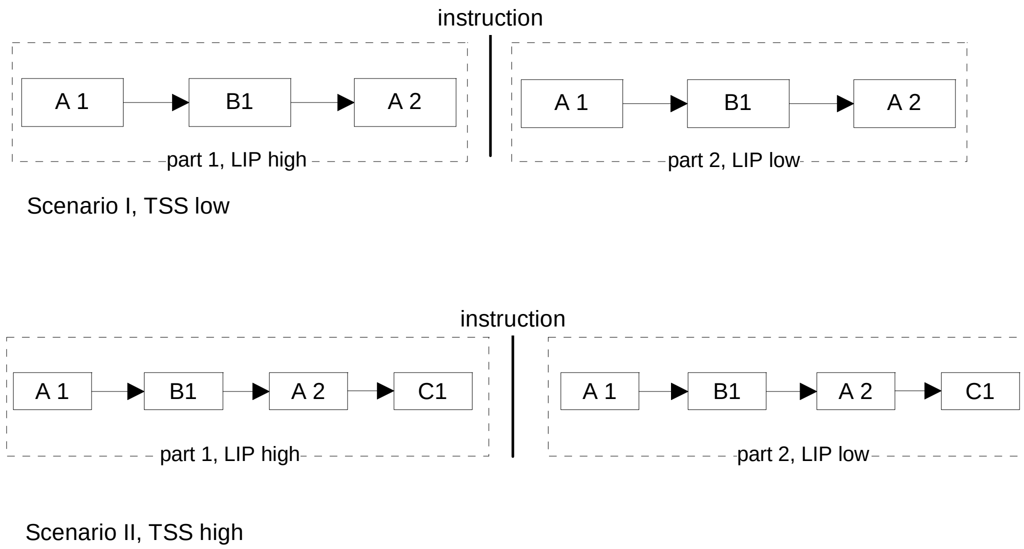

Figure 3: Simple flowcharts of two scenarios. The independent variable 'task-set switching' was altered between subjects by developing scenarios I and II. The independent variable 'level of information processing' was altered within subjects: after performing part 1 an instruction was given and part 2 was performed.

The following types of dependent variables were measured:

- performance
  1. fire alarm - correct actions
  2. fire alarm - time needed[1]
  3. fire alarm - correct spatial actions
     One point could be earned for each of the four actions of the fire alarm that had to be performed in the plot of the ship, for which in support condition a spatial advice appeared. For one action an incorrect advice appeared, to investigate the 'out of the loop' problems that could arise when giving advice.
  4. low-pressure alarm - correct actions
  5. time dealing with the incorrect alarm[1]
     When a new alarm appeared with a higher priority than the current active alarm the participant had to switch to the new alarm. The time until this switch was added to the score 'time dealing with the incorrect alarm'.
- knowledge

After each part of the experiment, the participants had to fill out a knowledge questionnaire. Questions were asked about *the chosen options* at the spatial advice actions and *the reasoning why* these options were chosen. The number of correct chosen options was taken as maximum score (100%), the percentage correct chosen options where a correct reasoning was given formed the score 'percentage correct and understood actions'.

- mental effort

Mental effort was measured using a one-dimensional rating scale: the Subjective Mental Effort (SME) scale (Zijlstra, 1993).

[1] The measured times and the number of task-set switches were determined by using the performed actions that belong to one task-set only.

Results

A repeated-measures analysis MANOVA with two between factors (support and number of task-set switches) and one within factor (level of information processing) will be applied to the data collected from the dependent variables. Only significant results ($p \leq 0.05$) are presented.

From the SME scale data, we found that the high-low manipulation of task load has been successful: a decrease in the load factor 'level of information processing' reduced mental effort with 38 %, a decrease of the load factor 'number of task-set switches' reduced mental effort with 19 %. The performance measures also showed the influence of the load factors. A decrease of the load factor 'level of information processing' resulted in: an increase of 24 % on the number of correct actions and a decrease of 21% on time needed for the fire alarm; an increase of 26 % of correct answers on the spatial advice actions; an increase of 43 % on the number of correct actions for the low-pressure alarm; a decrease of the time spent on the incorrect alarm of 72 %. A decrease of the load factor 'number of task-set switches' resulted in a decrease of the time spent on the incorrect alarm of 86 %.

The use of support leaded to a reduction of time needed for the fire alarm with 25 %. This reduction was larger at a high level of information processing: 270 seconds, compared to a reduction of 127 seconds at a low level.
The correct answers on the spatial advice actions from the fire alarm increased with 8 % by the use of support.
Using support leaded to an increase of 31 % of the number of correct actions on the low-pressure alarm. For the low-pressure alarm the effect of support on the number of correct actions was larger at a high level of information processing: at a high level of information processing the increase in correct answers using support was 0.7, on a low level the number of correct answers increased with 0.2. It should be noted that on a low level of information processing the score of the condition with support was at the ceiling (maximum score=2), as can be seen in Figure 4.

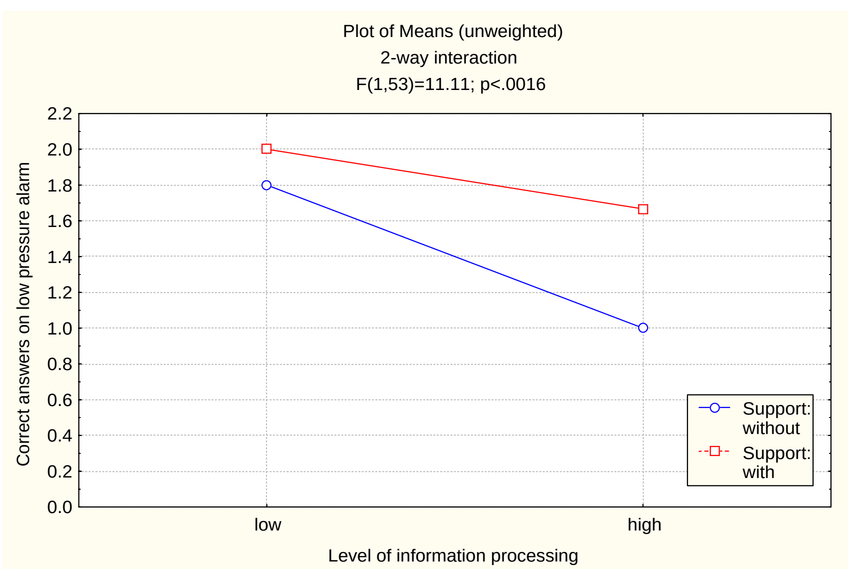

Figure 4: Interaction effect between level of information processing and support on the correct actions score of the low-pressure alarm (maximum score=2).

The time the users spent on the incorrect alarm was reduced with 69 % by the use of support.

Figure 5 shows the largest effect of support when both the load factors are high. Time dealing on the incorrect alarm decreases from 494 seconds without, to 118 seconds with support in this condition.
No out of the loop effects were found: the (out of the loop) costs of an incorrect spatial advice are outweighed by the profits of correct advice and the understanding of the performed spatial actions will not be reduced by the use of support. For the percentage correct and understood spatial actions no main effect of support was found.

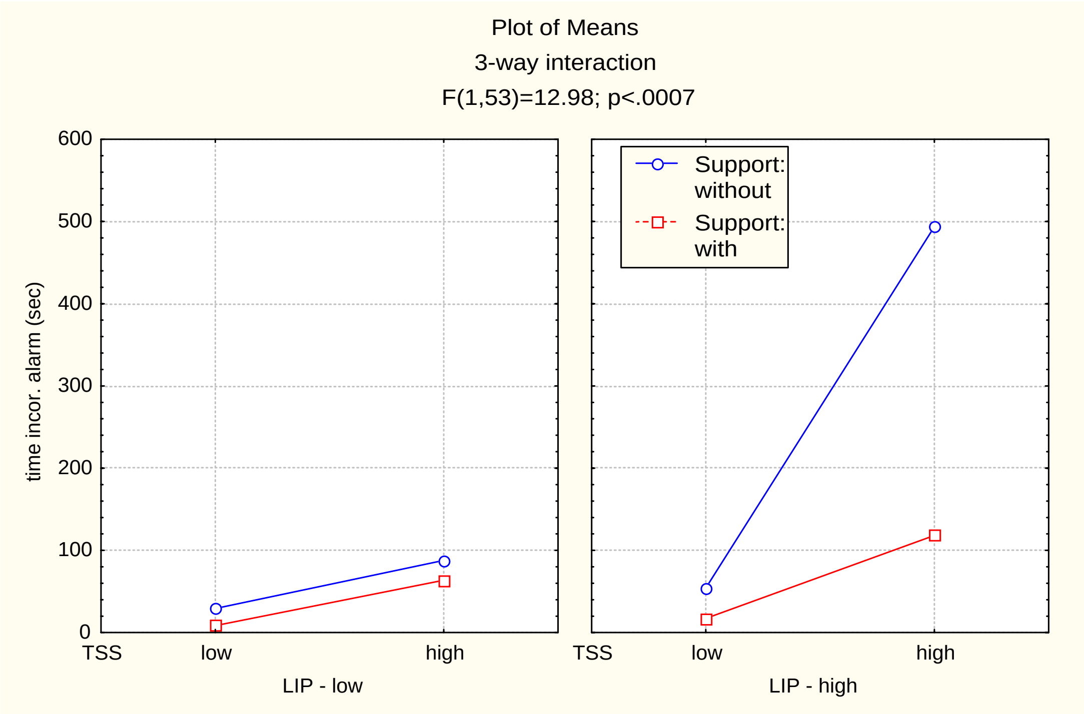

Figure 5: 3 way interaction between the level of information processing (LIP), task-set switching (TSS) and support on the time dealing with the incorrect alarm. The condition where both load factors are high shows the largest effect of support.

4 Discussion

This paper shows the design and evaluation of a prototype user interface based on a method for cognitive task analysis and four concepts for cognitive support.

Method for cognitive task design

The first general conclusion of this paper is that application of the information handler, task scheduler, diagnosis guide and rule provider is possible in the icebreaker domain. The method of cognitive task analysis is a valuable tool for developing a user interface consisting of these four support functions. Although application of the functions is possible for the chosen scenario, a wider application should be investigated. For this, discrete event simulation can be of use: modelling scenario's can provide information about the task load of the operator, and, when the interaction between support system and user is specified as well, about the effects of the support functions on task load.

The effects of cognitive support

The second general conclusion of this paper is that the use of support functions leads to a substantial increase in effectiveness and efficiency, especially at high task load. Costs on 'out-of-the-loop' effects like an implemented wrong advice and understanding of performed actions were not found.
Despite the positive results, extra effort will be made to attune the interface more to the state of the user with adaptive control (or: adaptive support). Adaptive control, or adaptive automation, represents an alternative to static automation in which computer assistance or task allocation between human operators and computer systems is flexible and context dependent rather than fixed (Parasuraman & Hancock). The possibility to use physiological measures to determine the state of the user has to be considered.

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