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Dynamic Task Load Scheduling for Platform Control and Navigation on a Naval Ship

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In process control, the ongoing automation and application of new technologies caused a radical change in the position of the operator. Due to this change, increasing manning constraints and the pressure to maximize the operational capability in the Navy, naval operators need personalized and dynamic 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 user evaluation of an interface with task allocation support. This kind of support enables the operator to redirect the alarm (system or operator initiated). Evaluation with 34 navy students shows positive results on performance and general usability. Performance increases because the most important problems are solved faster. However, performance on a less important task decreases and can be interpreted as 'reallocation costs'. Results on questionnaires show an increasing insecurity on the predictability of the system.

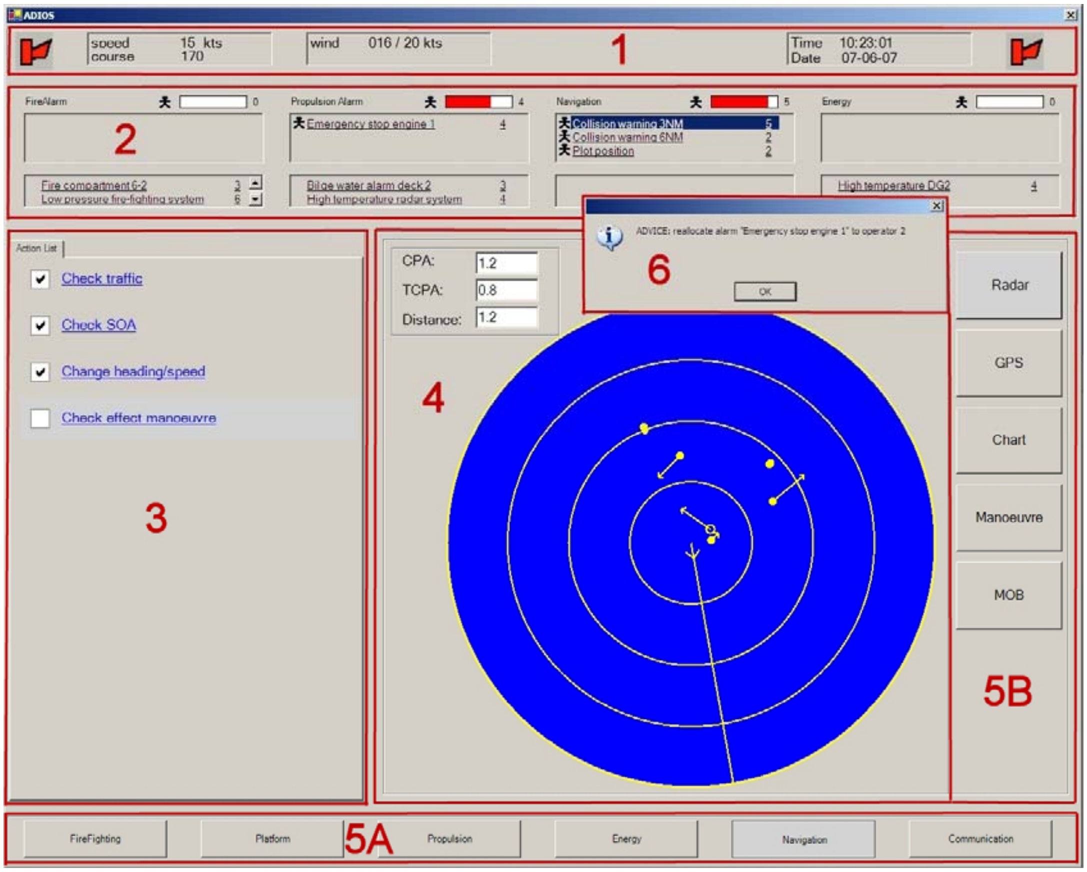
1. Introduction

Designing highly complex interactive human-machine systems in process control has been subject of many studies. Ongoing automation causes a radical change in the position of the operator from monitoring and control to supervision. Grootjen et al. (2006b) defined six main problem areas for naval ships: (1) Increasing complexity; (2) Changing of information type and volume; (3) Increasing system autonomy causing 'out of the loop' operator problems; (4) Task integration from different domains; (5) Decreasing personnel and training budgets; (6) Increasing legislative constraints.

Human-centered design methods are often proposed to establish for the human a central and distinct position from other aspects of the system (Stanton and Baber, 2006; Neerincx, 2003). In human-centered design of a new system, different configurations are tested and evaluated. This iterative process stops when the most efficient configuration, which fits on a generic set of constraints, is established and can be implemented. However, a different configuration could be more efficient for a specific situation or subset of constraints, although it would be less efficient generally. Even if we follow a "classical" human-centered design method, the six defined problem areas make it extremely difficult to develop static support concepts that cover all critical situations. Therefore, support systems in dynamic domains should be dynamic as the domain itself. For example Niwa and Hollnagel (2001) use dynamic mapping of alarm support to enhance operator performance in nuclear power plants. Another example is the alarm handling support system of Dutch navy ships, which has different levels of automation (Mulder, 2003).

At the moment, most implemented system in process control are developed with functional groups as described by Davidson and Nguyen (2003). During development of a new system, user groups are defined which each have authority over a certain set of functions. The operators have control only over functional groups they are properly trained for and certified to operate. A group can only be controlled by one workstation at a time, but there is the possibility to transfer the control to a different workstation (e.g. from Ship Control Centre to Bridge). To cope with problems arising from the 6 mentioned problem areas, we aim at the development of a more dynamic, adaptive system, in which tasks can be allocated and reallocated, and the level of automation can be altered when necessary. The necessity of adaptation will be based on a large variety of information (e.g. task load, operator state, context and system information). At the time of current work we were still specifying this information framework (Grootjen et al., 2006b; Grootjen et al., 2007). Parallel to this specification, current research should gain insight in user aspects of dynamic systems. We use a wizard of oz set up, where support is generated based on a fixed set of rules concerning alarm priorities. We will focus on the effects of task allocation support (TAS) under high and low task load (Neerincx, 2003) on performance and subjective mental effort (SME) and on the general usability of the dynamic interface.

This paper presents the design (Section 2) and evaluation (Section 3) of a dynamic interface for naval ships. Next to four support concepts evaluated in earlier research (Grootjen et al., 2002; Neerincx and Lindenberg, 2000; Grootjen et al., 2006a), this research adds a task reallocation feature for dynamic workload scheduling.



speed 15 kts
course 170
wind 016 / 20 kts
Time 10:23:01
Date 07-06-07

FireAlarm 0	Propulsion Alarm 4	Navigation 5	Energy 0
	Emergency stop engine 1 — 4	Collision warning 3NM — 5 Collision warning 6NM — 2 Plot position — 2	
Fire compartment 6-2 — 3 Low pressure fire-fighting system — 6	Bilge water alarm deck 2 — 3 High temperature radar system — 4		High temperature DG2 — 4

☑ Check traffic
☑ Check SOA
☑ Change heading/speed
☐ Check effect manoeuvre

CPA: 1.2
TCPA: 0.8
Distance: 1.2

ADVICE: reallocate alarm "Emergency stop engine 1" to operator 2

Figure 1: The interface with task allocation support, divided in six different area's (Grootjen et al., 2002; Neerincx and Lindenberg, 2000; Grootjen et al., 2006a).

FireAlarm 0	Propulsion Alarm 4	Navigation 5	Energy 0
	Emergency stop engine 1 — 4	Collision warning 3NM — 5 Collision warning 6NM — 2 Plot position — 2	

Figure 2: The interface without task allocation support.

2. Design of the user interface

This section presents the interface. Figure 1 shows the interface with TAS, an explanation will be given below according to the depicted numbers 1 to 6.

1. The *status area* is shown on the top part of the screen. In this area important 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, categorized into four groups. Each emergency is presented as a hyperlink that 'loads' the corresponding procedure in the procedure presentation area (area 3). Selection of an emergency is indicated by 'inverted' video (blue background in Figure 1). 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. With TAS, the alarm category has been split in two parts. In the top part the alarms of the operator are shown (i.e. the operator behind this display), the bottom part shows the alarms of the crew member. The operator can redirect the alarm, or an entire category, to another crew member by pressing the 🧍 icon.

3. The *procedure presentation area* provides web-browsing functionality and 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.

4. The *application presentation area* in the middle of the screen is used to present the active application.

5. The *common control area* contains buttons which can be used to switch from one application to another (5A and 5B). 6. *TAS-messages* are sent using pop-up boxes. In this case the message states: "ADVICE: reallocate alarm 'Emergency stop engine 1' to operator 2."

Figure 2 shows area 2 without TAS. Only the alarms of the operator working behind this display are shown. The operator is still able to redirect an alarm, but without the visual support of the alarms of the crew member. Accordingly, no extra advice is given. In this situation the operators have to determine the optimal strategy themselves, by communicating with each other.

3. Evaluation of the user interface

Method

Participants. For the experiment participants with a maritime background were needed. 34 students of the Royal Netherlands Navy College voluntarily participated, 33 males and 1 female between 20 and 28 years of age (mean= 22.3; SD = 1.7). All participants were 3 to 5 years in service and successfully ended their second year with a practical exam, which guaranteed a certain base level. Two couples with the highest performance scores were rewarded with a bonus. The participants were randomly assigned to a condition and couple. One couple was excluded because of system failure during the experiment.

Task. The participants' goal was to solve the problems together, as good and fast as possible. The scenario was designed following the cognitive task load method of Neerincx (2003), and consisted of platform supervision, damage control and navigation related problems. During the first part of the scenario a 'normal' watch was simulated. At the end of this part, hostile threats appeared, which resulted in a high task load second part of the scenario. Every couple had to deal with 2 fire alarms, a low pressure alarm of the fire-fighting system, an alarm concerning the cooling system of the ship, one bilge water alarm, a high temperature diesel engine alarm, a propulsion failure, man overboard alarm and 4 collision warnings. Besides these alarms, they had to plot the ship's position in an electronic sea chart 3 times. How to deal with these alarms was described in a predefined procedure (which is shown in Figure 1 area 3).

Procedure. Depending on the performance of the couples, the scenario took about 25 minutes. The total experiment took 2.5 hours. Before starting the scenario an instruction was given (60 minutes) and the participants used the system during a training scenario (20 minutes). Evaluation took 30 minutes. All sessions were recorded using the Observer XT of Noldus (Noldus, 2006). Figure 3 (in the back) shows a couple during the experiment. They were allowed to talk to each other, it was forbidden to look on each others screen.

Design & variables. The experiment has four conditions, each consisting 8 measurements, with the between subjects factor 'TAS' and the within factor 'task load' as independent variables. By manipulating task load, we are able to research the effects of TAS under different load conditions. The different levels of the independent variables are:

1. Without TAS, participants have to communicate verbally to adjust the task-allocation. The emergency presentation area shows only the alarms of the person operating the system (Figure 2).
2. With TAS. Participants can see each others alarms in the emergency presentation area and the system provides advice when to reallocate tasks.
3. Task load low. Simulation of a normal 'watch' scenario. Task load was manipulated using the task set switches variable of Neerincx (2003). In the task load low condition, switches between problems (i.e. task sets) were minimized.
4. Task load high. At the end of the low task load condition, hostile threats appear, which resulted in multiple problems at the same time. Task set switching in this part of the scenario was high.

The following dependent variables were measured:

1. Performance (total alarm time, alarm time and number of correct actions).
2. Subjective mental effort (Zijlstra, 1993)
3. User evaluation questionnaire (5 point scale) consisting of 19 questions.

Wizard of oz. The timing of alarms was identical for all conditions (i.e. everybody started with the same scenario). In the condition with TAS, advices were generated by the experimental leader using a wizard of oz protocol (Figure 3). Timing of those messages was dependent on the priorities of the active alarms. The operators together should work on the two alarms with the highest priority. For example, operator 1 is working on a priority 6 alarm, operator 2 on a priority 3 alarm. Next to his priority 6 alarm, operator 1 also has a priority 5 alarm, and, because this is higher than the one operator 2 has available, this alarm will be reallocated.

Figure 3: Experimental leader in wizard of oz setup. In the back a couple is performing the scenario.

Results

For performance and effort an independent samples t-test was used. Data from the questionnaire was analyzed using Mann-Whitney U. For performance and effort, only significant results ($p \leq 0.05$) and interesting trends ($0.05 < p < 0.1$) are presented.

Analyzing total alarm time (of the entire scenario) shows a trend, with TAS participants are 13% faster than without ($p=0.055$). With TAS and low task load, participants are 28%

faster than without TAS (p=0.028). The number of correct answers on the fire alarm of the low task load part of the scenario shows a trend (p=0.078), without TAS they score 13% better. The bilge water alarm shows a trend as well (p=0.069), with TAS they are 54% faster. Also for the time on the propulsion failure alarm in the high task load part, a trend was found: with TAS they are 27% faster than without TAS (p=0.086). The collision warning in the high task load part shows a trend (p=0.082). With TAS participants are 39 % faster. From the SME scale data, no significant effects were found.

A full overview of the data found on the user evaluation questionnaire can be found in Table 1.

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

Q	TA support		Sig.
	Without (M)	With (M)	p
1	1.56	1.28	0.311
2	4.00	4.44	0.179
3	4.38	4.50	0.693
4	1.06	1.06	0.933
5	1.19	1.22	0.806
6	1.13	1.39	0.147
7	4.25	4.50	0.375
8	4.69	4.83	0.508
9	1.50	1.61	0.846
10	2.50	1.67	0.019*
11	2.50	1.56	0.001*
12	4.28	4.13	0.773
13	3.89	4.13	0.352
14	1.61	2.13	0.048*
15	3.33	3.69	0.210
16	1.56	1.44	0.706
17	3.94	3.25	0.036*
18	4.00	4.00	1.000
19	4.11	3.75	0.310

1. The TA function was difficult to use.
2. The TA function was pleasant to use.
3. The TA function was useful.
4. I don’t know what to do with the alarms my colleague reallocates to me.
5. I get alarms of my colleague when I don’t want to.
6. It takes a lot of effort to reallocate alarms.
7. Because of the TAS we can work faster and better as a team.
8. When I’m busy it’s convenient that I can reallocate tasks.
9. Because I’m able to reallocate tasks, I lose total overview.
10. It was very hard to imagine what my colleague was doing.
11. I need a lot of communication to reveal what my colleague is doing.
12. This support system is easy to learn.
13. The lay-out of this support system is clear to me.
14. Sometimes I do not know the next thing to do when I’m solving problems.
15. It’s clear to me that the wishes of the end user have been taken into account in the design of this system.
16. This system is getting on my nerves.
17. The system always does as I expect it.
18. It’s easy to correct mistakes.
19. I feel I’m in control of the system.

4. Discussion and Conclusion

The increase in automation in process control emerged a strong need for dynamic support systems. This paper showed the design and evaluation of task allocation support for a dynamic interface. Two main conclusions can be made:

1. In general, participants were faster with task allocation support. No effects on subjective mental effort and the number of correct answers were found.
2. User evaluation shows very positive results on the support system in general and more specifically on the task allocation support. Findings are in line with earlier research (Grootjen et al., 2006a).

We expected no effects on performance with low task load, presuming the operators should be able to determine an optimal task allocation strategy themselves. However, we found a significant difference on the total alarm time, with TAS they are 28% faster. Analyzing alarms separately shows that with TAS participants are faster, but at the cost of the number of correct answers on the fire alarm. *Without* TAS they scored 13% better (p=0.078). From this we can see the importance of supporting in the right way, at the right time. In this case, the more important bilge water alarm was handled faster because of the right TAS. However we should investigate whether the negative side effects (i.e. a lower score on the fire alarm) can be reduced by improved support. Similar results were found by Bailey and Konstan (2001), who describe the effects of an application that initiated interruption on a user’s task performance, annoyance and anxiety. They suggest an attention manager which will manage user attention among applications that are competing for it. An attention manager would first observe or predict an opportunity for gaining user attention and then notify the next waiting application. Trafton et al. (2003) describe the benefits of ‘interruption lag’, a short period of time between the alert, indicating that there’s a secondary task, and the moment this task interrupts. Similar results were found by Nagata et al. (2005). This preparation time allows people to resume their primary task more quickly.

We expected a big effect of TAS at high task load, but we did not find effects on the total alarm time. Zooming in on alarms revealed two trends, one for the propulsion malfunction alarm (27% faster with TAS, p=0.086), and one for the collision warning (39% faster with TAS, p=0.082). An explanation could be that the possible benefits of TAS were simply to small. Depending on the couple’s performance, they got an advice once or twice in this part of the scenario. We expected such an advice would have a positive ‘chainreaction' on performance of other problems. However, possibly because time-pressure was too low, this wasn't the case.

From the questionnaire we can conclude participants find it more difficult to assess activities of their colleagues without TAS than with TAS. Accordingly they think they need more communication to achieve consensus.

It seems, according to the questionnaire, TAS causes a certain insecurity. Participants with TAS score higher on the question 'Sometimes I do not know the next thing to do when I'm solving problems'. Accordingly they score lower on the question 'The system does always act like I expect it'. From these results we can see the importance of supporting situational awareness in adaptive systems. Our next experiment will include a situational awareness display, shown in figure 4. As an example the scenario situation of Figure 1 has been used.

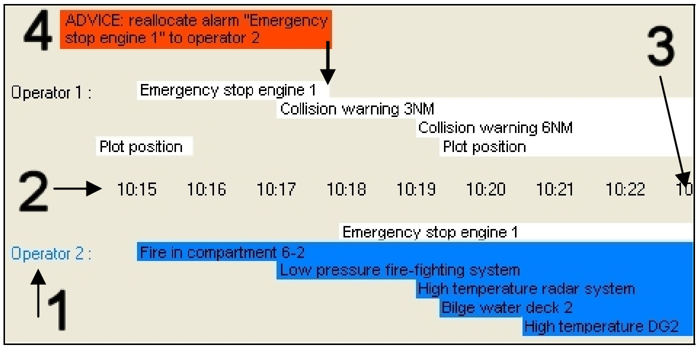


Figure 4: Situational awareness display using alarms of Figure 1 as an example.

All actors of the total human-machine system are presented on the vertical axis (1). The timeline is shown on the horizontal axis (2). The present is always shown on the right, so everything left from (3) is history. This screenshot was taken at 10:23, the same time as the screenshot of Figure 1. Using this window, the operators can get a quick overview of the distribution of all active tasks at present. Accordingly, they have a full history overview, including the time of appearance and ending, responsible actors and reallocations (e.g. (4), here by an advice). At the moment we are performing experiments on situational awareness with this display, in which we alter the level of automation. Next to the features of Figure 4, we added the system as actor (for fully automated tasks) and we depicted the level of automation on the timeline.

This prototype shows that TAS promises to be a powerful tool in keeping the operator's task load at an optimum. The next generation of Dutch navy ships will have a bridge with integrated platform control, which asks for such a dynamic support system. However, if we don't succeed to keep the operator at this optimum, and our 'additional' support is too late, it will only make things worse. Successful implementation of an adaptive human-machine system depends on the ability to adapt support *before* things go wrong.

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