Design and Evaluation of a Decision Support System for Naval Air-Track Controllers

Dr. Jörg Schweingruber
Dipl.-Biol. Mark Brütting
Research Establishment for Applied Science (FGAN)
'Ergonomics and Information Systems' Division
Neuenahrer Strasse 20
D-53343 Wachtberg
Germany
e-mail: {schweingruber | bruetting}@fgan.de

Abstract

The range of tasks of the German Navy has expanded within the last years. Missions in trouble-areas are going to play a major role and have to be carried out politically finely controllable and graduated at any time. This leads to a clearly higher workload and strain on the decision-makers. Therefore it is highly recommended to support these decision-makers with decision support systems adapted to tasks and situations. Especially the secure identification of aircrafts is a time-critical task with essential meaning for the actual development of the situation when operating in trouble-areas. For that reason a Graphical User Interface (GUI) was developed for the job of identification of aircrafts. Graphical elements for interaction were implemented in order to increase the operators situation awareness. A series of tests including the work on a realistic scenario were used for the evaluation of the decision support system, graphical user interface and operating procedures. The results were used to improve the user interface and the modified system is explained in detail.

1. Introduction

The range of operations of the German Navy has expanded within the last years. Missions in trouble-areas are going to play a major role and have to be carried out politically finely controllable and graduated at any time. Especially missions in coastal areas are, based on a high civil air-traffic density, very complex. This leads to significantly higher requirements in assessing and rating the situation for the command and control centers of the ships. Moreover the quickly changing situations require time-critical decisions and actions. This leads to a high workload and stress for the decision-makers and therewith possibly to wrong decisions with correspondingly serious consequences. Therefore the well adapted support of these decision-makers to the purpose of their relief and also to increase the security of planning, deciding and operating has a special meaning (Boller *et al.*, 1999). The basis for such supporting systems are user adapted operating systems and ergonomically optimized user interfaces for the required interactions at the corresponding workstations.

2. State of Concepts

Presently in the German Navy there is solely one class of ships in service, the frigate of the class F 123, that is equipped with consistently ergonomic realized user interfaces. An operating concept with procedures and user interfaces based on the technology available in the 80´s with a host system and specially programmed software was realized (Boller *et al.*

2000). The aim was to minimize the complexity of the operating procedures and user interfaces as well as to optimize the internal consistency. Therefore a stiff determined structure of windows was implemented on the screen surface. Features were invented to fit to the special working conditions on board of the ships which means in detail the organisational functioning background, the necessity of changing operators without time-loss at any time and any workstation, the possibility of reducing the staff by 40% and to maintain the protection of the ship even when losing parts of the subsystems. The operators functioning background is marked by a console work station with 5 different input and control devices, a communication control center with headset to 2 different communication channels as well as the feasibility to wear an extensive personal protection equipment. These special conditions have an authoritative influence on the possibilities for the ergonomic design of the work stations.

3. Design and Evaluation of the Decision Support System (DSS)

Under consideration of the introduced working conditions the goal was to develop a decision support system to help the operators in a task and situation adapted way with simultaneous reduction of the complexity as well as an optimization of the internal consistency of the operating procedures and screen surfaces. The implementation was exemplarily performed for a work station to the identification of air contacts. The linking of modern technologies was reduced on the look of the GUI because the hardware of these console work stations will not be changed within short and medium-terms. Therefore primarily graphical elements for interactions and to improve the operators situation awareness were implemented. A series of tests including the work on a realistic scenario were used for the evaluation of the decision support system, graphical user interface and operating procedures. The results were used for further optimizations.

3.1 Graphical User Interface (GUI)

The graphical user interface for identification of air contacts comprises the following three fields of functions:

- First identification of newly tracked contacts.
- ID changing of already identified contacts.
- Executing action sequences.

The basis for the support are task relevant events determined by the system and represented by the GUI. The perception of such events and proposed actions is supported by the representation of virtual Event-/Action buttons (VEAT) on the screen. These VEAT serve as a reference or warning for relevant events (e.g. interpreting a new contact) and/or as a request to carry out required actions (e.g. identification assignment) for certain contacts. VEAT are represented if identification relevant events of a contact are detected and/or operator actions are required or if contacts are not yet identified. After verifying the respective events and/or executing all required actions for a contact, the accompanying VEAT is deleted. The VEAT are represented if a special attention and/or activity of the operator is required. With this strategy an easy, uniform procedure was created that keeps the operator in the loop. If relevant changes are analyzed by the system, the operators attention is directed to the VEAT. The operator has to select this VEAT and then receives information for further processing. Task relevant events and the pertinent proposals that are indicated for required actions are listed in an Event-/Actionlist.

For proposed actions both the immediate status as well as past events of the respective contact are considered by the decision support system.
For realization of this concept, the graphical user interface as shown in Fig. 1 with 5 different areas was developed:

- User-/Statusline
- Air-track information
- Notebook
- Virtual Event-/Action buttons (VEAT)
- Tactical Display Area (TDA)

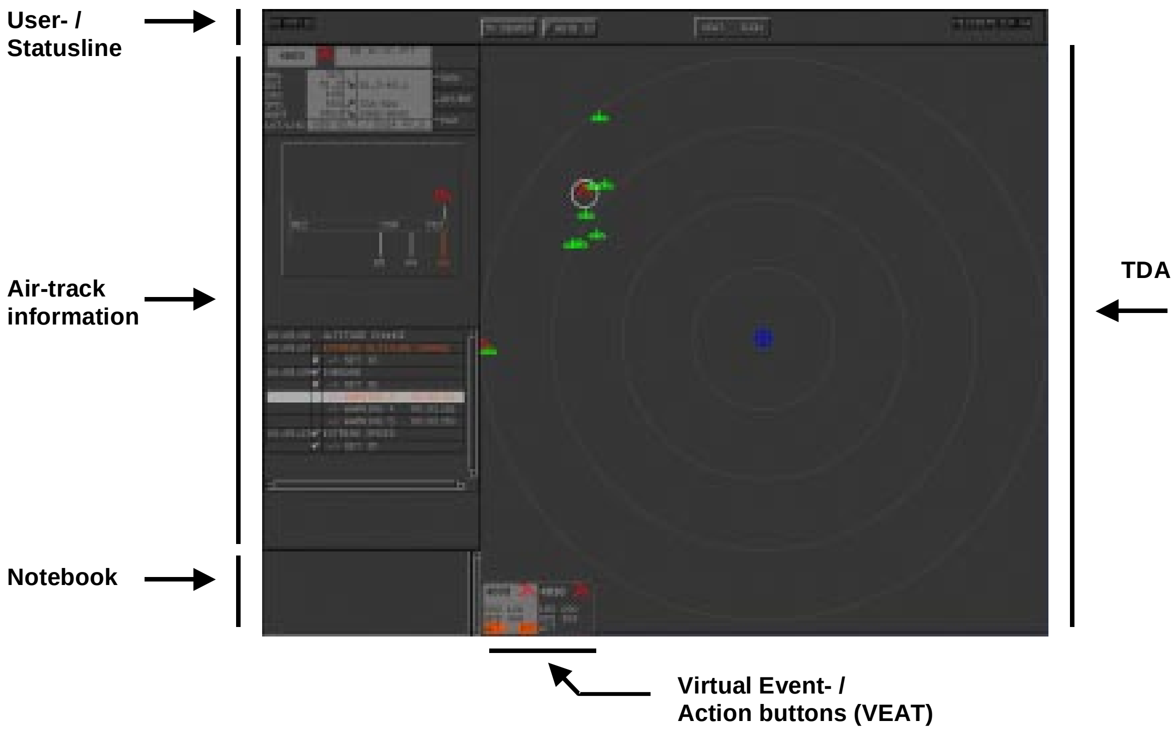


Fig. 1. Graphical User Interface

<u>User-/Statusline</u>

The User-/Statusline includes elements to adjust the work station to the task, the configuration of the representation as well as some task specific elements. The operations are performed by menus or virtual buttons. Information on the ship and selected attitudes for the representation on the screen are indicated by status readouts. These elements and readouts are rarely used and therefore positioned at the upper edge of the screen surface. By activating „Auto-ID“ the DSS assigns non-ambiguous tracks (based on IFF mode and track characteristics) an identity automatically (realized for ID „neutral“ only).

<u>Air-track information</u>

The window for air-track information is divided into three areas. The upper area (Fig. 2) permanently shows the most important information of the track in control, which are track number, identity (track symbol), category and further information on the contact. The shown information belongs to the track selected on the Tactical Display Area (TDA). If the track in control is not visible on the TDA´s range, the text „out of range“ as well as the track number and the distance to the ship are represented in yellow colour. The yellow colour of distance values indicates the operator to change the representation area of the TDA.
Below the tracks kinematic attributes (Bearing, Distance, Course, Speed, Height, Position) are indicated. These are represented with common abbreviations and units.

In the first column, the current values are indicated. If there is no actual data, the values are represented in grey instead of black colour. The second column shows the tendency of the values qualitatively as an arrow. In the third column, the minimal and maximal attribute values during the total tracking time are represented.

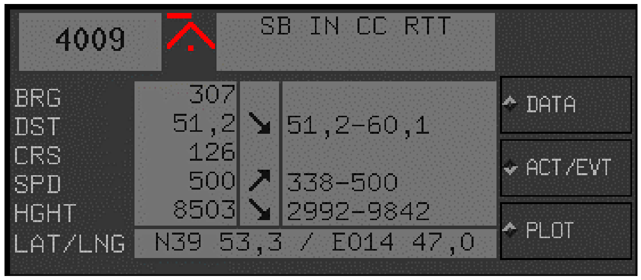
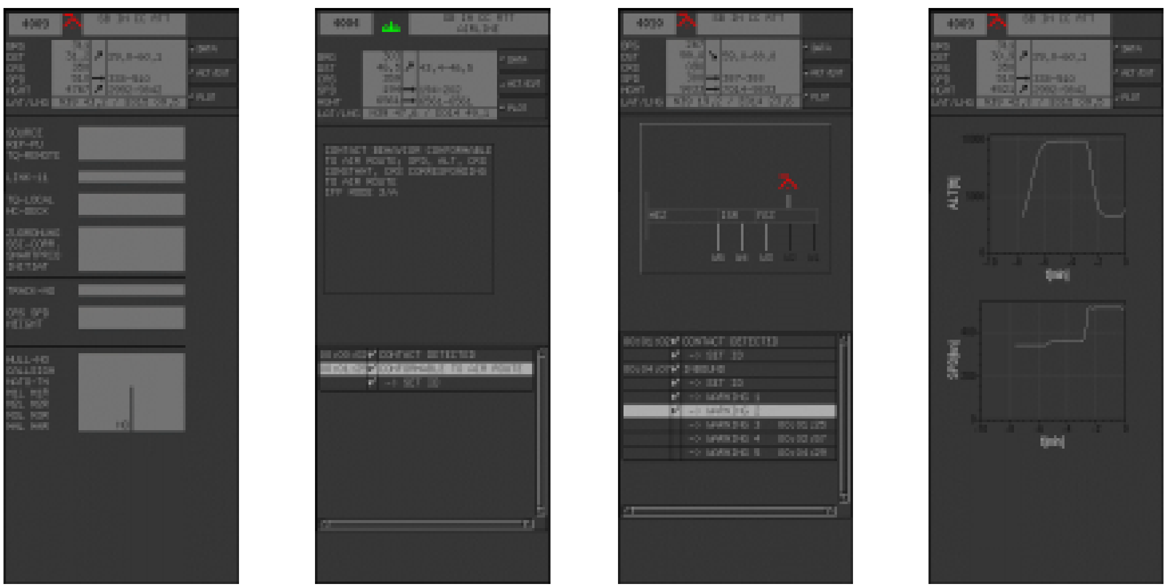


Fig. 2. Air-track information

In the middle area of the air-track information window, additional task specific information on the contact are represented. For the task of identifying air-tracks from four different information representations can be chosen (Fig. 3).



„DATA“ „EVT/ACT“ „EVT/ACT (Warnings)“ „PLOT“

Fig. 3. Different information representations

Numerical, graphical and written information on actual and historical data can be shown. Proposed time-critical actions are calculated and graphically displayed to increase the operators situation awareness. In the lower area of the air-track information window, task relevant events are listed in temporal sequence (Fig. 4). If the system proposes actions, these are marked with an arrow (->) beneath the accompanying event. Actions are concluded by actual events, actual status and past events. If an action has to be performed within a defined time span (10 sec.) or an important event appeared, the text is represented in orange colour. Corresponding to their speed and distance to the ship outgoing warnings to suspicious inbound tracks are calculated and suggested. The Event-/Actionlist has to be processed by the operator from down upward, i.e. the most current actions are to be proceeded first. This might appear as contradictious, there texts are usually read from above downward. This type of representation shall make the user, who possibly skims over the text, conscious to earlier events of this contact, before the lowest and most current line of the Event/Actionlist is processed. In this manner a more complete picture of the air contact and its characteristics can be arranged for the operator.

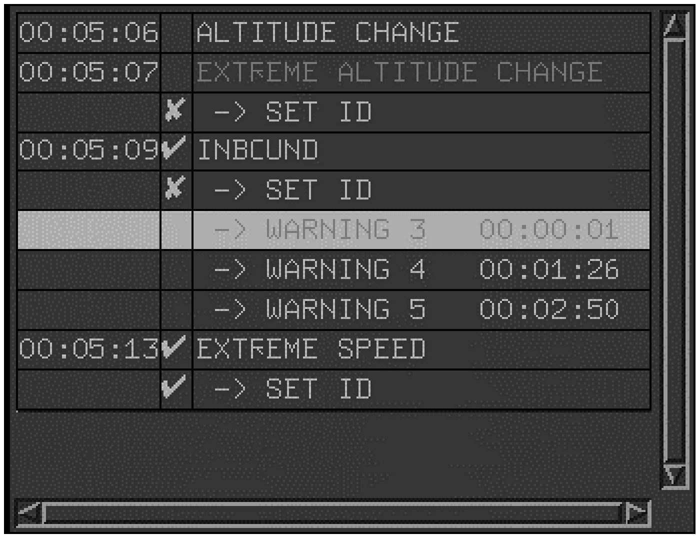


Fig. 4. Event-/Actionlist

The Event-/Actionlist consists of:

- point of time, when the event was determined by the support system
- event-/action status with following icons:

  - ▫ event not acknowledged/action not yet executed
  - ✓ event acknowledged/action executed
  - × event/action deleted
  - • action executed automatically by the DSS (Auto ID-mode)

(with planned actions additionally the remaining time up to the execution is noted. If the remaining time is even/less 10 sec. or if it is an „important event", the text is in orange colour). The operator may either take over the systems proposal for the identification of the tracks or due to further information assign another identity (Fig. 5).

Fig.5. ID-assignment

Notebook

The Notebook window is arranged beneath the contact information window. By doubleclicking the window, the height of the Notebook window will be enlarged. It includes an editor to fill it with any alphanumeric text.

Virtual Event-/Action buttons (VEAT)

The virtual Event-/Action buttons are arranged at the lower edge of the TDA by default. If important information on the TDA are covered by them, or the operator prefers the representation of the VEAT in vertical sequence, they optionally can be represented at the left, right or upper edge as well. Therefore the operator chooses from the menu „VEAT" in the upper User-/Statusline. Up to ten VEAT can be displayed simultaneously, the representations are sorted by priority. The one with the highest priority is displayed at most left or upper position. After complete processing of a VEAT, it will be deleted and the next high priority VEAT takes its place. In tangled situations, the procedure can be eased for the operator in the way that he works on the VEAT in the sequence of its representations one after the other. The VEAT include the contact number and symbol and additionally two attribute values (Fig. 6). The representation of the attributes is variable and can be changed by the operator in the menu in the User-/Statusline. The attribute couples CRS/SPD and BRG/DST are realized. In the lower line on required actions (ACT) and events (EVT) is referred. If an action has to be carried out within a defined time span and/or an important event appeared, the text ACT and/or EVT is represented in orange colour. If a VEAT is activated, the corresponding contact symbol is selected on the TDA (Icon with circle) and the contact information window shows the Event-/Actionlist of this track. If the VEAT´s accompanying contact lies outside of the representation area of the TDA the contact number in the VEAT is coloured yellow.

Fig. 6. VEAT

TDA

The layout of the TDA was restricted to the most necessary items. It includes the two-dimensional arrangement of the single contacts in relation to the ship and distance rings. The representation of the contact numbers can be turned on/off by the menu "ICON" in the User-/Statusline.

1.2 Scenario

In order to illustrate the GUI and to rate the experimental investigations a scenario was generated using the software tool STAGE™ (Scenario Toolkit And Generation Environment) by Virtual Prototypes Inc. In the developed scenario, a single ship is located for the purpose of identification of air contacts in an area next to an airway used by civil air vehicles and close to the coast.

The scenario is constructed in a modular way and consists of following two parts:

- supervision of airway
- attack on ship

For the experimental investigations to evaluate the graphical user interface and the decision support system, the above mentioned two parts were summarized to a scenario of about 15 minutes length to get a demanding task for the operators (Fig. 7).

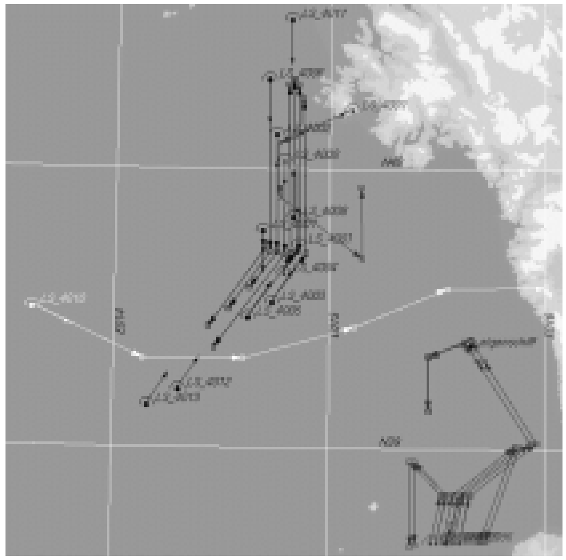


Fig. 7. Scenario

The scenario "airway supervision" represents the situation of a number of air tracks in the supervision zone of the ship. Here the operator is required to identify civil and/or neutral air-tracks and to distinguish from possibly critical air-tracks. A high frequency of aircrafts in the airway means a high demand on the operator identifying these aircrafts. The scenario "attack on ship" represents the attack of several tactical aircrafts on the ship. Approaching in low altitude from the south, they are only partially detected by the radar. The operators have to react on the missiles launched by the tactical aircrafts from a short distance rapidly.

1.3 Evaluation

The work on the described scenario by operators was used for a rating of the GUI, DSS and mental workload. The probands were recruited from German Navy personnel with more or less experience in identifying air-tracks.

<u>Experimental tests</u>

First of all the 27 participants took part in a half an hour introduction to the system with its details and operating procedures. Just before the test executed with single operators, all users had the opportunity to get used to the GUI by working on an example scenario. In order to estimate the intelligibility and to get an impression of the self-explanatory of the system, for the benefit of a larger number of probands and a longer period of training was deliberately renounced. Therefore the results are to be understood at the background of a training time of less than 60 minutes, which allows an interpretation of how fast the users got accustomed to the support system.
The rating was divided into two parts:

- subjective rating
- objective rating

The subjective rating was realised in form of answering a question catalogue and a rating-

scale to investigate the workload.
The criteria of estimation in the related "Two-Level-Intensity-Scale" (ZEIS) is the task difficulty experienced in working on the scenario, which is known as an essential dimension of workload (Pitrella & Käppler, 1988). Besides to the task difficulty the difficulty of learning the user interface as well as operating with the system in general was to be rated.
On the first level of ZEIS between easy, mean and hard is differentiated, while the second level consists of a more differentiated scale. The objective estimation resulted in recording the users inputs during the scenario and subsequent analysis, as well as by observating the probands while they were working on the scenario.

<u>Testresults</u>
In the following, the results of the subjective estimation with the ZEIS-rating scale are represented. Figure 8 shows the first level rating for experienced workload, difficulty of learning and difficulty of working with the DSS.

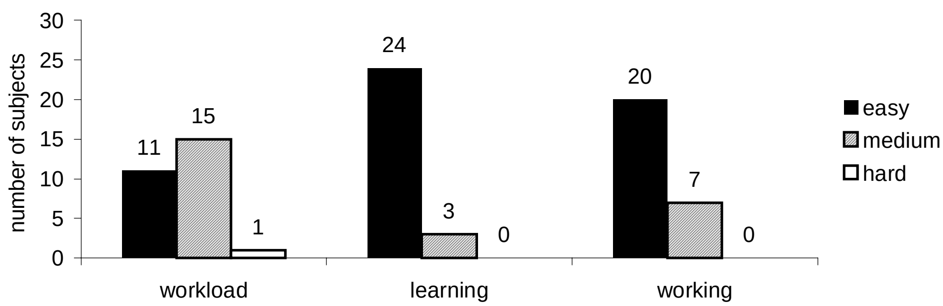


Fig. 8. ZEIS-first-level-rating

Concerning the second-level-rating 66% of the probands rated the mental workload in working on the scenario as relatively easy, 33% of them considered it to be rather more hard (Figure 9).

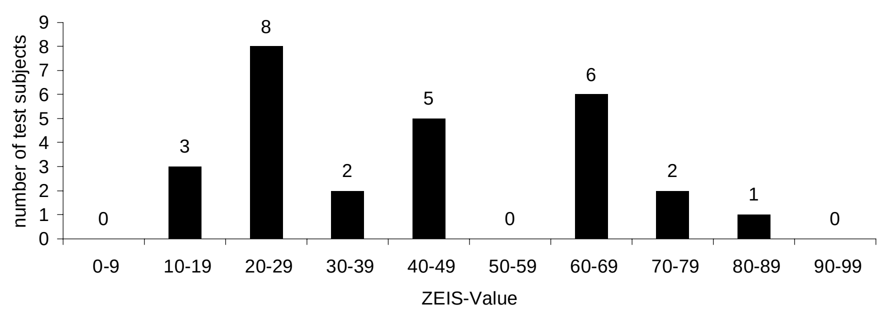


Fig. 9. ZEIS-rating mental workload

The test subjects can be divided into two groups, concerning their subjectively felt workload during the handling of the scenario, whereas the learning and operating with the graphical user interface and DSS was judged quite uniformly as easy.
Learning the GUI was maximally rated as "neither easy nor hard" (ZEIS-value=50) (Figure 10). The rating of the usability of the GUI was quite similar. With exception of four test subjects, whose ratings were still in the middle area, this difficulty was judged as easy, too (Figure 11). Two of those four test subjects gained relatively few experience in identifying air-tracks so far.

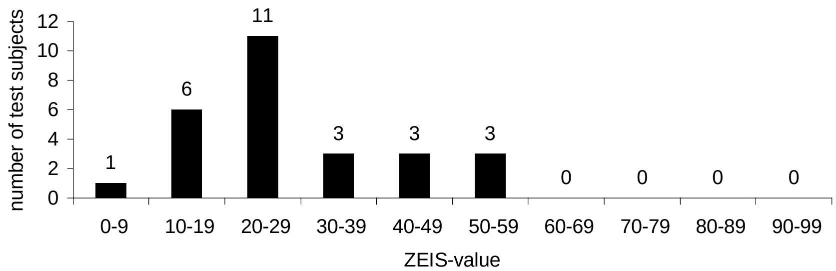


Fig. 10. ZEIS-rating of learning the DSS

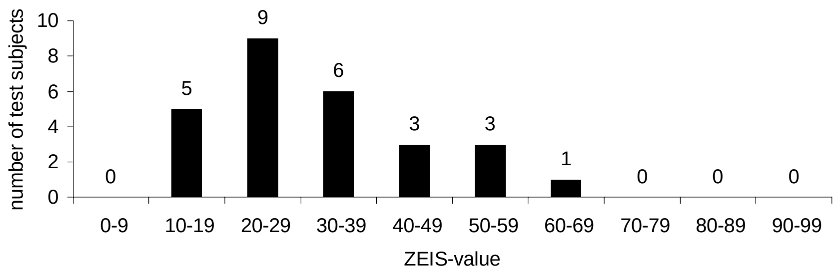


Fig. 11. ZEIS-rating of usability of the DSS

The answers to the questionnaires combined with the following results of the objective rating were used for optimization realized in the modified version of the GUI. For the objective evaluation of the work performed by the participants, all user inputs were recorded as logfiles. For the following analysis of the data as a measure for the test subjects performance, the time between the optical representation of a VEAT, up to the complete handling of the appropriate air contact, was calculated. For each proband there was a mean preparation time calculated, based on 24 exemplarily selected actions (Figure 12). The preparation times of 21 valid trial runs (6 runs were not usable) are only partly admissible to draw conclusions on the reaction time of the probands and the real preparation time of single contacts, because the perception

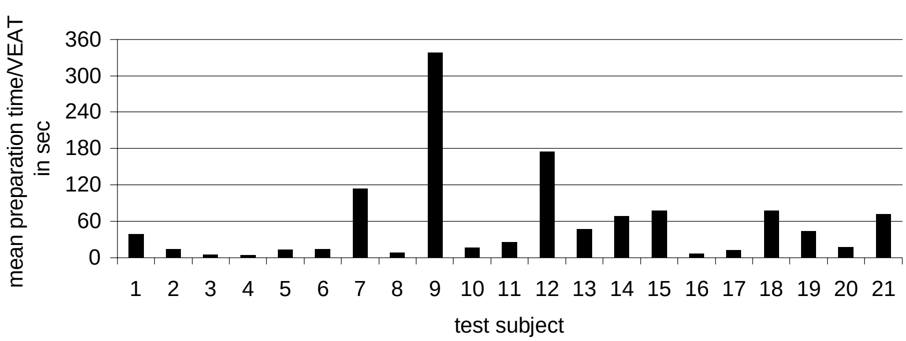


Fig. 12. Mean preparation time per VEAT of 21 test subjects

of a newly represented VEAT did not lead automatically to its immediate preparation, what the operators statements showed as well. Some of the operators did not agree to the priorities that were given by the sequence of the VEAT. They worked this in an own selected sequence, what as well as forgetting to verify an observed event, led to partially unusual long preparation times for single air contacts.

Another reason for long preparation times seemed to be the look of the Event-/Actionlist. Originally it was planned to indicate the line „Set ID“ to each event that could lead to a

change of the identity. This method was chosen in order to keep the operator informed about changing attributes of a contact and to change the tracks identity if necessary. If several relevant maneuvers were detected in a short time period, it was not immediately obviously, which line had to be worked out first in order to react to the most actual events. For this reason it occurred that for repeated requests "Set ID" only the first (the first one in the list, but temporarily the oldest one) one was worked out and then the operator took a new contact in control or went to the next VEAT. This could lead to following consequences: An air-track got an identity that was no longer actual because of newer events, which were not observated by the operator. On the second hand the VEAT were not deleted if there were any unverified events. That means this VEAT had to be worked on again which logically caused a time loss.
The required and realised consistency of the operating procedures in this screen surface was not judged in a positive way by all of the participants, but partially led to frustration. Several times the mostly quickly recognized routine (VEAT appears, verify/carry out events/actions, identifying air-track, VEAT deleted) was described as monotonous and troublesome. Probably this was a result of the multiple requests „Set ID“, which could be confusing and did not correspond to the demand for unambiguous representation of information.
The relationship between self-assessment of the test subjects (ZEIS-value of mental workload during working on scenario) and the registered time duration of representation of a VEAT up to its deletion, was calculated by Spearman´s rank-correlation coefficient (Bortz, 1993).
The correlation coefficient for the variables "preparation time/VEAT" and "ZEIS-value of mental workload" was significant ($r = 0{,}73$; $\alpha = 0{,}01$). Following conclusions are drawn:
The used rating-scale seems to be a suitable method to ascertain the subjectively perceived stress during the work on the scenario (assuming that culmination of VEATs cause temporal pressure which takes effect on experienced workload). The usefulness of the scale was documented repeatedly for measurement of mental workload (Käppler & Godthelp, 1989; Pitrella, 1989; Pfendler, 1993; Schweingruber & Grandt, 1999). The GUI gives an impression of the urgency of the work to be carried out and the pressure of the temporal load to the operator. The operator is informed about the effectiveness of his proceeding and a visual feedback of the action in progress is given. Further it was reviewed, whether the test subjects previous experience in identifying air-tracks had an influence on the preparation time. The correlation coefficient for the variable "experiences in years" and "preparation duration/VEAT" had a non significant value of $r = 0{,}16$ ($\alpha = 0{,}01$). It can be maintained that long-time experience with other systems for identifying air-tracks are not advantageous for the interaction with this system, nor that untrained users have to suffer from a lack of experience. The work with the GUI seems to be similarly easy/hard to all of the participants, independent of their previous knowlegde and experiences. On the one hand this is contradictious to the demand that a GUI has to be adaptable to the users experience, on the other hand the results show that even untrained operators were able to obtain good results even after a short introduction to the system.

1.4 Optimization

The results of the observations of the test subjects during the experiment as well as the analysis of the users inputs during the work on the scenario led to a review of some details of the GUI. The following variations were performed:
Originally the VEAT included the representation of the track number, track symbol and the abbreviations ACT/EVT in addition to the actual track attributes CRS/SPD or selectively BRG/DST. This was contradictious to the requirement not to represent information repeatedly and participants did not show much attention on this values, so therefore they were deleted.
Now the operator is compelled to get the relevant information in the track information

window, where all contact attributes are itemized. In that way, the risk of incomplete information to a contact is diminished and the function of the VEAT as a general reference to actions and events is maintained.
Further the track number and the track symbol were placed amongst each other for easier perception and the abbreviations ACT and EVT were represented at a more central position in order to reduce mix-ups with adjoining VEAT (Fig. 13).

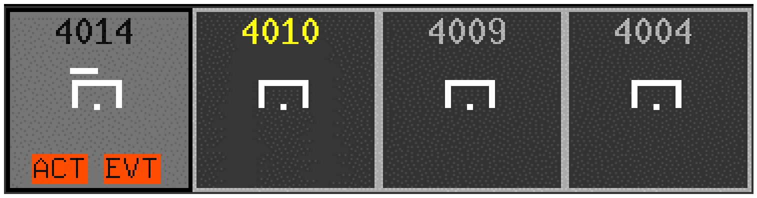


Fig. 13. Optimized VEAT

Based on doctrines, the priorities for sorting the VEAT will be newly implemented. Therefore an optionale selection for different configurations according to the tactical situation in a Pop-Up-Menue is imaginable. The Event-/Actionlist was modified in a way, that even after several events the request "Set ID" is represented only once at the lower end of the list. The confirmation of all events is considered as so important that this procedure has been retained unchanged (Fig. 14). Further a „Hooking Algorythm“ was implemented (Fig. 15) in order to facilitate the selection of Tracks on the TDA and to minimize Trackball movements (Track in control indicated by solid ring, hooked track indicated by dashed ring). Several other modifications were done, which are not explained in detail here.

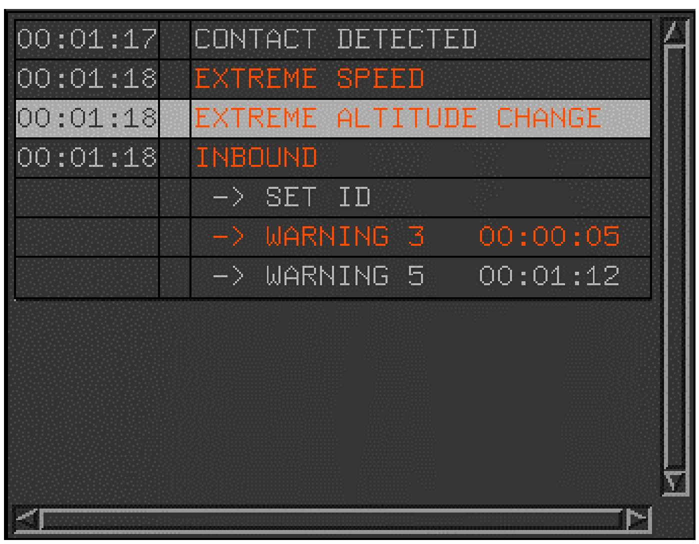


Fig. 14. Optimized Event-/Actionlist

2. Conclusions

The special restrictions based on the conditions on board of the ships nevertheless offer possibilities to optimize the interaction between operator and the system.
This was realized by inventing graphical elements for interaction (VEAT), increasing the operators situation awareness by obvious representations of the situation (air-track information window), as well as by optimizing the operating procedures (identification).
The complexity of the operating procedures and user interfaces was reduced by the development of a GUI for a selected work station and by optimizing the internal consistency of operating procedures and screen surfaces. In order to fulfil the systematical procedure in developing this GUI, repeated experimental investigations with the modified version under

identical conditions (same scenario, same training, test subjects with similar experience) are planned. Finally, the GUI in it´s modified version (Figure 15) is represented.

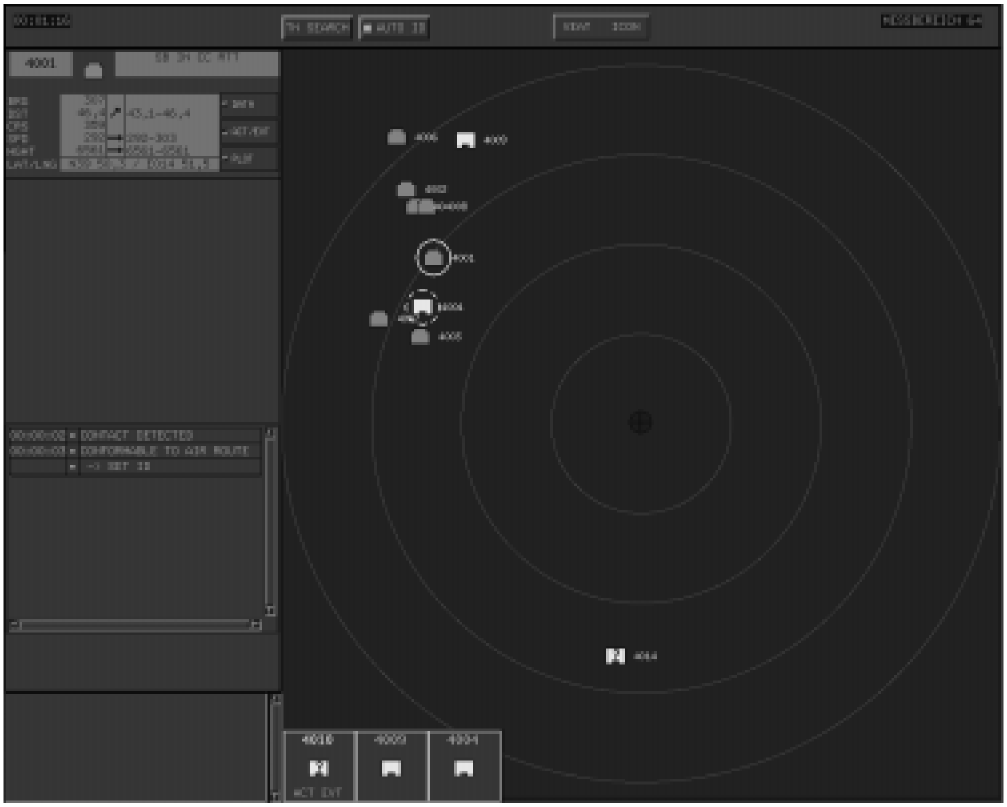


Fig. 15. Modified version of the GUI

References

Boller, H.E., *et al.*, (1999): *Unterstützungskonzept für Identification/Recognition in Anti-Air Warfare der Marine*. Abschlussbericht. Forschungsgesellschaft für Angewandte Naturwissenschaften e.V. (FGAN). FKIE. EFS. Wachtberg.

Boller, H.E., *et al.*, (2000): *Bewertung der Nutzbarkeit der US-Studie/ des US-Simulationsprogramms NAIMES für die Deutsche Marine*. Abschlussbericht. Forschungsgesellschaft für Angewandte Naturwissenschaften e.V. (FGAN). FKIE. EFS. Wachtberg.

Bortz, J. (1993): *Statistik für Sozialwissenschaftler*. 4. Auflage. Springer.

Käppler, W.-D., Godthelp, H. (1989): *Design and Use of the Two-Level Sequential Judgment Rating Scale in the Identification of Vehicle Handling Criteria: I. Instrumented Car Experiments on Straight Lane Driving*. Forschungsinstitut für Anthropotechnik. FAT-Bericht Nr. 79. Wachtberg.

Pfendler, C. (1993): *Vergleich der Zwei-Ebenen Intensitäts-Skala und des NASA Task Load Index bei der Beanspruchungsbewertung während Lernvorgängen*. Z.Arb.wiss. 47 (19NF).1993/1. 26-33.

Pitrella, F.D., Käppler, W.-D. (1988): *Identification and Evaluation of Scale Design Principles in the Development of the Sequential Judgment, Extended Range Scale*. Forschungsinstitut für Anthropotechnik. FAT-Bericht Nr. 80. Wachtberg.

Pitrella, F.D. (1989): *A Cognitive Model of the Internal Rating Process*. Forschungsinstitut für Anthropotechnik. FAT-Bericht Nr. 82. Wachtberg.

Schweingruber, J., Grandt, M. (1999): *Ergonomische Systembewertung am Beispiel WS-TORNADO*. Forschungsgesellschaft für Angewandte Naturwissenschaften e.V. (FGAN). FKIE. EFS. Wachtberg.