A Knowledge-Based Human-Machine Interface for Future Naval Combat Direction Systems

Morten Grandt, Helmut Distelmaier & Claudius Pfendler
FGAN – Research Institute for Communication, Information Processing, and Ergonomics
Ergonomics and Information Systems Department
Neuenahrer Str. 20, D-53343 Wachtberg
GERMANY

{grandt; distelmaier; pfendler}@fgan.de

ABSTRACT

Future command and control systems for naval ships must particularly meet the specific requirements emerged from the shift from blue-water scenarios of the past towards multinational peacekeeping missions, joined and combined operations and littoral warfare. Rapidly changing situations found especially in the Anti-Air warfare require decisions to be made in high dynamic and complex, i.e. mixed, environments. Since a support of operators by human personnel is out of discussion for financial reasons and is associated with questionable prospects of success, an essential basis for operator performance and situation awareness is an ergonomically optimized and operator-adaptive human-machine interface that facilitates all aspects of human handling. Supporting the cognitive phase of decision-making by means of computer-based assistance in the form of decision-support systems is another important aspect of future combat direction systems. This paper introduces a concept for an enhanced knowledge-based, human-machine interface for future combat direction systems of naval ships, including the underlying models, techniques, and presumptions. The concept has been realized to some extend so that examples for the transformation from theory to practice can be given.

1 REQUIREMENTS AND APPROACH

Future command and control systems for naval ships must particularly meet the specific requirements emerged from the shift from blue-water scenarios of the past towards multinational peacekeeping missions, joined and combined operations, and littoral warfare. To cope with these new scenarios advanced Command Control Information Systems (CCIS) have been realized. These new CCIS show a tremendous increase of information available to the operator. However, human resources for information processing, i.e. attention resources and memory capacity, are limited. Therefore, it is to fear that technical improvements could lead to information overflow and to high mental workload. Both aspects may result in degraded situation awareness and false decisions with disastrous consequences. This applies especially to Anti-Air Warfare (AAW), where dynamic and complex situations require fast and definite decisions, and prompt actions.

For these reasons a concept has been developed aiming at the support of all stages of information processing, i.e. information collection, situation evaluation, and measure execution, in order to enable the human operator to cope with a huge amount of information and to achieve high situation awareness. Ideas, to ease information perception and human-machine interaction on the one hand and to facilitate decision-making and action planning by computer-based inference techniques on the other, have been integrated into a concept for an adaptive knowledge-based support system (Figure 1).

Grandt, M.; Distelmaier, H.; Pfendler, C. (2005) A Knowledge-Based Human-Machine Interface for Future Naval Combat Direction Systems. In *Visualisation and the Common Operational Picture* (pp. 21-1 – 21-14). Meeting Proceedings RTO-MP-IST-043, Paper 21. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

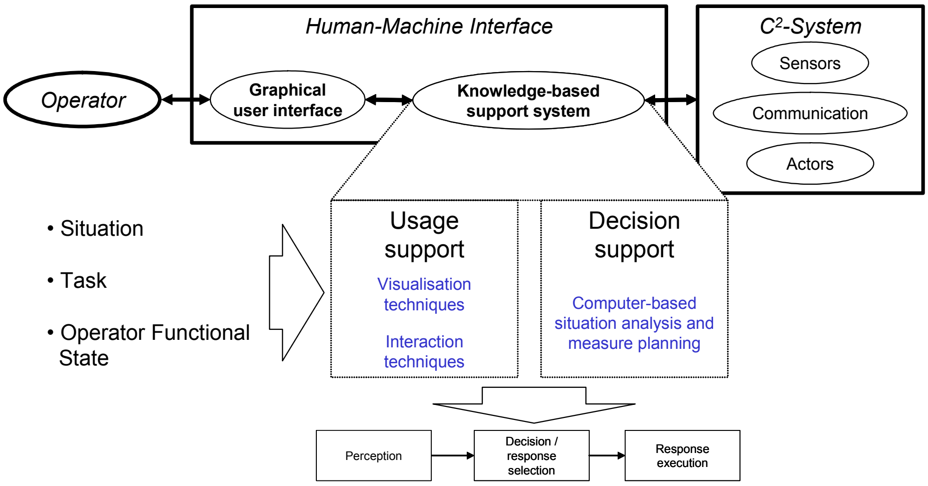

Figure 1: Issues Addressed by the Knowledge Based Support System.

Techniques for usage-support, embedded in the human-machine interface, shall enable an intuitive human-system interaction, i.e. understanding of information and manipulation of system behaviour in an easy and natural manner, so that the stages perception and response execution are supported. In addition Wickens' multiple resource theory states that information processing is supported by multiple resources depending upon the coding of information (verbal vs. spatial) and – for the encoding stage – by the modality (visual vs. auditory) used for perception [11][12]. Therefore the aim of human-machine interface design should be to obtain an equal utilisation of resources in information processing.

Decision-support tools should deliver proposals for situation evaluation, which is the basis for decision-making and action planning, taking into account the state of the own system and the environmental condition. In other words, these techniques synthesise situation awareness by means of inference techniques. It is obvious that the results of decision-support systems have to be visualised to the operator in an intuitive manner. So this techniques need to be linked to the usage-support closely.

The following general requirements are applicable for a user support system:

- The system's behaviour must adapt to the situation, to the currently performed task and to the operator functional state. Situational adaptation means that both the current external situation in the environment and the current internal situation, i.e. the state of the own ship and its subsystems, must be taken into account. Adaptation to the task refers to the demand, to support the operator at the currently performed task or to give advice if other tasks with higher priority have to be done. In order to offer as much support as necessary it might be useful to adapt the support extent to the current demands of the operator that may be derived from the operator functional, i.e. cognitive, state.
- The system's ability to adapt to all these aspects demands knowledge, represented by models about the situation, the task and the human operator. Therefore, this adaptive system is called knowledge-based. This term does not directly correspond to the knowledge-based behaviour mentioned later in connection with Rasmussen's model of human decision-making [8].
- In contrast to automated systems, the support system should only offer proposals and advises to ensure that the operator remains "in the loop", i.e. the operator keeps an adequate situational awareness and the exclusive power of decision.

1.1 Approaches for Improved Human-System Interaction

To obtain an adequate performance in AAW a huge amount of information from own sensors and by data links related to a high number of observed tracks have to be visualised in a way that enables the operator to evaluate the situation and make decisions within the short reaction time available. Apart from position data which are visualised by means of the tactical situation display, in today's CCIS most information is visualized usually in textual and alphanumerical form. Before the operator is able to evaluate the situation, variables like speed, altitude, acceleration, turn radius, IFF-mode etc., have to be integrated mentally in order to build up a representation of the track.

For HMI-design especially new approaches for the visualisation of complex dynamic information are pursued. The visualisation of such data aims at "the use of computer-supported, interactive, visual representations of abstract data to amplify cognition" [1], with respect to the following aspects:

- Resources are relieved so that capacity becomes available for other information-processing tasks,
- Recognition of – otherwise covered – patterns of track behaviour and tendencies becomes easier,
- Information seeking is made easier,
- Drawing conclusions becomes possible by utilisation of visual attention at supervisory tasks and by decoding of information within a manipulatable medium.

The Proximity Compatibility Principle (PCP) [13] makes use of the Gestalt laws which organize the perceptional field and aims at the reduction of cognitive demands for information processing by making displays compatible to the task and the mental model of the operator. Human experts are usually very skilled in pattern recognition. Especially in critical situations in which knowledge-based behaviour is necessary appropriate visualisation techniques make use of this ability leading to fast and suitable decisions without prolonged cognitive processes.

The principle of ecological interface design (EID) aims at the reduction of the cognitive level which is needed to evaluate a situation visualised [10]. Visualisation on a higher level of abstraction makes it easier for the operator to understand the system especially in unforeseen critical events. Additionally it is useful to reduce the level of cognitive demands for the interpretation by visualising information at the level of signals and signs – according to [8] –, which initiate actions directly or trigger the interpretation of rules. EID also stresses the importance of taking into account knowledge concerning the environmental conditions in which the operator performs the task, i.e. the constraints and rules the system underlies.

Both design approaches are not mutually exclusive. In fact, it is necessary that perceptual demands are lowered and displays are designed flexibly so that they enable the operator to cope with critical situations not considered in the system design.

A good example for a display, designed in accordance with these principles is the nuclear power plant safety parameter display (Figure 2) [14] (cited in [12]). By means of such polar displays, it is possible to integrate hundreds of parameters within one multidimensional display. The resulting patterns are either symmetric indicating normal operation or asymmetric indicating system errors. The resulting pattern of a deviation from symmetry enables the operator to diagnose the cause of the fault. This way, the display makes use of the special abilities for pattern recognition.

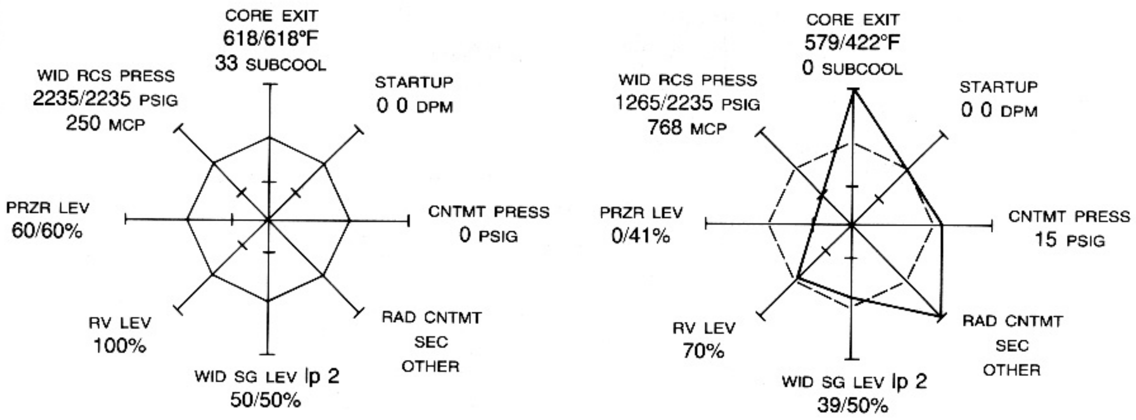

Figure 2: Nuclear Power Plant Safety Parameter Display; left part shows normal operation, the right one by asymmetry indicates a system error ([14], quoted in [12]).

For identification/recognition of tracked objects in AAW there are information on the air track from different sensor systems like radar, ESM etc. which have to be integrated by the human operator. These are e.g.

- IFF mode: behaviour on IFF interrogations
- Kinematics: velocity, acceleration, altitude, climb rate, turn rate, etc.
- Manoeuvres: performs holding pattern, sudden turn away, splitting target, manoeuvres indicating a missile track, other suspicious manoeuvres
- Routing: course of the air track from/within/towards friendly or hostile origin, restriction zones, identification safety range (ISR), in accordance with civil or military corridors, etc.
- Emitters: type of emitter, lock-on indication

Figure 3 shows a draft of a polar diagram in the area of AAW. The design of this type of display primarily depends upon the relevance of information with respect to decision-making. It is obvious that some of the track attributes mentioned above overrule the other ones, e.g., if the track performs a lock-on it must be a hostile military track even if the track's kinematics do not indicate the track to be military. Other single attributes do not force the operator to make a certain decision, e.g., a "no-reply" attribute following an IFF-interrogation is not enough information to evaluate the track to be hostile.

Another approach to improve human-system interaction refers to the utilisation of alternative control techniques, e.g. speech input and voice output. The intention is to distribute information processing on different resources and enable operators to interact with the system in a natural way aside from complex, ill-structured menus. In order to examine the benefits of advanced input technologies a conventional computer mouse, two different trackballs as well as touch and speech input were compared in respect to response time, correctness, and subjective workload in a simplified AAW task. Furthermore, popup menus and conventional buttons at the screen's upper edge were compared [5]. The results demonstrate that in general touch input and mouse show the fastest response times, where speech input and the trackballs constitute the other extreme. Popup menus were inferior to the buttons in response times. Workload was mostly consistent with these results, except for speech input, which showed high response times but low workload ratings.

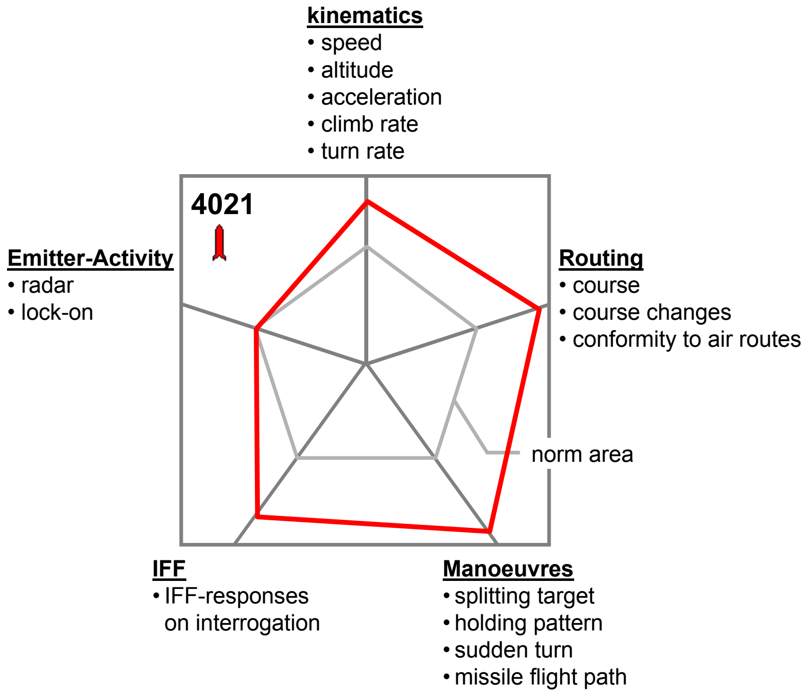

Figure 3: Draft of a Polar Display for Visualisation of Air Track Attributes.

1.2 Knowledge-Based Decision-Support

The main goal of decision support techniques is to draw conclusions from the available data taking into account all accumulated knowledge from the past, i.e. to build up artificial situation awareness, and to offer proposals regarding situation evaluation and action planning to the operator. To get reasoning, otherwise performed by human decision makers, from an automatic system, technically sophisticated inference techniques are needed.

Many currently realised computerised support systems try to describe all anticipated situations fully by means of rules. Such rules act upon Boolean logic and deduce or exclude solutions assuredly. There is no uncertainty in the result. However in the military sphere frequently situations occur which do not fit to rule-based situation evaluation for one or more of the following reasons:

- Situations are ambiguous and cannot be described on the basis of univocal rules. These kinds of situations can only be described and solved by calling in previously acquired knowledge.
- Situations have not been expected and considered within the system development process and are not accounted for in the system concept therefore.
- Due to physical and tactical restrictions of sensors, a complete and up to date set of data does not necessarily always exist for all objects in the operational environment.
- Situations can lead to diffuse interpretations. In the AAW domain, an enemy warplane probably will try to behave like a commercial aircraft in terms of speed, course, and altitude.

By definition, rule-based support systems can never be capable of supporting the human decision maker in a situation in which knowledge-based behaviour is essential. Therefore, approaches beyond rule-based artificial intelligence have to be taken into consideration.

As it is shown in Figure 4, human decision making can be divided into the steps "situation assessment" and "solution generation" [2]. Information processing, as indicated by the cognitive level on which a decision is made, can be assigned to [8]:

- Skill-based acting: Predetermined signals are recognized and interrelated directly with one or more actions to be performed.
- Rule-based acting: Situations are interpreted according to rules. Therefore, knowledge is extracted from the situation. Actions are triggered depending on the ascertained situation. The action planning results from the existing system knowledge that determines the manner of potential actions.
- Knowledge-based acting: If there are no rules for a situation, it is tried to assess the situation by retrieving experiences from the past. Based on this knowledge and having regard to overall mission objectives a goal is defined and an action is planned.

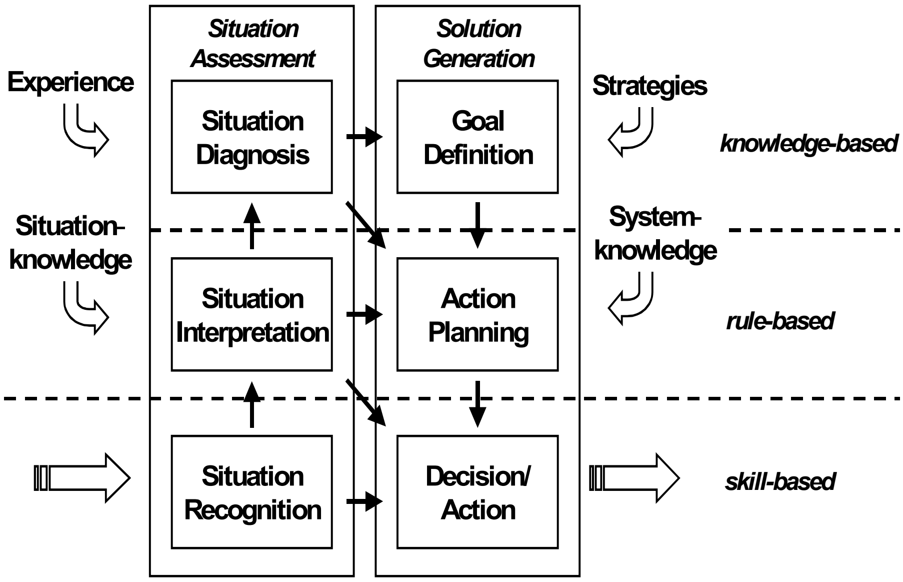

Figure 4: The Tree Levels of Performance (after [2]).

By utilising computer-based inference techniques, it can be tried to emulate the corresponding human decision-making processes. Eligible techniques are e.g. [6]:

- Boolean inference techniques, like decision trees or decision tables,
- Fuzzy systems,
- Bayesian belief networks, or
- Case-based reasoning.

Depending upon the cognitive level of the decision-making process the techniques mentioned above might be more or less suitable for the modelling of expert decision-making. Common to all of them is the fact that the basis of the model is formed by the expert knowledge. This has to be described and formalised, e.g. by means of so-called case-bases. One solution for collecting the information, which is needed to build up such databases, is to conduct an empirical knowledge acquisition.

In order to guarantee compatibility to the decision-making process of the human operator the following requirements have to be taken into account with regard to the visualisation of results delivered by inference systems:

- Results have to be assigned to the phases “situation assessment” and “solution generation” adequately.
- Output of results has to be compliant to the content and to the sequence of questions emerging during the decision-making process. During situation assessment, decisions on lower level (according to Rasmussen’s model) are executed before higher order decisions. Therefore, information of inference systems assigned to skill-based decisions should be presented previous to those of rule-based or knowledge-based decisions.
- Arguments leading to system results and alternative solutions should be displayed so that the operator is able to comprehend and evaluate computer-generated proposals. In many cases, support system’s output is aggregated on a higher level of information. That is the case if all sensor information is processed and a single proposal, e.g. for identity, is derived without justifying the conclusion. The operator gets no idea about the circumstances that lead to the system’s proposal so that any possibility of understanding system behaviour is eliminated. Additionally, the system does not inform about alternative solutions and their probabilities that may have only minor differences. Studies have shown that decision support systems should provide both information about object’s features and explanatory descriptions which support “story generation” [7].

2 HMI CONCEPT

2.1 Knowledge Acquisition and Structuring

To learn which events and attributes in AAW are relevant for object identification, intent recognition, and threat evaluation decision-making drivers were identified by:

- analysis of AAW-relevant decision-making during a manoeuvre on board of the German destroyer LÜTJENS (Z 103 B),
- structured interviews and questionnaires with experts from German Navy,
- examination of specifications elaborated for a tactical situation analysis software to be used by the German Navy.

Parameters available in current and future systems were rated by operators according to their importance for situation evaluation (“need to know” vs. “nice to know”), their influence on decision-making, and the underlying decision rules.

2.2 Visualisation Concept

Within the next years console workplaces in combat direction systems (CDS) of ships from the German Navy will not be modified very much. These consoles usually consist of two vertically or horizontally aligned visual display terminals (VDTs). However, it is clear that no single display could offer all required information in an optimal way, see e.g. [9]. Input devices currently used are a keypad, and an additional input device, e.g. a trackball or a COTS computer mouse. A touch input device and a speech input module may be used in future systems. A major design criterion is to concentrate the operator’s working process on the centrally positioned Tactical Situation Display (TSD). The display has to provide input and output components, which enable the operator to obtain and to maintain an overview of the tactical situation. Furthermore, this display should provide information and input facilities that make it possible to routinely handle non-critical, i.e. non-threatening, objects by means of only one VDT so that attention-shifts between different displays are not necessary. That way capacity for the handling of critical objects is kept free for the secondary display. This display has the purpose to show information necessary for detailed examination of sensed objects, e.g. parameter's ranges, tendencies, and time series. The graphical output of an inference module should also be displayed there.

Based on the results of the analysis, a display concept has been derived with the following requirements and ancillary conditions:

- Since nowadays, operators are well trained in interaction by means of civil software applications it is reasonable to apply interaction techniques with regard to both hard- and software that are known from the civil world (COTS, commercial off the shelf). As it was mentioned earlier the usage of computer mouse and touch input have shown to achieve better performance in means of handling times and mental workload than roll- or trackball devices.
- The main working area is limited to one display element, i.e. visual display terminal. The tactical situation display (TSD) has to visualize geo-referenced information including:
  - dynamic objects (air-tracks) from sensors,
  - positions of relevant abstract elements within the scenario (a-priori knowledge), e.g. airways, military zones, territories etc.
  - static elements of the environment, i.e. topography, airports, rivers etc., obtained from an ENC (electronic navigational chart).

  in a comprehensive manner enabling the operator to obtain an overview of the tactical situation within a short period of time.

  The most important (need to know) information elements of dynamic objects are visualized on user demand or on system generated events by means of polar displays presented on the main VDT. These displays enable the operator to detect easily critical parameter combinations and deviations. On occurrence of new objects or critical events, the operator may use this display to obtain an impression of the object's behaviour.
- Additional information on dynamic objects including "nice-to-know" items shall be displayed on user demand or on system generated events by means of a secondary display unit (track detail display, TDD) positioned either above or aside the main-display.

2.3 Knowledge Structuring

The collected rules for the classification and identification of dynamic objects, i.e. air-tracks, were pooled into four groups based on the kind of objects to which they are related in the respective rule:

- on its own, e.g. kinematical attributes of an air-track like minimum, maximum and range of parameters, frequency of parameter variations etc.,
- in relation to static objects like civil airways (flying in accordance with airway) or territories and zones (hostile origin, intrusion into base defence zone),
- in relation to the own ship, e.g. identification of an inbound manoeuvre,
- in relation to other dynamic objects, e.g. identification of several air-tracks making-up a formation.

To allow the different object types and the connecting rules to be used in the knowledge-based user interface it was necessary to transform the different, partly mathematical descriptions into an object-oriented software specification. This was done based on a framework which makes use of the Unified Modelling Language (UML) [3][4]. As it is shown in Figure 5 real-world objects have been transformed to object classes on a general level (e.g. DTO_AirTracks) from which subclasses (here DTO_Aircrafts) may be derived. The rules, which process both information of dynamic objects and information of static objects, are implemented by means of inference processes in which methods for the computer-based situation evaluation are embedded. In the example shown in Figure 5 the inference process IPS_ActivityAirway verifies the behaviour of a single dynamic object of the type aircraft in relation to a static object airway. Since UML is not a programming language, the object-oriented structure generated by means of UML has to be converted into programming languages like Java by software-tools, like "Together".

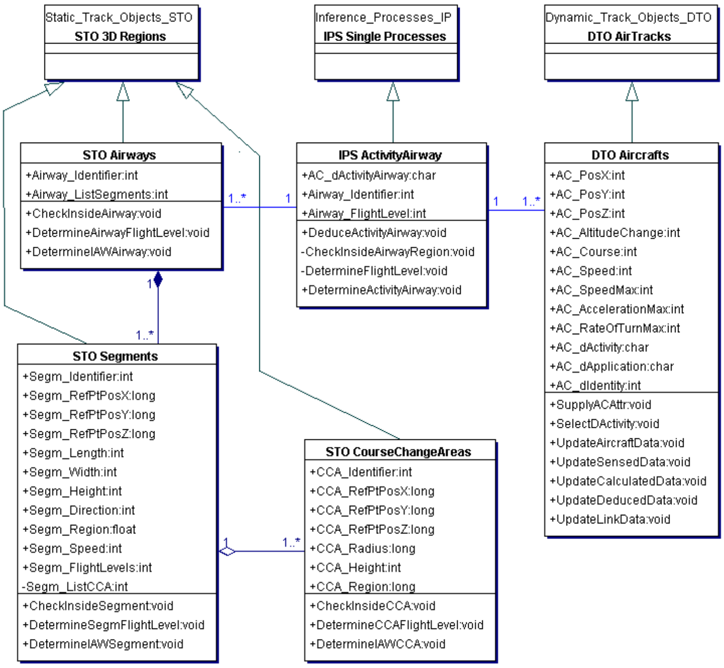

Figure 5: Structure of Static (STO) and Dynamic (DTO) Objects and the Rules Related to them Implemented as Inference Processes (IP) [4].

With regard to today's scenarios another result was, that in principle all objects to be classified can be evaluated by application of classification and identification rules, which are specified in form of operation orders and procedures, i.e. existing rules are designed to cover the whole range of possible situations within a mission. In fact, there are situations in which the decision-maker will tend to decide in contradiction to the rule. This may happen if information on the object is ambiguous, e.g., no clear distinction can be made between civilian and military traffic. In such situations the decision-maker has to estimate the probability whether the object poses a threat for the own ship which may be frequently made on a gut level and based on complex, non-describable situation characteristics or operator experience.

Such situations can't be evaluated to the full extent by artificial systems, because there is no way to describe and to model the essential decision-making drivers. Therefore, a design goal in the concept realization was to provide the most achievable support for the rule-based evaluation of air-tracks in order to unburden operator's cognitive resources for the evaluation of ambiguous objects.

3 HMI PROTOTYPE

3.1 Tactical Situation Display

The Tactical Situation Display positioned in the central visual field of the operator provides essential information necessary for situation evaluation and handling (Figure 6). It shows all sensor-detected dynamic objects (DTOs) overlaid to a chart of geo-referenced information that is provided by an ENC embedded in the computer network.

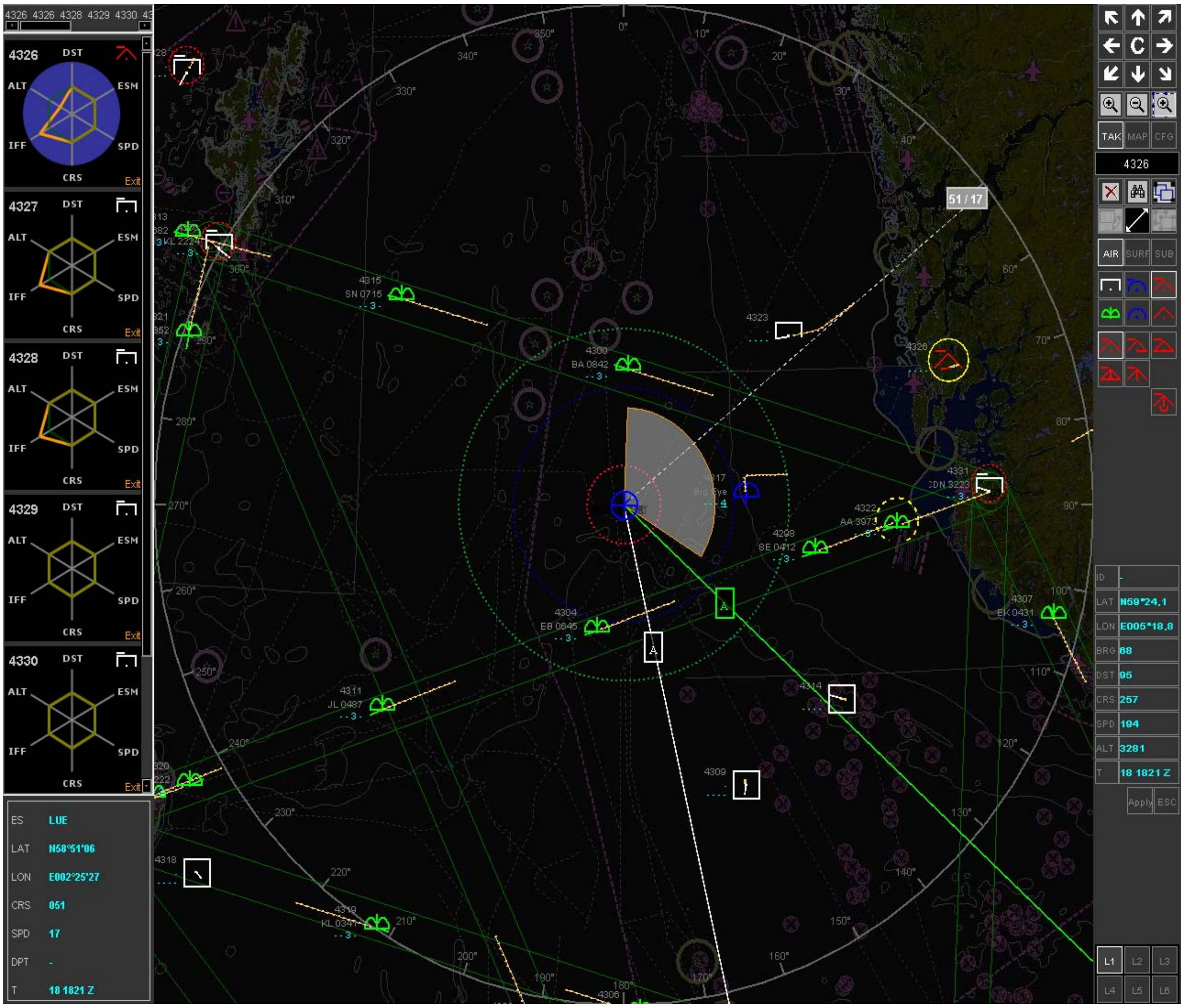

Figure 6: Prototype of the Tactical Situation Display (TSD).

The attributes of dynamic objects are visualized by miscellaneous display elements: Positions of object are shown by geo-referenced symbols positioned in the electronic chart. Shape and colour indicate the object's classification and identity. Speed and course of the objects are visualized by means of vectors. The occurrence of events and action proposals are shown by rings respectively squares around the object symbol. Additional information is displayed by history lines, and in form of text labels assigned to the symbol or shown in a more detailed track-label frame that temporarily comes up on track selection. At the TSD's left edge important information about objects are displayed in an integrated way by means of polar displays. For continuous parameters like speed or altitude, the position on the axis is calculated as the deviation from the parameter's moving mean value. The green line represents the moving value during the last minutes of detection whereas the red line represents the deviation of the momentary value. If the momentary parameter value changes, deviation will be non-zero so that the red polygon's shape will become asymmetric which the operator can detect easily. Static input devices in form of soft-buttons are positioned at the TSD's right edge. For operation of the TSD three different modes have been implemented.

In the tactics mode, the operator can handle the dynamic objects. The configuration mode facilitate the modification of static objects which describe the a-priori knowledge, e.g. airways, military zones etc. Operation in map mode enables the operator to obtain information on objects displayed in the interactive electronic chart, e.g. names of harbours, water depth etc. In all operational modes it is possible to move the cut-out and display range of the chart. In a separate window a larger scaled cut-out can be obtained. To adapt to lightning conditions the display can be operated in daylight or night mode.

3.2 Track Detail Display

Enhancing situation awareness by means of an integrative and easy perceptible polar display encounters difficulties, if object evaluation requires detailed information about decision-making drivers. For this reason the Track Detail Display (TDD) has been realized which is shown in Figure 7 and displayed on a secondary VDT.

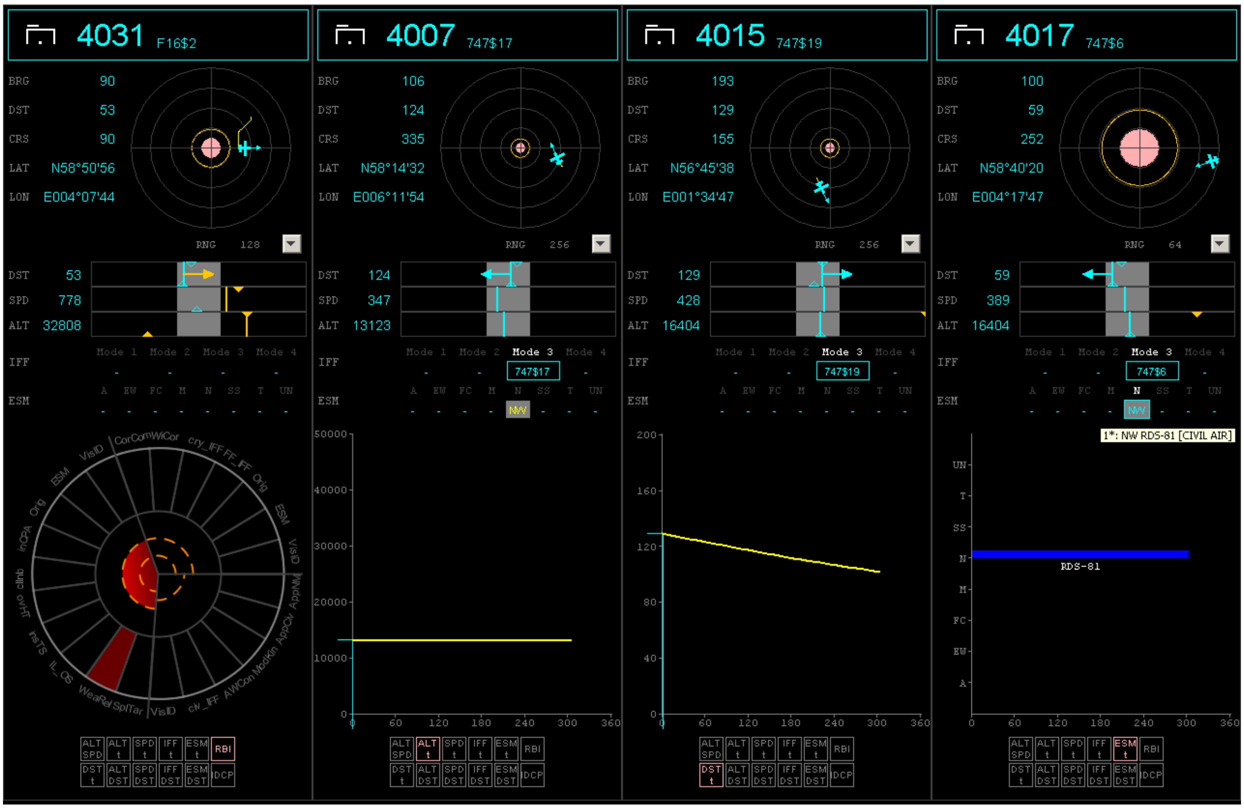

Figure 7: Prototype of the Track Detail Display (TDD).

Within the upper area the operator finds an isolated geo-referenced view on the object relative to the own ship. Parameters that are necessary for a verbal assignment, i.e. bearing, distance, course, speed, and position are aligned aside from this display element. Interval-scaled decision-making drivers like speed, altitude, and distance are represented graphically with regard to tolerance ranges. Nominal-scaled parameters like identification friend / foe (IFF) and emitters detected by the own ship's ESM (electronic surveillance measures) equipment are enriched with additional information in form of tool tips which come-up if the pointer is on the relevant display element. Underneath, in the graphical area time series of parameters can be displayed with regard to either time or distance. This display element may unburden working-memory and enhance the detection probability of short-term parameter deviations. In this prototype there is also a display for the inference system's output. Further evaluations will show whether this implementation meets the operator's requirements.

3.3 Track Attribute Evaluation Display

The decision-support for classification and identification of objects was realized in form of a graphical representation of decision-relevant attributes that are provided by a simplified inference system embedded in the computer network (Figure 8). These attributes are listed in Table 1.

Table 1: Detectable Track Evaluation Attributes

FRIEND-Attributes		HOSTILE-Attributes		NEUTRAL-Attributes	
Visual ID friendly	Vis_ID	Visual ID hostile	Vis_ID	Visual ID neutral	Vis_ID
Blue emission	ESM	Red emission	ESM	Civilian IFF	CivIFF
Friendly origin	Orig	Hostile origin	Orig	Airway conform	AWCon
Friendly IFF	FF_IFF	Inbound CPA	InCPA	Always moderate kinematics	ModKin
Cryptic IFF	CryIFF	Close inbound	Cl_Inb	Application civilian	AppCiv
Within corridor	WiCor	Overflown hostile territory	OvHT	Application non merchant	AppNM
Corridor completed	CorCom	Inside threat sector	insTS		
		Illuminates ownship	IL_OS		
		Weapon release	WeaRel		
		Split target	SpTar		

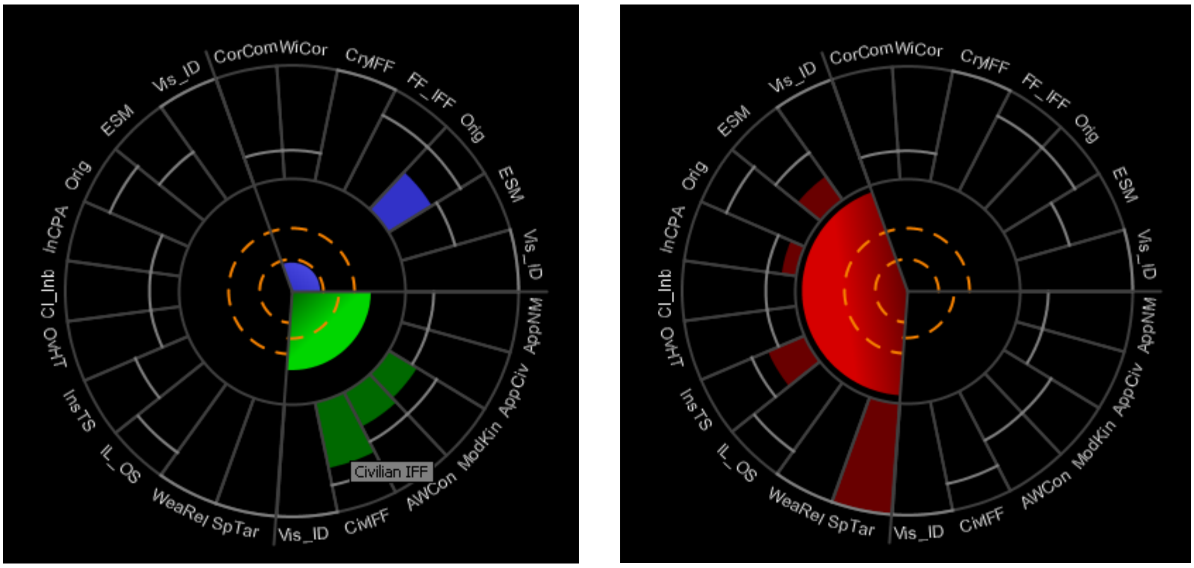

Figure 8: Track Attribute Evaluation Display.

The graphical display consists of two parts: an outer ring which shows the specific attributes which have been found by computer-based inference and an inner ring in which the integrated result of the inference process is displayed. The outer ring is divided in sectors so that each sector represents one detectable evaluation attribute. Attributes with the same tendency for classification respectively identification are pooled. Each attribute is described by its weight, which represents the attribute's importance within the inference process, and its momentary probability that the attribute is true. Using a Boolean inference technique this probability is either 0 (false) or 1 (true). The weight determines the maximum filling of a sector whereas the probability determines its actual filling. Tendency of an attribute is indicated by the sector's filling colour.

The integrated result of object evaluation is shown in the inner ring of the display. Three sectors with different colours represent three different identification groups, i.e. friendly tendency (blue), hostile tendency (red), and neutral tendency (green). Degree of filling is calculated as the weighted-combined probability of the evaluation attributes assigned to this tendency and is a measure for the reliability of the proposal with regard to this tendency. The dashed lines represent the transitions within the tendency areas, for instance from unknown to assumed friend to friend.

4 CONCLUSION AND FUTURE WORK

The realized prototype is a result of a system-ergonomic driven process that integrates analysis, concept development and (rapid) prototyping of a HMI. The last phase of the system-ergonomic approach, i.e. system evaluation, has not been performed yet. An empirical evaluation with regard to operator performance, situation awareness and operator mental workload will be the next step in this design process. Comparisons with currently operating systems will show whether effectiveness and efficiency are improved. Furthermore, this evaluation will provide information for subsequent iterative steps directed toward the optimization of this prototype.

The integration of inference systems compatible to the identification data combining process described in STANAG 4162 will probably lead to an extension of the Track Attribute Evaluation Display. In the long run the development efforts will focus on the implementation of modules for action planning. The adaptation of system behaviour to operator functional state in terms of situation awareness, mental workload and (partly derivable from these) vigilance is an important challenging issue of research. A promising way to reach this is the application of assessment techniques like eye-tracking and actigraphy which allow an online evaluation of aspects affecting operator capacity.

REFERENCES

[1] Card, S.K., Mackinlay, J.D., and Shneiderman, B. (eds.) (1999). Readings in Information Visualization. Using Vision to Think. San Francisco: Morgan Kaufmann Publishers.

[2] Dörfel, G., Distelmaier, H., and Döring, B. (1999). Modeling Problem-Solving in Natural Settings. Proceedings of the 1999 Command and Control Research and Technology Symposium, Vol. 1, 29.06.-01.07.1999, pp 500-509, United States Naval War College Newport, RI.

[3] Döring, B., Dörfel, G., and Distelmaier, H. (2002). Modelling Situational Awareness Information on the Basis of A Priori Scenario Knowledge. Proceedings of the RTO-HFM Panel Symposium on “The Role of Humans in Intelligent and Automated Systems”. 7.-9.10.2002, Warsaw, Poland.

[4] Döring, B., Dörfel, G., and Distelmaier, H. (2003). Object-oriented Modelling of Situational Awareness Information for Knowledge-Based User Assistants. Proceedings of the 9th European Conference on Cognitive Science Approaches to Process Control (CSAPC’03), 16.-19.09.2003, Amsterdam, The Netherlands.

[5] Grandt, M., Pfendler, C., and Mooshage, O. (2003). Empirical Comparison of Five Input Devices for Anti-Air Warfare Operators. Proceedings of the 8th International Command and Control Research and Technology Symposium on “Information Age Transformation”, paper #35, National Defense University, Washington, DC, USA.

[6] Mooshage, O., and Distelmaier, H. (2002). A methodology to build a knowledge-based support system for tactical decision making. Proceedings of the 6th World Multi-Conference on Systemics, Cybernetics and Informatics, SCI 2002. 14.-18.7.2002, Orlando/FL, USA.

[7] Morrison, J.G., Kelly, R.T., Moore, R.A. and Hutchins, S.G. (1997). Tactical Decision Making Under Stress (TADMUS) - Decision Support System. 1997 IRIS National Symposium on Sensor and Data Fusion, MIT Lincoln Laboratory, Lexington, MA, 14-17 April 1997.

[8] Rasmussen, J. (1983). Skills, rules and knowledge; signals, signs and symbols, and other distinctions in human performance models. IEEE Transactions on Systems, Man and Cybernetics, Vol. SMC-13, 1983, pp. 257-266.

[9] Van Delft, J.H., and Schraagen, J.M. (2003). New MMI concepts for situation assessment and decision making in naval command and control. Proceedings of the SCI-129 Symposium on "Critical Design Issue for the Human-Machine Interface", 19.-21.05.2003, Prague, Czech Republic.

[10] Vicente, K., and Rasmussen, J. (1992). Ecological Interface Design: Theoretical Foundations. IEEE Transactions on Systems, Man, and Cybernetics, Vol. 22, No. 4.

[11] Wickens, C.D. (1984). Processing Resources in Attention. In: R. Parasuraman and R. Davies (eds.): Varieties of Attention. New York: Academic Press.

[12] Wickens, C.D. (1992). Engineering Psychology and Human Performance. 2nd Ed.. New York: Harper Collins Publishers.

[13] Wickens, C.D., and Carswell, M. (1995). The Proximity Compatibility Principle: Its Psychological Foundation and Relevance to Display Design. Human Factors, 37(3).

[14] Woods, D.D., Wise, J., and Hanes, L.. (1981). An Evaluation of Nuclear Power Plant Safety Parameter Display Systems. Proceedings of the 25th Annual Meeting of the Human Factors Society, p. 111, Santa Monica, CA: Human Factors.