

Modeling Problem-Solving in Natural Settings

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Abstract

Solving problems in natural settings by decision-making and taking action by means of complex technical systems represents difficult tasks for human operators involved, especially in military situations. Obviously, problem-solving tasks in such situations may be supported by knowledge-based systems. For this purpose, knowledge about situations has to be acquired, described, formalized, represented in a computer, and manipulated by suitable problem-solving strategies.

The framework presented provides a systematic approach for the design of such knowledge-based support systems for problem-solving in natural settings by an generic description and modeling of dynamic situations as well as of the human problem-solving process itself. For describing and structuring knowledge about natural settings the paradigm of a theatrical performance is used. For describing and structuring knowledge about the human problem-solving process a special task performance matrix has been developed.

The application of the proposed model for design and implementation of a knowledge-based user support system and its interface is described using the identification/recognition process in naval air defense as an example.

1. Introduction

Solving problems by decision-making and action-taking by means of complex technical systems sets high standards to human operators involved, especially in natural settings. Natural settings are particularly specified by uncertainty, changing situation dynamics, time pressure, and ill defined goals where different goals might be competing or even contrary [Orasanu and Connolly, 1993]. Complex technical systems provide a multitude of situational data or information which have to be perceived and interpreted by an operator by means of individual skill and knowledge in order to perform problem-solving tasks. In the military area, for example, technology pushes for sensor and weapon systems as well as for command and control systems (C2/C3/C4I systems) have increased the amount and complexity of information at hand while the time available to process that information has dramatically decreased with modern combat systems. Additionally, requirement pulls because of changes in military situations and doctrines have given rise to the need for decision-making and problem-solving aids that can support the human operator in assessing and reacting to complex situations in natural settings.

Intelligent and adaptive knowledge-based user interfaces are considered to be a viable approach to overcome some of those difficulties military decision-makers are faced with when having to cope

with situations which are characterized by extremely rapid changes in the tactical situation, highly uncertain information, and a large variety of potential situational hypotheses. Such interfaces consist of a knowledge-based assistance system and an interactive graphical user interface (Fig. 1). The knowledge-based assistant can support decision-makers in performing information gathering and information processing in all phases of a command and control cycle, i.e., situation assessment, decision-making, and action-taking.

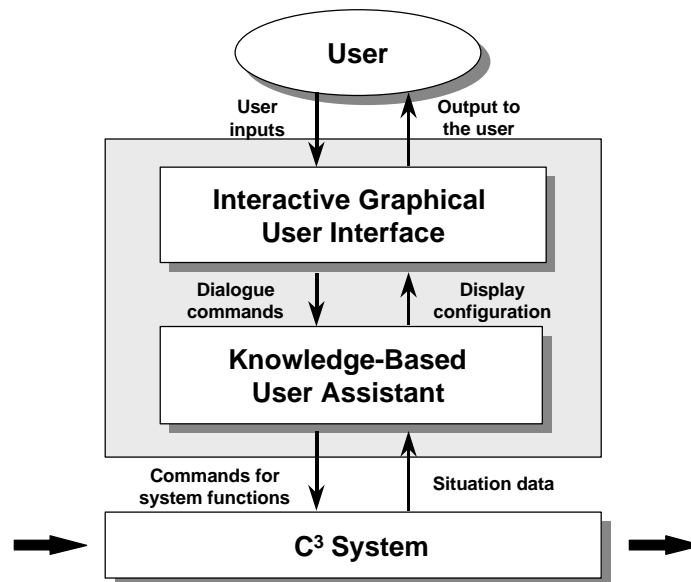


Figure 1. Concept of a knowledge-based user interface

Contrary to conventional software programs where actual data are processed by mathematical algorithms, in knowledge-based systems (KBSs) there exists a clear partition between actual data, domain-specific knowledge, and general problem-solving strategies (Fig. 2). This modular structure is the basis for application and maintenance friendliness of knowledge-based systems and enables an easy modification or extension of the domain knowledge to be processed and of the problem-solving strategies, as well.

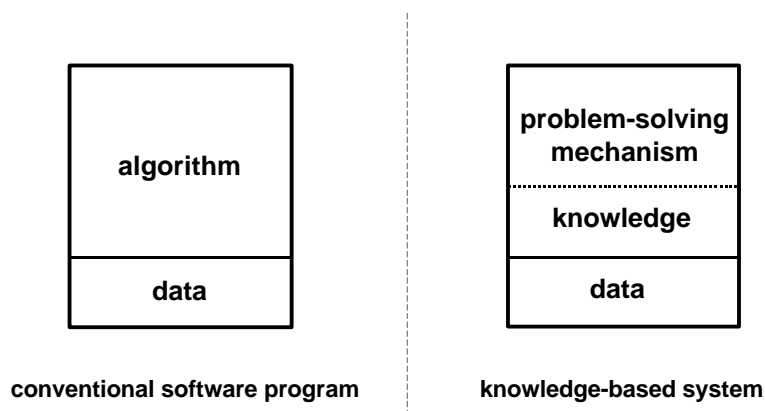


Figure 2. Difference between conventional programs and knowledge-based systems

In the beginning of knowledge-based systems their development process was seen as some kind of transferring human knowledge to an implemented knowledge base. Typically, this knowledge was implemented in some type of production rules which were executed by an associated rule interpreter. However, that rather simple representation formalism of production rules did not support an adequate representation of different types of knowledge. Therefore, this approach was only feasible for the development of small prototypical systems, but it failed to produce large, reliable, and maintainable knowledge bases. This unsatisfactory situation made clear the need for more methodological approaches to construct KBSs in a systematic and controllable manner. It resulted in a paradigm shift from the transfer approach to a modeling approach where the knowledge is modeled independently from its implementation and structured with respect to different knowledge types [Studer et al., 1999].

Thus, for solving problems in natural settings by means of KBSs, different types of knowledge have to be considered. These types are: a) domain knowledge, i.e., overall situational knowledge about a specific problem domain, b) task knowledge, i.e., decision-making and action-taking knowledge, as well as c) knowledge about the dynamic problem solving mechanisms. All types of knowledge have to be described, structured, modeled, formalized, implemented into and manipulated by a computer [Puppe, 1988].

Due to the diversity and dynamics of natural settings and the possible interactions of the participating objects, eliciting, analyzing and describing the relevant knowledge is a very difficult task. Additionally, modeling is a complex activity of abstracting knowledge from a particular domain in order to achieve a model containing the essentials from the perspective of modelers and their given goals. At present, not only in the military area, there exist mainly particular descriptions and models for specific problems. With regard to the effort as well as time and cost consumption in creating different models for different applications it would be worthwhile developing and using generic situation and task descriptions as well as models, respectively, for knowledge-based operator support.

The framework presented in this paper provides a systematic approach for the design of knowledge-based systems for supporting problem-solving in natural settings by an generic description and modeling of dynamic situations as well as of the human problem-solving process itself. For describing and structuring knowledge about natural settings the paradigm of a theatrical performance is used. For describing and structuring knowledge about the human problem-solving process a task performance matrix has been developed.

2. Modeling Natural Settings

As an approach to describe and model the knowledge about natural settings the scenario paradigm of a theatrical performance is used. This paradigm comprises such elements like a stage, the wing, actors, supernumeraries, a scene, roles, active and passive relations, directions, and a screenplay. A scene represents a situation. In this approach actors as well as supernumeraries play their individual roles with goals and activities on a stage with a defined wing. Active and passive relations between actors, supernumeraries and the wing themselves as well as between each others have to be described. Events evoke status changes. Directions are the rules for the occurrence of events or for the course of actions and the screenplay is the script for all the actions of a scenario. In the following, the general scenario description with its elements will be explained in more

detail. Structuring and modeling happens by means of theater-specific elements which will be explained in some detail on the basis of a traffic scenario:

- *Stage with wing*
Stage and wing represent the scene of actions with a passive environment like area, geography, weather etc.
Example: In a traffic scenario stage and wing are the location where the actions takes place with all environmental conditions.
- *Actors*
Actors are active elements of a scene with respect to the relevant problem.
Example: In a traffic scenario they are the different objects which influence the scenario actively, e.g. persons, cars, aircrafts.
- *Supernumeraries*
Supernumeraries are active elements of an action, whose behavior is not relevant with respect to the problem considered.
Example: In a traffic scenario they are the different objects which do not participate in the scenario actively, e.g. pedestrians in an air traffic scenario.
- *Roles*
Roles represent higher level tasks of actors and supernumeraries with respect to their activities, i.e., they are behavior-determining requirements (goals of activities). Particular activities are associated with each role.
Example: In a traffic scenario the activities of a taxi driver are associated with the role “taxi driver”. This role contains, e.g., all activities which have to be accomplished with the transport of persons between two places, including: waiting at a specific place, picking-up and dropping passengers, cashing in the transportation fee, etc.
- *Activities*
Activities are decisions and/or actions by the actors, which have to be accomplished to reach their goals with respect to their roles.
Example: In a traffic scenario they are, e.g., the decision of a taxi driver to take a specific route because of the traffic situation or picking up and dropping passengers.
- *Active relations*
Active relations occur between actors, supernumeraries, and the wing. They cause an exchange of material, information and/or energy.
Example: In a traffic scenario communications between taxi drivers or between pilots and the air traffic control represents such active relations.
- *Passive relations*
Passive relations represent connections between scene elements without the exchange of material, information and/or energy. They occur between actors, supernumeraries, or the wing themselves or between the elements of different groups They are organizational or structural connections.
Example: In a traffic scenario the organizational structure of the rail-road system represents such a passive relation.

- **Events**
An event occurs because of a change of the Boolean value of a condition, where a condition represents a Boolean combination of logical expressions consisting of the status attributes of the actors, supernumeraries, and the wing.
Example: In a traffic scenario such events related to a taxi are represented by reaching a station or an enforced stop because of an engine failure.
- **Rules**
Rules are direction instructions to guide the course of a scenario.
Example: In a traffic scenario these rules are traffic regulations or air traffic schedules.
- **Screenplay**
A screenplay describes the course of a scenario, i.e., a specific order of situations and actions. Contrary to predefined actions and processes, in natural settings there does not exist any fixed screenplay but the course of actions evolves analog to an improvisational performance or on the spur of the moment.

On the basis of this generic description of dynamic natural settings by theater-specific elements a model has been developed. This model consists of six components: 1) actors and supernumeraries; 2) stage with wing; 3) roles and active relations; 4) rules and passive relations; 5) activities (processes); 6) events. The model does not only describe and summarize all interesting aspects of dynamic situations but shall additionally show different views of those situations by a suitable grouping of the defined elements or components into three description categories. These description categories are: a) an element description, b) a functionality description, and c) a course of actions description (process description). The three categories together represent the overall knowledge about dynamic natural settings (Fig. 3):

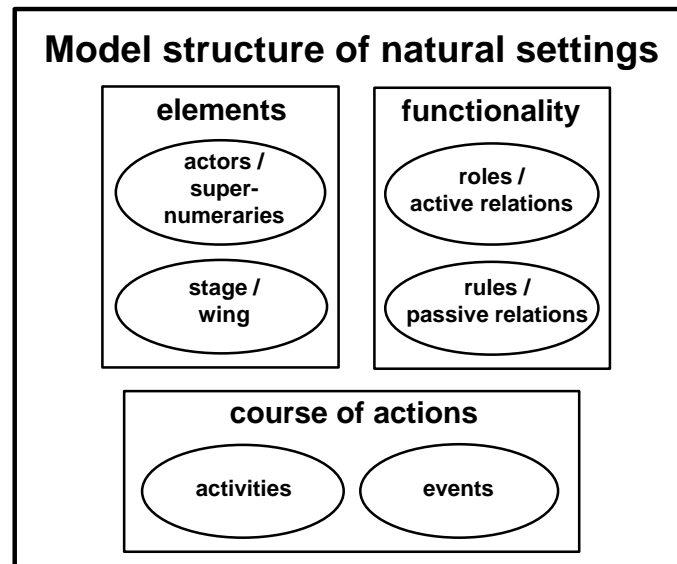


Figure 3. Model structure of natural settings

- The *element description* contains the knowledge about the active elements (*actors and supernumeraries*) involved in the occurrences as well as the knowledge about the area and environment (*stage and wing*) of natural settings.
- The *functionality description* contains the *roles* performed by actors and/or supernumeraries, the *active as well as passive relations* between elements, and the *rules* (of behavior) of the elements.
- The *course of actions description* contains *activities* as well as *events* and serves as the representation of the scenario dynamics. This representation of decisions and actions with definitions of start and stop events describes status changes which may activate or deactivate other activities (processes) and thereby influence the course of actions.

The proposed model using the paradigm of the theatrical performance with the descriptions presented offers a coherent framework to describe and integrate declarative, behavioral, and interactive aspects in a comprehensive model of natural settings. In addition, this approach allows an object-oriented description of dynamic natural settings by transforming the description elements into the elements of the Unified Modeling Language (UML) [Fowler and Scott, 1998]. Actors, supernumeraries, stage and wing may be described as classes with attributes. For describing an actual situation the specific objects have to be derived from these classes. The passive relations between actors, supernumeraries, and wing can be defined as associations, the active relations as messages, and the roles of the actors or supernumeraries with their decisions/actions as methods or functions, respectively. Events are activating or deactivating methods. The screenplay corresponds to action and interaction diagrams. Due to its modular structure, such an object-oriented approach is the prevailing way of systems analysis and related software design with the advantage of easy maintenance and extension by changing or adding elements.

Together, all of the aforementioned aspects establish a systematic and generic access for the design of knowledge-based decision support systems in natural settings.

3. Model-Structure of Human Task Performance

Besides the generic model of the problem domain in natural settings, a second model will be necessary for developing knowledge-based operator support systems, i.e., a model of the human decision-making and problem-solving process in complex situations. For the purpose of operator support this model has not to be an exact reproduction of the human cognitive processes. Rather, it has to be a general concept enabling situation-, task-, and user-based assistance for the decision-making and problem-solving process by information presentation, information processing, and operator guidance for task execution.

According to the normal approach of operator problem-solving behavior: (1) situation perception, (2) situation/problem assessment, and (3) solution generation, complex operator tasks are divided into three different performance phases. Additionally to structuring problem-solving tasks horizontally into phases, a vertical structure seems to be appropriate for each of the three performance phases. This vertical structure is related to the different and specific types of situations one has to cope with and relevant tasks to be performed in natural settings. For this structure Rasmussen's conceptual model for skill-based, rule-based, and knowledge-based

operator behavior in performing complex tasks [Rasmussen, 1983] has been adapted as a framework. This concept takes into account the different situations which arise, for instance, in novel military scenarios, i.e., routine, familiar, and unfamiliar situations. The hierarchical differentiation dependent on situational familiarity and cognitive operator demand is closely related to the steps of mental activity in a model by Lim et al. for human-computer interaction [Lim et al., 1996]. This model contains the following steps: perception, interpretation, evaluation, goals and intentions, planning, and execution. Applying the hierarchical differentiation to all three performance phases for problem-solving tasks and using the cognitive steps of the model from Lim et al. results in a 3 x 3 matrix taken as a model for human decision-making and problem-solving in natural settings (Fig. 4).

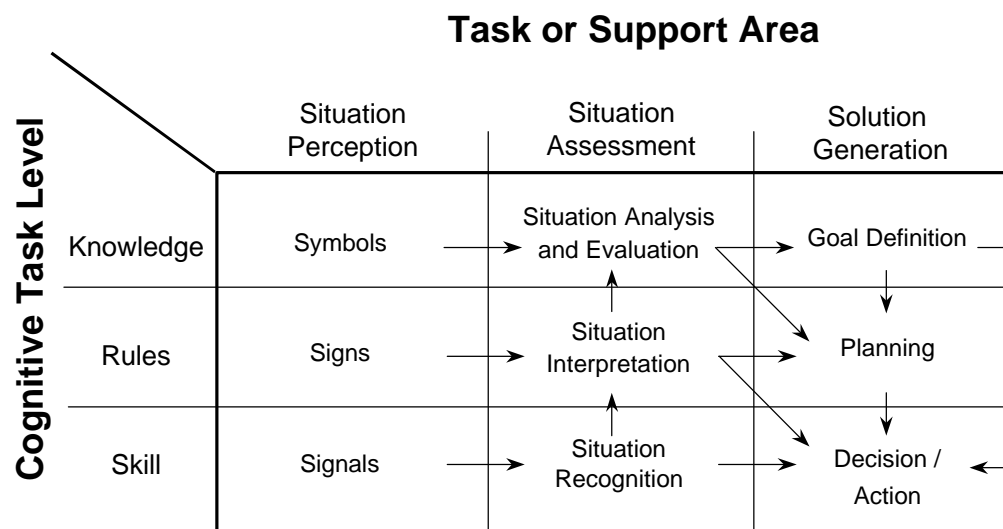


Figure 4. Concept structure of human problem-solving activities

Skill-based behavior corresponds to nearly unconsciously processing of routine situations and tasks. Rule-based behavior corresponds to stereotyped processing of well-known situations. Knowledge-based behavior corresponds to a consciously and analytically processing of novel situations using solution-generating and planning activities. Using the proposed hierarchical model structure of problem-solving performance, already existing solutions for reactive, planning, and decision-making systems can be identified and integrated advantageously into a support concept in order to quickly react on certain and unambiguous situations, to plan in familiar and frequent situations, and to solve problems by reasoning about unfamiliar, infrequent and ambiguous situations. In this way the matrix structure with its elements allows a modular implementation and a stepwise realization of a knowledge-based support concept.

4. Application of the Proposed Models

A general support concept for military missions may include all steps of the military command and control cycle as well as all steps of human problem-solving behavior. To establish the space of support possibilities for military missions the described model of human task performance is

combined with the steps of the command and control cycle, for example in combat information centers. Considering different design and support aspects of a knowledge-based user interface, i.e., information presentation, information processing, and information input using different technical solution approaches, a space of support possibilities for problem-solving in the military command and control cycle can be established (Fig. 5).

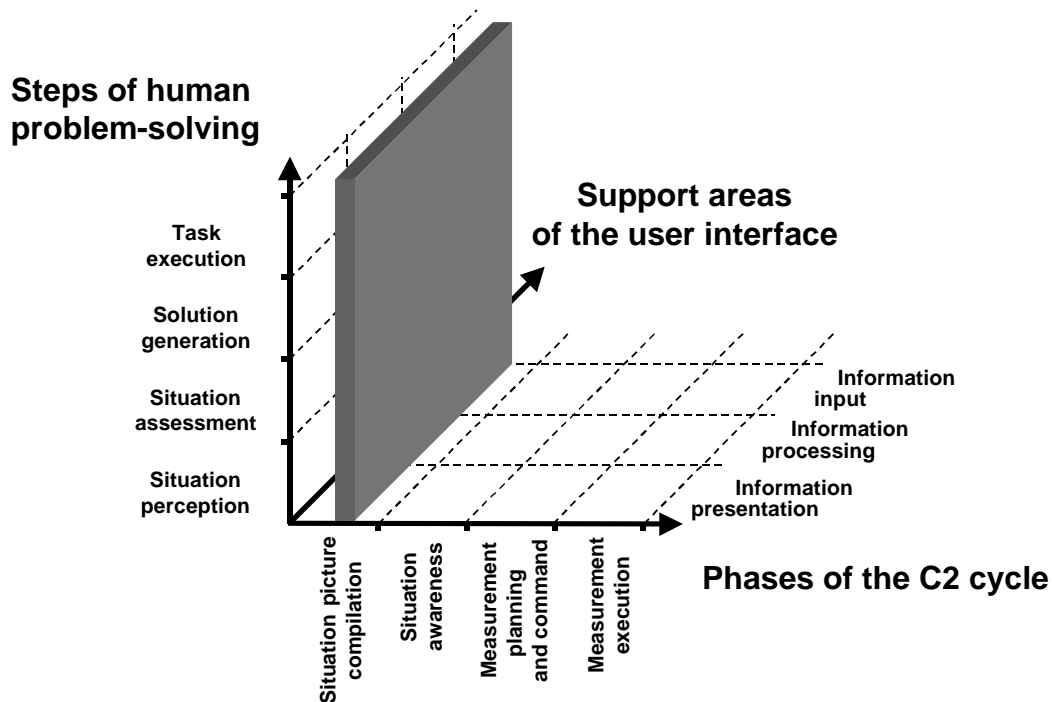


Figure 5. Support areas for problem-solving in the military command and control cycle

In a recent research project for the German Navy the concept of a knowledge-based user interface using the generic model for describing natural settings as well as the hierarchical structure of human problem-solving activities has been applied for supporting the Identification/Recognition (ID/REC) process in ship air defense. The support possibilities involved are represented in Fig. 5 by a gray shaded cut of the situation compilation phase.

Starting with a realistic and relevant crisis reaction scenario, the following operator tasks have been identified for support: monitoring the established air picture to detect specific task relevant events, identifying newly detected tracks, changing the identity of already identified tracks, and performing the investigate procedure for suspect tracks. For each task situation-adapted information presentation, information pre-processing, and dialogs for information inputting facilitate improved situation perception, situation assessment, solution generation, as well as task execution [Dörfel et al., 1998].

To support the ID/REC process by presenting actual data as well as preprocessed situation and task relevant information and by providing information input possibilities a specific information/action window has been developed (Fig. 6).

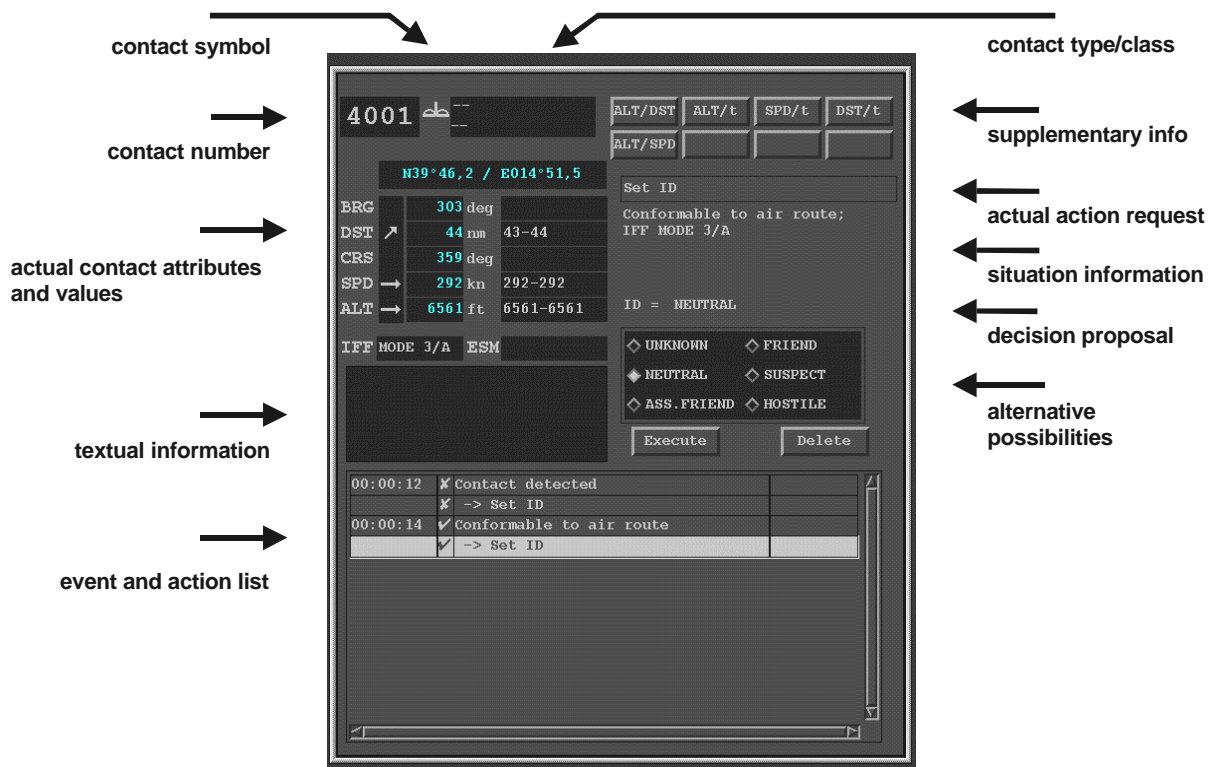


Figure 6. Information/action window for operator support

Situation perception as well as situation assessment is supported by the presentation of actual contact/track attribute values and preprocessed information like trend information, min/max values of the kinematic track data, histories of speed, altitude, and distance as well as relations of altitude versus distance or speed. Non-quantitative task relevant information is presented textually.

Additional support for situation perception and assessment is given by the presentation of task relevant events in an event/action list. This list contains events occurred combined with relevant action proposals in a timely chronological order. Selecting a special event from the list will show additional information characterizing and explaining that event. Selecting a proposed action from the list will show additional information related to the causing event as well as a decision or action suggestion with explanation for that special suggestion. These decision/action suggestions together with the presentation of alternatives support the solution generation of human operators.

In task execution the human operator is supported in the way that he is able to directly confirm the systems suggestion, choose and execute an proposed decision/action alternative or delete the decision/action suggestion. Additionally, the execution of actions consisting of an activity sequence is supported by the presentation of a time-line of the activities to be performed as well as of specific alerts to perform these activities correctly in time and space (not shown in Fig. 6).

5. Summary and conclusion

Difficulties of human operators handling complex man-machine systems in naturalistic settings have given rise to the need for support systems that can assist them in assessing and reacting to ambiguous and rapidly changing situations. Obviously, problem solving tasks in such situations, especially including military situations, may be supported by knowledge-based systems. At present it may not yet be possible to design a totally automated system to address all possible events in highly ambiguous situations, such as those found, for instance, in military crisis reaction operations, but it is possible to develop support systems to complement human's ability to perceive novelty and adapt an appropriate response to manage that novelty.

The concepts presented in this paper provide a systematic approach for the design of knowledge-based support systems for problem-solving in natural settings based on a generic description and modeling of dynamic situations as well as of the human problem-solving process itself. In addition, the proposed model structures enable their transformation into the building elements of the Unified Modeling Language (UML) what allows the development of knowledge-based support systems by an actual and prevailing software technique.

The general concept of a knowledge-based user assistant system and its implementation for the identification/recognition process in naval air defense demonstrates the potential of such an approach. With the use of a recently developed interface demonstrator, the advantages of this concept for decision making support in complex situations could be shown. By means of situational user guidance through prompts, warnings, and specific action proposals, operators are alerted to task-specific events and prompted to the appropriate actions to be taken. This improves situation awareness in addition to decision making and action command. However, the ultimate decision about the action to be taken resides with the operator himself, thus, keeping him as an integral and critical part of the decision making loop.

6. References

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