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ABSTRACT

Having subject matter experts (SMEs) identify the skills and knowledge to be taught is among the more difficult and time-consuming steps in the training development process. A procedure has been developed for identifying specific tactical decision-making knowledge requirements and translating SME knowledge into appropriate multimedia representations. The procedure, which is called Sea Stories, is based on construction and analysis of a scenario by one or more SMEs. The Sea Stories procedure allows a team of domain experts to "articulate" their knowledge by describing a scenario (their sea story) in a series of computer-based storyboards. The major knowledge elicitation tasks performed by the SMEs are as follows: construct a scenario illustrating a particular problem or procedure; test the scenario's logic by identifying key variables in the scenario and their relationships; identify the knowledge required of decision makers to perform successfully in the scenario; and provide graphical, auditory, and verbal representations of the key knowledge elements. Possible storyboards include spatial situation overviews, team interaction diagrams, task flowcharts, and equipment diagrams. The Sea Stories procedure will be automated by using a suite of tools that are largely available as commercial off-the-shelf products. (MN)

SEA STORIES: A COLLABORATIVE TOOL FOR ARTICULATING TACTICAL KNOWLEDGE

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ABSTRACT

Among the more difficult and time-consuming steps in the training development process is the elicitation from subject matter experts (SMEs) of the skills and knowledge to be taught. As the use of advanced multimedia training technology has become more common, training development increasingly involves translating SME knowledge into appropriate media representations. This paper describes a procedure for identifying specific tactical decision making (TDM) knowledge requirements, and possible media-based representations of that knowledge. The intent of this procedure is to provide the basis for constructing tactical training documents using multimedia technology. The procedure, called ories, is built around the construction and analysis of a scenario by one or more SMEs. Sea Stories allows a team of domain experts to "articulate" their knowledge by describing a scenario (their sea story) in a series of computer-based storyboards. These storyboards include, for example, spatial situation overviews, team interaction diagrams, task flow charts, and equipment diagrams; and are integrated though a detailed timeline. Applied training research provides knowledge frameworks that can be used to guide and prompt experts to identify and refine components of the knowledge. The storyboards provide the basis for identifying these knowledge requirements, and the media representations that are associated with a tactical problem. Computer Supported Collaborative Work (CSCW) technologies facilitate communication among groups of subject matter experts using annotation techniques and revision control and tracking.

BIOGRAPHICAL SKETCH

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BACKGROUND AND OBJECTIVES

Among the more difficult and time-consuming steps in the training development process is the elicitation from subject matter experts (SMEs) of the skills and knowledge to be taught. Despite the variety of techniques for eliciting knowledge from SMEs that have been developed, knowledge elicitation (KE) remains one of the primary "bottlenecks" in the process.

All KE methods involve tradeoffs (Cooke, 1994). These tradeoffs typically balance the depth against the breadth of the knowledge elicited from the SME. Consequently, it is necessary to tailor the method to the content domain and to the ultimate use to which the products of the analysis will be put. Declarative knowledge is typically extracted as verbal information through structured or unstructured interviews, think-aloud, or retrospective protocols. Procedural knowledge is usually extracted by analyzing actual task performance of experts on real or synthetic tasks.

As the use of advanced multimedia training technology has become more common, training development increasingly involves translating SME knowledge into appropriate media representations. The translation is complicated by the fact that most KE methods produce verbal representations of knowledge that are often several conceptual steps removed from the form and context of the SME's original articulation. When the content consists of context-independent declarative knowledge, this translation may not significantly alter the validity of the analysis products. However, when the knowledge to be elicited is procedural in nature, is embedded in the context in which it is to be used, or when the knowledge is typically represented in non-verbal, perceptual forms, the translation of the SME's output may significantly affect the completeness and accuracy of the analysis and the resulting media representations. This problem suggests the need to explore alternative analysis methods that preserve the context and non-verbal aspects of the elicited knowledge.

This discussion describes a procedure for identifying specific tactical decision making (TDM) knowledge requirements, and possible media-based representations of that knowledge. The intent of this procedure is to provide the basis for constructing electronic tactical training documents using multimedia technology. The intent of the KE procedure is to

- Build on procedures and practices already used by SMEs;
- Keep the amount of time or effort needed to perform the procedure in approximate proportion to the scope of the final product;
- Ensure that the products of the procedure conform to standards of validity, consistency, accuracy, and completeness; and
- Provide the basis for identifying and constructing effective multimedia objects and presentation strategies.

The procedure, called ***Sea Stories,*** is built around the construction and analysis of a scenario by one or more SMEs. It is a modified version of a procedure described by McNeese and Zaff (1991) as *design storyboarding*. The technique was used to help subject matter experts to "translate their conceptual knowledge and expertise into a representation and design prototype that could be perceptually experienced by other viewers of the storyboard" (McNeese and Zaff, 1991, p. 1184).

The proposed method borrows from several existing KE methods. The method requires SMEs to identify specific knowledge requirements imposed on decision makers by analyzing a scenario that illustrates a particular problem or process. The advantage of this approach is that the

SMEs are asked to respond to the requirements of a specific context rather than a general, abstract problem. However, unlike the approach in which SMEs must interpret and respond to a prescripted scenario, the SMEs first construct the scenario and, thus, they are free to insert the events and conditions to which they will respond. The rationale behind this approach is that the SMEs will construct the scenario to reflect how they stereotypically conceptualize a problem, based on previous experiences and personal insights. This procedure forces SMEs to externalize at least part of their personal mental model of the problem.

An additional advantage of this approach is that it builds on a task already performed by many TDM SMEs -- the construction of scenarios to facilitate specific training objectives. This procedure attempts to formalize this familiar task, and forces the SMEs to identify the linkage between scenario events and knowledge requirements.

MAJOR KE TASKS

The SMEs performs four major tasks in this procedure:

1. The SME constructs a scenario illustrating a particular problem or procedure;

2. The SME tests the logic of the scenario by identifying key variables in the scenario, and their relationships;

3. The SME identifies the knowledge required of the decision maker to perform successfully in the scenario; and

4. The SME provides graphical, auditory, and verbal representations of the key knowledge elements.

Constructing a Scenario:

Specifying a Topic. The procedure focuses the SME on a single topic or problem to be illustrated. Examples of tactical problem or topics might include: managing tactical resources, dealing with equipment casualties, managing high workloads, or dealing with difficult environmental conditions. The SME can be asked to construct a scenario for a particular type of learner, such as a novice or an expert decision maker. Alternately, the SME could be asked to develop a scenario at a certain level of difficulty or complexity, or to emphasize a particular aspect of the problem -- teamwork versus individual performance.

Defining the scope of the topic is a critical step in the process. The narrower the scope, the more easily the SME can focus on the key variables and relationships in the scenario. The broader the scope of the topic, the more complex the scenarios must be to encompass its full range. It may be easier for a SME to construct many specific, narrowly defined scenarios than to create a few very large, complex scenarios to illustrate all possible variations on a topic.

Building a Background. Once the topic has been specified, the first step for the SME is to lay out a background for the scenario. The purpose of this step is to provide a broad, common framework within which to fit specific events of the scenario. The framework identifies events and requirements that would normally occur in a scenario such as shift changes, routine reports, or other operational cycles.

The background should include the environment in which the scenario will take place: geographic location; the geopolitical situation; the mission and status of one's ownship; the order of battle; and any standing orders, taskings, rules, or procedures under which the ship is operating. Examples might include the Rules of Engagement (ROE), that impose limitations on the scenario. Unless these background elements will play a significant part in the scenario, they should be made as neutral or routine as possible. The background should not include variables that play a major part in the scenario or the way actors in the scenario should or will perform. These elements should be explicitly considered in the key events of the scenario.

Building Key Events. Once the scenario background has been specified, the next step is for the SME to insert events that will drive the illustration. It may be desirable to begin with a general outline of events in the scenario, and to then add detail in successive layers. At the end of this step, the scenario should include a detailed script of the scenario including descriptions of times, distances, locations, and behaviors of the actors, platforms and systems in the scenario. The steps might include...

1. Identifying key event or events that will illustrate the problem.

2. Identifying key actors in each event, tasks they will perform, and actions they will take.

3. Identifying equipment, platforms, and systems that will be employed, or that will be affected by the events.

4. Describing the event in terms of locations, movements, and other behaviors (for example, communications, IFF, EW, etc.)

Analyzing the Logic of the Scenario.

After the scenario has been constructed, the next step is to verify the logic of the scenario to ensure that it represents the problem or procedure as the SME intends, and that the events contain a coherent set of identifiable variables and relationships. To verify the logic behind the scenario for each event the SME should be asked to

- Identify important factors or variables in the event, and
- Specify causal or logical links between the variables and the problem or process it is intended to illustrate.

For example, if an event is intended to illustrate the problem of determining the intent of an unknown track that is demonstrating erratic behavior, the SME would be asked to identify the variables that make the track's behavior "erratic" --e.g., sudden changes in altitude, frequent changes in course or speed.

Second, the SME would be asked to identify the causal or logical relationship between the variables--for example, erratic behavior indicates an unskilled pilot, mechanical difficulties, a possible diversion, etc. Obviously, it is important that the number of variables be kept to reasonable size, and that the SME focuses on the most important variables and relationships. The product of this step is a list of the key variables operating at each event in the scenario, and a description of the relationships among the key variables.

Analyzing the Knowledge Requirements of the Scenario.

The variables and relationships identified in the previous step form the basis for identifying the knowledge requirements for a decision maker performing in this scenario. The analysis could be performed in several ways. The SME could work through the scenario event by event, or variable by variable to identify specific knowledge requirements. To help the SMEs identify this knowledge, they might be prompted to focus on specific categories of knowledge. Working systematically through the scenario, the SME would follow a standard checklist of knowledge categories to ensure that they consider all relevant knowledge requirements. Within each knowledge category the SME would be asked to identify specific knowledge and skills needed by the decision maker to make a correct response to each event. An alternative approach might be to ask the SME to identify both correct and incorrect responses to events -- particularly common errors made by novice decision makers -- and the outcomes of the events associated with each.

Identifying Graphical and Verbal Representations of Key Knowledge Elements.

A major goal of this procedure is to provide the basis for creating media representations of the knowledge identified in the analysis. This goal could be pursued as a separate step after the knowledge requirements have been identified, or could be integrated into each of the previous steps. For example, during the scenario construction step, the artifacts of the process could be used as the basis for representing the knowledge elements identified earlier. This could be done by asking the SME to identify the external indicators and cues associated with each major event, or each variable in the scenario. Similarly, during the second step, when the SME identifies the key variables and relationships he could be asked to identify the external indicators that allow the decision maker or operator to know that a variable's value or state has changed. In the last step in the procedure the SME could be asked to specify the observable external indicators of correct and incorrect performance (e.g., voice phraseology, keypress sequence, balltab movement, etc.) It may be possible to solicit sketches, diagrams, maps, or other illustrations from the SME that can be directly translated into media objects by a graphic artist or illustrator. Similarly, verbal protocols that represent voice communications between persons during the scenario should be collected from the SME.

This procedure does not assume that one scenario can capture all possible aspects of a problem or procedure, nor does it assume that one SME will necessarily understand all aspects of the problem equally well. The procedure contemplates the need for multiple scenarios and multiple SME input. It is also possible for the process to be carried out by a team of SMEs working together as a group. However, the requirements on the SMEs are thought to be no greater than that imposed by other KE proce-

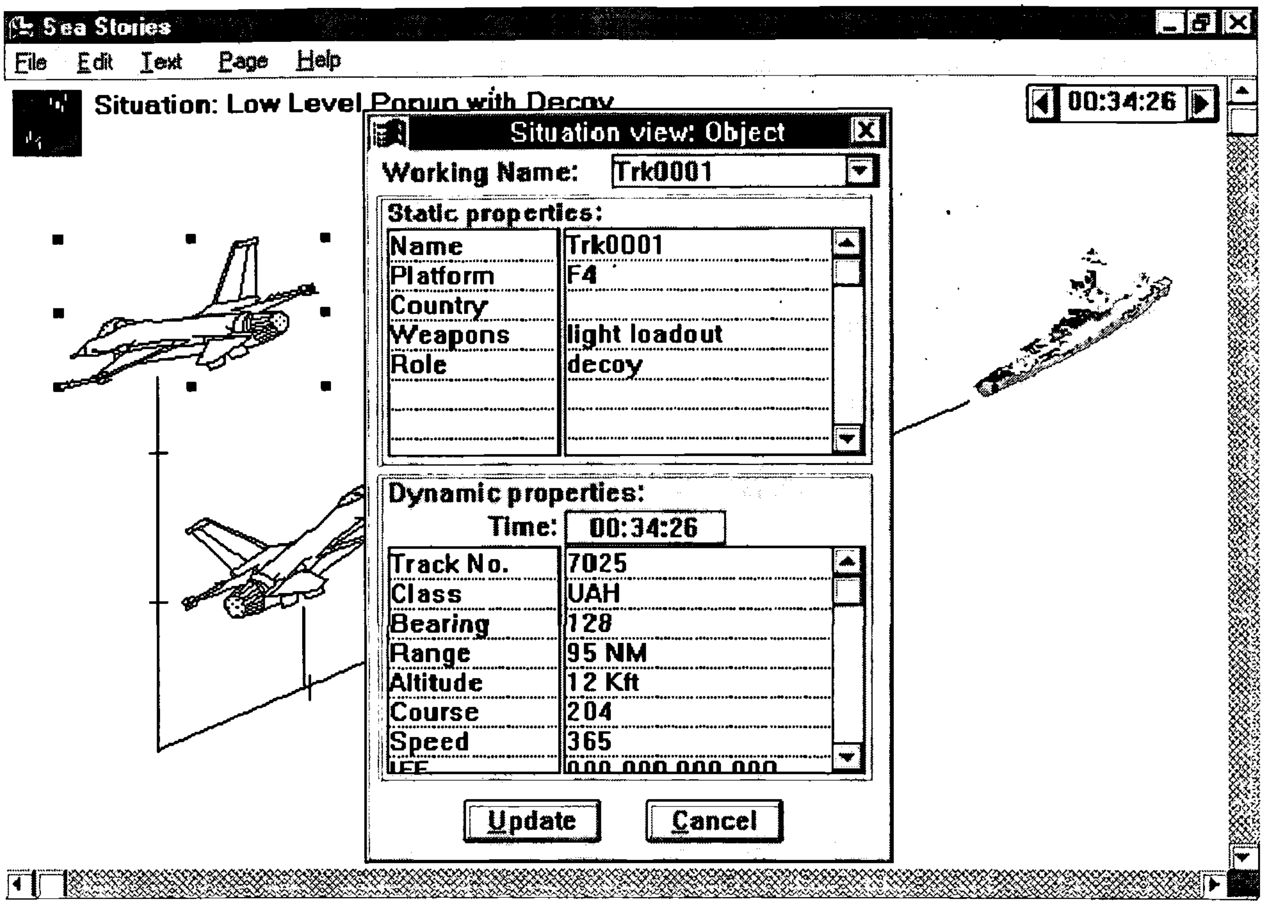

Figure 1. The External "Situation" Interface

dures, and given the nature of the task, may be easier for the SME to understand what is required.

SEA STORIES: AUTOMATING THE PROCESS

Parts of this KE procedure could be significantly improved by providing automated tools to accelerate the construction of the scenario, completing the analysis of the scenario's logic, and recording the knowledge requirements of the scenario. Such a device would have the capability of depicting all elements of a typical tactical scenario in a naturalistic format, and ordering and correlating the SME's inputs to produce a coherent scenario timeline and consistent, integrated knowledge structure.

Sea Stories Prototype

Describing the different types of knowledge involved in a scenario requires several different abstractions which may be depicted using a range of media types. Creating and editing these depictions requires a suite of tools, most of which are available as commercial-off-the-shelf (COTS) software products. The design and development of ***Sea Stories*** will leverage these commercial tools and provide domain experts with a high-level integrating framework for composing knowledge elements. The contribution of ***Sea Stories*** is to integrate and organize these depictions into a complete description of tactical knowledge.

Starting from the mental models associated with TDM identified by Search Technology (Duncan, Rouse, Cannon-Bowers, Salas, Johnston, & Burns, 1996), such a tool would enable the SME to depict events in the following categories:

- Situation,
- Tasks,
- Team,
- Equipment & Systems, and
- Ship/Group.

The *Situation* interfaces would permit the SME to depict scenario events within both the external environment and the internal environment of the Combat Information Center (CIC).

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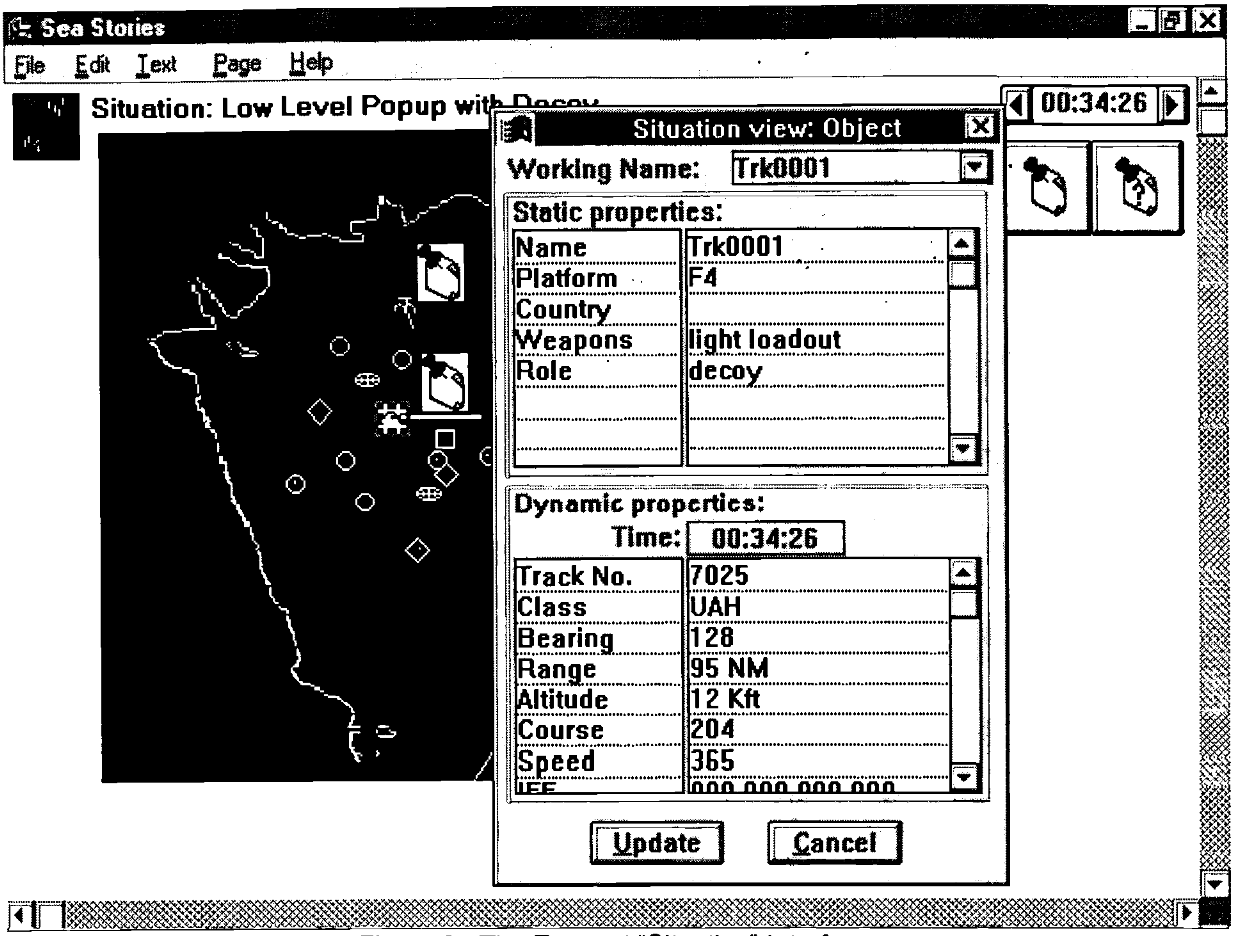

Figure 2. The External "Situation" Interface

This depiction would include, for example, the physical location of platforms, their heading, speed, altitude; their detectable behaviors such as electronic emissions, communications, changes in course or altitude, weapon release, or any other changes that materially affect the scenario. The *Situation* interfaces would allow the SME to place the platforms and specify their performance characteristics and behaviors at each point in the scenario. The interfaces should also permit the SME to depict the influence of environmental factors in the scenario such as weather, time of day, geophysical effects.

Figure 1 shows a high level depiction of the external "situation" knowledge in a story. In this storyboard, the depiction of the situation is simplified to include only the most important entities in the story -- two threatening aircraft and ownship. The clock in the upper right corner of the screen indexes the frame of the story as a time offset from the beginning of the scenario. The number of these "key-frames" is dependent upon the complexity of the story and the number of key events in the scenario.

The dialogue window in the middle of Figure 1 illustrates a key aspect of the computer-based tool. ***Sea Stories*** is essentially a detailed database of knowledge elements with a variety of visual representations serving as stimuli to aid the analysts in articulating the details of the knowledge. This dialogue window shows the current record in the database pertaining to one of the aircraft in the storyboard during this event in the scenario. Details about the aircraft can be interactively defined and the dynamic values can be updated for different points in time in the story. The details include both "ground truth" knowledge (i.e., knowledge that ownship cannot be certain of, such as the threatening aircraft's role) and local knowledge (i.e., ownship's data readouts about the track). One important aspect of the power of ***Sea Stories*** comes from the capability provided to the analyst to query the database to access and compare knowledge elements at different levels of abstraction and at different points of time in the story.

Figure 2 shows another visual depiction of the situational knowledge from the perspective of

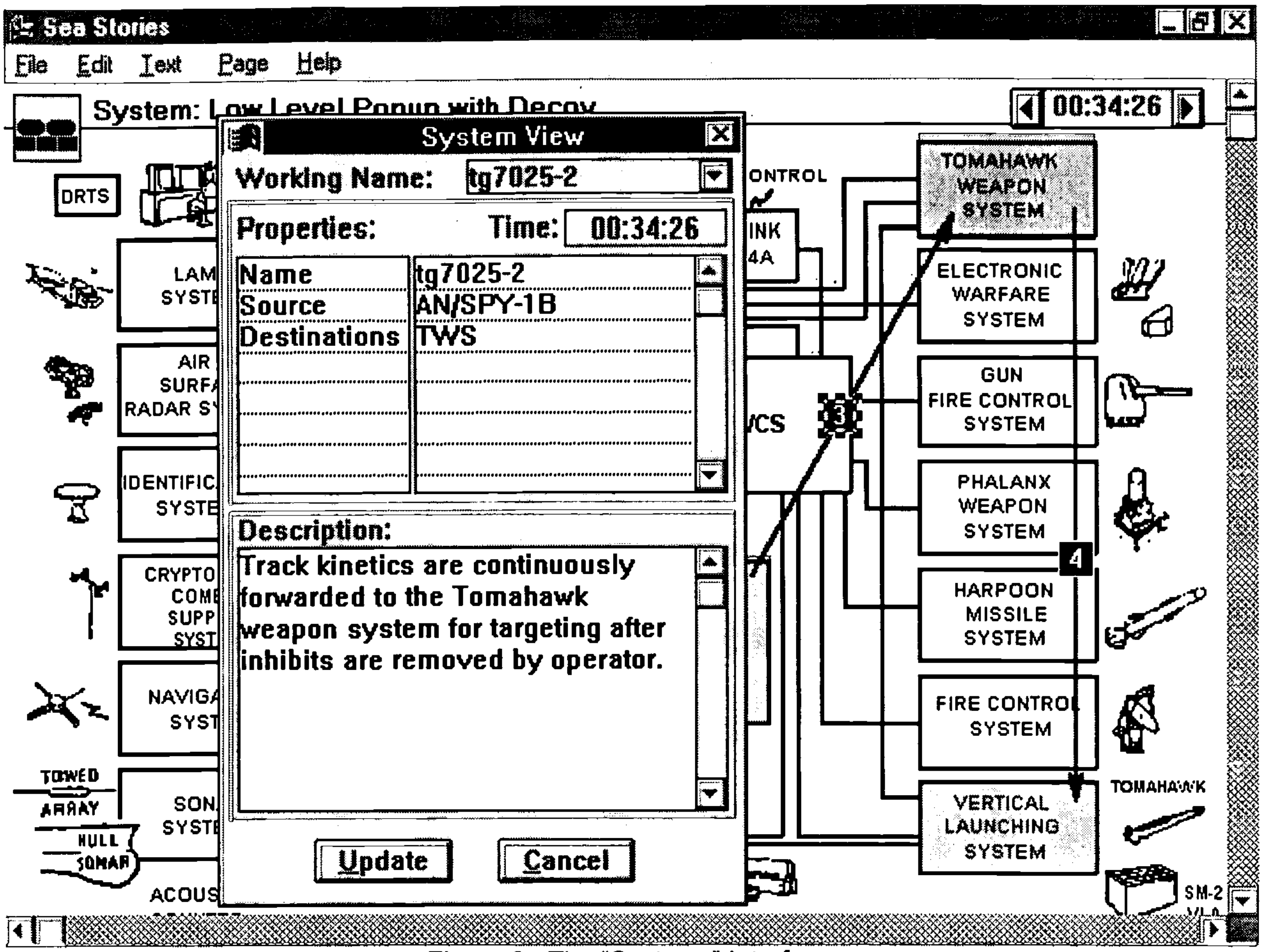

Figure 3. The "Systems" Interface

ownship's CIC. Ownship's picture of the situation is more complicated and more abstract than the simplified "ground truth" version presented in Figure 1. The presence of many other tracks reflects the real complexity of the environment, and it begins to introduce the difficult nature of the visual task of picking the signal -- the significant events in the story -- from the noise.

The dialogue window in the middle of Figure 2 shows the detailed information about the track of interest at this point in the story from the perspective of the CIC. The track of interest is represented in this depiction by the highlighted symbol just to the left of the popup window. This illustrates how ***Sea Stories*** connects the underlying data to related storyboards, and how different storyboards can be accessed from a single data point.

The *Systems* interfaces would allow the SME to depict the key equipment- and systems-related events in the scenario. For example, the Systems interfaces should depict factors relating to the operational performance of ownship displays, the capabilities and limitations of the ship's sensors or weapons, the lag between a track's actual change in course and speed and its detection by the SPY radar. The interface may include the ability to depict the physical effects, both visible and invisible, that underlie the operational characteristics of a system or piece of equipment, such as the effect of distance on a radar signal, or how changes in the environment affect different sensors.

Figure 3 shows an example storyboard diagram of *System* knowledge for a particular point in the story. The Figure shows the high-level system components and the interconnections among them. The graphical annotations are linked to database records that describe or explain how the system interactions are important at this point in the story. For example, in response to a new type of threat or a new operating environment, a system may need to be set up in a non-standard mode.

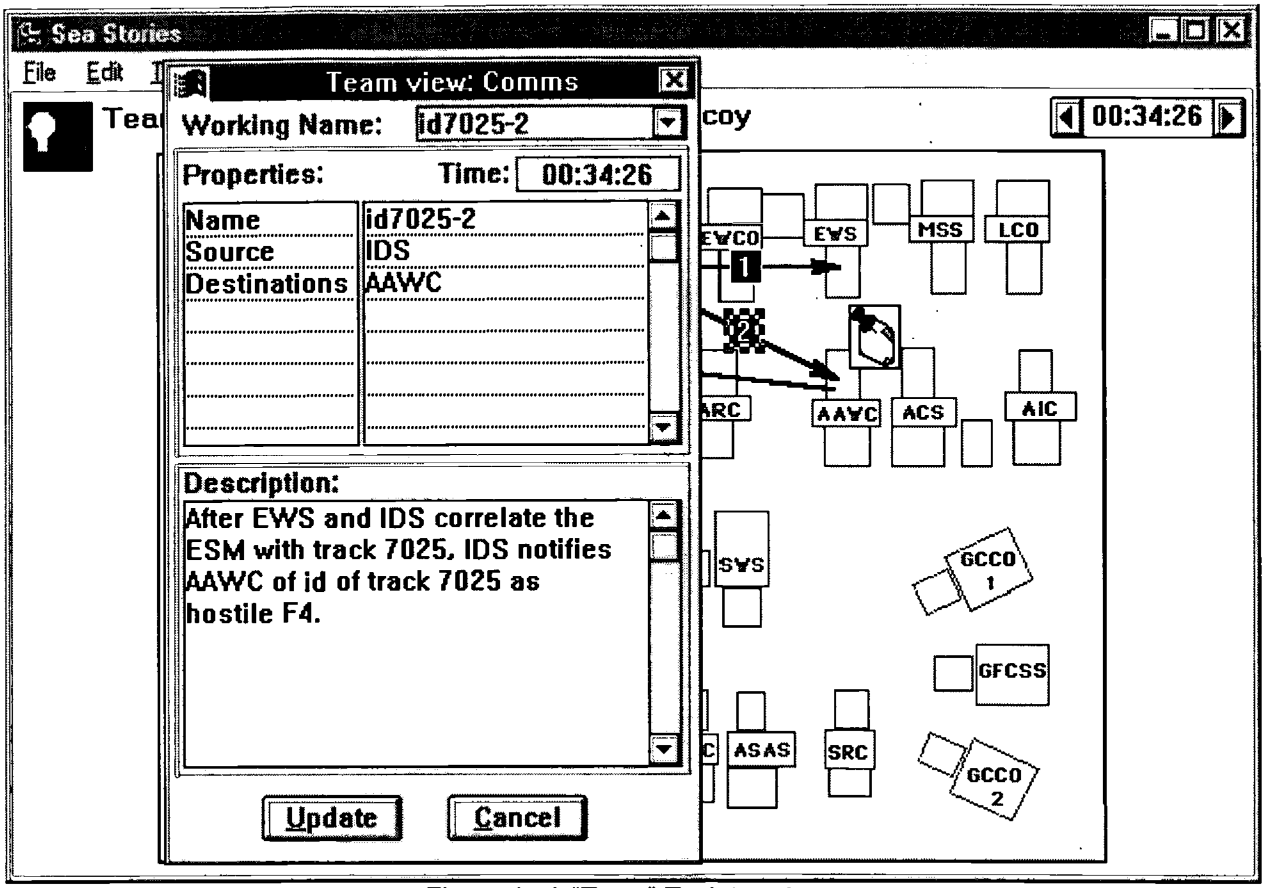

Figure 4. A "Team" Task Interface

The *Task* Interfaces permit the SME to depict the specific procedures that are associated with a particular scenario. This would include the activities of different watchstations in the CIC or other major players in the scenario. The procedures might be related to console operations, communications, application of the ROE, weapon allocation and use, or setting shipboard conditions. The *Task* interfaces also will include planning tasks such as positioning assets, pre-planned responses, or setting tripwires. The level of detail at which a task can be described will vary. For example, the SME might say, "at time X the AIC should vector the CAP to intercept the incoming track at distance Y from ownship," without describing what this task actually involves. Alternately, the SME might describe this task in detail because the scenario requires a variation in the way the task is normally done. The interface would allow the SME to decompose the tasks to the level necessary to capture the significant factors in the scenario.

The *Team* interfaces would be similar to the *Task* interfaces, except that the nature of the tasks should be at the team rather than the individual watchstation level. Team-level tasks focus on tasks such as communications, team leadership and initiative, and workload allocation. Figure 4 illustrates the *Team* knowledge representation screen. The example shows, through an annotated visual picture, a pattern of communication that should occur at a particular moment when a team is responding to the threat described in the story. If the nature of the communication justified it, audio depictions could also be used to illustrate this type of knowledge.

In a similar manner, other knowledge types can be described. Knowledge about a particular item of equipment could be illustrated from a line drawing or a photograph, and annotated using simple graphic tools linking visual annotations (e.g., lines, arrows, or boxes) to elements in the database. A task description might be illustrated and annotated using a flow chart.

Collaborative Work

As we suggested earlier, this procedure does not assume that knowledge regarding a particular tactical problem resides with one individual. Sea

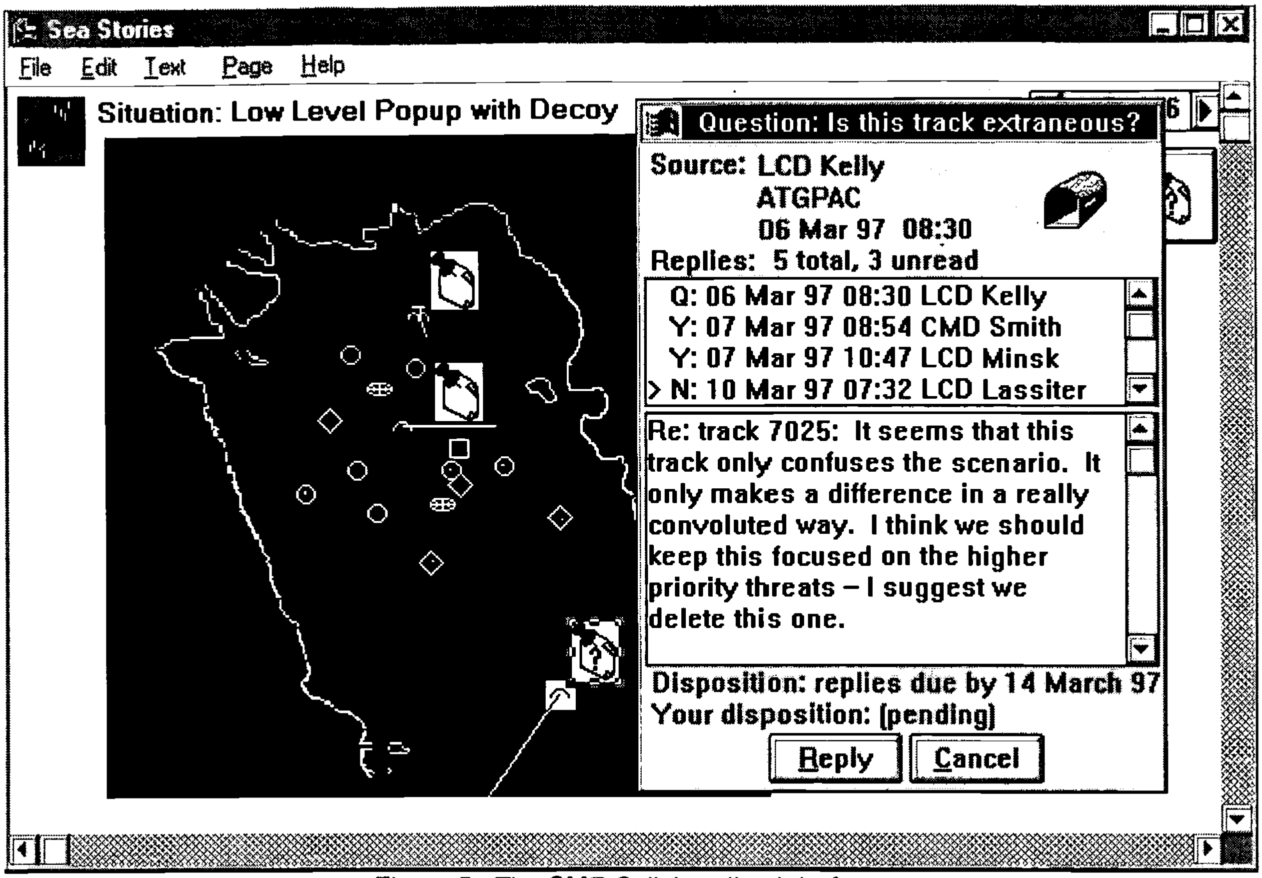

Figure 5. The SME Collaboration Interface

Stories facilitates the collaboration of a team of SMEs to cover the landscape. Frequently SMEs are in different locations and are available to work on the analysis at different times. The pervasive presence of computers and the rapid growth of wide area networks makes it easier and faster for persons to collaborate despite the barriers of time and distance. The field of computer science known as Computer Supported Collaborative Work (CSCW) has grown to study the promises and problems of these technologies. Commercial applications abound, from single-function tools to integrated desktop tools.

Figure 5 shows a concept for CSCW capabilities within ***Sea Stories***. In this example, a team member has raised a question about a particular track, and the other team members carrying on a discussion about the point using electronic mail. In the illustration, the electronic mail messages are linked with objects in the knowledge base, providing a flexible means for accessing and reviewing all the group's discussion issues related to, for example, a track or a workstation.

Along with context sensitive dialog, other important CSCW capabilities include maintaining an "institutional memory" by maintaining alternative storyboards, tracking who made revisions when, and providing personalized summaries of changes on request.

Using CSCW techniques within ***Sea Stories*** has some potential pitfalls. Research has shown that "depictional lock-on" sometimes occurs when developing design artifacts using CSCW. Depictional lock-on is the tendency of users to eventually focus on the depiction of the artifact rather than the goal of the analysis (Whitaker, Selvaraj, Brown, & McNeese, 1995). Given the strongly visual nature of ***Sea Stories*** artifacts, this could be a potential weakness, although it is certainly not unique to computer-based tools or CSCW. On-going CSCW research should be followed for guidelines and lessons-learned that can be applied to manage this problem for ***Sea Stories***.

OPEN ISSUES FOR RESEARCH

Besides the CSCW issues, there are two other research issues that will influence the success of ***Sea Stories*** as a computer-based knowledge articulation and analysis tool. The first issue relates to the flexibility (or the lack of flexibility) that pre-defined knowledge frameworks introduce. Will pre-defined frameworks constrain or bias knowledge elements? Can the knowledge frameworks within ***Sea Stories*** be flexible enough to accommodate radically different types of knowledge, or will they "force" the analysis along certain pre-defined paths?

As initially conceived, ***Sea Stories*** will provide a great deal of flexibility in defining and refining the knowledge frameworks. However, there will be a trade-off between flexibility and the guidance and/or on-line help that will be available to the users. For ***Sea Stories*** to provide significant help for users (experts in domain knowledge but not necessarily in this type of analysis), it must have a guiding framework. Pre-defining and providing that framework may constrain the user from doing certain things. A proper balance between these questions will need to be studied.

The second issue is the cost/benefit ratio that the user perceives in using the tool. Analysis is by its nature a difficult and tedious task that can be accomplished with ordinary tools (e.g., paper, pencil, telephone, voice mail, electronic mail, and fax machines). If a tool adds a layer of complexity to that task, the benefit of dealing with that complexity must be readily perceived.

The promised payoff in the ***Sea Stories*** concept is 1) the ease of entering, organizing, and accessing the knowledge prompted by creating the storyboards and 2) the opportunity to bring several highly qualified people in on the analysis without having to travel or coordinate schedules. Insofar as these promises can be realized, a degree of inconvenience will be acceptable.

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