Team Coordination and Shared Situation Awareness in Combat Identification

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Introduction

At its core, situation awareness (SA) involves being aware of what is happening around you to understand how information, events, and your own actions will impact your goals and objectives, both now and in the near future. SA is especially crucial in any domain where the effects of ever-increasing technological and situational complexity on the human decision-maker are a concern. In particular, poor SA in combat identification can lead to higher casualties due to combat errors, fratricide, and failing to anticipate enemy actions. Thus, meeting the combat identification requirements across the full range of military operations requires developing and maintaining high levels of SA of the current and future status of the operation in order to achieve an accurate characterization of entities (both friendly and enemy) in a combatant's area of responsibility. To optimize combat identification processes and enhance combat/mission effectiveness, greater emphasis must be placed on developing technologies that promote a coherent view of the battlespace through a common operating picture. Incoming data must not only be accessible, but filtered, analyzed, and integrated to develop an overall situational picture to support team coordination and shared SA. To address this issue, in this paper, we begin with a brief overview of the situation awareness construct, including defining the three levels of SA as well as distinguishing between team and shared SA. We then demonstrate, with examples from our own work, how a theoretical model of team SA can guide the development of new technologies, or enhance the utility of existing technologies (e.g., Blue Force Tracker), to improve combat identification. We conclude with implications for future research.

Situation Awareness Defined

Situation awareness can be defined as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988, 1995, 2000). This definition highlights three levels or stages of SA formation: perception, comprehension and projection. Level 1 SA (perception) involves the processes of monitoring, cue detection, and simple recognition, which lead to an awareness of multiple situational elements (objects, events, people, systems, environmental factors) and their current states (locations, conditions, modes, actions). Level 2 SA (comprehension) utilizes the processes of pattern recognition, interpretation, and evaluation to synthesize and integrate disjointed Level 1 SA elements to understand how this information will impact upon the individual's goals and objectives. Level 3 SA (projection) is achieved through knowledge of the status and dynamics of the elements and comprehension of the situation (Levels 1 and 2 SA), and then extrapolating this information forward in time to project the future actions and states of the elements in the operational environment. SA also involves both temporal and spatial components. Time is an important concept in SA, as SA is a dynamic construct, changing at a tempo dictated by the actions of individuals, task characteristics, and the surrounding environment.

Team and Shared SA

In many systems, people work not just as individuals, but as members of a team. Thus, it is necessary to consider the SA of not just individual team members, but also the SA of the team as a whole, including both team SA and shared SA. *Team SA* is defined as "the degree to which every team member possesses the SA required for his or her responsibilities" (Endsley, 1995, p. 39; see also Endsley, 1989). The success or failure of a team depends on the success or failure of each of its team members. If any one of the team members has poor SA, it can lead to a critical error in performance that can undermine the success of the entire team. By this definition, each team member needs to have a high level of SA on those factors that are relevant for his or her job. It is not sufficient for one member of the team to be aware of critical information if the team member who needs that information is not aware.

Shared SA can be defined as "the degree to which team members possess the same SA on shared SA requirements" (Endsley & Jones, 1997, p. 47; 2001, p. 48). As implied by this definition, there are information requirements that are relevant to multiple team members. A major part of teamwork involves the area where these SA requirements overlap. In a poorly functioning team, two or more members may have different assessments on these shared SA requirements and thus behave in an uncoordinated or even counter-productive manner. Yet in a smoothly functioning team, each team member shares a common understanding of what is happening on those SA elements that are common — shared SA. Thus, shared SA refers to the overlap between the SA requirements of the team members. However, not all information needs to be shared. Clearly, each team member is aware of much that is not pertinent to the others on the team. Sharing every detail of each person's job would only create a great deal of "noise" to sort through to get needed information. It is only that information which is relevant to the SA requirements of each team member that is needed.

Model of Team Situation Awareness

The situation awareness of the team as a whole, therefore, is dependent upon both (1) a high level of SA among individual team members for the aspects of the situation necessary for their job; and (2) a high level of shared SA between team members, providing an accurate common operating picture of those aspects of the situation common to the needs of each member (Endsley & Jones, 2001). Endsley and Jones (1997; 2001) describe a model of team situation awareness as a means of conceptualizing how teams develop high levels of shared SA across members. Their model specifies how four factors — SA requirements, SA devices, SA mechanisms, and SA processes — act to help build team and shared SA. In the remainder of this paper, we will demonstrate, with examples from our own research, how consideration of these four factors can enhance the design of technologies to effectively promote team coordination and shared SA during combat identification.

SA Requirements

SA Requirements has to do with the degree to which team members know which information needs to be shared, including their higher level assessments and projections (which are usually not otherwise available to fellow team members), and information on team members' task status and current capabilities. These critical SA requirements can by identified utilizing a Goal Directed Task Analysis (GDTA), a unique form of cognitive task analysis developed by SA Technologies that involves conducting extensive knowledge elicitation sessions with domain subject matter experts (for a detailed description of this methodology, see Endsley, Bolte, & Jones, 2003). The objective of the GDTA is to identify the major goals and decisions that drive performance in a particular job/position as well as to delineate the critical, dynamic information requirements associated with each goal and decision. The GDTA methodology provides a "technology independent" analysis of operator information requirements at all three levels of SA for each major goal and subgoal (see Figure 1). The resultant hierarchy of goals, decisions, and SA information requirements can be utilized for interface design, training development, system evaluation, and job/task analysis.

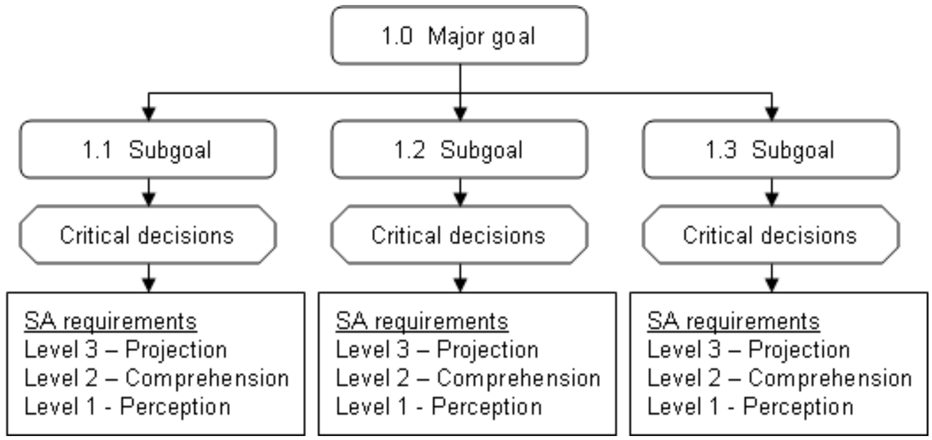

Figure 1. Format of Goal-Directed Task Analysis.

For example, we conducted a GDTA for several Army Brigade staff positions (Intelligence (S2), Operations (S3), Logistics (S4), and Engineer) to define the goals, decisions, and information requirements relevant to successful mission completion with respect to each specific position (for a detailed description of this research, see Bolstad, Riley, Jones, & Endsley, 2002). Overlaps in the goals of each team member exist in that they all share a common goal. These goal overlaps lead to the ability to identify overlapping (shared) SA requirements (Endsley, 1995, Endsley & Jones, 1997). Figure 2 shows an example of information requirements that are shared across positions. It should be noted, however, that Level 3 SA elements (projections) are rarely conveyed in display design, but instead must be communicated verbally by team members for successful coordination in most systems. Unfortunately teams are often poor at sharing Level 2 and 3 SA requirements, communicating only low level data (Level 1 SA) (Endsley & Robertson, 2000).

Implications for Combat Identification

As a necessary first step to improving SA in combat identification, a GDTA would be conducted to delineate the major goals and subgoals, decisions, and information requirements associated with this complex military operation. To illustrate, a major goal for combat identification may be "Maximize combat/mission effectiveness while reducing total casualties due to enemy action and fratricide," followed by the subgoal "Avoid friendly fire accidents." A key decision for this subgoal would be "Where are friendly forces located?" The associated SA information requirements for this decision include current and projected location of friendly units and enemy targets. This information would help ensure that no friendly units are within range of ongoing and planned fires and effects operations. However, it is not sufficient to simply identify the information requirements needed at the individual (soldier) level. Equally important is determining the shared information requirements across team members and how each team member will use this overlapping information. The insights gleaned would, in turn, feed into the design of system displays to enhance combat identification, as described next.

Intelligence Officer S2	Operations Officer S3	Logistics Officer S4	Engineer
Level 2 Terrain			
• Enemy limitations/ advantages due to terrain • Friendly limitations/ advantages due to terrain • Effect of terrain on enemy and friendly assets • Effect of terrain on anticipated troop movement time • Effect of terrain on system detection capability	• Accessibility of routes • Effect of terrain on movement times/time to position troops • Effect of terrain on rate of enemy closure • Effect of terrain on visual capabilities • Effect of terrain on communication capabilities • Effect of terrain on route difficulty	• Suitability of land for unit • Effect of terrain on ability to access location with each vehicle type • Effect of terrain on type of vehicles to be supported	• Potential approaches and exiting areas • Potential staging areas • Potential terrain suppression areas • Traffic ability • Visibility of the locations • Critical obstacle information • Past enemy usage of obstacles • Effect of terrain on location of enemy counter attacks.
Level 3 Terrain			
• Predicted effects of terrain on enemy COAs • Projected effects of terrain on friendly COAs • Projected terrain • Projected effect of terrain on troop movements	• Predicted effects of terrain on enemy COAs	• Projected effect of terrain on usage rates per item per unit • Projected effect of terrain on security of resources	• Estimated obstacle effectiveness • Predicted most secure location for assets, soldiers, vehicles • Predicted most survivable routes

Figure 2. Shared SA Level 2 and 3 terrain elements.

SA Devices

SA Devices include the different types of devices available for sharing critical SA information requirements, such as direct communication (both verbal and non-verbal), shared displays (e.g., visual or audio displays, or tactile devices), or a shared environment. In distributed command and control (C2) teams, in particular, non-verbal communication, such as gestures and display of local artifacts, and a shared environment are usually not available; thus, this places a far greater emphasis on explicit verbal communication and creating effective communication technologies and shared information displays to support distributed team performance. Along these lines, we developed an integrated decision support display suite, called Synergy, to support shared SA and collaborative planning and execution processes in Army Brigade C2 operations.

Following the Situation Awareness-Oriented Design (SAOD) process (Endsley, Bolte, & Jones, 2003), the Synergy display suite was designed to explicitly support the transmission of critical SA requirements across positions within distributed C2 operations in a mobile battlefield (Endsley, Bolstad, Jones, & Riley, 2003). Instead of loading operators down with hundreds of pieces of miscellaneous data, provided in haphazard fashion, our Synergy displays were designed to enhance operators' SA by bringing data together to form meaningful integration and groupings that could be easily absorbed and assimilated in time critical situations. Features and information were presented on the displays based on high priority operator goals and critical information requirements, as identified using a domain-specific GDTA. In addition, special overlays allowed tailoring of the displays to different positions while the common look and feel of the displays across the different positions supported shared SA (see Figure 3).

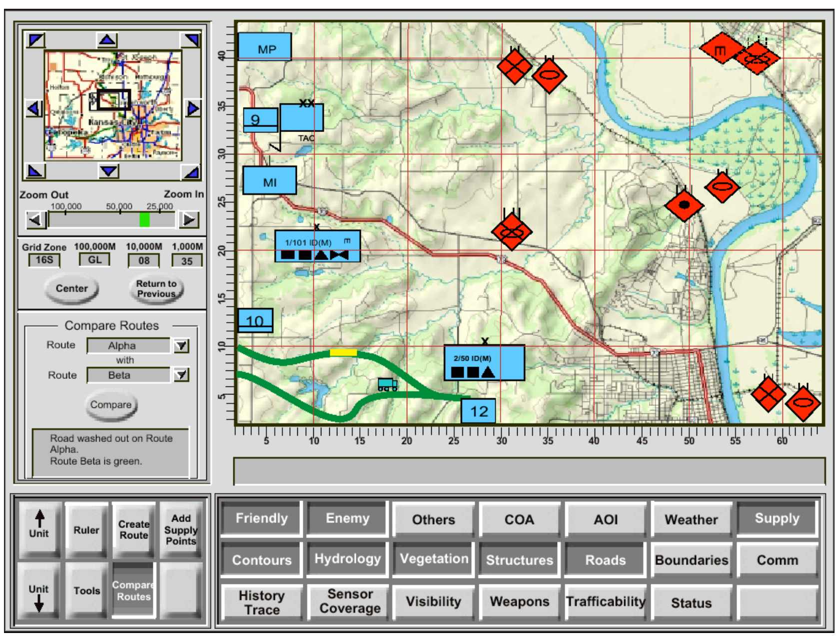

Figure 3. Logistics Officer Battlefield Map showing activation of relevant overlays.

In another example from our own work, we ran a set of experiments to test if shared displays and *shared mental models* (an important SA mechanism, described in the next section) would assist team members in performing joint tasks involving aviation theater defense (Bolstad & Endsley, 1999; 2000). Results indicated that the way in which people use shared displays is actually quite complex. Shared displays aided team performance by helping to build shared mental models. However, while the overall results support the use of certain types of shared displays, the use of shared displays that completely duplicated the other team members' display were found to be detrimental. Notably, teams without either shared mental models or shared displays performed most poorly.

Implications for Combat Identification

As in the design of the Synergy displays, the SAOD process can guide the development of technologies that support team coordination and shared SA during combat identification operations by providing team members with a coherent view of the battlespace through a common operating picture. Systems need to display incoming data in such as way as to assist operators in developing an accurate overall situational picture in a timely manner as well as effectively communicate critical shared SA information requirements across team members. Further, the SAOD process can also be applied to enhance the display design for existing technologies such as Blue Force Tracking (BFT). As noted earlier, a critical requirement for successful combat identification is enabling the sharing of a common operational picture and maintaining timely information regarding the location of friendly and enemy targets. Unfortunately, time lags between BFT signal reception and display of icons on the screen often occur, such as due to blindspots, deadspace, weak or disrupted signals, etc., leading to update delays that can sometimes be considerable. These disruptions may result in the display of outdated and inaccurate information regarding the exact location of vehicles. To address this issue, BFT display design could incorporate, for example, a feature that projects "predicted" location of vehicles given their current location, trajectory, and rate of movement, as indicated by the most recent update, as well as a confidence rating for the accuracy of the information displayed.

SA Mechanisms

SA Mechanisms involve the degree to which team members possess internal mechanisms, such as shared mental models and shared experiences, which support their ability to interpret information in the same way and make accurate projections regarding each other's actions. Shared mental models can be defined as "knowledge structures held by members of a team that enable them to form accurate explanations and expectations for the task, and, in turn, to coordinate their actions and adapt their behavior to demands of the task and other team members" (Cannon-

Bowers, Salas, & Converse, 1993, p. 228). Research has shown that when team members possess similar mental models their team performance is enhanced (Stout, Cannon-Bowers, Salas, & Milanovich, 1999). Conversely, when teams are not allowed to generate shared mental models, they perform significantly worse (Bolstad & Endsley, 1999). Shared mental models are thought to aid team members in their ability to anticipate information needs of other members, increase coordination between individuals, and reduce the need for explicit communication (McCann, Baranski, Thompson, & Pigeau, 2000). Shared mental models are also crucial to achieving a team's SA (Stout, Cannon-Bowers, & Salas, 1996).

One effective method for fostering shared mental models is via *cross-training*, that is, training each team member on the duties and tasks of the other team members. Several studies have shown that team members who are cross-trained outperform teams that are not (Bolstad & Endsley, 1999; Volpe, Cannon-Bowers, Salas, & Spector, 1996). Cross-trained teams also exhibit more taskwork- and teamwork-specific knowledge (Cooke, Kiekel, Salas, Stout, Bowers, & Cannon-Bowers, 2003). In our own research, we have also demonstrated the utility of cross training for improving team SA. Results of a study we conducted at the Personnel Recovery Education and Training Center revealed that cross-training, particularly in a leadership role, led to better SA. Participants, on average, exhibited greater SA following experience in the director role than prior to director experience.

Implications for Combat Identification

In the previous section, we discussed how shared displays may improve team performance by promoting shared mental models. The research cited in this section suggests that another approach to enhancing shared SA of essential information requirements related to combat identification is to focus on training specifically targeted at improving shared mental models within the team, such through cross-training on various team member roles. Taken together, consideration of essential SA Mechanisms, such as shared mental models, coupled with well-designed user-adaptable shared displays, can lead to improved team coordination during combat identification operations.

SA Processes

SA Processes refer to the degree to which team members engage in effective processes for sharing SA information which may include a group norm of questioning assumptions, checking each other for conflicting information or perceptions, setting up coordination and prioritization of tasks, and establishing contingency planning. SA

Technologies has been involved in conducting a series of workshops for the aviation domain aimed at providing participants with a heightened awareness of SA concepts and their relevance to successful individual and multi-crew operations, together with an introduction to practical skills for use in guarding against the loss of SA during critical periods of operation (Henderson, Endsley, & Hayward, 2000; Taylor, Endsley, & Henderson, 1996). Findings from experiential simulation exercises conducted during the workshops highlight several key team processes and behaviors that impact a team's ability to develop sufficient team SA to perform their tasks (see Table 1).

Table 1

Effective and Ineffective SA Processes

Ineffective	**Effective**
• SA black hole -- one member would lead others off	• Self-checking -- checked against others at each step
• Didn't share pertinent info -- group norm	• Coordinated -- to get information from each other
• Failure to prioritize -- members went in own directions; lost track of main goal	• Prioritized -- set-up contingencies; re-joining
• Relied on expectations -- unprepared to deal with false expectations	• Questioning -- as a group

In our past research, we have also developed training programs specifically aimed at enhancing essential SA processes, such as those cited above. For example, during a three-year program of research, we conducted a series of experiments to evaluate the effectiveness of six training modules designed to teach skills that underlie the development and maintenance of SA in General Aviation pilots (Bolstad, Endsley, Howell, & Costello, 2002; 2003). Modules focused on basic skills training (e.g., checklist completion, air traffic control comprehension, psychomotor skills) as well as higher order skills training (e.g., attention sharing, contingency planning) and intensive preflight planning. Overall, the modules were shown to be successful at improving these fundamental skills and also led to improvements in SA. In another project, we developed and validated the Infantry Situation Awareness Training (ISAT) Program designed to specifically enhance SA in Infantry Platoon Leaders (Strater et al., 2004). The ISAT modules focused on schemata training, SA communications, time management training and prioritization, and contingency planning (see illustrative example in Figure 4). In general, results supported the utility of computerbased training programs as a tool to enhance development of the skills necessary to gain and maintain the higher levels of SA that provide the foundation for decision making and action.

Figure 4. *Sample program screen from SA Trainer module of ISAT Program*.

Implications for Combat Identification

In terms of SA Processes, our past research highlights the value of training programs aimed at developing the skills that support SA in combat identification. Initial lessons in such a training program would target the basic skills underlying Level 1 SA (perception) in combat identification, such as monitoring, cue detection, simple recognition, and psycho-perceptual/discrimination of situational elements. More advanced training would build upon this foundation and emphasize higher order cognitive skills associated with Levels 2 and 3 SA (comprehension and projection), including, for example, explicit communication of critical shared SA information requirements, training on schemata that would support pattern matching in combat identification operations, and contingency planning to deal with unforeseen risks to friendly units during combat operations (e.g., delay in update from BFT due to signal disruption). In addition, specific training on the limitations of BFT would help calibrate soldiers' trust in the information displayed, prompting verification / confirmation of potentially outdated data, as needed.

Conclusions

In this paper, we described how a model of team situation awareness can be applied to meet the team coordination and shared SA challenges associated with successful combat identification in today's complex military battlefield. Consideration of SA requirements, devices, mechanisms, and processes all can serve to guide the design, development, and evaluation of the training programs and systems needed to improve soldiers' ability to process and understand the large volumes of oftentimes ambiguous data inherent in Army combat identification operations. Realizing the benefits of advanced information technology is dependent upon first meeting the challenge of managing this dynamic information base to provide soldiers with the situation awareness they need on a real-time basis. The line of research reported in this paper offers a promising theoretically-based, empirically-validated approach for addressing this critical requirement.

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