TR-01-812

# The Role of Shared Mental Models in Developing Team Situational Awareness: Implications for Training


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## ABSTRACT

This paper examines a skill that is critical to performance in complex team environments - team situational awareness. Specifically, it describes how the concept of shared mental models can be used to explain team situational awareness. A model is presented which explains how shared mental models are transformed into team situational awareness to enable effective team performance in dynamic task situations. Potential training strategies for enhancing team situational awareness are derived from this model and are discussed.

The importance of the situational awareness to the accomplishment of complex task performance has become widely recognized (Endsley, 1988; 1995; Sarter & Woods, 1991). Situational awareness has been defined as "the perception of the 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, 1995, p. 36). Moreover, it is apparent that a lack of situational awareness among team members can lead to severe consequences. For example, an analysis of 175 military aircraft mishaps that were attributed to human error revealed that the majority were caused by problems in situational awareness (Hartel, Smith, & Prince, 1991). This type of problem was exemplified by the well known and often discussed example of an airline crash attributed to poor situational awareness on the part of the flight crew - that of the Eastern Airlines Flight 401 crash into the Florida Everglades, December, 1972. This crew demonstrated surprisingly deficient situational awareness when they became preoccupied with a faulty landing gear indicator light and failed to recognize that their autopilot had become disengaged, which sent them to the ground and to their deaths. Evidence such as this has led researchers to consider situational awareness to be one of the most important factors for attaining task success and safe performance in complex environments (Endsley, 1995). Moreover, given that tasks that must be accomplished in complex and dynamic environments most often require teams for their successful completion (Salas, Dickinson, Converse, & Tannenbaum, 1992), the criticality of situational awareness to achieving effective teamwork is obvious. Further, whereas the need for situational awareness is most typically discussed in an aviation context, the importance of situational awareness in a variety of other operational contexts has been noted as well (Wellens, 1990).

Unfortunately, even though the importance of situational awareness has been recognized, several conceptual and methodological problems surround research regarding this construct (Stout, Cannon-Bowers, & Salas, 1994). Two of these difficulties will be addressed here. First, there has been insufficient attention paid to the construct of team situational awareness. Specifically, there is little conceptual and theoretical understanding of team situational awareness because most efforts have focused instead on individual situational awareness (Salas, Prince, Baker, & Shrestha, 1995). Indeed, a review of the literature reveals that no clear definition of team situational awareness has been provided. This lack of definitional clarity is not trivial in that it hinders the cumulation of knowledge in this area. It is only by providing a concrete conceptualization of team situational awareness that we can set boundaries in this area and provide a focus to guide research in this arena.

A second problem in this area is that there is a dearth of specific training strategies for enhancing team situational awareness (Salas et al., 1995), partially due to the lack of definitional clarity of this construct noted above, but additionally due to sparse guidance from the instructional design/training literature itself. For example, this literature is generally oriented toward individual rather than team-level change. This is an important limitation for designing training for team situational awareness because we are just beginning to understand the team element in training. Indeed, Salas et al. (1992) indicated that very little training research has been applied to team level change; it is much more common for studies to investigate behaviors of individual team members in a team setting than to focus on team-level behavioral change resulting from training. Furthermore, Salas and Cannon-Bowers (in press) noted the need to enhance specific methods, tools, and strategies for initiating team level change.

Another reason that the instructional design literature provides little guidance for identifying training strategies for improving team situational awareness is that it focuses predominately on behavioral rather than cognitive change, even though there have been several calls for the necessity of integrating cognitive theory and research into existing training research (Ford & Kraiger, 1995;

Jonassen & Tessmer, 1996, this issue; Kraiger, Ford, & Salas, 1993). Indeed, Royer (1986) contended that emphasizing behavioral components in training almost to the exclusion of cognitive factors has hindered the advancement of training. Moreover, Schmidt and Bjork (1992) suggested that using only behavioral indices of change due to training is an inadequate approach because this does not provide an understanding of underlying cognitive mechanisms. Training and assessing cognitive and learning outcomes may be more useful for predicting the transfer of complex team skills than simply observing immediate examples of behavioral change (Kraiger et al., 1993). The need for training higher-order cognitive skills is apparent in many team settings, such as for aviation teams, military tactical teams, surgical teams, and fire fighting teams. In these cases, the use of technological innovation results in a requirement for the processing of information from a variety of sources and the involvement of multi-skilled team members. In such environments, team situational awareness is critical and highly cognitive, and not understanding the mechanisms that underlie this construct seriously obstructs designing training for its improvement.

Given the problems inherent in the study of team situational awareness, research is needed to refine and understand the underpinnings of team situational awareness, as well as to delineate training strategies for its improvement. We believe that <u>understanding</u> team situational awareness is a prerequisite to accomplishing the more practical goal of identifying potential training strategies for team situational awareness. Therefore, the purpose of this paper is to present a clearer theoretical understanding of team situational awareness and to derive specific training strategies for enhancing team situational awareness. We draw on our experience in analyzing and investigating team phenomena and in training teams in a variety of settings (see Prince & Salas, 1993; Salas, Cannon-Bowers, & Johnston, in press) to address the relevant theoretical constructs, their definition, and potential training strategies for team situational awareness. We accomplish this by first presenting evidence of how cognitive mechanisms can help to explain team performance. Next, our work expands upon that of Salas et al. (1995), cited above, by proposing a conceptual model which extends their line of reasoning to show and describe how shared mental models can contribute to the development of team situational awareness. Finally, and perhaps most importantly, implications for training team situational awareness are derived from this model. We do this in the hope that we can contribute to the design, development, and testing of training strategies for team situational awareness.

## TEAM PERFORMANCE IN COMPLEX ENVIRONMENTS

Despite the recognized importance of teams in organizations (see Sundstrom, DeMeuse, & Futrell, 1990), only recently has an explanation of what teamwork is and how it affects performance begun to emerge. This lack of understanding is compounded when considering the manner in which situational awareness affects team performance, since little team research considers situational awareness, and little situational awareness research considers the team as a unit of analysis (Shrestha, Prince, Baker, & Salas, 1995). To begin to address this problem, it is important first to define what a team is, as well as to describe the common characteristics of the teams of interest in the current paper. It is also important to describe the types of team processes or teamwork skills that have been investigated in teams before considering how they relate to situational awareness.

### Defining Teams

Several definitions of teams exist in the literature, and common to all of these definitions is the need for team members to share and engage in cooperative action (Stout et al., 1994). It is this requirement for interaction and task interdependency that seems to truly define a group of individuals as a team. Therefore, we define or conceptualize a team as "a distinguishable set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited life-span of membership" (Salas et al., 1992, p. 4).

Some types of teams, such as tactical decision making teams, have additional characteristics which can affect the level of situational awareness that they achieve. For example, operational tactical teams engaged in modern warfare are hierarchically structured, have members with specialized roles, have members that receive information from multiple sources, have high levels of interdependence, and have strong requirements to adapt to changing conditions (Orasanu & Salas, 1993). In addition, these teams operate in stressful environments characterized by incomplete or conflicting information, rapidly changing or evolving scenarios, adverse physical conditions, performance pressure, time pressure, high work/information load, auditory overload or interference, threat of hostile engagement, and severe (often catastrophic) consequences of error (Cannon-Bowers, Salas, & Grossman, 1991). All of these demands can potentially make it more difficult for teams to interact effectively, and they may moderate the level of situational awareness achieved by the team (Shrestha et al., 1995).

Teamwork

Given the definition of teams provided here, we can now begin to describe the nature of teamwork in complex environments. Teamwork can be thought of as an identifiable set of behaviors, cognitions, and attitudes that contribute to the team's overall functioning. McIntyre and Salas (1995) summarized the empirical work conducted with military command and control teams and concluded that teamwork is comprised of a set of interrelated actions that include performance monitoring, giving and receiving feedback, closed-loop communication, backing-up behaviors, adaptability/flexibility, and coordination of action. However, as noted by Cannon-Bowers, Salas, & Converse (1993), the majority of the empirical investigations on teams have essentially ignored the more elusive elements of teamwork, such as adaptability and coordination of action. Past research has instead focused on more readily observable teamwork factors (such as communication). Furthermore, as noted previously, little attention has been paid to how teamwork components or interactive processes affect team situational awareness (Shrestha et al., 1995). We next discuss a construct that specifically considers the more elusive aspects of teamwork -- shared mental models -- that may in turn help us to understand team situational awareness.

## SHARED MENTAL MODELS AND TEAM PERFORMANCE

In recent years, several researchers have suggested that shared mental models are critical to team performance (see Cannon-Bowers et al., 1993). This construct may be useful for understanding how teamwork processes and situational awareness are related as well. This contention is supported also by the work of Salas et al. (1995) who attempted to identify components of team situational awareness and noted the importance of shared mental models to team situational awareness. Research on mental models has been conducted in a variety of domains, including situational awareness, and researchers have provided several definitions of mental models (see Rouse & Morris, 1986). Mental models have been used to explain coordination in teams, although much more literature is available to describe how mental models affect individual cognitive functioning and acquisition of knowledge (e.g., Frese, Albrecht, Altmann, & Lang, 1988; Hong & O'Neil, 1992; Jonassen & Tessmer, 1996, this issue; Montgomery, 1988; Sein & Bostrom, 1989), expert and novice differences (e.g., Glaser & Chi, 1988; Schvaneveldt et al., 1985), and human-system interaction (e.g., Palumbo & Lidwell, 1992; Zirk & Adelman, 1987).

In order to explain the more elusive aspects of coordination in teams, researchers have hypothesized that shared mental models are necessary for effective team coordination because they allow team members to anticipate and predict each other's needs and to adapt to task demands in an efficient manner (Cannon-Bowers & Salas, 1990; Cannon-Bowers, et al., 1993; Klimoski & Mohammed, 1994; Orasanu, 1990; Orasanu & Salas, 1993; Rouse, Cannon-Bowers, & Salas, 1992; Stout, 1995). In particular, researchers have argued that effective team members are able to develop accurate expectations for the performance of their team members (as well as their own performance) by drawing on common knowledge bases (mental models). Effective coordination is therefore enabled, without the need for extensive overt strategizing, because of these expectations. This is particularly critical when rapid, adaptive performance is required.

Types of Shared Mental Model Knowledge

When discussing shared mental models in teams, one question that arises is "what aspects of the mental model are most important for team members to share?". The type of knowledge that must be shared by team members, to successfully complete their tasks in complex environments, must be considered when addressing this issue. Cannon-Bowers et al. (1993) suggested that common knowledge of factors such as the overall task and team goals, individual tasks, team member roles, and the team members themselves are all important for effective team task accomplishment (also see Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995).

Converse and Kahler (1992) expanded upon the notion of Cannon-Bowers et al. (1993) and, through an extensive literature review, they proposed that declarative, procedural, and strategic knowledge are three knowledge types that team members can hold in common. When discussing shared mental model knowledge across several task situations, these knowledge types serve as a useful categorization system, and they are compatible with the Cannon-Bowers et al. (1993) distinction. As noted by Stout, Cannon-Bowers, and Salas (1994), Converse and Kahler defined declarative models as containing "information about the concepts and elements in the domain, and about the relationships between them" (p. 5). Stout, Cannon-Bowers, and Salas (1994) also indicated that they "contain knowledge of facts, rules, and relationships, and include knowledge of: the overall system, task goals, the relation among system components, equipment/hardware, positions/roles, and the team members themselves" (p. 298-299). Procedural mental models "store information about the steps that must be taken to accomplish various activities, and the order in which these steps must be taken" (Converse & Kahler, 1992, p. 6). As Stout, Cannon-Bowers, and Salas (1994) suggested, "procedural knowledge is essentially a sequential and timing type of knowledge, which also includes an understanding of task action/goal relationships and of the manner in which other team member actions affect this relationship" (p. 299).

Given that they each contain both knowledge-based and rule-based components, both declarative and procedural knowledge are consistent with Rasmussen's (1986) behavioral taxonomy (i.e., knowledge-based, rule-based, skill-based). By identifying that team members must share aspects of knowledge, however, the declarative and procedural knowledge categories go a step further than Rasmussen's taxonomy. That is, portions of declarative and procedural knowledge bases must be shared among team members. Without empirical investigation, it is difficult to specifically identify which portions of these knowledge bases must be shared; however, it seems intuitive that it is more important for team members to share some aspects of the model than others. For example, it is probably not necessary for team members to share an understanding of detailed information regarding the operation of each other's equipment. However, one could speculate that team members should understand: 1) what information a fellow team member needs from them in order for him/her to complete his/her tasks, and 2) when in a task sequence this information should be presented. An example may help to clarify this point. Consider a sophisticated fighter aircraft flown by a pilot and Navigational Flight Officer (NFO). The pilot probably does not have to understand how the on-board radar operates in detail (which is the NFO's responsibility), however, the pilot should understand when crucial flight information is not available from the radar scope so that he/she can provide that information to the NFO as necessary.

Perhaps more important than the declarative and procedural models proposed by Converse and Kahler (1992) is the strategic model. Strategic mental models "are comprised of information that is the basis of problem solving, such as action plans to meet specific goals, knowledge of the context in which procedures should be implemented, actions to be taken if a proposed solution fails, and how to respond if necessary information is absent" (Converse & Kahler, 1992, p. 6). According to Converse and Kahler (1992), strategic models hold declarative and procedural knowledge which is compiled. As Stout, Cannon-Bowers, and Salas (1994) stated, "through experience, strategic knowledge allows for automatic performance and enables expert team performance via the application of appropriate task strategies" (p. 299). This contention was also supported by Anderson (1983). While not referring to teams, he indicated that, when cognitive resources are mobilized through the automatization of task components, the development of task strategies is made possible.

Rasmussen's (1986) skill-based category seems to describe the essence of strategic knowledge. That is, consistent, effective team performance is enabled only when strategic knowledge is shared among team members. Considering the example provided above for shared declarative and procedural knowledge, these models only provide general and global knowledge for understanding the information requirements of fellow team members and for knowing when in task accomplishment these requirements are crucial. As indicated by Stout, Cannon-Bowers, and Salas (1994), declarative and procedural knowledge "is static, while strategic knowledge is dynamic and is updated based upon task parameters and team member interactions in response to task events/demands. Thus, the strategic model takes knowledge stored in declarative and procedural models and applies that knowledge" (p. 299) within a dynamic, changing task. As a result, an understanding is provided of:

cue/action sequences (i.e., which cues should trigger which responses), cue patterns and their significance (i.e., which cue patterns are associated with particular task strategies), team resources and capabilities (i.e., what resources/expertise are available in the team in order to solve a problem), and appropriate task strategies (Cannon-Bowers et al., 1995). It can be hypothesized that, in order to interact effectively and to adapt to changing task conditions in complex team environments, information on each of these factors must be shared among team members.

Investigations of Shared Mental Models

Although several authors have discussed the importance of shared mental models in teams (including specifying the types of knowledge contained in these models), there is a clear lack of empirical research related to this phenomenon and related to how shared mental models among team members affect team situational awareness. Specifically, very few studies have actually measured shared mental models in teams and related them to effective coordination, situational awareness of the team, or team performance. However, general support for the importance of shared mental models among team members has been provided: 1) indirectly from the results of several studies (Cream, 1974; Hemphill & Rush, 1952; Oser, McCallum, Salas, & Morgan, 1989); 2) post hoc to explain results of other studies (Orasanu, 1990; Kleinman & Serfaty, 1989); and 3) via empirical investigation (Adelman, Zirk, Lehner, Moffett, & Hall, 1986; Brehmer, 1972; Heffner, Mathieu, & Goodwin, 1995; Minionis, 1994; Stout, 1995; Volpe, Cannon-Bowers, Salas, & Spector, 1996).

Perhaps one of the first studies to find indirect support for the importance of having shared mental models in teams was conducted by Hemphill and Rush (1952). These researchers studied B-29 aircrews who were completing combat crew training. Each crew member was required to complete a multiple choice exam regarding how well he/she knew the duties and responsibilities of seven different crew members with whom he/she interacted in the aircraft. Results indicated that crew members who scored better on the exam, and thus knew more about their fellow crew members' duties and responsibilities, were also rated as performing more effectively as crews. The assumption is that crew members who knew each other's functions and role responsibilities shared knowledge of these factors, which allowed them to perform more effectively.

Cream (1974) also indirectly supported the importance of shared mental models in teams. He investigated the relationship between the knowledge held by aircrew members of one another's role responsibilities and crew effectiveness. Results indicated that more effective crews were those that contained members who possessed more accurate information about the functional requirements of one another. Cream concluded that crew members who had this knowledge were able to form more accurate expectations of each other's actions. In addition, Cream suggested that it is critical for crew members to be aware of the operational demands (i.e., who performs which tasks and what interactions are made with which piece of equipment) and interactional demands (i.e., who tells whom which piece of information) of one another for these expectations to develop.

Further indirect support for the importance of shared mental models in teams can be seen in the results of an investigation of operational tactical teams (Oser et al., 1989). These authors found that more effective teams were more likely to offer information before it was requested. It can be hypothesized that the team members were able to anticipate the information needs of one another via shared mental models, and thus were able to provide required information in advance.

Using shared mental models as a post-hoc explanatory construct, Orasanu (1990) derived conclusions about decision making and performance in an aircrew team. She re-analyzed transcripts of ten two-person crews (i.e., a Captain or pilot and a First Officer or copilot) flying a scenario developed by Foushee, Lauber, Baetge, and Acomb (1986). Results indicated that different patterns of communications were demonstrated by effective and ineffective crews, although the crews were not found to differ in the overall frequency of communications they demonstrated. Captains of effective crews were more planful and less reactive. Orasanu (1990) noted that these plans allowed the communications of the Captains to take on meaning and helped "to build a shared mental model of the situation" (p. 15). She concluded that "shared mental models assure that all participants are solving the same problem and create a context in which all can contribute efficiently" (p. 15).

Kleinman and Serfaty (1989) also used the notion of shared mental models to explain performance in teams. They reviewed an investigation by Kohn, Kleinman, and Serfaty (1987) which employed a low-fidelity command and control simulation task where teams of two individuals were required to destroy enemy threats with limited resources. They interpreted the results of this study as indicating that teams adjust their coordination strategy depending upon task load. That is, in high workload conditions, the subjects were able to accurately transfer resources to their teammate (to destroy threats in a timely manner) without being asked and without the need for overt action plans, thereby engaging in what Kleinman and Serfaty called an <u>implicit coordination</u> strategy. The assumption is that shared mental models among the team members allowed them to do this.

Through empirical investigation, Adelman et al., (1986) attempted to manipulate shared mental models in team members. These researchers, like Kohn et al. (1987), were interested in examining team behavior in a command and control type of environment. Subjects were undergraduate students who participated in teams of three to defend a ninety-degree sector of space against enemy threats. Results of this effort did not support the hypothesis that teams with shared mental models would perform better. However, according to Cannon-Bowers et al. (1993) and Stout (1994), it can be debated whether shared mental models were actually manipulated in this study at all. Specifically, the manipulation described by Adelman et al. appeared to cause only a small portion of knowledge to be shared among team members.

Volpe et al. (1996) also attempted to manipulate shared mental models in teams, although they used the term Inter-Positional Knowledge (IPK) instead, which they defined as "a type of role knowledge in which team members have information regarding the appropriate system operation behavior for each interdependent member within the team structure" (p. 4). This definition is consistent with the "team interaction" type of shared mental model proposed by Cannon-Bowers et al. (1993). Subjects in the study interdependently performed a low-fidelity flight simulation task as two person teams. Results indicated that high IPK teams were rated significantly higher in terms of coordination and performed their task significantly better than low IPK teams, although high IPK teams did not communicate significantly differently in terms of overall frequency than low IPK teams. However, high IPK teams were found to volunteer information more frequently than low IPK teams, suggesting that they were able to anticipate and predict the information requirements of fellow team members without the need for explicit requests.

Finally, three studies were found that attempted to measure shared mental models and relate them to team performance and other team variables (e.g., Heffner et al., 1995; Minionis, 1994; Stout, 1995). These studies all used techniques which assessed the degree to which knowledge structures of team members were similar, and they postulated that this is a representation of the degree of shared mental models present among team members.

First, Heffner et al. (1995) examined the relationship between team shared mental models, team process behaviors, and performance in a low-fidelity flight simulation task. Mental models were assessed by having participants complete paired comparison ratings of a set of concepts that represented both the team and the task models of Cannon-Bowers et al. (1993). These ratings were analyzed using UCINET (Borgatti, Everett, & Freeman, cited in Heffner et al., 1995) to determine the extent of convergence in the models of team members. Results revealed that teams with "team" models that had greater convergence performed their task significantly better, although this relationship was not found for the "task" model. Results also showed that both the team and task models related directly to the process behaviors demonstrated by the team. However, the authors also found that, when controlling for variance in performance, it was the process behaviors that had the direct effect on performance, while variance in the process measure was accounted for by both types of mental models. This suggested a mediated relationship for process variables and performance.

Second, Minionis (1994) studied whether teams that had mental models with greater overlap were found to engage in better coordinated performance. As teams of three, participants completed a mock tank platoon task in which they were to defeat enemy assets while preserving their own. While mental models of the equipment, task, and team (Cannon-Bowers et al., 1993) were assessed using a concept mapping technique, analysis of the relationship between shared mental models and other team variables considered the mental models as an aggregate, rather than treating them separately. These models were analyzed to determine the extent to which the three team member's concept maps overlapped. This was described as either a 3-way (100%) overlap, a 2-way (66%) overlap, a 1-way (no overlap), or a 0-way (no overlap and not correct answers). Results revealed that the degree of shared mental models present significantly affected coordination (measured by the average distance between tanks), one of seven communication content types (i.e., feedback), and team output variables (i.e., overall performance and coordinated performance). Results also showed that communications related to several content categories predicted coordination, as well as team output variables (i.e., overall performance, coordinated performance, and noncoordinated performance). Contrary to the results of Heffner et al. (1995) (that team process variables mediated the relationship of shared mental models and performance), the Minionis results did not support this relationship, given that six of the seven communication content categories were not significantly influenced by the shared mental model variable.

Finally, Stout (1995) investigated the relationship between team planning behaviors and shared mental models among team members. Participants were required to perform as a team to complete a surveillance/defense mission using a low-fidelity helicopter flight simulation. The degree of similarity in the knowledge structures of team members was assessed by having participants complete paired comparison ratings of a set of concepts intended to represent the information sharing requirements of team members to effectively complete their mission. These ratings were analyzed to determine the degree of similarity present among team members using Pathfinder C (see Schvaneveldt, 1990). Stout noted that special instructions were given to subjects in order to extend the use of this procedure and to tap deeper levels of shared understanding akin to the notion of strategic mental models used here (see also, Stout, 1994). Results revealed that teams that were rated as higher in the quality of their planning were shown to develop more similar knowledge structures of the interaction requirements of the task, suggesting that they had greater shared mental models of each other's informational requirements. In addition, these teams were found to use more efficient communication strategies in completing their tasks, when it was presumably more important for them to do so (see also, Stout, 1994).

In summary, support for the importance of shared mental models in teams can be found in several research investigations in the literature. Essentially, some support has been found that shared mental models are influenced by planning behaviors and can be used as an explanatory mechanism for: implicit coordination in teams, maintenance of performance under stress or high workload, and the ability of team members to anticipate and predict each other's needs. Shared explanations, leading to shared expectations for task performance, have been proposed to be the underlying mechanism of shared mental models that allows the above to take place (Rouse et al., 1992).

Investigations of Team Situational Awareness

Salas et al. (1995) noted that most investigations of situational awareness have focused at the individual level of analysis rather than delineating the specific factors which characterize team situational awareness. They suggested that team situational awareness is more than the sum of each individual team member's situational awareness and includes team process behaviors as well. Furthermore, they indicated that team situational awareness is due, at least in part, to the shared mental models of team members. Thus, investigations of team situational awareness should seek to determine the relationship of shared mental models and team process behaviors to situational awareness assessed at both the individual and the team level.

While we agree with the supposition of Salas et al. (1995) that investigations of team situational awareness per se are desperately lacking from the literature, several investigations warrant discussion because their results provide some insight about the concept of team situational awareness indirectly. For example, Orasanu (1990) investigated team decision making in effective and ineffective aircrews. Crews were categorized based upon the types and severity of errors that they demonstrated. She analyzed the problem solving and decision making strategies used by the crews in dealing with a problem situation in their mission. Results indicated that "high performing crews showed twice the level of situation awareness as low performing crews, and about 50% more decision-relevant actions" (p. 6).

Mosier and Chidester (1991) investigated the relationship between situational awareness and team performance in three-person aircrews flying a Boeing-727 simulator. These authors reasoned that the handling of abnormal or emergency situations could be affected by the accuracy and completeness of situation assessment. They investigated crews flying two problem or nonroutine flight segments. Performance data consisted of expert ratings of crew coordination and performance errors classified according to severity. Communications between the crew members were analyzed to obtain an assessment of situational awareness. The authors concluded that, "the level of crew situation awareness, as indicated by the accuracy and completeness of information transfer processes, is related to overall performance" (p. 800). In addition, they noted that situation assessment appeared to be a dynamic process. That is, crews seemed to make quick, reflexive decisions (consistent with the notion of recognition-primed decision making of Klein, 1989) based upon a few critical pieces of information. However, crews then gathered new pertinent information <u>after</u> making the decision and rechecked previous information, seemingly ensuring that the situation had not changed and that the validity of their assessment remained.

Stout, Salas and Carson (1994) investigated the relationship between team interaction processes and effective team performance in teams performing a low-fidelity simulation task. They defined (and measured) situational awareness as a set of behaviors, which included: 1) commenting on deviations; 2) providing information in advance; 3) identifying problems/potential problems; 4) demonstrating an awareness of task performance of self/others; 4) verbalizing a course of action; and 5) demonstrating an awareness of mission status. Results indicated that both "pilot" and "copilot" situational awareness were significantly, positively related to mission performance, and that the situational awareness of the "pilot" was significantly, positively related to number of targets destroyed.

Brannick, Prince, Prince, and Salas (1995) also investigated the relationship between team coordination behaviors and team performance using a low-fidelity simulation task. Subjects were instructor and students pilots from a naval aviation training community, who performed two scenarios that varied in difficulty. Results indicated that the level of situational awareness (defined as Stout, Cannon-Bowers, & Salas, 1994) demonstrated by a crew was found to correlate significantly and positively with team performance across both scenarios.

Jentsch, Sellin-Wolters, Bowers, and Salas (1995) re-analyzed a subset of the data collected by Brannick et al. (1995). They assessed communications of the crews related to several team skill categories, including situational awareness, five minutes prior to the onset of a problem in the scenario that the team was performing. Results indicated that situational awareness behaviors, as measured by the communication analysis, were one of the predictors of how quickly the crew detected the problem with which they were faced.

Finally, Stout (1994) examined the relationship between planning, shared mental models, and one element identified as critical to team situational awareness, namely provisions of information in advance (Prince & Salas, 1993). Results revealed that during high workload segments of the flight task studied, teams that were better at planning provided more information in advance of explicit requests, presumably demonstrating higher situational awareness on this dimension.

It should be pointed out that most of the studies on team situational awareness cited above rely on a common metric in their assessments. That is, situational awareness is measured via communications. An exception to this was the study by Stout (1995), which also assessed team member shared mental models. Also, all of the studies employed an aviation cockpit as the context of investigation. In a cockpit environment, it may be argued that some elements that are needed for crews to be situationally aware are only obtained through communications with fellow crew members, air traffic control, or ground resources. However, a limitation of assessing situational awareness by using only communications is that one cannot be certain of whether situational awareness was truly lacking or simply not talked about. Furthermore, some types of teams operate in environments where communications are severely restricted, yet high levels of situational awareness are critical. As indicated by Kleinman and Serfaty (1989), other mechanisms must exist for teams under high workload conditions, with restrictions on their communications, to maintain their performance. This argument can be logically extended to include an explanation for how team situational awareness is obtained and maintained under such conditions.

Taken together, the work on team situational awareness has several implications. These include: 1) existing mental models shape individual situational awareness; 2) shared mental models seem to be critical to team performance because they allow each member to form adequate explanations and expectations of task and team actions; and 3) team situational awareness enhances team performance. Therefore, we contend that team situational awareness is influenced significantly by shared mental models as well. In fact, it has been suggested that the overlap of each individual team member's level of situational awareness represents the level of team situational awareness attainable[1]. Moreover, work previously cited by Salas et al., (1995) suggested that shared mental models among team members are a critical requirement for team situational awareness.

However, the attainment of situational awareness is not guaranteed simply by having an adequate model of the situation. Instead, it is a necessary prerequisite (Sarter & Woods, 1991). According to Sarter and Woods (1991) situational awareness refers to "a continuously updated and integrated mental representation of a mission" (p. 23). Expanding upon this notion, it would seem that a prerequisite for achieving team situational awareness is for team members to hold shared mental models or shared knowledge bases. Further, differential utilization and continuous updating of shared

[1]We would like to clarify that we do not believe that the "overlap" of knowledge is what is critical for enhancing team situational awareness; rather it is crucial that knowledge in mental models is *compatible* and thus allows for expected behavior than can be accurately interpreted, explained, and predicted (see also Cannon-Bowers & Salas, in press).

knowledge bases would seem to be dictated by the dynamics of the task situation and consequent behavior of team members. We next begin to delineate how shared information among the team members is transformed into team situational awareness in teams performing under dynamic task conditions.

## A MODEL OF TEAM SITUATIONAL AWARENESS

Figure 1 attempts to illustrate the process of how shared mental models are transformed into team situational awareness (see also Stout, Cannon-Bowers, & Salas, 1994). The model can be used to explain the development of mechanisms that allow for team situational awareness across a range of task environments and situations. It also describes the process by which shared mental models are used to achieve team situational awareness in particular situations.

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Insert Figure 1 About Here

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The model shown in Figure 1 addresses three related situations with respect to shared mental models and team situational awareness: 1) those which virtually preclude any explicit strategizing among team members, 2) those that allow for only the most timely and efficient explicit strategizing, and 3) those that allow for extensive or unlimited explicit strategizing. From a developmental standpoint, we would argue that teams primarily use the third of these task situations to develop and refine shared mental models. These shared mental models then allow the team to cope with even the most demanding situations when explicit strategizing is not possible. It should be noted that by "explicit strategizing" we are referring to behaviors engaged in by team members that clarify, confirm, and/or disseminate information, plans, expectations, roles, procedures, strategies, future states, etc. among team members. Most often, this is accomplished via verbal communication, but it can also occur via non-verbal communication (e.g., hand signals or electronic messages).

Before discussing team situational awareness in the three situations noted above, we must first provide a discussion of the overall flow of processes outlined in Figure 1. In a general sense, Figure 1 suggests that members of effective teams enter the performance setting with pre-existing knowledge bases that are shared. That is, there is a common understanding among members of effective teams due to their compatible declarative and procedural knowledge bases. This shared declarative knowledge enables them to form a compatible understanding of the overall task or mission and of member roles and activities necessary to meet task or mission demands. Shared procedural knowledge allows them to commonly understand the general sequence of task activities required to perform efficiently. Especially when conditions are dynamic and unpredictable, this shared understanding is necessary, but not sufficient, to enable teams to adapt to changing task demands.

Shared strategic knowledge, which goes beyond declarative and procedural knowledge, is more important for effective performance in dynamic task situations. That is, it is also important for team members to have a compatible understanding of several additional task parameters, including: 1) the operational context in which performance is occurring; 2) actions that must be taken when unexpected events occur; and 3) information that is required to make critical decisions, as well as how to obtain and to transmit this information in order to respond appropriately to the situation and to implement correct actions. When team members share strategic knowledge, it enables them to interpret cues in the environment in a compatible manner and to take action on these cues that is both accurate and expected by their teammates.

In summary then, Figure 1 hypothesizes that when task or environmental parameters require action, effective teams draw on shared knowledge bases to arrive at a common or team level of situational awareness among members. It should be noted that some understanding of information that must be passed to team members may be held in declarative and procedural knowledge bases. However, it is assumed that the information that must be passed when conditions are dynamic, have changed, and must be adapted to is most critical. This information is contributed only by exercising strategic knowledge bases.

Environmental Demands and Team Situational Awareness

As noted, Figure 1 is meant to describe the development of team situational awareness in three related situations: when explicit strategizing is not possible; when explicit strategizing is possible, but limited; and when explicit strategizing is extensive or unlimited. Taking the first case, Figure 1 predicts that information shared in team members' strategic mental models allows them to: 1) draw common explanations of the meaning of task cues, 2) make compatible assessments of the situation, 3) form common expectations of additional task and information requirements, 4) form accurate predictions regarding the behavior of teammates, 5) arrive at compatible task strategies, and 6) take action that is in keeping with what teammates expect of them. Thus, when teams are faced with dynamic task situations, members are able to perform effectively by forming compatible understandings of cue/action sequences, cue patterns and their significance, team resources and capabilities, and appropriate task strategies, due to the utilization of their pre-existing shared strategic knowledge. Moreover, the model predicts that all of this can occur *without the need for team members to strategize overtly*; rather, it can be considered an automatic process that is enabled by pre-existing shared knowledge (in terms of the model, the sequence of events is across paths 1, 2 and 3). Team coordination in this case can be considered "seamless", or what Kleinman and Serfaty (1989) termed implicit coordination.

Figure 1 predicts further that once an action is performed, its impact is evaluated to determine whether the intended outcome was attained. Further assessment of the situation and determination of potential additional necessary actions is required. The result is adaptive performance that occurs when feedback from previous actions updates existing team mental models (path 4). When there are shared explanations and expectations throughout this cycle, there should be compatible assessments of the situation throughout task performance because updated information itself should remain consistent and compatible. When appropriately updated based upon task parameters and the behavior of teammates in response to task events, shared strategic knowledge bases that team members bring to the operational context allow for sustained team situational awareness.

Given a shared understanding of "the big picture", this continual reassessment allows for a fine tuning of team coordination and performance. In fact, there has been evidence from research that members of effective teams engage in this "fine tuning" behavior, which enhances situational awareness in the team (Mosier & Chidester, 1991). According to the model, shared strategic knowledge permits effective teams to know what additional information to look for in order to maintain a valid assessment of the situation, and therefore, dynamic reassessment can take place. This is especially true when conditions are unpredictable and changing.

An example of this type of performance may help clarify our thoughts. Consider the blind pass in basketball. If the decision to pass the ball blindly were random, we would see guards tossing the ball indiscriminately and to no avail (i.e., the intended receiver would miss it a preponderance of the time). Obviously this is not the case in effective teams. Instead, we would hypothesize that the guard and intended receiver are simultaneously assessing a pattern of cues in the environment that trigger a compatible behavior sequence (i.e., the guard throws the ball and the intended receiver is there to catch it). In many cases, this is done without the need for the guard and receiver to communicate (either verbally or non-verbally). In addition, the completed cue/interpretation/behavior sequence provides feedback for both players (and other teammates) whether or not the pass is successful. That is, it provides positive or negative information with which players can update their knowledge bases.

In the second case described above–where team members can engage in limited explicit strategizing–a similar procedure is hypothesized in Figure 1. However, in this case, team members are able to engage in some strategizing prior to taking action or making a decision (paths 5, 6, 2, 3, 4). This may (and perhaps should) be as simple (and quick) as using efficient communications to highlight or verify a piece of information or course of action (e.g., when one member points something out that another member had not noticed, enabling both to consider the overall significance of the information based on their strategic knowledge). Going back to the blind pass example, this case may be illustrated as one in which the guard shouts something to teammates that alerts them to the fact that he/she intends to pass the ball. Once again, team members can use information provided by these situations (e.g., the cues that led to it; the nature of the pass, etc.) to update and refine their shared knowledge bases.

In the final case listed above–when team members are free to strategize extensively–Figure 1 predicts a similar sequence of events as when strategizing is limited (i.e., paths 5, 6, 2, 3, 4), except that in this case teams can make extensive use of strategizing time. In fact, such occasions foster the development of shared knowledge bases both prior to and during the task performance situation (e.g., as when teams make long term plans prior to the task performance situation, and short term contingency plans during task performance). These planning behaviors help teams understand what each member will be responsible for, what each member expects given a set of task events or cues, and which strategies are appropriate under various conditions. Results of the studies by Orasanu

(1990) and Stout (1994) support this contention. Namely, Orasanu found that crew effectiveness was related to the extent of prior planning (strategizing) engaged in by crews in the routine segments of flight, while Stout found that pre-mission planning helped teams use more efficient communication strategies during high workload periods of the mission.

Essentially, extensive strategizing allows the team to form more accurate explanations and expectations for the performance of teammates, and for understanding what is expected of them. When task conditions turn dynamic and are high in workload, this prior strategizing reinforces shared knowledge bases and enables quick and efficient communications (as in case 2) or seamless performance with no communications at all (as in case 1). Turning again to the blind pass analogy, this case might be best illustrated when the team is in practice and can discuss how and when the blind pass is appropriate. Such discussions provide a primary mechanism for building shared knowledge bases among team members.

A complete example of the processes suggested by Figure 1 (taken through the entire model) may provide a useful illustration. Consider again a sophisticated fighter aircraft with a pilot and NFO engaged in a terrain clearance mission. Components of the task are to: remain at a very low altitude so as not to be detected by enemy radar; maintain a high speed; avoid obstructions (such as mountains); hit turnpoints on their route at a precise time and altitude; and turn to a specific heading after hitting each turnpoint. Flight is accomplished almost exclusively via instruments.

In this situation, the display presented to the pilot provides much less detail and a much shorter range than the display for the NFO. Thus, the NFO must continually inform the pilot of what will be coming up on his/her display. (An analogy might be for one to imagine driving a car in which a hood is placed over one's visual field, such that one can see only a few feet in front of the car. Imagine also that a passenger is aboard with a full field of view, and that he/she must provide direction through an obstacle course). To be effective under these conditions, each aviator must have a shared understanding of several sources of information. First, shared declarative knowledge would include a compatible understanding of pilot and NFO roles in the mission (i.e., the pilot must fly the aircraft and the NFO must direct him/her to appropriate headings and altitudes throughout the mission). Second, shared procedural knowledge would include an understanding that, on route to a given turnpoint, a call out prior must be made at a designated time. Finally, shared strategic knowledge would apply these shared knowledge bases to the dynamic mission, allowing both team members to maintain a dynamic, accurate awareness of the situation, especially when things go wrong. For example, if a turnpoint is missed, the crew must rapidly assess where they are, how they can correct the deviation, whether they can get back on course within an appropriate time, and whether they can complete the remainder of their mission once back on course.

Efficient (limited strategizing) is important in this time pressured task environment. For example, the NFO must tell the pilot when to turn, how hard to turn, and when to stop the turn, in a timely manner. Also, the pilot must verbalize his actions so that the NFO knows when they are being implemented. These communications can help the pilot and NFO build a shared understanding of the dynamic situation.

In addition, pre-flight briefing and in-flight planning, that set crew expectations, can enhance performance by building shared knowledge and reducing the need to strategize overtly, and by increasing the ability to use only the most basic strategizing in terms of communicating extremely efficiently. For example, if planned, the NFO can be aware that the pilot expects to hear a call on a turnpoint two minutes prior, and that the pilot expects a heading to be provided as soon as he/she starts the turn. These shared expectations are crucial to maintaining an awareness of the task situation, especially in degraded performance conditions as when an extremely noisy environment restricts the amount of verbal communications that is possible.

The dynamic nature of the situation cannot be overemphasized. Teams must continually assess and reassess their situation in relation to their mission goal. Terrain must be continually assessed and a determination of factors such as whether they are on time, on altitude, and at the correct heading must be repeatedly made. If any of these parameters are off, the crew must draw upon their strategic knowledge and the state of their current situation to determine what actions to next take.

Another way of looking at this dynamic nature of situational awareness is to consider the degree to which a given situation requires each of the three types of strategizing previously discussed. A model of team situational awareness, which considers the dynamics of the situational context, is presented in Figure 2. This model is consistent with the model presented by Salas et al. (1995) on team situational awareness, yet it expands upon this earlier model to consider the dynamic nature of situational awareness due to situation assessment. Team situational awareness can be conceptualized as depicted in Figure 2, where it is the combination of each individual team member's situational awareness, based on existing knowledge bases and cue and pattern assessments, and the degree of shared understanding of the team. Thus, team situational awareness is depicted as the dashed circles around the models shown in Figure 2 to indicate each instantaneous state of situational awareness at times 1-3. The degree of shared understanding is depicted as the shaded area of overlap in each of these models, which occurs via shared mental models and team process behaviors (Salas et al., 1995). Cue/pattern assessments and team process behaviors are part of situation assessment, and this assessment leads to a given state of situational awareness at any point in time. (Cue assessments have been recognized as necessary to expert performance in a variety of domains, Cannon-Bowers, Salas, & Grossman, 1991; Glaser & Chi, 1988).

The state of awareness itself changes instantaneously due to subsequent assessments (i.e., cue/pattern assessments and team process behaviors). Based on elements such as the situation context, environmental factors, time pressure, and the degree of shared strategic models present, more or less strategizing through communications or team process behaviors may be required at any given time. This dynamic change is shown by differences in the models, at times 1-3, in the sizes of the dashed circles (i.e., level of team situational awareness), the solid circles (i.e., each individual's level of situational awareness due to cue and pattern assessments and due to input from other crew members), and the shaded areas (i.e., the level of shared understanding of the team due to shared knowledge bases or mental models and team process behaviors). Specifically, the state of situational awareness at time one occurs when both individual situational awareness and shared understanding are moderately high. (The size of each solid circle, or each individual's level of situational awareness, is depicted as the same size for simplicity sake). At time 2, the level of team situational awareness is as high as it was at time 1 (i.e., the dashed circles are the same size). This is because the level of individual situational awareness is higher than it was at time 1 (i.e., the solid circles are larger at time 2) . The degree of shared understanding is lower than it was at time 1 (i.e., less area is shaded), although a high degree of shared understanding is unnecessary due to the situational context, environment factors, and temporal factors. (Therefore, the degree of shared understanding necessary to achieve that level of team situational awareness was less at time 2 due to these and other factors). At time 3, there is a shift toward greater team situational awareness as depicted by the increase size of the dashed circles. The level of each team member's individual situational awareness is the same as it was at time 1 (i.e., the solid circles at times 1 and 3 are the same size), although the level of shared understanding is much greater than it was at either time 1 or 2 (i.e., a larger portion of the two solid circles overlap and are shaded).

Considering all of this information, we contend that team situational awareness is a dynamically changing state affected by the process of situation assessment (i.e., individual cue and pattern assessments and team process behaviors). The state of team situational awareness present at any given moment in time is influenced by the situational context, environmental factors, and temporal factors. In addition, this state of team situational awareness is due to: 1) the level of situational awareness present for each individual team member (caused by the accuracy of the three types of mental model knowledge discussed previously, most important of which is strategic knowledge, and cue and pattern assessments); and 2) the level of shared understanding among team members (developed due to shared knowledge in each of the three types of mental models, again, most important of which is shared strategic knowledge, and developed via team process behaviors).

Insert Figure 2 About Here

We next present potential training strategies for team situational awareness. Specifically, these are derived from our theoretical conceptualization of team situational awareness.

## TRAINING FOR TEAM SITUATIONAL AWARENESS

In addition to describing how we think shared mental models affect team situational awareness, Figures 1 and 2 are useful in providing a basis upon which training interventions or strategies for team situational awareness can be drawn. By "training strategies", we mean that training interventions should combine relevant methods and tools to deliver instruction geared at changing knowledge and skills in a content specific domain -- in this case, knowledge bases and processes related to team situational awareness (see Salas & Cannon-Bowers, in press). The training implications derived here fall into two general categories: training to enhance shared knowledge bases directly; and training to foster development of mechanisms in the team that encourage these crucial processes to occur. The following sections provide more detail on each of these.

Training Shared Knowledge Bases

A number of training interventions are appropriate for providing team members with knowledge crucial to the formation of team situational awareness. To begin with, declarative knowledge mental models can be enhanced in several ways, including:

1) Direct Information Presentation--lectures, manuals, video tapes and similar methods can provide an effective means to present team members with declarative knowledge about the task domain (Jonassen & Tessmer, 1996, this issue). While the content of such training should be based on a thorough analysis of the task, the following types of information are likely to be necessary: knowledge about the overall system or task domain; the vocabulary or language that characterizes the task; rules, facts and relationships among crucial task components, and specific member roles and functions. In addition, the use of conceptual models and advanced organizers may foster initial knowledge base development (Jonassen & Tessmer, 1996, this issue). Thus, to enhance team situational awareness, direct information presentation can be used to help build declarative knowledge related to such factors as the overall system, task goals, the relation among system components, and equipment.

2) Positional Knowledge Training--as noted by several researchers (e.g., Cannon-Bowers, Salas, & Baker, 1991; Cannon-Bowers, Salas, & Grossman, 1991; Volpe et al., 1996), training team members to understand the specific requirements of their own jobs, as well as of the jobs of teammates, may be an effective means to build required declarative knowledge. According to Cannon-Bowers et al. (1993), such training can contain knowledge about the equipment used by team members, the tasks

and responsibilities of each position, and the interdependencies between team members. In terms of training methods, positional clarification training may be accomplished via direct presentation (e.g., lectures, video tapes), part-task training (i.e., where positional knowledge is separated from other task components), and/or some form of cross training. It is critical for team members to possess declarative knowledge of team roles and responsibilities for team situational awareness, and positional knowledge training can ensure that this information is clarified and shared among team members. This forms the basis for them to be able to form accurate expectations and explanations of each other's performance on line.

3) Demonstration/Modeling–another potential mechanism for building shared declarative knowledge is to demonstrate or model task behaviors to trainees (Decker & Nathan, 1985). The emphasis here would be on gaining a conceptual understanding of how the task is performed effectively by various team members, and highlighting crucial task information (Jonassen & Tessmer, 1996, this issue). Once again, it is important for fostering team situational awareness that team members share knowledge of the facts, rules, and relationships of each other's task, equipment, and team needs, and seeing behaviors modeled can point out salient relationships among these elements.

Turning to procedural mental models, the following potential training strategies may apply:

1) Direct Information Presentation–it may be possible to build procedural knowledge bases by presenting team members with a conceptual model of the procedures and task (Jonassen & Tessmer, 1996, this issue). In addition, providing cuing that highlights important information and advanced organizers may be useful (e.g., see Ford & Kraiger, 1995; Kraiger, Salas, & Cannon-Bowers, in press). In this case, what is important to team situational awareness is that team members understand the general sequence of task activities such that they will know what to expect during task performance. An example of this training could be to show a videotape which demonstrates the steps

that need to be taken to complete the task while highlighting particularly critical steps on the video for emphasis.

2) Concept Learning--according to Ford & Kraiger (1995), concept learning can also aid in the instruction of both declarative and procedural knowledge. It involves a two-step process where conceptual knowledge is first learned and then transitioned to procedural knowledge (Tennyson & Cocchiarella, 1986). The objective of concept learning is to aid learners in how to generalize knowledge to similar (and dissimilar) instances. By focusing on the links between steps in task action sequences, concept training can help to foster procedural knowledge through the development of expectations of the protypical sequence of task activities. This can then be used to make team members aware of the distinctness of actual task sequences being performed, which enables them to refine their procedural knowledge for application to subsequent performance.

3) Demonstration/Modeling--as with declarative models, demonstration or modeling of a task may be an effective means to convey procedural information. In this case, the emphasis would be on steps required to accomplish the task, particularly when multiple team members are involved. That is, shared procedural knowledge must convey not only how an individual member should perform his/her task, but also how task inputs are sequenced by various team members. A dynamic demonstration presented either via live (or recorded models) can help team members understand crucial action sequences (or strategies) needed to accomplish the task, such that they can be aware of these sequences during task performance. According to the model in Figure 1, the information conveyed in task modeling can help team members understand what information a fellow team member needs from them in order for him/her to complete his/her task, and when in the task sequence this information should be presented.

4) Computer Animation--a recent study by Augustine and Coovert (1990) indicated that computer animation may be an effective means to convey knowledge in a complex domain. In the present case, we contend that animated graphics showing appropriate sequences may be an effective means to help team members build accurate procedural mental models. To improve team situational awareness, it is important that procedural knowledge bases contain information about not only task sequences but also the appropriate timing for task actions. Computer animation can focus on both of these aspects.

Training to build strategic mental models differs from interventions for declarative and procedural mental models in one important regard; it must require the active participation of team members. We contend this because the knowledge contained in strategic models is by its nature dynamic; that is, what is learned and stored in the strategic model reflects how and when particular task strategies are appropriate. Therefore, trainees must learn to recognize the cues (or cue patterns) that trigger particular behavioral sequences (strategies) in the team. This means that trainees must actually experience the task in order to build up required knowledge. This is a similar notion to situated learning, which requires the instruction of knowledge and skills to occur in contexts reflective of the way that they will actually be used on the job. Collins (1991) provided a number of advantages of training in this context, including that trainees should learn to organize and apply knowledge in the appropriate conditions and that trainees can learn to encode novel solutions to problems, storing knowledge in ways that makes it accessible when they later need to solve problems on the job. With this in mind, we hypothesize that the following training interventions will be effective in building strategic mental models:

1) Task Simulation--in many domains, practice on the actual task is too costly or dangerous to be practical. In such cases, task simulations can be an appropriate means to build shared strategic knowledge because they provide rich contextual instruction (Jonassen & Tessmer, 1996, this issue;

Salas & Cannon-Bowers, in press). For team situational awareness, it is critical that these simulations involve scenarios that require both individual cue assessments and relevant and efficient team process skills for effective performance. Also, according to the model in Figure 1, the emphasis must be on feedback so that trainees understand the implications of various task contingencies on their performance and the performance of the team. In addition, an analysis must be conducted to determine which scenarios are most likely to confront the team, which are most critical to goal attainment, and which are most difficult to perform, so that practice on these is provided.

2) Cross-Training--allowing team members to "walk in the shoes" of teammates is a potentially effective means for conveying strategic knowledge in team members (Cannon-Bowers, Salas, & Grossman, 1991; Volpe et al., 1996). By learning the responsibilities of teammates, particularly in a dynamic situation, team members can gain a richer understanding of how their behavior affects teammates, and what teammates need from them at various stages of task performance. This can allow for the formation of accurate explanations and expectations for performance (Rouse et al., 1992). Implementation of cross-training may involve short sessions where team members can switch roles, or it may be as extensive as full job rotation. This training can have an important impact on team situational awareness by allowing team members to actually test out their shared mental models in relation to the accuracy of task actions taken, allowing feedback from this mechanism (as well as through external sources) to update and refine their strategic knowledge bases.

3) Guided Task Practice--it has been shown that simply allowing trainees to interact with a system can lead to the development of impoverished and/or inaccurate mental models (Frederiksen & White, 1989). For this reason, we recommend that trainees be allowed to engage in the task while their performance is being guided by instructors or intelligent systems. Specifically, feedback or cuing (via instructor comments or system prompts, such as highlighting or fading) should be used to teach

trainees to recognize cues accurately when strategy adjustments are required. According the models in Figures 1 and 2, guiding task practice via cuing can help to enhance team situational awareness by providing team members with an understanding of cue/action sequences, cue patterns and their significance, team resources and capabilities, and appropriate task strategies, all of which are necessary to meet task demands in an evolving simulation scenario.

4) Cognitive Apprenticeships--at the individual level, the notion of cognitive apprenticeships has gained in popularity as an on-the-job training strategy (Collins, 1991; Druckman & Bjork, 1994). According to Collins, Brown, & Holum (1991), cognitive apprenticeships include coaching, scaffolding (i.e., providing supports), articulation, reflection, and exploration. Applied to teams, the apprenticeship strategy could mean that team members are encouraged to use their job experiences as a basis to build shared strategic knowledge. In terms of fostering team situational awareness, cognitive apprenticeships can accomplish all of the goals listed under guided practice above. However, in this case, practice is typically guided in the real world setting rather than via task simulation. It should be noted that an approach could be developed to include the components of cognitive apprenticeships (e.g., articulation and reflection) and to apply these in a simulation setting as well.

Training Strategies to Foster Shared Mental Model Development

As stated, effective teams continually refine their shared knowledge bases over time based on feedback from performance situations. Therefore, we propose that training which increases the likelihood that task performance information will help to improve the accuracy of shared mental models should lead to more effective team situational awareness. Several training strategies are possible in this regard:

1) Communication Training--interventions that train or encourage team members to communicate in a common task language will reduce ambiguity and confusion among team members. In addition, training team members to communicate clearly and concisely can improve the team's ability to engage in limited, more efficient task strategizing when necessary. In both cases, we maintain that team members will be better able to use performance information to update and refine their mental models when it is communicated in a clear, unambiguous manner. Direct presentation of required vocabulary, instruction in the use of brevity codes, and appropriate practice of communication skills are all potentially useful to improve communication behavior.

2) Training in Planning--results of Orasanu's (1990) study indicate that effective team leaders use low workload periods to plan for task contingencies. In addition, results of Stout's (1994) investigation revealed that planning behaviors helped team members to develop a shared understanding of each other's informational requirements, as well as to use efficient communication strategies in high workload periods where overt strategizing was limited. We agree with Stout that such planning behavior will help team members to form more accurate expectations and explanations for team performance. Potential methods for enhancing team planning behaviors may be behavioral modeling, coaching, role playing, and guided practice.

3) Team Leader Training--Cannon-Bowers, Salas, and Grossman (1991) suggested that training team leaders to foster a climate in the team that encourages discussion and feedback can improve shared mental model development. Specifically, when team leaders indicate (through instruction or action) that they value intra-team feedback, team members may be more inclined to engage in task-clarifying conversation. For example, when overt strategizing is possible, team leaders may solicit input from other team members to aid in dealing with problem situations. Once again, particular methods that

might be appropriate to train team leaders include behavior modeling, role playing and guided task practice.

4) Team Self-Correction Training--related to the above, we would also advocate interventions that encourage team members to engage in detailed post-performance debriefs (Blickensderfer, Cannon-Bowers, & Salas, 1994). In fact, under high workload conditions, there probably will be insufficient time for team members to explain their behavior to one another. A risk here is that team members may draw inaccurate conclusions about why a teammate behaved in a particular manner. This situation is avoided when team members "process" what occurred and provide explanations for their behavior at different times (a sports analogy here would be when a team discusses their performance in the bar after a game--essentially, they are clarifying the reasons for their behavior at particular points). Indeed, Blickensderfer et al. (1994) indicated that post-briefing behavior may be particularly useful for clarifying confusions that occur during task performance and for enhancing subsequent accurate explanations and expectations of team member behavior. In short, post-performance debriefs allow team members to update their knowledge bases accurately. Behavior modeling and role playing may be appropriate methods for accomplishing this type of training.

Table 1 displays a summary of the training strategies that are suggested for developing each of the three types of knowledge bases, as well as for enhancing team processes that themselves can influence shared mental models and thus team situational awareness. While some of the potential strategies were considered as particularly relevant to one (or more) particular type(s) of knowledge, Table 1 shows that they may have application to the development other types of knowledge as well, even if they were not specifically discussed under that type of knowledge. For example, cognitive apprenticeships were described as particularly important to developing shared strategic knowledge, although this training strategy is obviously also germane to declarative and procedural knowledge.

That is, it may be most important to use cognitive apprenticeships to enhance shared strategic knowledge through hands-on, real-time practice, yet the apprentice can also obtain declarative and procedural knowledge from a task expert as well. Space simply did not permit a discussion of each instance in which a training strategy has a degree of relevancy for building a type of knowledge base.

Insert Table 1 About Here

## CONCLUDING REMARKS

Obviously, there are a variety of factors that can influence team performance. These include situational factors (e.g., the nature of the environment, presence of stress, and so forth); the nature of the task and its demands (complexity, pace, uncertainty, etc.); groups factors (e.g., norms, roles, peer pressure, and the like); and individual factors (e.g., personality, decision-making style, collective orientation, skill level, etc.). In this paper, we have argued a potentially important factor that can affect team effectiveness is the level of team situational awareness. Moreover, we have demonstrated that team situational awareness development and maintenance is importantly influenced by shared mental models possessed by team members. Specifically, we contended that effective team situational awareness is attained when team members draw on shared declarative, procedural, and strategic mental models. This team situational awareness provides a foundation for quick, seamless, implicit coordination, which is especially crucial when the task environment restricts the team's ability to strategize overtly. In cases where overt strategizing is less restricted, team members can engage in rapid, efficient strategizing, leading fairly quickly to task action. In still other cases, when strategizing can be extensive, effective teams engage in behaviors that build common knowledge about the task, thereby preparing them to cope with difficult task contingencies. In all three cases, we maintained that feedback (regarding the outcome of the action or other team member's behavior) helps to refine and make more accurate team members' mental models.

Finally, we linked the model of team situational awareness to training by highlighting a number of training interventions that are implied by the model. It should be noted that these suggestions for training have not been validated empirically. Future research is needed to develop, test, and refine training interventions that are successful in fostering development of team situational awareness. We hope that this paper stimulates thinking and research in this regard.

Table 1

Training Strategies that can Enhance the Development of Declarative Knowledge Bases, Procedural Knowledge Bases, Strategic Knowledge Bases, and Team Processes that Apply to Team Situational Awareness

| | Training Strategy | Declarative Knowledge Bases | Procedural Knowledge Bases | Strategic Knowledge Bases | Team Processes |
|---|---|---|---|---|---|
| 1. | Direct Information Processing | ✓ | ✓ | | |
| 2. | Positional Knowledge Test | ✓ | | | |
| 3. | Demonstration/Modeling | ✓ | ✓ | | |
| 4. | Concept Learning | ✓ | ✓ | | |
| 5. | Computer Animations/ Simulations | | ✓ | | |
| 6. | Cross Training | | | ✓ | ✓ |
| 7. | Cognitive Apprenticeships | ✓ | ✓ | ✓ | |
| 8. | Guided Task Practice | | | ✓ | |
| 9. | Task Simulations | | ✓ | ✓ | |
| 10. | Communication Training | | | | ✓ |
| 11. | Planning Training | | | | ✓ |
| 12. | Team Leader Training | | | | ✓ |
| 13. | Self Correction Training | | | | ✓ |

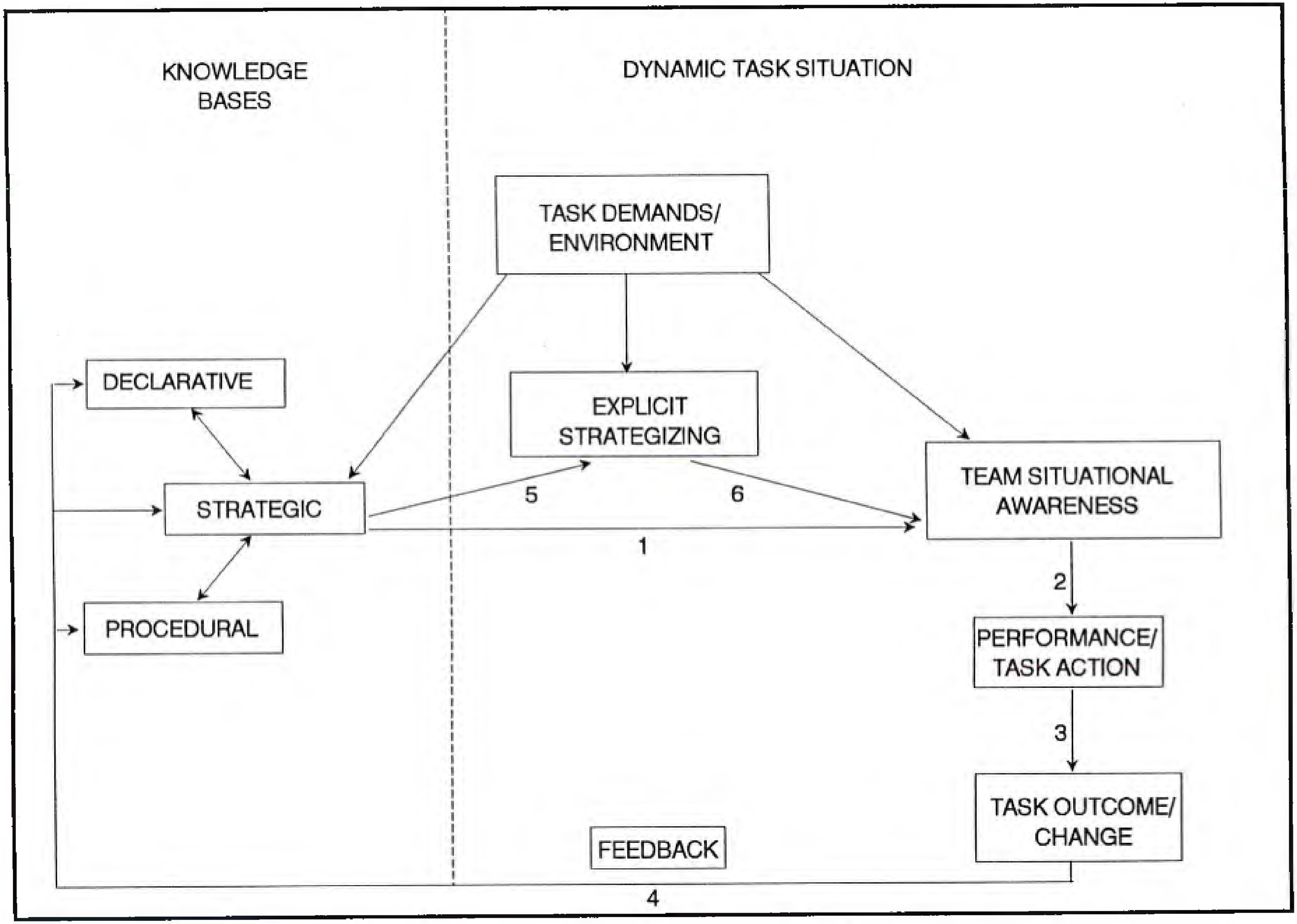


Figure 1. How shared mental models contribute to the development of team SA

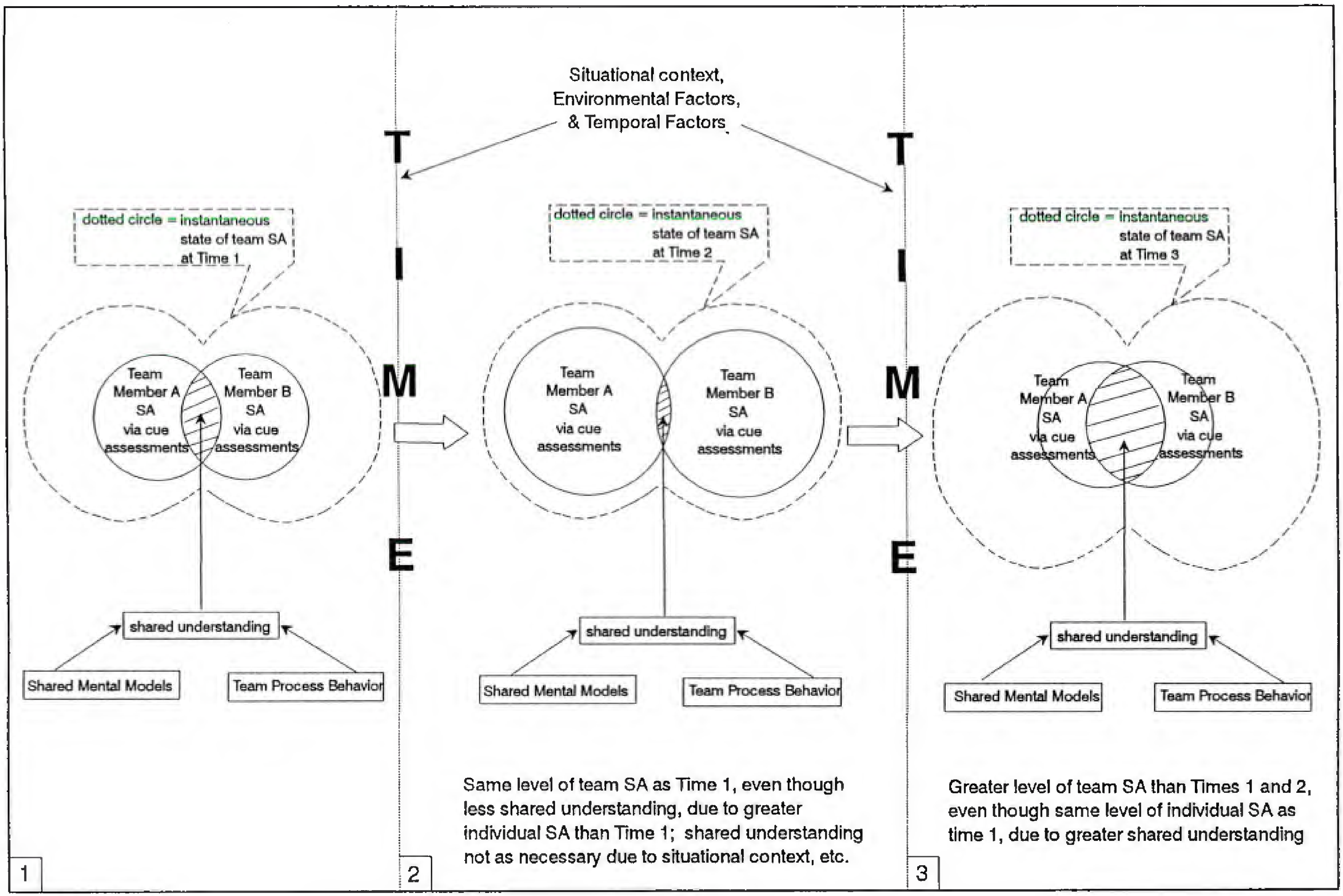


Figure 2. Dynamic Team Situational Awareness

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