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ANALYZING KNOWLEDGE REQUIREMENTS IN TEAM TASKS

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Teams and their associated cognitive requirements have received an increasing amount of attention over the last 10 years (e.g., Cannon-Bowers, Salas, & Converse, 1993; Orasanu, 1990). Numerous articles and books address critical issues related to team decision making (Guzzo & Salas, 1995), team training (Swezey & Salas, 1992), and team performance measurement (Brannick, Prince, & Salas, 1997). However, it is only recently that researchers have begun to analyze teamwork in terms of its component tasks and associated knowledge, skill, and attitude requirements (e.g., Baker, Salas, & Cannon-Bowers, 1998; Bowers, Baker, & Salas, 1994; Campion, Medsker, & Higgs, 1993; Stevens & Campion, 1994). In particular, a thorough analysis of the cognitive components that underlie effective team performance is lacking. Such an analysis—cognitive task analysis for teams—would be useful for decisions regarding team selection, design, and training and would also be useful for building more complete and accurate models of team performance (Salas, Dickinson, Converse, & Tannenbaum, 1992).

Cognitive task analysis (CTA) for teams differs from that of individuals in two major areas. First, this analysis must identify, define, and describe the cognitive processes and knowledge associated with teamwork processes (e.g., communication, coordination, adaptability). Second, it must be capable of addressing the issue of team knowledge. The purpose of the present chapter is to assess and describe CTA methods to capture team knowledge. To accomplish this, we begin with a theoretical overview of team knowledge. We next review knowledge-elicitation methods that have been used previously to tap team knowledge. Finally, we suggest alternative methods to enhance team CTA.

What Is Team Knowledge?

A major requirement of team CTA is to identify, define, and describe team knowledge. Team knowledge (referred to as *shared mental models* by Cannon-Bowers and her colleagues) is thought to relate directly to team performance (Cannon-Bowers et al., 1993; Orasanu, 1990). Team knowledge is knowledge that is shared across members of the team. Cannon-Bowers and her colleagues suggested that this knowledge has the potential to affect teamwork at two levels. First, when communication channels are limited, team knowledge enables team members to anticipate other team members' behavioral and informational requirements. Second, team knowledge of the team task enables team members to perform these tasks from a common frame of reference (see Cannon-Bowers et al., 1993, for a detailed discussion). Other authors refer to team knowledge as schema similarity (Rentsch & Hall, 1994), shared cognitive schema (Moussavi & Evans, 1993), and shared cognitive maps (Langfield-Smith, 1992). Despite terminology differences, researchers tend to agree that team knowledge of this sort seems to help teams coordinate smoothly and effectively (Rouse, Cannon-Bowers, & Salas, 1992; Cannon-Bowers et al., 1993; Hinsz, 1995; Kraiger & Wenzel, 1997; Rentsch & Hall, 1994). In fact, several researchers have attempted to assess the degree of sharedness in knowledge and have found evidence that suggests a positive relationship between the degree of team knowledge and team performance (Blickensderfer, Cannon-Bowers, & Salas, 1997; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, in press; Minionis, Zaccaro, & Perez, 1995).

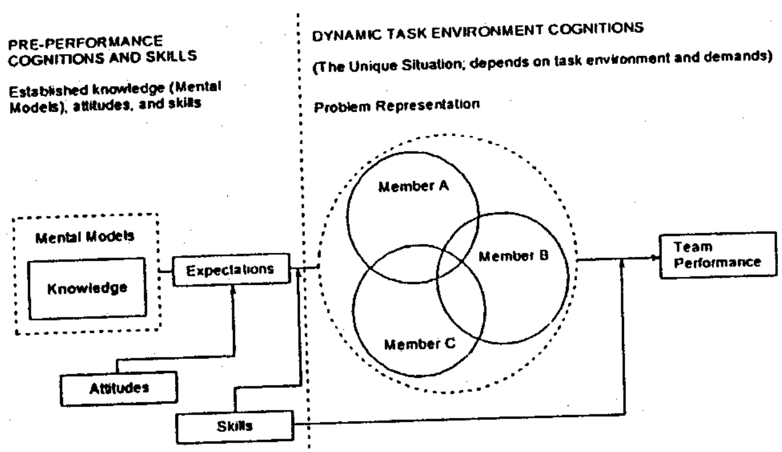

FIG. 26.1 Model of shared cognition.

Although the prior description gives an overview of team knowledge, we next provide specific definitions. Consider the conceptual model in Fig. 26.1. Based on Stout, Cannon-Bowers, and Salas (1996), this model depicts team knowledge as composed of two major elements: knowledge existing prior to task activities (pretask team knowledge) and knowledge and understanding that develops dynamically during performance. Researchers believe that both types of knowledge have implications for team performance (Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994; Rentsch & Hall, 1994). The fundamental argument behind sharing each type of knowledge is that this knowledge enables teammates to attend to, interpret, communicate about, and respond to the world more similarly than individuals with discrepant or incomplete knowledge (Rentsch & Hall, 1994).

Pretask Team Knowledge

Pretask knowledge is knowledge that resides in long-term memory. Team members carry it with them into task performance. The extent to which team members come to the task with compatible knowledge and mental models we consider their level of pretask team knowledge. Many researchers have postulated about the specific content of pretask shared knowledge that is most beneficial. First, teammates who possess compatible knowledge of the overall mission objectives (Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995) and team goals (Kraiger & Wenzel, 1997) may help team performance. The basic premise for this is straightforward: Team members need to understand the team's objectives to ensure everyone is working toward the same goal. For example, consider a basketball team. In a particular game, if the overall objective is showing off particular players for recruitment scouts, the focus of the plays could be different from those used to win the game. If the players involved do not focus on the same overall objectives, they may have different expectations concerning plays. Conflicting expectations could cause them to misinterpret plays and play against each other rather than performing as a team.

In addition, team knowledge of teammates' roles and responsibilities may also be vital for effective team performance (e.g., Cannon-Bowers et al., 1993, 1995; Orasanu, 1990; Rentsch & Hall, 1994; Stout et al., 1996/1997; Volpe, Cannon-Bowers, Salas, & Spector, 1996). Pretask knowledge of roles and responsibilities should help ensure that each team member understands the interdependencies inherent to the team, and that teammates understand how to help each other and, in turn, to help the team (Cannon-Bowers et al., 1993). Furthermore, teammates who understand each other's duties will be able to predict the team's behavior in frequently encountered situations (Rentsch & Hall, 1994). For example, Orasanu (1990) examined two-member pilot crew aircraft flights.

She observed that effective teams talked in detail during preflight plans about possible situations the crew may encounter and what the team should do if those situations occur. Orasanu (1990) argued that this planning includes building an understanding of roles and responsibilities.

Teammates may also need to be familiar with teammate characteristics (e.g., the knowledge, skills, attitudes [KSAs], preferences and other task-relevant attributes of their teammates; Cannon-Bowers et al., 1993). Teammates' expectations of behaviors vary as a function of the individuals who compose the team. A basic example would be performance speed: Some individuals will perform the task slightly slower or faster than other individuals. This may require their teammates to adjust their expectations of when certain events will happen. The specific characteristics teammates should be aware of vary with the task.

Other preperformance knowledge important for team members to share may be knowledge of the equipment, relationships among equipment, and task operations (Orasanu, 1990; Rouse et al., 1992). This includes declarative knowledge about the task such as typical situations and decision criteria. However, Rouse et al. (1992) argued that this knowledge is important only as much as it helps individuals form expectations about the task, equipment, and team, and that those expectations enable individuals to perform more effectively. Knowledge of acceptable team behaviors also may be useful for effective team performance (Jenkins & Rentsch, 1995; Rentsch & Hall, 1994; Smith-Jentsch, Zeisig, Acton, & McPherson, 1998). Rentsch and colleagues argued that teams develop schemas (or scripts) that enable them to perform effectively. One type of schema of particular interest to these researchers has been schemas describing acceptable team behavior and teamwork processes (e.g., asking for help, leader behavior, team goal setting). Rentsch and Hall (1994) contended that a similar understanding of these behaviors among teammates will enhance team processes by improving communication among team members. They predict that team members will be better able to anticipate information that other team members will need and give it to them in the most useful form. In a related vein, Smith-Jentsch et al. (1998) advocated that team members must understand the definition of effective teamwork. They argued that teammates will not be able to communicate effectively, for example, if they do not have a clear mental model of effective communication.

Cannon-Bowers and colleagues (Cannon-Bowers et al., 1995; Rouse et al., 1992; Stout et al., 1996) posited that shared knowledge of sequences and timing related to task actions and behaviors are both useful for teams to possess. Rentsch and Hall (1994) agreed that the sequence or temporal ordering of team behaviors is key. Klimoski and Mohammed (1994) postulated that learned response patterns may be part of a team mental model. Duncan et al. (1996) considered knowledge of how teammates perform their respective duties and knowledge of how teammates perform together important for team performance. Finally, Kraiger and Wenzel (1997) argued that shared procedural knowledge is useful in team tasks with high interdependencies, but may not be as important for tasks with fewer interdependencies. The bottom line is that knowledge of task procedures, sequences, and timing enables the team to expect or predict what will happen next and thus what should be their next action.

Although not focusing on procedures per se, Hinsz (1995) argued that we need to focus on the exact view the individual has of the implications of his or her interactions for the system. If an individual does not have accurate expectations, it is likely that he or she will interact ineffectively with the system. Consider an individual with an unclear cause-and-effect model of using a calculator. That individual may hit the clear key repeatedly even although once is enough. Similarly, in a team task, an individual may have incorrect beliefs about the outcomes of various behavior patterns. Believing that certain behaviors yield desired results, this person may act in a manner that actually adds nothing or even hinders the team. To avoid this problem, researchers argue that it is critical to assess each individual's understanding of outcomes that result from behavior patterns (Cannon-Bowers et al., 1993; Hinsz, 1995). In other words, we need to examine what the individual expects to happen as a consequence of his or her actions.

In general, a knowledge of procedures and patterns of team interactions and functions drives procedural expectations. For example, if team members understand the normal procedures, they can predict when teammates will need information passed to them, when a teammate may need help, and when something is wrong. If teammates can make these predictions, they reduce their need for overt communication (Kleinman & Serfaty, 1989). In addition to building expectations, understanding procedures enables individuals to explain why certain events are occurring. For example, consider a team member who understands why an event occurred when it did. The team member knows that Event A caused Event B. The next time a particular event occurs (Event A), the team member will predict or expect what will happen down the road (Event B). Although not all expectations and explanations are products of procedural knowledge, procedural knowledge does seem to foster many expectations and explanations.

Dynamic Team Knowledge

In addition to preperformance knowledge, another element of team knowledge develops when the team is actually performing the task (Orasanu, 1990; i.e., the right side of Fig. 26.1). As previously noted, we refer to this as *dynamic task understanding*—it occurs dynamically during the performance episode. Dynamic understanding is the degree to which teammates develop compatible assessments of cues and patterns in the situation, the implications of these for the team and task, how the team is proceeding, and particular actions that certain team members need to take. We consider this dynamic understanding qualitatively different from, but related to, the sharedness or compatibility of the preexisting knowledge discussed previously. Dynamic understanding combines preperformance knowledge with cognizance of the specific characteristics of the current situation. During performance, team members interpret cues and patterns in a situation (Stout, Cannon-Bowers, & Salas, in press). These interpretations are influenced by preexisting knowledge and by the execution of appropriate team processes (e.g., clear team communications; Stout et al., 1996). The degree to which teammates develop compatible interpretations on the fly is crucial. For example, although an aviation crew may have a high degree of knowledge going into a flight, the situation may change suddenly from an average flight to an unusual situation that requires changes in team strategy. Similarly, an organization project team may have a high degree of shared knowledge going into a new task; however, once the task has begun, it may not match their expectations. Unexpected problems may occur, changes in procedures may be needed, the team may lose a member and gain a new member, and so on. Teams that are able to develop a shared understanding of these issues (and act accordingly) are likely to perform better than those that do not (Orasanu, 1990).

In summary, team knowledge may provide the foundation for certain team skills. Teammates with team knowledge know what to do when, know when and how to compensate for their teammates, know which materials and information to provide to their teammates, and can fulfill responsibilities and manage their resources without prompting by other members. When the task demands it, teammates with team knowledge can work together effectively with a limited amount of overt communications (Kleinman & Serfaty, 1989). Therefore, it is crucial for a cognitive team task analysis to identify team knowledge requirements for a team task. This includes identifying both the essential pretask knowledge in addition to the much more elusive dynamic performance understanding.

Analyzing Team Knowledge

To date, there has been little or no research on which specific cognitive task analysis methods are useful for eliciting team members' knowledge about their team and its task. Most approaches to analyzing cognitive task requirements have focused on individuals as opposed to teams. Indeed, research is needed to determine methods that best identify the knowledge needed by team members, including a determination of how much of this knowledge must be shared by

team members to maximize task performance. It may be that some knowledge needs to be shared, whereas other knowledge simply needs to be compatible. Further effort is needed to sort out this important issue and develop methods to assess the sharedness or overlap required in the knowledge of various team members.

Another issue that must be addressed is the manner in which the elicited information is represented. As is the case with CTA data at the individual level, there are several representational formats that might be useful as a means to describe knowledge elicited from a team CTA. For example, task-action hierarchies, concept maps, semantic nets, concept graphs, task network models, or simple lists or tables could be useful as means to represent team CTA data. At the team level, it might also be useful to employ communication or link analyses to describe the flow of information among team members, models of shared knowledge, or analyses of knowledge overlap among team members. These latter techniques have not received much attention in the literature, but are crucial if a true picture of team-level cognitive concepts is desired. In fact, the issue of how to cast individual- and team-level knowledge stemming from a team CTA is a central question that must be addressed if team-level CTAs are to be useful. This includes an understanding of what each team member needs to know to function effectively, as well as an understanding of what information must be dynamically shared among members. Research aimed at addressing this issue is clearly needed.

Despite the gaps in research, a number of knowledge-elicitation methods available from research on individual CTA seem adaptable to a team environment. Some of these have been used in the team performance arena, whereas others have not. This section suggests potential methods for the different types of team knowledge described in the previous section: methods for eliciting pretask team knowledge and dynamic team knowledge. We list the type of team knowledge and discuss previous attempts (if any) to elicit this knowledge. We also suggest other methods that have potential to tap this knowledge. Although a detailed description of all potential methods is beyond the scope of this chapter, we have attempted to include a brief description of a variety methods. This information is summarized in Table 26.1.

Task Objectives and Goals

Although it has not been tested in team research, we suggest separate interviews of all team members, observations of the team performing the task, and examination of documents regarding the team task to gather this information. To represent this knowledge, we suggest using a variation of taskaction mapping (e.g., Coury, Motte, & Seiford, 1992) or goal-directed analysis (Woods & Hollnagel,

TABLE 26.1
Potential Methods to Elicit Team Knowledge

Pre-Task Team Knowledge Element	Possible Elicitation	Possible Representation	Possible Agreement Comparison
Knowledge of task objectives and goals	• Document analysis • Observation • Separate interviews • Group interviews	• Adaptation of task-action mapping (e.g., Coury et al., 1992) • Adaptation of goal-directed analysis (e.g., Woods & Hollnagel, 1987)	• Agreement metric (e.g., Minionis et al., 1995)
Knowledge of task procedures, sequences, and timing	• Document analysis • Observation • Separate interviews • Group interviews • Concept rating tasks (Stout et al., in press)	• Adaptation of task-action mapping (e.g., Coury et al., 1992) • Adaptation of goal-directed analysis (e.g., Woods & Hollnagel, 1987) • Knowledge structures (e.g., Cooke et al., 1996; Stout et al., in press)	• Agreement metric (e.g., Minionis et al., 1995) • Pathfinder agreement metric (Schvaneveldt et al., 1987)
Knowledge of roles and responsibilities	• Document analysis • Observation • Separate interviews • Group interviews	• Basic tables, lists • Adaptation of task-action mapping (e.g., Coury et al., 1992) • Adaptation of goal-directed analysis (e.g., Woods & Hollnagel, 1987)	• Interrater agreement metrics applied to responses to specific scenarios developed by knowledge engineer or teammates (e.g., Blickensderfer et al., 1997) • Agreement metric (e.g., Minionis et al., 1995)
Knowledge of roles and responsibilities	• Questionnaires (Smith-Jentsch et al., 1998) • Adapted critical incident (Flanagan, 1954) or critical decision method (Klein et al., 1989)	• Lists of characteristics	• Interrater agreement metrics applied to responses on questionnaires (Smith-Jentsch et al., 1998) • Comparisons of characteristics lists
Knowledge of teamwork	• Numeric similarity ratings of teamwork concepts (Mathieu et al., 1998) • Sorting teamwork concepts (Smith-Jentsch et al., 1998) • Questionnaires	• Knowledge structures (Mathieu et al., 1998; Smith-Jentsch et al., 1998) • Lists, tables	• Knowledge structure agreement metrics • Concept grouping agreement metric (Smith-Jentsch et al., 1998) • Interrater agreement metrics applied to questionnaire responses (Jenkins & Rentsch, 1995)
Dynamic Performance Understanding: During actual task performance: compatible assessments of cues and patterns in the environment, the implications of those for the team and task, how the team is proceeding, and particular actions that certain team members need to take.	• Adaptation of SAGAT (Endsley, 1995) • SALIENT (Muniz et al., 1998) • Retrospective protocol analysis of videotape performance (Means, 1993) • Structured interview during videotape-simulated mission (Fowlkes et al., in press)	• Tables, charts, and lists (e.g., Baker et al., under review; Muniz et al., 1998)	• Basic comparisons of cues and information elicted

1987), where team members identify the task goals, subgoals, and actions needed for the team to complete each task element. This should include the team goals, the goals and actions of each team member, and how the individual actions enable the team to accomplish the task. This decomposition of goals in terms of action sequences provides the level of detail necessary to specify the interactions that must occur among the team members and between the team members and the system. Once a basic task structure (in terms of goals, relationships among the goals, and means to achieve the goals) is achieved, we suggest a follow-up group interview of the team to ensure the structure is accurate and to fill in any gaps that may be present. The emphasis of the group interview should be to obtain different team members' perspectives on what should happen during those crucial moments where teammates must coordinate and/or communicate with each other.

Knowledge of Task Procedures, Sequences, and Timing

Similar to the overall task objectives and goals, we suggest interviews with information represented in a variation of task-action mapping (Coury et al., 1991) or goal-directed analysis (Woods & Hollnagel, 1987) for knowledge of task procedures, sequences, and timing.

Once knowledge of task procedures was obtained, Minionis et al. (1995) used a simplified variation of the concept mapping approach to assess agreement among team members regarding the domain elements and relationships among those domain elements. They asked team members to complete basic concept maps of the team procedure and then computed agreement among team members. Agreement on team procedures was related to aspects of team performance that required heavy interdependence.

Other researchers have used knowledge structure assessment to elicit sequential understanding. Although not focusing on teams, Cooke, Neville, and Rowe (1996) used Pathfinder (Schvaneveldt, Durso, & Dearholt, 1987) to analyze sequential data. In the team performance arena, Stout, Cannon-Bowers, Salas, and Milanovich (1999) had some success using Pathfinder assessments of knowledge structures of team communication sequences. Their results indicate that teams with effective preperformance planning had higher degrees of agreement in terms of knowledge structures of team sequences.

Team Member Roles and Responsibilities

To elicit the roles and responsibilities of the various team members, we suggest first bootstrapping (Hoffman, Shadbolt, Burton, & Klein, 1995) to gain basic task knowledge via analysis of documentation and job observation. We then recommend conducting individual interviews of the team members and, finally, a group interview. The individual interviews should be used to elicit individual position processes and knowledge—information that team members who had never performed that exact position would not necessarily know. Again, the group interview should focus on moments of inter-dependence revealed in the initial interviews and obtain different team members' perspectives on what should happen during those crucial moments where teammates must coordinate and/or communicate with each other.

If basic task knowledge of roles and responsibilities of team members is available, the knowledge engineer could also create a probing test or questionnaire to assess degree of knowledge overlap. For example, Blickensderfer et al. (1997) used a questionnaire to assess team members' degree of agreement on expectations concerning aspects of the teammate roles, responsibilities, and communications with respect to a variety of task situations. The questionnaire described scenarios that might occur during task performance. Participants were asked to give estimates regarding the likelihood of various team member actions and communications. Degree of agreement was related to team processes and overall team task performance.

Teammate Characteristics

To elicit knowledge of teammate characteristics, Smith-Jentsch, Kraiger, and Cannon-Bowers (1998) used a questionnaire approach. Each team member answered items with respect to his or herself and every other team member. The questions focused on task-related preferences and abilities, responses to stress, knowledge of the tasks, and personal characteristics such as flexibility, competitiveness, and willingness to accept feedback. Overall ratings of these characteristics may then be obtained by combining the teammates' ratings (e.g., Alice's and Tom's ratings of Susan's characteristics).

For a more detailed assessment of teammate characteristics, we suggest using probed recall of past events, situations, or salient cases. This is a variation of Flanagan's (1954) critical incident and Klein, Calderwood, and MacGregor's (1989) critical decision method. Instead of recalling a decision that was made or cue that occurred, team members would be asked to describe how their teammates responded in terms of task-related knowledge and/or personal characteristics. For example, when considering how a teammate responds to stress, the other teammates could think of stressful incidents that occurred in the past and recall how the particular teammate responded to that situation. Alternatively, a fictional scenario could be presented to a team member and that team member asked to predict how a teammate would respond.

Teamwork Behaviors

One method to elicit knowledge of teamwork behaviors has been structural analyses (Mathieu et al. in press; Smith-Jentsch et al., 1998). Two studies were found that used teamwork-related concepts extracted from previous taxonomies of team skills. To elicit knowledge organization of the teamwork related-terms, Mathieu et al. (in press) asked team members to rate a number of teamwork concepts in relation to other teamwork concepts (e.g., coordination of action, liking, team spirit, cooperation, roles). This was followed by a network analysis of the data, which included obtaining agreement metrics among teammates. Smith-Jentsch et al. (1998) required team members to sort the teamwork-related concepts into relatedness groups (via card sorting). The groups were then compared to an expert model and level of agreement with the expert model computed. The Mathieu et al. (in press) results indicate a positive relationship between team agreement and team performance. Although performance data were not available, the Smith-Jentsch et al. (1998) results indicate that team members' understanding of teamwork did change as a result of a team training program.

Dynamic Performance Understanding

A second issue in team CTA is how to assess dynamic shared understanding. The ideal measure would be one that allows dynamic assessment of shared understanding during task performance. Even with current human performance modeling technology, however, this is not yet possible. Until dynamic assessment is possible, two basic approaches come to mind. First, the researcher could stop the task at a particular point and assess shared understanding at that point. A variety of knowledge-elicitation methods might be used during task performance intermissions. For example, although not assessing overlap among teammates, Endsley's (1995) Situation Awareness Global Assessment Technique (SAGAT) method to assess situation awareness is an example of this type of task-interruption approach. In SAGAT, the knowledge engineer freezes a simulated mission after various intervals of time and asks the operator to recall certain pieces of information pertaining to the mission. Although used previously for individuals, this technique could be expanded to a team setting by asking all team members the questions individually and then comparing where the members agree and disagree. Further work along these lines is required, along with methods that involve multiple team members in the elicitation process.

The other basic approach is to avoid performance interruptions. For example, Muniz, Stout, Bowers, and Salas (1998) used an observation and inference approach. Muniz et al. examined team behaviors in key task situations and, based on the behaviors observed, inferred the degree of knowledge of the team

situation (i.e., situation awareness) that was present. In another approach, Fowlkes, Baker, Salas, Cannon-Bowers, and Stout (in press) avoided task performance interruption by eliminating actual task performance altogether. In this study, pilots observed a videotaped mission and answered questions as if they were actually performing the mission. First, each pilot was given a description of the planned flight and the weather conditions of the route, in addition to approach plates, charts, a pocket checklist, and a cockpit diagram. The pilots then watched a videotape of a helicopter flight (from the initial briefing through the flight). The tape was stopped at specific times and the participants responded verbally to questions. The probing questions elicited task, team, and environmental cues that appeared during the mission and information regarding which knowledge was important to be shared among teammates during the mission.

In addition, a variation of a retrospective protocol methodology may also be useful. For example, a researcher could videotape a team task performance and later replay the performance for that particular team while stopping it periodically to ask questions (e.g., Means, 1993). Consider a training run in a flight simulator that is later replayed for the crew to review the run. At certain points during the replay, the researcher could use any of the shared knowledge assessment methods to assess team members' understanding of the situation and then calculate the degree of agreement among the teammates. This type of replay approach seems particularly useful for tasks performed under severe time pressure—a characteristic of many team tasks. Although not examining agreement between team members, Means (1993) used this method as a form of CTA for air traffic control. Means noted that air traffic controllers make hundreds of individual decisions in an hour, and that they do this often with little conscious awareness of the many criteria they are combining to arrive at a solution. Wanting to elicit controller understanding of these situations, yet realizing that task interruptive forms of CTA would not be possible, Means used the strategy of videotaping experts performing realistic air traffic control scenarios on full-scale simulators and later eliciting commentary on the situation from other expert controllers. Using some assessment of agreement, this same strategy seems a strong candidate to assess shared dynamic performance understanding in a team task.

SUMMARY

Clearly, the challenge of optimizing team performance is a formidable one. At the team level, a rich understanding of the cognitive demands of a task requires that information at both the individual and team levels must be elicited. Moreover, evidence suggests that, to understand fully the nature of team functioning, it is crucial to delineate those knowledge elements that must be common among team members as a precursor to performance as well as the team's ability to construct a shared picture of the task during the performance episode. In this chapter, we attempted to specify the nature of these types of knowledge and provided recommendations regarding promising team CTA methods to capture and represent such knowledge. The benefits of developing techniques that provide valid, useable team CTA data are many. In fact, such data are required so that team selection, training, task design, and management systems can be optimized. Our hope is that work in this crucial area will continue.

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REFERENCES

Baker, D. P., Salas, E., & Cannon-Bowers, J. A. (1998). Team task analysis: Lost but hopefully not forgotten. *The Industrial - Organizational Psychologist, 35*, 79–83.

Blickensderfer, E. L., Cannon-Bowers, J. A., & Salas, E. (1997, April). *Training teams to self-correct: An empirical investigation.* Paper presented at the 12th annual conference of the Society for Industrial and Organizational Psychology, St. Louis, MO.

Bowers, C. A., Baker, D. P., & Salas, E. (1994). The importance of teamwork in the cockpit: The utility of job/task analysis indices for training design. *Military Psychology, 4*, 205–214.

Brannick, M. T., Prince, C., & Salas, E. (1997). *Team performance assessment and measurement.* Mahwah, NJ: Lawrence Erlbaum Associates.

Campion, M. A., Medsker, G. J., & Higgs, A. C. (1993). Relations between work group characteristics and effectiveness: Implications for designing effective work groups. *Personnel Psychology, 46*, 823–850.

Cannon-Bowers, J. A., Salas, E., & Converse, S. A. (1993). Shared mental models in expert team decision making. In N. J. Castellan, Jr. (Ed.), *Current issues in individual and group decision making* (pp. 221–246). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cannon-Bowers, J. A., Tannenbaum, S. I., Salas, E., & Volpe, C. E. (1995). Defining competencies and establishing team training requirements. In R. Guzzo & E. Salas (Eds.), *Team effectiveness and decision making in organizations* (pp. 333–380). San Francisco, CA: Jossey-Bass.

Cooke, N. J., Neville, K. J., & Rowe, A. L. (1996). Procedural network representations of sequential data. *Human-Computer Interaction, 11*, 29–68.

Coury, B. G., Motte, S., & Seiford, L. M. (1991). Capturing and representing decision processes in the design of an information system. *Proceedings of the Human Factors Society 35th annual meeting* (1223–1227). Santa Monica, CA: Human Factors Society.

Duncan, P. C., Rouse, W. B., Johnston, J. H., Cannon-Bowers, J. A., Salas, E., & Burns, J. J. (1996). Training teams working in complex systems: A mental model-based approach. In W. B. Rouse (Ed.), *Human/technology interaction in complex systems* (Vol. 8, pp. 173–231). Greenwich, CT: JAI Press.

Endsley, M. R. (1995). Measurement of situation awareness in dynamic systems. *Human Factors, 37*, 65–84.

Flanagan, J. C. (1954). The critical incident technique. *Psychological Bulletin, 51*, 327–358.

Fowlkes, J. E., Baker, D. P., Salas, E., Cannon-Bowers, J. A., & Stout, R. J. (in press). The utility of interviews and guided verbal reports for knowledge elicitation. *Human Factors.*

Guzzo, R., & Salas E. (1995). *Team effectiveness and decision making in organizations.* San Francisco, CA: Jossey-Bass.

Hinsz, V. B. (1995). Mental models of groups as social systems: Considerations of specification and assessment. *Small Group Research, 26*, 200–233.

Hoffman, R. R., Shadbolt, N. R., Burton, A. M., & Klein, G. (1995). Eliciting knowledge from experts: A methodological analysis. *Organizational Behavior and Human Decision Making, 62*(2), 129–158.

Jenkins, N. M., & Rentsch, J. R. (1995, May). The effects of teamwork schema similarity on team effectiveness and fairness perceptions. In J. Mathieu (Chair), *Mental models and team effectiveness: Three empirical tests.* Symposium presented at the 10th annual conference of the Society for Industrial and Organizational Psychology, Orlando, FL.

Klein, G. A., Calderwood, R., & MacGregor, D. (1989). Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man, and Cybernetics, 19*, 462–472.

Kleinman, D. L. & Serfaty, D. (1989). Team performance assessment in distributed decision making. In R. Gilson, J. P. Kincaid, & B. Goldiez (Eds.), *Proceedings of the Symposium on Interactive Networked Simulation for Training* (pp. 22–27). Orlando, FL: The Institute for Simulation and Training/University of Central Florida.

Klimoski, R., & Mohammed, S. (1994). Team mental model: Construct or metaphor? *Journal of Management, 20*, 403–437.

Kraiger, K., & Wenzel, L. H. (1997). Conceptual development and empirical evaluation of measures of shared mental models as indicators of team effectiveness. In M. T. Brannick; E. Salas, & C. Prince (Eds.), *Team performance assessment and measurement: Theory, methods, and applications* (pp. 63–84). Hillsdale, NJ: Lawrence Erlbaum Associates.

Langfield-Smith, K. (1992). Exploring the need for a shared cognitive map. *Journal of Management Studies, 29(3)*, 349–367.

Mathieu, J. E., Heffner, T. S., Goodwin, G. F., Salas, E., & Cannon-Bowers, J. A. (in press). The influence of shared mental models on team process and performance. *Journal of Applied Psychology.*

Means, B. (1993). Cognitive task analysis as a basis for instructional design. In M. Rabinowitz (Ed.), *Cognitive science foundations of instruction* (pp. 97–118). Hillsdale, NJ: Lawrence Erlbaum Associates.

Minionis, D. P., Zaccaro, S. J., & Perez, R. (1995, May). Shared mental models, team coordination, and team performance. In J. Mathieu (Chair), *Mental models and team effectiveness: Three empirical tests*. Symposium presented at the 10th annual conference of the Society for Industrial and Organizational Psychology, Orlando, FL.

Moussavi, F., & Evans, D.A. (1993). Emergence of organizational attributions: The role of a shared cognitive schema. *Journal of Management, 19(1)*, 79–95.

Muñiz, E. J., Stout, R. J., Bowers, C. A., & Salas, E. (1998). A methodology for measuring team situation awareness: Situation awareness linked indicators adapted to novel tasks (SALIANT). *Proceedings of the RTO Meeting: Collaborative Crew Performance in Complex Operational Systems* (pp. 11-1-11-8). Quebec, Canada: Canada Communication Group.

Orasanu, J. (1990, October). *Shared mental models and crew performance*. Paper presented at the 34th annual meeting of the Human Factors Society, Orlando, FL.

Rentsch, J. R., & Hall, R. J. (1994). Members of great teams think alike: A model of team effectiveness and schema similarity among team members. In M. M. Beyerlein & D. A. Johnson (Eds.), *Advances in interdisciplinary studies of work teams: Theories of self-managing work teams* (Vol. 1, pp. 223–262). Greenwich, CT: JAI Press.

Rouse, W. B., Cannon-Bowers, J. A., & Salas, E. (1992). The role of mental models in team performance in complex systems. *IEEE Transactions on Systems, Man, and Cybernetics, 22*, 1296–1308.

Salas, E., Dickinson, T. L., Converse, S., & Tannenbaum, S. I. (1992). Toward an understanding of team performance and training. In R. W. Swezey, & E. Salas (Eds.), *Teams: Their training and performance* (pp. 3–29). Norwood, NJ: Ablex.

Schvaneveldt, R. W., Durso, F. T., & Dearholt, D. W. (1987). *Pathfinder: Networks from proximity data*. Memorandum in Computer and Cognitive Science, MCCS-87-9, Computing Research Laboratory, New Mexico State University.

Smith-Jentsch, K. A., Kraiger, K., & Cannon-Bowers, J. A. (1998, April). A data driven model of precursors to teamwork. In K. Kraiger (Chair), *Team effectiveness as a product of individual, team, and situational factors*. Symposium presented at the 13th annual conference of the Society of Industrial and Organizational Psychology, Dallas, TX.

Smith-Jentsch, K. A., Zeisig, R. L., Acton, B., & McPherson, J. A. (1998). Team dimensional training: A strategy for guided team self-correction. In J. A. Cannon-Bowers, & E. Salas (Eds.), *Making decisions under stress: Implications for individual and team training* (pp. 271–297). Washington, DC: American Psychological Association.

Stevens, M. J., & Campion, M. A. (1994). The knowledge, skill, and ability requirements for teamwork: Implications for human resource management. *Journal of Management, 20*, 503–530.

Stout, R. J., Cannon-Bowers, J. A., & Salas, E. (1996). The role of shared mental models in developing team situational awareness: Implications for training. *Training Research Journal, 2*, 85–116.

Stout, R. J., Cannon-Bowers, J. A., & Salas, E. (in press). Team situational awareness (SA): Cue recognition training. To appear in M. McNeese, E. Salas, & M. Endsley (Eds.), *New trends in collaborative activities*. Santa Monica, CA: Human Factors and Ergonomics Society.

Stout, R. J., Cannon-Bowers, J. A., Salas, E., & Milanovich, D. M. (1999). Planning, shared mental models, and coordinated performance: An empirical link is established. *Human Factors, 41*, 61–71.

Swezey, R. W., & Salas, E. (1992). *Teams: Their training and performance*. Norwood, NJ: Ablex.

Volpe, C. E., Cannon-Bowers, J. A., Salas, E., & Spector, P. (1996). The impact of cross-training on team functioning. *Human Factors, 38*, 87–100.

Woods, D. D., & Hollnagel, E. (1987). Mapping cognitive demands in complex problem-solving worlds. *International Journal of Man-Machine Studies, 26*, 257–275.