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CREW RESOURCE MANAGEMENT AND SHARED MENTAL MODELS: A PROPOSAL

Rosemarie Reynolds and Elizabeth Blickensderfer

Abstract

Crew Resource Management (CRM) training focuses on situation awareness, communication skills, teamwork, task allocation, and decision making. More recently, an interest in cognitive skill is beginning to appear in relation to CRM. One aspect of cognitive skill that has been examined in a variety of team domains is the notion of overlapping or "shared" mental models among teammates. While a growing amount of evidence on the relationship between shared mental models and team performance exists, only limited research has focused on the role that shared mental models have in crew resource management. The purpose of this paper is to provide CRM researchers and practitioners an understanding of the shared mental model construct and the role of shared mental models in team performance, as well as to encourage additional research on this topic within the aviation domain.

Crew Resource Management and Shared Mental Models

Human error is a major factor in aviation accidents. As a result, pilot training has shifted from an emphasis on purely technical skills, to a combination of both technical and teamwork skills (Reynolds & Rhoades, 2004). These training programs have a variety of names, but the most common is Crew Resource Management (CRM). CRM is currently required by all 185 International Civil Aviation Organization members, is incorporated into each of the US military branches, and is gaining steady support outside aviation in industries as diverse as nuclear power producers and medical practitioners (American Psychological Association, 2005; Flin, Meams, & O'Connor, 2002).

Typically, three main skill clusters are targeted: communication, team building and workload management. Within these broad categories, however, content may vary to include: adaptability, assertiveness, communication, leadership, mission analysis, situational awareness, forward planning, risk assessment, group dynamics, stress and coping techniques, and how to monitor automated equipment (Naval Education and Training Command, 2003).

The Federal Aviation Administration (FAA) (2004) suggests that "CRM training focuses on situation awareness, communication skills, teamwork, task allocation, and decision making within a comprehensive framework of standard operating procedures (SOP) (p.1)."

Under the topic of team building, the FAA notes that "This topic includes interpersonal relationships and practices. Effective leadership/followership and interpersonal relationships are key concepts to be stressed. Curricula can also include recognizing and dealing with diverse personalities and operating styles (p.12)." One area *not* emphasized is team cognition. The goal of this paper is to foster an understanding of the impact of team cognition in promoting effective team work, and to suggest the addition of team cognition, particularly shared mental models, as a focus of CRM.

To accomplish this, we begin by discussing the evolution of CRM. Next, we discuss one aspect of team cognition, shared mental models, and how both implicit communication and team performance can be linked to shared mental models. This discussion includes a review of current research on shared mental models, as well as methods of measuring and training such models. We conclude by suggesting that future CRM research and training incorporate shared mental models.

Evolution of CRM

Kern (2001) suggested that the roots of CRM can be found in a 1951 U.S. Air Force Inspector General's report which analyzed data from 7518 major accidents between 1948 and 1951, and found that poor teamwork and

human errors caused the majority of aircraft accidents.

By the 1970's, the Federal Aviation Administration, the US Air Force, and the National Aeronautics and Space Administration had programs under development that focused on reducing human error in aviation. Simultaneously, several commercial carriers were also developing training programs, focusing on crew coordination and communication.

After a 1978 accident when a United Airlines DC-8 crashed into a suburb of Portland, Oregon, United Airlines set up a formal training program, known as Cockpit Resource Management, to focus 'on human factors in aviation. An evolution of CRM has been underway since the birth of this pioneer program.

In general, the first CRM programs emphasized games and exercises unrelated to aviation; many pilots dismissed the majority of CRM as manipulation of their personalities, and other pilots derided it as "charm school" (Helmreich, Merritt, & Wilhelm, 1999). Some improvement came with the next evolution of CRM.

According to Helmreich et al. (1999), this next evolution of CRM focused on mission effectiveness in more typical aviation environments such as flight deck automation, and also offered a broader perspective of cockpit resources, including pilots, crew members, and air traffic controllers. Although aviators accepted this second generation of CRM more readily than the first, many still scoffed at it as "psycho-babble." The third generation of CRM appeared in the early 1990s (Helmreich et al., 1999).

At this time, most airlines had integrated CRM into training and had extended the application of CRM to include maintenance crews and cabin crews. The FAA decision in 1990 to implement the Advanced Qualification Program (AQP) prompted the fourth generation of CRM. As a part of the AQP program, airlines were required to produce detailed training programs for each aircraft model and to incorporate the relevant human factors issues.

The current focus in CRM is on error management training. In this training, participants are explicitly encouraged to make errors and learn from them, rather than adopt an error avoidant approach (Heimbeck, Frese, Sonnentag & Keith, 2003; Keith & Frese, 2005). Responding to the error management trend, Petrilli and Thomas (2004) point out that the error management model of CRM necessitates a greater requirement to focus on cognitive skill development. Indeed, an emphasis on cognitive skills is explicitly and implicitly recommended in much of the current research on CRM.

For example, a focus on cognitive skill development was emphasized in recent work by Keith and Frese (2005), who investigated self-regulatory processes in error management training, and found that volunteers who learned a computer program using error management training, or error management training supplemented with a metacognitive module, performed better than those using error avoidant training.

Orasanu (2005), working with space crews, recently suggested that successful performance in stressful conditions depends in part on the ability to make effective decisions under pressure and ambiguity, and that training in Naturalistic Decision Making (NDM) should be part of training crews to work in high risk environments, as classic decision strategies take too long to be effective under time pressure

This need for cognitive skills operates on both the individual and team levels. Pedersen and Cooke (2006) note that the interaction of team members gives rise to cognition on the team level that is not simply the aggregation of individual cognition, adding that "There is evidence that teams "think" (p. 426)." Cooke, Salas, Cannon-Bowers and Stout (2000) note that team performance requires coordination, planning, decision making, and problem solving; and as a result, team cognition is critical to understanding team performance.

More specifically, Fiore and Salas (2004) point out that team cognition invariably is paired with team coordination; that the *symptom* of effective cognition is the execution of coordinated behaviors. One cognitive construct that has been useful in the study of team coordination and performance has been the notion of overlapping or "shared" mental models.

Shared Mental Models

The notion of shared mental models is an extension of the concept of mental models. Mental models are a form of cognitive structure that allows humans to interact effectively with their environment by organizing knowledge into meaningful patterns.

In reviews of work considering the purpose of mental models, the common themes of description, explanation, and prediction appear (Rasmussen, 1983). The mental model has been invoked to describe human operators' understanding of various mechanical systems.

In terms of team performance, the mental model construct has been used to describe the individual team members' understanding of their particular team as a system. Consider the following: as a team performs, individual team members continually make predictions about what will happen next, and in turn, anticipate how he or she should respond. Since the process by which a team member arrives at a prediction (e.g., anticipates a need)

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cannot be observed, it has been surmised that team members utilize an internal knowledge base, or mental model, that helps them to decide which behaviors are necessary, and when and how to perform them. .

The term "shared mental model" refers to the extent to which individual team members' mental models overlap; or the extent to which members share the same understanding of the task and the team. There is considerable evidence to support the idea that the greater degree of shared knowledge, the better the team will perform (Cannon-Bowers, Salas & Converse, 1993).

One early study on shared knowledge and team performance was presented by Hemphill and Rush (1952). They investigated the extent to which the performance of a team or crew depended upon individual team members' understanding of the duties of other crew positions. The results indicated that a crew index of overlap of knowledge was related to the effectiveness of crew coordination as judged by the crew instructor. More recently, research has focused on shared mental models and stress, situation awareness, team performance, and implicit communication. Each of these topics has implications for CRM.

Shared Mental Models and Stress

At least two studies have examined the relationship between shared mental models and arousal. First, Espevik, Johnsen, Eid, and Thayer (2006) investigated the effect of knowledge about team member characteristics on performance and team processes in submarine attack crews. They found that knowledge about team members contributed to performance, over and above the contribution from operational skills. Additionally, teams with team members who were familiar had less physiological arousal than teams whose members were unfamiliar with each other, and the authors attributed the reduction in arousal to the presence of shared mental models among those teammates. On a related note, Ellis (2006) examined the mediational role of mental models and transactive memory in the relationship between acute stress and team performance.

The results indicated that acute stress negatively affected both mental models and transactive memory. The impairment of mental models may be one reason that teams perform more poorly under acute stress.

Shared Mental Models and Situational Awareness

The shared mental model construct may also have implications for team situational awareness. Millward (2005) examined the effect of shared mental models on situational awareness, or the extent to which a mental model of a given situation accurately reflects reality. In this work, shared situation awareness was defined as the overlap in individual situation awareness. The author found that groups that implemented good communication practices training were more aware than groups who did not. Additionally, Bolstad and Endsley (1999) tested the impact of shared mental models and shared displays on team situation awareness, and found that effective team performance was enhanced by a shared mental model.

Shared Mental Models and Performance

Importantly, a number of studies have indicated a relationship between shared mental models and task performance (Cooke, Kiekel, & Helm, 2001; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Marks, Sabella, Burke, & Zaccaro, 2002; Marks, Zaccarro, & Mathieu, 2000; Stout, Cannon-Bowers, Salas, & Milanovich, 1999; Smith-Jentsch, Mathieu, & Kraiger, 2005). Smith-Jentsch, Mathieu, and Kraiger (2005) looked at two different types of shared mental models, and found that they interacted with one another to predict both tower safety and efficiency in air traffic controllers. Marks, Zaccaro and Mathieu (2000) and Marks et al. (2002) found evidence that a shared understanding of specific procedures predicted team performance. Mathieu et al (2005) investigated the effect of mental model quality on team performance, and found that team processes and performance were better among teams sharing higher-quality team mental models than among teams evidencing less sharedness or lower-quality models. Similarly, Edwards, Day, Arthur, and Bell (2006) examined the relationship between the similarity and accuracy of team mental models and team performance. Their results indicated that similarity and accuracy of team mental models were significantly related, and accuracy partially mediated the relationship between team ability and team performance, but similarity did not.

Finally, while the majority of the studies described above assessed similarity of mental models of domain specific taskwork knowledge, Smith-Jentsch, Rosopa, Sanchez, Lima and Crippen (2003) advocated the importance of mental models of the notion of teamwork itself (e.g., back-up behavior, monitoring, communication and the like). Smith-Jentsch et al. (2003) found that teamwork mental model similarity scores were significantly related to team performance.

Shared Mental Models and Implicit Communication

Eccles and Tenenbaum (2004) differentiate among four methods of communication in teams, intentional and unintentional, and verbal and non-verbal. Intentional verbal communication is very flexible, but costly in terms of cognitive resources, while unintentional non-verbal communication is less costly, but "the ability to interpret observed operations relies on the recipients having achieved

an SK (shared knowledge) of team operations (p. 551)." Because intentional verbal communication during performance is problematic, an effective communication system that enables team members to coordinate behaviors without extensive discussion is important.

The idea that teams could maintain coordinated functioning without using a great amount of overt communication was noted by Kleinman and Serfaty (1989), who argued that this type of implicit coordination required that teammates have knowledge of what to do when, when and how to compensate for their teammates, which information and resources to provide to their teammates and when to provide these.

Since then, Cannon-Bowers and Bowers (2006) defined implicit coordination as "... adaptive behavior where team members act on pre-existing knowledge about the task and team in order to coordinate (p. 451)." Espinosa, Lerch, and Kraut (2004) are referring to implicit coordination when they discuss "...high-paced contexts like sports competitions and medical emergency rooms in which members act in a highly coordinated fashion with very little coordination because of their prior experience working and/or training together (p. 109)." Evans, Harper, and Jentsch (2004) also imply implicit communication when they state "The most commonly used example of this type of effort is the 'no-look' pass performed between basketball teammates. This task requires that teammates not only anticipate a pass but know when and where to anticipate either their teammate being or the pass coming from."

The shared mental models construct has been adopted by a number of team researchers as the mechanism which allows successful teams to coordinate and have smooth, implicit coordination (Cannon-Bowers, Salas, & Converse, 1993; Kraiger & Wenzel, 1997; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2005). For example, Swain and Mills (2003) compared implicit communication in expert and novice teams, and found that expert teams use more implicit communication strategies, apparently based on shared mental models. McComb (2005), in a review of the shared mental model literature, concluded that such shared mental models are useful in promoting both team performance and implicit communication. Entin and Serfaty (1999) hypothesized that highly effective teams adapt to stressful situations by using effective (implicit) coordination strategies based on shared mental models.

Measuring and Training Shared Mental Models

In order to be useful for training purposes, a mental model measure must be able to diagnose specific underlying knowledge deficiencies (Smith-Jentsch et al., 2003). Unfortunately, there is no "Universal Measure" of mental models, as the specific content of a shared mental model is domain specific (McComb, 2005). There are, however, a number of techniques for developing measures of shared mental models; reviews can be found in Cooke, Salas, Cannon-Bowers, and Stout (2000), as well as Smith-Jentsch et al. (2003).

A number of team researchers have suggested potential training interventions to foster various aspects of shared knowledge (e.g., Stout, Cannon-Bowers, Salas & Milanovich, 1999; Volpe, Cannon-Bowers, Salas, & Spector, 1996). One approach is team self-correction (Blickensderfer, Cannon-Bowers, & Salas, 1997). The notion behind team self-correction is that following performance, effective teams tend to discuss their performance, including what went well, what was problematic, why things did not work effectively, and how to change for the future. This exchange of observations, ideas, and plans for improvement is likely to foster shared knowledge among the team members concerning the task and team. Indeed, Blickensderfer et al. (1997) found that teams who had self-correction discussions demonstrated greater shared knowledge, and, during subsequent performance, communicated more efficiently than teams who did not receive the training.

Other approaches to training shared mental models include: providing feedback to trainees regarding their model (Smith-Jentsch et al. 2003); scenario-based training (Thomas, 2004); providing teams with sufficient information to build a shared mental model of each other's tasks and goals, either through direct instruction, or through provision of shared displays (Bolstad & Endsley, 1999); and training teams to shift from explicit to implicit coordination during periods of high stress and workload (Entin & Serfaty, 1999).

Integrating the Shared Mental Model Concept into CRM

As with most training methods, CRM is evolving, and recent directions emphasize the cognitive aspects of teamwork. One cognitive concept is that of shared mental models, which have been shown to impact many aspects of team dynamics, including stress, situation awareness, team performance, and implicit communication, a critical skill for teams operating in fast paced, high stress environments. We suggest mental models as a useful addition to CRM because there is considerable evidence that mental models can be both measured and trained.

At this juncture, we offer a model to demonstrate how the shared mental model construct fits into CRM. As shown in Figure 1, team performance can be considered a

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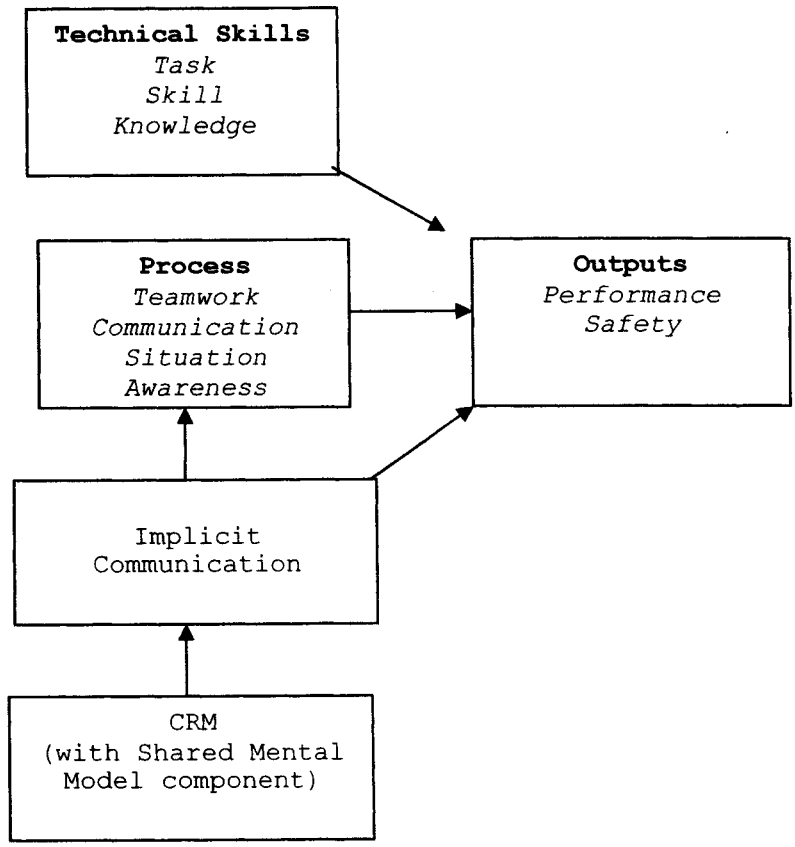
combination of technical task performance and team processes.

Figure 1. Shared Mental Models in CRM



Technical task performance is based on the knowledge and skills of individual team members. Team processes, on the other hand, are composed of the behaviors (e.g., communication) and cognitive processes (e.g., situation awareness) relating to teamwork. Both taskwork and teamwork influence team outputs. Furthermore, the shared mental model concept can influence overall outputs (team performance) via its influence on certain team processes, such as implicit communication.

To integrate the shared mental model construct into CRM, work is needed. A few possibilities for research in this area include:

1. In which aviation tasks do shared mental models correlate with performance? Research is needed to identify the types of aircrews and environments that show the strongest impact of shared mental models.
2. What measurement tools can be used to measure shared mental models in the aviation domain? The methods and techniques used to assess shared knowledge in non-aviation domains need to be tested in aviation tasks. Additional measures are also needed.
3. What types of interventions foster shared mental models in aviation tasks? Previous work has identified training interventions such as cross-training and team leader training to improve shared knowledge among team members. Research is needed to assess the efficacy of these and other strategies for aviation tasks.
4. How does the shared mental model concept fit with automation? Automation technology could be considered a teammate. Just as human-human teams need a degree of overlapping knowledge to best perform together, so do human-technology teams. The human teammate needs an understanding of what the automation is doing and vice-versa. The shared cognition concept may be useful in helping researchers assess how much overlap is necessary and whether the human-technology relationship achieves that.
5. How can the notion of shared mental models be used to improve Air traffic control (ATC)/pilot communications? Despite years of efforts, communication problems still occur between ATC and pilots. Could the continued problems indicate a mismatch of mental models? If so, would interventions designed to help teammates acquire shared knowledge be used with ATC personnel and pilots?
6. What is the implication of shared mental models for aircraft display designs? How can displays be designed to foster shared mental models in aircrews?

Conclusions and Future Directions

Research has shown the importance of the shared mental model concept for team performance. Unfortunately, the shared mental model concept has not yet been integrated into crew resource management. It is our opinion that this is an issue that merits attention. One of our goals for this paper was to introduce those not familiar with the shared mental model concept to the theories. At the same time, we hoped to stimulate thought amongst researchers and CRM practitioners regarding the potential of integrating the shared mental model concept into CRM. Finally, we have listed some intriguing questions for shared mental model research. It is our hope that we have conveyed our enthusiasm for both CRM and the shared mental model construct. and, in so doing, have stimulated work in this area.✈

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