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Crew Resource Management and Shared Mental Models

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An interest in cognitive skill is beginning to appear in relation to crew resource management. 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 occurred in respect to the role shared mental models have in crew resource management. The purpose of this paper is to provide researchers and practitioners an understanding of shared mental models and their role in team performance, and to encourage additional research on this topic within the aviation domain.

Introduction

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 (Flin, 1997; 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).

Bowers and Salas (2003) note that traditional CRM has two goals: a) to create more positive attitudes to increase the likelihood of coordination and (b) to practice the necessary skills. 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, decision-making, leadership, mission analysis, situational awareness, forward planning, risk assessment, prioritization skills, delegation, group dynamics, stress and coping techniques, and how to monitor automated equipment (Driskell & Adams, 1992; Naval Education and Training Command, 2003).

In the following sections, we begin by discussing the history of CRM, as well as some of the current research focusing on the future of CRM. We then discuss one aspect of effective team performance, implicit communication, and show how implicit communication can be fostered through the development of shared mental models. We conclude by suggesting that future work on CRM incorporate shared mental model research.

History of CRM

Kern (2001) suggests 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 (Flin, 1997). In 1978, a United Airlines DC-8 crashed into a suburb of Portland, Oregon. As a result of this accident, in 1980, United Airlines set up a formal training program (known as Cockpit Resource Management) to focus on human factors in aviation, and pioneered the first generation of CRM (Boser, 1997).

A few of these first generation programs incorporated simulator flights into training, but many programs involved games and exercises unrelated to aviation. Although there was acceptance of some aspects of the training, many pilots dismissed CRM as manipulation of their personalities or derided it as "charm school" (Helmreich, Merritt, & Wilhelm, 2001). According to these same authors, the next evolution of CRM focused on mission effectiveness in more specific environments, flight deck automation, and a broader perspective of cockpit resources, including everyone in the organization 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."

Helmreich, Merritt and Wilhelm (2001) suggest that the early 1990s marked the advent of the third generation of CRM. By then, most airlines had integrated CRM into training, and extended the application of CRM to include maintenance crews and cabin crews. The fourth generation of CRM stemmed from an FAA decision in 1990 to implement the Advanced Qualification Program (AQP). As a part of this program, airlines were required to produce detailed training programs for each aircraft model, and incorporate the relevant human factors issues into each module.

Currently, the trend in CRM is to focus on error management training, in which 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). Petrilli and Thomas (2004) point out that this model requires three new critical developments: a greater requirement to focus on cognitive skill development, a requirement to better integrate technical and non-technical skills in decision making, and a requirement to better prepare aviators by increasing the experiential component of error management training.

The Future of CRM

Much of the current research on CRM either explicitly or implicitly recommends incorporating knowledge from other bodies of work, especially teamwork and cognitive skills, into CRM training. For example, a focus on cognitive skill development as an important aspect of CRM was emphasized in recent work by Keith and Frese (2005). They 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.

Alonso, et al., (2006) discussed the development of two CRM programs for the Department of Defense military health system, and noted that a recent evaluation of the programs identified several limitations, including the failure to incorporate the larger body of team training research. Similarly, a systematic debriefing method, based on existing team performance research outside the CRM domain, was an element added by Prince, Salas, Brannick, and Orasanu (2005) in order to address one of the weaknesses of CRM. A research area so far neglected by the CRM community, however, is that of implicit coordination and shared mental models.

Implicit Coordination

A team's ability to adjust its strategy and react appropriately is crucial in fast-paced, stressful environments. Researchers have argued that *implicit coordination* is the mechanism that helps teams to adapt and adjust (Kleinman & Serfaty, 1989). Espinosa, Lerch, and Kraut (2004) are referring to implicit communication 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 communication because of their prior experience working and/or training together." 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."

Implicit coordination occurs when team members work together effectively without overt strategizing or other communication. This occurs because team members know their respective duties, how to compensate for other team members, what information or materials they must provide to other team members, and when to provide it. Authors have stressed that teams whose members anticipate what information, materials, or assistance their teammates will need and, in turn, give those in advance of their teammates' requests, tend to perform better than those teams whose members do not anticipate what will be needed by their teammates (Entin, Serfaty, & Deckert, 1994; Krumm & Farina, 1962; Volpe, Cannon-Bowers, Salas, & Spector, 1996).

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; Rentsch & Hall, 1994).

Shared Mental Models

The shared mental model concept stems from the concept of mental *models*, or knowledge organization 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; Veldhuyzen & Stassen, 1977; Wickens, 1992).

Since the process by which a team member arrives at a prediction (e.g., anticipates a need) 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. In other words, team theorists have taken the term "mental model" and applied it to the understanding of a team task, including predictions of other team members' needs and actions. The term "shared mental model", then, is the extent to which individual team members' mental models overlap--the extent to which team members share the same understanding of the task and the team. It is argued that the greater degree of shared knowledge of the team, the task, and the equipment among teammates, the better the team will perform (Cannon-Bowers, Salas & Converse, 1993; Rouse, Cannon-Bowers & Salas, 1992). The argument is that teammates with a shared model concerning team member roles and responsibilities can anticipate what information is needed at what time, and deliver the information without further prompting. In other words, they achieve implicit coordination.

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. A crew index of overlap of knowledge was found to be related to the effectiveness of crew coordination as judged by the crew instructor. Minionis, Zaccaro, and Perez (1995) examined shared knowledge among team members in a computer simulation of a tank exercise. The results indicated that shared mental models enhanced performance on collective tasks requiring interdependence among team members but did not impact those tasks that could be completed without coordinated actions.

More recently, research has focused on shared mental models and stress, situation awareness, and team performance. Espevik, Johnsen, Eid, and Thayer (2006) studied submarine attack crews to test whether knowledge about team members had an effect on performance and team processes. They found that knowledge about team members added to performance, over and above the contribution from operational skills. In addition, teams with known team members had less physiological arousal, which the authors attributed to the shared mental models of team members. Ellis (2006) examined the mediational role of mental models and transactive memory in the relationship between acute stress and team performance, and found that acute stress negatively affected mental models and transactive memory, which helped to explain why teams performed more poorly under acute stress.

Millward (2005) examined the effect of shared mental models on situational awareness, or the extent to which a person's mental model of a given situation accurately reflects reality, with shared situation awareness defined as the overlap in individual situation awareness. The author found that groups that implemented good communication practices training were more likely to form high levels of shared situation awareness and perform better than untrained groups.

With regards to performance, 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. Thomas and Petrilli (2006) investigated the relationships between crew familiarity, non-technical performance, and error management. The rate of error occurrence was found to be higher for unfamiliar crews. 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. Lim and Klein (2006) examine the relationship between team mental model similarity and accuracy and performance. Both taskwork mental model and teamwork mental model similarity predicted team performance.

Finally, Marks, Zaccaro and Mathieu (2000) and Marks et al. (2002) found evidence that a shared understanding of specific procedures predicted team performance. Thus, a growing body of evidence indicates that the shared mental model construct plays an important role in variety of team tasks.

Despite this, little research on this construct has appeared with respect to CRM.

Conclusion

As with most training methods, CRM is evolving; recent changes include an emphasis on error management rather than error prevention, and more emphasis on the cognitive aspects of teamwork. One such cognitive area that could be useful is that of shared mental models. We suggest mental models as a useful addition to CRM both for their direct impact on performance, but also on their indirect impact through improving implicit communications, a critical skill for teams operating in fast paced, high stress environments.

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