13th ICCRTS: C2 for Complex Endeavors

Title:

Macrocognition in Command and Control: Understanding and assessing verbal and non-verbal communications during complex collaborative problem solving

Topic(s):

Topic 4: Cognitive and Social Issues
Topic 6: C2 Assessment Tools and Metrics

Name of Author(s):

Dr. Stephen M. Fiore (UCF)
Mr. Michael A. Rosen (UCF) [student]
Dr. Eduardo Salas (UCF)
Dr. Mike Letsky (ONR)
Dr. Norm Warner (NAVAIR)

Point of Contact:

Organization: University of Central Florida
Complete Address: Dr. Stephen M. Fiore
3100 Technology Parkway, Suite 140
Orlando, FL 32826
Phone: 407-882-0298
Email: sfiore@ist.ucf.edu

INTRODUCTION

Individual and team knowledge processing issues have typically been undervalued in assessing complex endeavors. The coming emphasis on special operations and the communication demands of effecting "power to the edge" have put the development of metrics for measuring knowledge interoperability at the forefront of assessing the effectiveness of complex endeavors. In this paper we discuss theoretical considerations in the area of macrocognition in teams, that is, cognition in collaborative contexts encompassing internalized and externalized processes occurring during team interaction (Letsky, Warner, Fiore, Rosen, & Salas, 2007). Macrocognition theory encompasses concepts ranging from internalized individual and contextually-bound cognitive processes such as mental model development (Klein et al., 2003), to externalized processes such as solution alternative negotiation (Fiore, Rosen, Salas, Burke, & Jentsch, in press) and we describe how this approach can provide a richer understanding of Command and Control components. For this paper we focus specifically on externalization of cognition and show how understanding and measuring the characteristics of communication patterns can contribute to the diagnosis of effective and ineffective behaviors in Command and Control. We propose that measuring macrocognitive processes is fundamental to: 1) furthering the conceptual understanding of macrocognition that will be needed to develop effective technology to support performance in modern C2; and, 2) managing performance in real-time in modern C2 operations. As discussed later, the need for real-time measurement is much more salient in modern C2 than in its traditional counterpart.

First, we lay the ground work for our discussion by providing an overview of the types of demands that will be placed on performance with the newly envisioned organizational structures of modern C2. Second, we provide an overview of the macrocognitive in teams (MIT) perspective, a theoretical framework developed to understand collaborative performance in environments characteristic of modern C2. Third, we discuss the role of communication analysis in understanding and improving collaborative problem solving. Specifically, we discuss a largely

ignored area of communication analysis in military research, that of group communication theory (e.g., Frey, Gouran, & Poole, 2004). We describe the "Functional Perspective" to communication theory as well as "Decision-Emergence" and "Multiple Sequence Models of Group Decision Making" theory (Fisher & Hawes, 1971; Gouran & Hirokawa, 1983; Poole, Seibold, & McPhee, 1986). Each of these uniquely account for important elements of communication during complex problem solving, capturing elements ranging from the social to the cognitive. Fourth, we conclude by illustrating how these approaches complement each other in such a way that both basic and applied research in Command and Control can benefit complex collaborative problem solving.

Modern Command and Control and Teams

The traditional vision of Command and Control involves an explicitly structured organization with tight top-down control of components. Information can flow up the command structure, but decisions about courses of actions always flow down the command hierarchy. Organizations of this type have their benefits. For Command and Control in the past, a salient advantage of this arrangement involved the stability in organizational structure over time increasing the reliability of performance given a relatively static environment (e.g., aspects of how to respond to certain situations were built into the structure of the organization). Once critical features of the adversaries' tactics and capabilities were known, the problem of dealing with them could be solved once and designed into the structure of the organization. These organizational routines then maximized the efficiency with which Command and Control could respond to this finite and relatively mapped set of possible actions by the enemy. However, the assumption that Command and Control operations function in an environment characterized as relatively stable is no longer defensible. Now, the rate of change in the environment far exceeds the capacity of a traditional Command and Control structure to adapt.

Intended to directly address these deficiencies rooted in the shift of the nature of adversaries, the vision for modern Command and Control is fueled by complexity science and

ideas of emergent structures in organizations (e.g., Alberts, 2007). Aspects of modern Command and Control can be characterized by the rapid reconfiguration of personnel that may be spatially or temporally distributed to address a specific and unique problem (Letsky, Warner, Fiore, Rosen, & Salas, 2007). Teams may no longer have and extended history of work experiences together or formalized procedures to draw from during performance. None the less, these teams will still share common goals and interdependencies and therefore, the existing scientific understanding of teamwork does apply (Rosen, Salas, Fiore, Letsky, & Warner, in press). However, these differences in the nature of teamwork in modern Command and Control pose several challenges to the extant understanding of team functioning. It is the aim of efforts from the macrocognition in teams perspective to extend the present understanding of teams to include performance in these types of highly dynamic and knowledge driven task environments.

Teamwork and Macrocognition Overview

Teamwork, by its very definition, is achieved when members interact interdependently and work together towards shared and valued goals. Further, expert teamwork involves the adaptation of coordination strategies through communication and a collective understanding of their task so that they can reach their goals (Salas & Cannon-Bowers, 2000). Cognitive science has substantially influenced this study of teams and it has been over a decade since the original applications of constructs from cognitive psychology were utilized to foster the development of the team cognition movement (e.g., Cannon-Bowers & Salas, & Converse, 1993; Hutchins, 1991; Orasanu, 1990). Since then, much cross-disciplinary attention has focused on determining how cognitive processes contribute to effective team performance. What is invariant across these disciplines is the notion that shared information processing among group members has both inter- and intra-individual outcomes (e.g., Levine, Resnick, & Higgins, 1993), whereby constructs such as encoding, storage, and retrieval of information are thought to be equally applicable to both individuals and groups (e.g., Hinsz, Tindale, & Vollrath, 1997; Larson & Christensen, 1993; Tindale & Kameda, 2000).

Although there has been recent multidisciplinary integrations in investigations of team process and performance (Salas & Fiore, 2004), there is much to be done to examine how we can better understand command and control through theorizing arising in multidisciplinary research areas such as macrocognition. We broadly define macrocognition in teams as "the internalized and externalized high-level mental processes employed by teams to create new knowledge during complex, one-of-a-kind, collaborative problem solving" (Letsky et al., 2007). "High-level" can be considered cognitive processing involved in the combining, visualizing, and aggregating of information to resolve ambiguity in support of the discovery of new knowledge and relationships. These are processes utilized by teams in complex environments where collaboration focuses on one-of-a-kind situations.

It is the cognitive processes arising during the complex and dynamic interaction of teams that are the focus of this paper and our emphasis is on command and control. Here teams have to rapidly deal with difficult situations, often in the short-term. Additionally, given the complexity of the problems these teams face, they are often quite heterogeneous, possessing unique skills and knowledge. Finally, these teams must typically work within environments that are ill-defined and which often have associated with them grave consequences for mistakes. As our understanding of the macrocognition in teams concept evolves we can pursue the development of theoretically-driven and empirically-based guidelines for designing, managing, and developing teams in areas such as command and control. Essentially, as the science of teams matures (Salas & Cannon-Bowers, 2001), we must examine how these theories and findings apply to differing domains, particularly those more complex team contexts as is found in modern command and control. Only in this way can we hope to address the variety of needs surrounding dynamic team functioning. Specifically, in order for the macrocognition in teams perspective to achieve the broad power and scope that is necessary for it to benefit performance in operational environments, it is important for findings in one domain to be examined in a variety of domains. Toward this end, in the remainder of this paper we investigate how theory and methods arising

from the area of group communication theory can help our understanding of macrocognition in teams (for a more detailed review of the macrocognition in teams perspective, see Letsky, Warner, Fiore, & Smith, in press).

ANALYZING COMMUNICATION TO UNDERSTAND PROBLEM SOLVING

Communication has been identified as a critical component of team cognition (Fiore, & Salas, 2004; Cooke, Salas, Kiekl & Bell, 2004) as it is the primary means by which groups of individuals process information (Hinsz, Tindale, & Vollrath, 1997). Specifically, whether verbal or non-verbal, it is how they share, distribute, pool, and integrate information and knowledge about each other, the task, and the environment. Because of the central role communication plays in theories of teamwork and complex team problem solving, the measurement of and analysis of team communication has received much attention, increasingly so with efforts to develop automated systems for diagnosing and facilitating team performance processes (e.g., Rosen, Feldman, Fiore, & Salas, 2007). The measurement evaluation of team communication has focused on such issues as brevity, clarity, proper phraseology, and completeness (e.g., Smith-Jentsch, Zeisig, Acton, & McPherson, 1998) and recent efforts have focused on either the content of communication or the flow of communication (i.e., patterns of communication between team members regardless of content). Automated analysis of communication content (e.g., Foltz, 2005) and flow (e.g., Keikel, 2005) show promise as valuable tools in furthering the scientific understanding of macrocognition in teams as well as developing tools for analyzing and facilitating macrocognition in the operational contexts. For example, it has been found that specific sequences of communication are associated with higher levels of team performance. Specifically, patterns of closed-loop communication are markers of more effective flight crews (Bowers, Jentsch, Salas, & Braun, 1998). However, efforts in both of these directions have been criticized for lacking a strong theoretical basis. And many of the findings to date relate to action/performing teams where behavioral coordination is the fundamental feature of performance. These findings may not be readily generalizable to the knowledge-based

performance that characterizes complex team problem solving (Rosen, Salas, Fiore, Letsky, & Warner, in press). There remains a relatively rich and untapped research tradition (i.e., group communication) that has the potential to inform both theories of macrocognition and theoretically based measurement and analysis of communication data in complex team problem solving. We next discuss a subset of this area of inquiry. Although not an exhaustive review, this set of theories is representative of the types of theorizing that can help us understand the richness of communication, and the patterns of those communications, that would occur in complex team problem solving situations.

Functional Theory of Group Decision-Making Effectiveness

In general, the functional approach to groups is defined by a set of four core assumptions: 1) groups are goal oriented, 2) performance and behavior within a group varies and can be evaluated, 3) the interaction processes of the group vary and can be evaluated, and 4) various internal and external factors influence the groups performance outcomes through interaction processes (Hollingshead et al., 2005). This general perspective has been adapted to investigate why certain groups make better decisions than others. One important development in this tradition has been the functional theory of group decision-making effectiveness. The essence of this theory is that the performance level of the group is dependent upon the degree to which group interactions contribute to the fulfillment of critical task requirements (Hirokawa, 1980); that is, all decision making groups must accomplish some set of sub-tasks, or general functions, in order to successfully arrive at an acceptable decision. The amount and quality of group interactions focused on these functions determine the quality of decision making outcomes. The functional perspective stands in contrast to phasic models of group decision making (like decision emergence discussed below) that seek to organize the group decision making process around a set sequence of decision making processes. While functional theory has evolved over time, the most

recent variants propose that decision making groups must complete the following five functions (Orlitzky & Hirokawa, 2001):

Problem analysis. In order to arrive at an effective decision outcome, a group must utilize the information it has available to create an accurate understanding of: 1) the nature of the problem; 2) the seriousness, criticality, urgency, or extent of the problem; 3) feasible and likely causes of the problem; and, 4) foreseeable consequences of not solving the problem.

Establishment of evaluation criteria. The group must define what an acceptable solution to the problem should look like. This involves setting the standards by which decision alternatives will be judged and an acceptable solution selected.

Generation of alternative solutions. The group must also generate or in some other way have available to them (e.g., through standard operating procedures), a set of decision alternatives that are practically feasible and acceptable given the evaluation criteria.

Evaluation of positive consequences of solutions. In order to arrive at an effective decision outcome, groups must explore the relative merits, the likely positive outcomes, associated with decision alternatives. The group will frequently have more than one option judged to be acceptable given the set evaluation criteria, so determining the degree and likelihood of positive outcomes associated with each option is a critical group function.

Evaluation of negative consequences of solutions. Similar to the evaluation of positive outcomes, a group must be aware of the relative disadvantages, or likely negative outcomes, associated with a decision alternative. Any one decision option will frequently have both positive and negative consequences associated with it and becoming aware of both of these is a critical group function.

In sum, the functional theory of group decision making effectiveness proposes that the amount and quality of group interaction processes dedicated to each of the above described functions plays a causal role in determining the effectiveness of group outcomes. This theory has received support from meta-analytic synthesis, especially for the evaluation of negative consequences of solutions, problem analysis, and establishment of solution criteria which were the strongest predictors of decision making effectiveness (Orlitzky & Hirokawa, 2001).

Implications for Macrocognition in Teams

There are significant points of agreement between the functional perspective of group decision making and the macrocognitive model as proposed by Letsky and colleagues (see Letsky et al. in press). While the macrocognitive model proposes a set of phases, there are tasks associated with each of these phases (i.e., functions that the team carries out during each of the phases). A significant contribution of the functional theory of group decision making effectiveness to macrocognition is the idea that the amount and quality of interaction processes focused on specific group functions are the key to understanding and predicting group outcomes. Specifically, the functional approach can help to focus the analysis of interaction to a manageable subset of critical tasks the group must complete. The macrocognitive model proposes a very robust set of processes and functions at work during collaborative problem solving. While there is support for each of these playing an important role, undoubtedly, some contribute to higher levels of performance outcomes more so than others. Because rapid adaptation is one of the core requirements in macrocognitive environments, the opportunity for dynamic measurement and feedback/intervention will likely be limited and should focus on the most critical group functions. For example, the most predictive of the five functions is the analysis of negative consequences of decision alternatives. If the interaction pattern of a group reveals that it has not evaluated the possible costs of an alternative, this may be a marker for poor critical thinking or even something comparable to groupthink in that a solution is proposed and no one voices dissent. A group with

this interaction pattern could be prompted to consider negative consequences of decision alternatives or be provided with interaction tools that require them to do so.

Decision Emergence

Decision emergence is based on the idea that groups do not 'make' decisions; rather, decisions emerge over time from group interaction (Ellis & Fisher, 1994). There is usually no 'Eureka!' moment in group decision making in which the group comes to the single best solution to a problem. Instead, the group progressively comes to terms with the problem and its solution through discussion. Like the functional perspective, decision emergence focuses on the quality and type of interaction process as being a major determinant of group decision making outcomes; however, instead of focusing on critical functions that need to be met, the decision emergence perspective is based upon observational studies that track the progression of group decision making from the introduction of preliminary ideas to the solidification of a group consensus around a solution. The decision proposal is the focus of analysis and each group member's communication acts on the decision proposal in one of the following ways: expressing an opinion about the decision proposal (favorable, unfavorable, ambiguous), modifying or clarifying the decision proposal, providing evidence to support an opinion, or agreeing or disagreeing with another group member's stated opinion. This approach yields a perspective attached to the content of group interaction (i.e., the various decision proposals). Investigations of this type have yielded four distinct phases of group decision making: orientation, conflict, emergence, and reinforcement.

Orientation phase. This phase of group decision making is characterized by attempts to build a social climate (i.e., group members get acquainted with each other), clarifying the decision task and possible alternatives, and expressing initial and tentative attitudes and opinions. Group members generally express ambiguous attitudes towards decision proposals as they are unsure of the direction the group will take and attempt to

avoid committing themselves to a particular solution alternative. Additionally, social inhibition may keep group members from expressing strong opinions at the beginning of interaction with the group (i.e., no one wants to rock the boat early on in group formation).

Conflict phase. In the conflict phase, the ambiguous opinions expressed during the orientation phase are replaced with dispute or conflict over various decision proposals. Group members are aware of the decision proposals available and commit themselves to one of them by expressing favorable opinions about their choice and unfavorable opinions about competing proposals. Attitudes become polarized and conflict inevitable. Interaction is characterized by one group member expressing a favorable attitude about a decision proposal followed by another member expressing an unfavorable attitude about that proposal, and vice versa. Over time, two factions of group members emerge, those expressing favorable opinions about the proposal that ultimately becomes the consensus group decision and those expressing unfavorable opinions about that decision proposal.

Emergence phase. Conflict from the preceding phase dissipates as the group progresses to the emergence phase. Here, opposition from the sub-group of members voicing unfavorable opinions about the decision proposal around which the group will ultimately form a consensus wanes. This occurs through the return of increased levels of ambiguity in communicative acts from those who were in opposition to the consensus decision proposal. This is viewed as an intermediary step where these individuals back away from opposition to the decision proposal and ultimately come to be in favor of it. That is, in the conflict phase group members are either in favor or opposed to decision proposals. Ambiguity serves no role here because the alternatives are all known. In the emergence phase, group members either express opinions in favor of, or are ambiguous towards the decision proposal. Ambiguity here is a form of modified dissent; group

members that have already expressed opposition to the decision proposal can not move so abruptly to being in favor of it and hence take the intermediary step of expressing ambiguous opinions.

Reinforcement phase. While decisions are reached during the emergence phase (i.e., the final accepted decision proposal begins to emerge), consensus is reached ruing the reinforcement phase. Here, virtually all dissent to the consensus proposal vanishes, interaction patterns involve expression of favorable opinions about the decision proposal, and the group develops a sense of unity as social and ideational conflict subsides almost entirely.

In sum, the decision emergence perspective describes the group decision making process in terms of patterns of group member interactions which are focused on decision proposals. These patterns of interaction naturally form clusters of activity described by the four phases listed above.

Implications for Macrocognition in Teams

The decision emergence perspective suggests that by monitoring sequences of exchange between group members, inferences about the progression of the group towards a decision can be made. Like decision emergence, macrocognition is organized around a series of phases (i.e., stages). What is unique to decision emergence, which can inform macrocognition, is the idea that there are patterns of interaction that are characteristic of each phase; that is, there will be detectable, reliable, and unique differences between the type of communication between team members in each phase. These patterns can be used to diagnose the progression of the group and how each of these patterns may differentially emerge within each of the stages of macrocognition as articulated by Letsky and colleagues (Letsky et al., in press). It is likely that the patterns of orientation, conflict, emergence, and reinforcement, will vary dependent upon which stage of macrocognition a team is in – for example, more conflict during the middle stages, and more reinforcement during the ending stages. Additionally, the decision emergence perspective is

unique in that the focus of analysis is on the substantive content of group discussion (i.e., the decision proposal). All communicative acts are seen in light of the action they perform on this decision proposal. This provides a novel analytic framework that can be applied to understanding collaborative problem solving.

Multiple Sequence Models of Group Decision Making

Phasic models of group decision making, such as decision emergence, propose that all groups follow a single path and progress through the same phases in the same order. This assumption has been challenged (e.g., Poole, 1981) and data and models suggesting that groups will follow different sets of phases depending on such factors as the nature of the decision task, relationships between group members, and existing structures within the group (e.g., procedures, routines, characteristics of communication technology, etc.). To address this complexity, Poole (1981) has proposed multiple sequence models of group decision making. At the core of this perspective is that groups interweave multiple threads of interaction patterns over time. Poole and Roth (1989) delineated three fundamental types of group threads: 1) task process activities (i.e., threads of interaction focused on how the group structures its activity); 2) relational character (i.e., threads of interaction focused on the relationships between group members); and, 3) topical focus (i.e., threads of interaction focusing on the substantive issues the group is dealing with). Each of these threads can change independently over time and on different time scales. This change in patterns of interaction on these three threads defines a group's *trajectory*. This trajectory can further be characterized by breakpoints, points in the flow of communication where one pattern of interaction is replaced by another (e.g., pauses, adjournments, topic shifts). When intentionally interjected by group members, breakpoints are called routing statements (Fisher & Stutman, 1987), and are a means by which the development of the group's decision making processes can be controlled by its members. Overall, Poole and Roth (1989) propose that a group's development can be characterized into one of three paths. The unitary path is the most

simple. The decision emergence approach is an example of this path. Complex decision paths are characterized by cycles of problem analysis and solution generation. Solution-oriented paths are characterized by a focus on confirming a solution and little group effort is expended on problem analysis.

Implications for Macrocognition in Teams

The multiple paths approach to understanding group decision making is by far the most complex and nuanced discussed thus far and as such likely has the most to offer macrocognitive research. Macrocognitive phases are said to be nonsequential and recursive which makes the model consistent with the central propositions of multiple path models. However, the idea that there are identifiable trajectories or courses of development towards decision solution is novel for understanding macrocognition in teams. Essentially, groups are thought to pass through different phases of interaction in different orders, but there are a relatively finite set of possible paths groups will take and these paths are predictable from (or diagnostic of) certain features of the group or task being addressed. Similarly, given a specific team and task, a different trajectory may indicate different levels of outcomes (i.e., some paths of development more consistently lead towards better outcomes than others). This highlights the importance of breakpoints and routing statements. If a group is exhibiting interaction patterns characteristic of a trajectory associated with poor task outcomes, interventions can be developed that will change the trajectory of the group, essentially putting them on a course of development associated with higher levels of outcomes. Further, this approach can complement more recent work in dynamic modeling as applied to the assessment of communication in teams. Here non-linear interaction patterns are diagnosed such that the processes engaged by the team can be analyzed for the purposes of understanding causal effects on performance outcomes (e.g., Gorman, Cooke, & Kiekel, 2004; Kiekel, Gorman, & Cooke, 2004).

INTEGRATING GROUP COMMUNICATION THEORY, MACROCOGNITION IN TEAMS, AND EFFECTIVE MODERN C2

In this final section, we provide a high level synthesis of our review and focus on the implications for macrocognitive metrics, theory, and applications. We bring together these notions with the emerging emphasis on special operations and the communication demands of effective collaboration. Our goal is to show how the integration of these approaches can contribute to a more theoretically driven set of metrics for measuring collaboration and knowledge interoperability.

First, *communication plays a functional role in macrocognition in teams.* From the functional perspective of group decision making, the idea that communication subserves a limited set of functions emerges. The functional perspective makes no specification of the types of processes used to accomplish these functions. For example, the function of problem analysis can be fulfilled by team consensus (e.g., when the environment is highly uncertain, this approach would be reasonable) or team mental model development and pattern recognition. The implications for metrics then is that the mapping of processes to functions is not one to one; different processes can fulfill a given function. Consequently, to provide a robust and diagnostic picture of performance, metrics should capture both the processes being enacted as well as the functions that these processes are fulfilling.

Second, *communication acts on information.* From the decision emergence perspective comes the notion that the communicative acts of team members alter shared information (or create new shared information). This highlights the necessity to track communicative acts in relation to specific decision proposals (i.e., pieces of information). This has unqiue implications for communication analysis of macrocognitive processes in that the content (or object) of communication is the focus of measurement and that meaningful information can be extracted by capturing the types of communication directed at the communication content.

Third, *communication patterns define developmental trajectories.* Consistent with dynamical systems based approaches for measuring and understanding macrocognition, the multi-sequence models of group decision making propose that communication patterns can be associated with specific paths of development, and these paths are diagnostic of how the team is solving the problem. In this case, the implication for measurement of macrocognition is that specific patterns, or trajectories, provide information about the team's approach to solving a problem. However, the full range of trajectories and their meanings have yet to be explored.

To conclude, by 'loosening' the organizational constraints on the components (e.g., individuals and teams) of the C2 system, the possibility for greater variations in performance outcomes increases. That is, whereas tightly structured traditional C2 achieved reliable and reproducible performance in a relatively static environment by codifying performance processes in terms of standard operating procedures and communication patterns, individuals and teams in modern C2 will not be able to rely to the same extent on these routinized performance processes. Consequently, in modern C2 there will be great opportunities to exceed the norm in terms of performance as well as to fall far short of that level. This highlights the general rule that there is a far greater need for continuous performance monitoring in modern C2 than in its traditional counterpart so that performance can be diagnosed and aided in near real-time. The macrocognitive framework has been advanced in order to account for the processes in performance that ultimately determine performance outcomes in this type of situation. Because of the complexities of macrocognition, developing metrics that tap the full extent of proposed processes is a herculean task, but, in the end, this is a necessary step to ensure high levels of performance in 'loosely' constrained performance contexts. In this paper, we have provided a survey and integration of several longstanding streams of research that are: 1) theoretically complimentary or compatible with the macrocognitive in teams perspective; and, 2) provide unique insights into the development of communication based metrics diagnostic of macrocognitive performance processes. In this way, current efforts at developing macrocognitive

metrics can be 'bootstrapped' by leveraging past successes and augment research and development designed to support command and control.

REFERENCES

Alberts, D. S. (2007). Agility, Focus, and Convergence: The future of command and control. *The International C2 Journal, 1*(1), 1-30.

Cooke, N. J., Kiekel, P.A., Salas, E., Stout, R.J., Bowers, C., Cannon-Bowers, J. (2003). Measuring Team Knowledge: A Window to the Cognitive Underpinnings of Team Performance. *Group Dynamics: Theory, Research and Practice, 7,* 179-199.

DeSanctis, G., & Poole, M. S. (1994). Capturing the complexity in advanced technology use: Adaptive structuration theory. *Organization Science, 5*(2), 121-147.

Ellis, D. G., & Fisher, B. A. (1994). *Small Group Decision Making: Communication and the Group Process* (4th ed.). New York: McGraw Hill.

Fiore, S. M., Rosen, M., Salas, E., Burke, S., & Jentsch, F. (in press). Processes in Complex Team Problem Solving: Parsing and Defining the Theoretical Problem Space. To appear in M. Letsky, N. Warner, S. M. Fiore, & C. Smith (Eds.). *Macrocognition in Teams.* London: Ashgate.

Fisher, B. A. & Hawes, L. C. (1971). An interact system model: Generating a grounded theory of small groups. *Quarterly Journal of Speech, 42,* 444-453.

Fisher, B. A., & Stuttman, R. K. (1987). An assessment of group trajectories: Analyzing developmental breakpoints. *Communication Quarterly, 35,* 105-124.

Foltz, P. W. (2005). Tools for Enhancing Team Performance through Automated Modeling of hte Content of Team Discourse. In D. D. Schmorrow (Ed.), *Foundations of Augmented Cognition* (pp. 1239-1248). Mahwah, NJ: Lawrence Erlbaum Associates.

Frey, L. R., Gouran, D. S., & Poole, M. S. (Eds.). (2004). *The Handbook of Group Communication Theory and Research*. Thousand Oaks, CA: Sage.

Gorman, J.C., Cooke, N.J., & Kiekel, P.A. (2004). Dynamical perspectives on team cognition. Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting. *Proceedings of the 48th Annual Meeting of the Human Factors and Ergonomics Society*. Santa Monica, CA: Human Factors and Ergonomics Society.

Gorman, J.C., Foltz, P.W., Kiekel, P.A., Martin, M.J., and Cooke, N.C. (2003). Evaluation of latent semantic analysis-based measures of team communications content. *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting.*

Gouran, D. & Hirokawa, R. (1983). The Role of Communication in Decision-Making Groups: A Functional Perspective, In M. Mander (Ed.), *Communications in Transition* (pp. 168-185). *New York:* Praeger.

Hinsz, V. B., Tindale, R.S., & Vollrath, D.A. (1997). The Emerging conceptualization of Groups as Information Processors. *Psych Bull, 121*(1), 43-64.

Hirokawa, R. Y. (1980). A comparative analysis of communication patterns within effective and ineffective decision making groups. *Communication Monographs, 47*, 312-321.

Hollingshead, A. B., Wittenbaum, G. M., Paulus, P. B., Hirokawa, R. Y., Ancona, D. G., Peterson, R. S., et al. (2005). A look at groups from the functional perspective. In M. S. Poole & A. B. Hollingshead (Eds.), *Theories of Small Groups: Interdisciplinary Perspectives* (pp. 21-62). Thousand Oaks, CA: Sage.

Kiekel, P. A. (2005). FAUCET: Using Communication Flow Analysis to Diagnose Team Cognition. In D. D. Schmorrow (Ed.), *Foundations of Augmented Cognition* (pp. 1249-1256). Mahwah, NJ: Lawrence Erlbaum Associates.

Kiekel, P. A., Gorman, J. C., & Cooke, N.J. (2004). Measuring speech flow of co-located and distributed command and control teams during a communication channel glitch. *Proceedings of the 48th Annual Meeting of the Human Factors and Ergonomics Society*. Santa Monica, CA: Human Factors and Ergonomics Society.

Klein, G., Ross, K. G., Moon, B. M., Klein, D. E., Hoffman, R. R., & Hollnagel, E. (May/June 2003). Macrocognition. *IEEE Intelligent Systems,* 81-85.

Letsky, M., Warner, N., Fiore, S. M., Rosen, M. A., & Salas, E. (2007). Macrocognition in Complex Team Problem Solving. *Proceedings of the 12th International Command and Control Research and Technology Symposium* (12th ICCRTS), Newport, RI, June 2007. Washington, DC: U.S. Department of Defense Command and Control Research Program.

Letsky, M. Warner, N., Fiore, S.M., & Smith, C. (Eds.). (in press). *Macrocognition in Teams.* London: Ashgate Publishers.

Orlitzky, M., & Hirokawa, R. Y. (2001). To err is human, to correct for it divine: A meta-analysis of research testing the functional theory of group decision-making effectiveness. *Small Group Research, 32*(3), 313-341.

Poole, M. S. (1981). Decision development in small groups I: A comparison of two models. *Communication Monographs, 48,* 1-24.

Poole, M. S., & Roth, J. (1989). Decision development in small groups IV: A typology of group decision paths. *Human Communication Research, 15,* 323-356.

Poole, M. S., Seibold, D. R., & McPhee, R. D. (1986). A structurational approach to theory-building in group decision-making research. In R. Y. Hirokawa & M. S. Poole (Eds.), *Communication and group decision making* (pp. 2437-264). Beverly Hills: Sage.

Rosen, M. A., Feldman, M., Fiore, S. M., & Salas, E. (2007). *Augmented Team Cognition for Complex Problem Solving: A Framework and Research Agenda.* Paper presented at the Augmented Cognition International, Baltimore, MD.

Rosen, M. A., Salas, E., Fiore, S. M., Letsky, M., & Warner, N. (in press). Tightly Coupling Cognition: Understanding how Communication and Awareness Drive Coordination in Teams. *International Journal of Command and Control (online).*

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.