Ineffective Organizational Practices at NASA: A Dynamic Network Analysis

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Ineffective organizational practices: a multi-level problem

Ineffective organizational practices have consistently re-emerged in the NASA system

In 2003 many organizational problems within NASA were cited by the Columbia Investigation Board (CIB) as contributing to the Columbia disaster. Among the problems cited were barriers to communication, including information technologies, structural integration and databases, ineffective leadership and practical drift. Structural integration is assembling interdependent actions into coherent sequences and outcomes. Practical drift is local adaptation to demands that require work practices to fall outside the formal procedures of the organization.

These same organizational problems were also cited as contributing factors of the Challenger disaster. As noted in the CIB report (2003), the ineffective institutional practices present at the time of the Challenger disaster re-emerged at the time of the Columbia disaster. Despite the recommendations of the Presidential Commission on the Space Shuttle Challenger Accident (1986) and the subsequent interventions to correct the organizational problems, the system retained the ineffective patterns. The seventeen year span indicates that these organizational patterns are a long-standing risk concern within NASA; a concern that has eluded a solution.

Ineffective organizational practices emerge from socio-technical system component interactions

The difficulty in addressing these risks lies in the fact that these are complex multi-level problems of the system. NASA programs are administered over a complex system of highly connected, interdependent but autonomous parts. These parts include the NASA centers, independent contractors and information technologies that connect the distributed environment. Several analyses have shown how organizational accidents and the associated ineffective organizational practices are due to emergent behavior in the socio-technical system as a result of interactions among the interdependent parts (Perrow 1999; Reason 1997; Snook 2000; Vaughan 1996; Weick and Sutcliffe 2001). In other words, organizational practices are system level behaviors due to the complex interactions at subsystem levels (work units, people, technologies…).

Single level analysis insufficiently addresses the problem

Due to the complex nature of the NASA socio-technical system, new techniques for analyzing the problem need to be developed. Subsystems analysis and a reductionist approach will only partially address the problem. Although analysis of each unit is important the scope needs to include the complex relations and interdependencies that exist in the NASA overall program structure. Likewise, analysis only at the system level will be incomplete. The emergent higher level organizational practices can only be understood by taking the lower level interactions into account.

Dynamic Network Analysis: a multi-level approach

Dynamic network analysis is a holistic approach that models the multi-level dynamics of the socio-technical system

To understand the emergent organizational dynamics we need to understand the basic network evolutionary processes. Dynamic network analysis combines multi-level, multi-mode social network analysis with cognitive science and multi-agent simulation to provide a methodology for modeling the dynamics of complex and adaptive socio-technical systems. The basic interactive processes of the sub-systems are modeled to produce emergent system-level behavior. Analysis occurs at all appropriate levels. The two advances enabling dynamic network analysis are the MetaMatrix and multi-agent network modeling.

The MetaMatrix (Carley and Hill 2001; Carley 1999b; Carley 2002; Carley 2003; Carley and Ren 2001; Carley, Ren and Krackhardt 2000; Krackhardt and Carley 1998) is a theoretical framework for representing the various network relations of an organizational system. This framework is important to this study of risk because it allows for the definition, measurement and analysis of the organizational nodes and relational ties across various organizational networks. In the MetaMatrix framework, organizations are defined by a set of networks under five classifications: personnel, knowledge, resources, tasks and organizations.

Multi-agent network models allow for the representation of individual cognitive agents who can take action, learn and alter the network – organizational adaptation. Based on well-known social and cognitive processes that influence the agent interactions, agents will go through the process of action, learning and network alteration to produce emergent behavior. Emergent behavior that, under certain conditions, can result in communication breakdown, structural disintegration and practical drift.

Agents, human and technological, can be modeled as information processing entities with heterogeneous attributes particularly in terms of organizational role, knowledge, experience, and response to stress. As such, multi-agent network models can capture the complexities of NASA structure at various levels.

NASA Team X: A study of leadership style and structural integration

Differences in leadership style

Differences in leadership style may effect structural integration and information flow

Observations of Team X design sessions made in April, 2003 indicate that facilitators have leadership styles that vary greatly. These observations were made of Team X design sessions where there was a facilitator change midstream for the team. Observations and subsequent interviews conclude that facilitator 1 has a directive style and facilitator 2 has a participative style.

Differences in leadership style can lead to different network structures due to individual response to the facilitator and as such different structural integration and information flow. Such differences can be especially important in dynamic environments where adaptability is essential for organizational performance. Some have argued that a leader's main role in an information-intensive, dynamic environment is to facilitate structural integration among the distributed expertise of the organization (Marion and Uhl-Bien 2001; McKelvey 2003).

Leaders should strive to foster structural integration for greater organizational adaptability and effectiveness

Data collected on the task dependency network verifies that the difference in leadership styles of the two facilitators resulted in different network structures. Figures 1 and 2 show the task dependency network among Team X members when each facilitator is in charge.

Figure 1 - Task dependency network, Facilitator 1

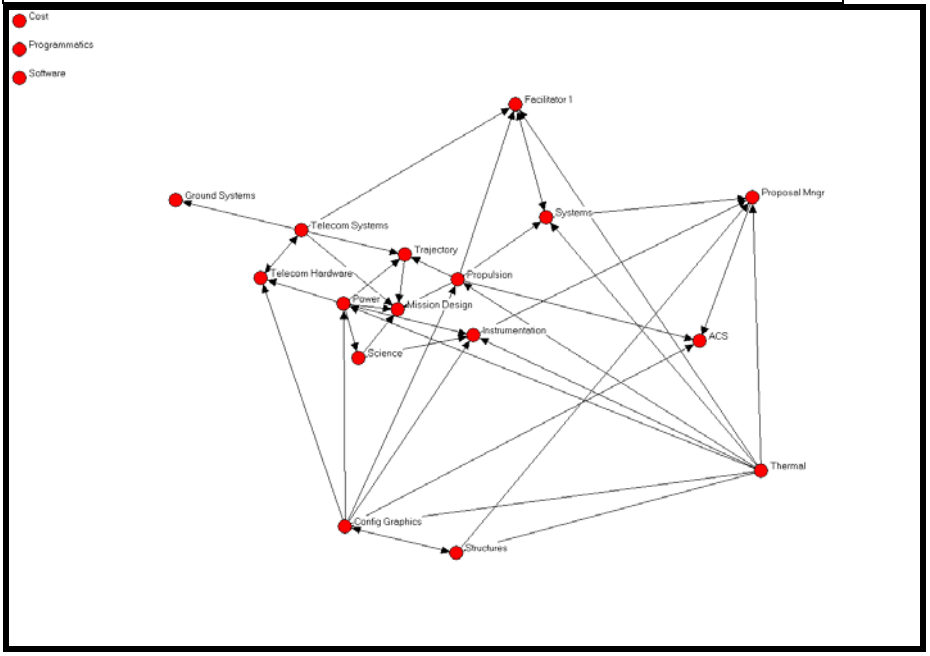


Figure 2 - Task dependency network, Facilitator 2

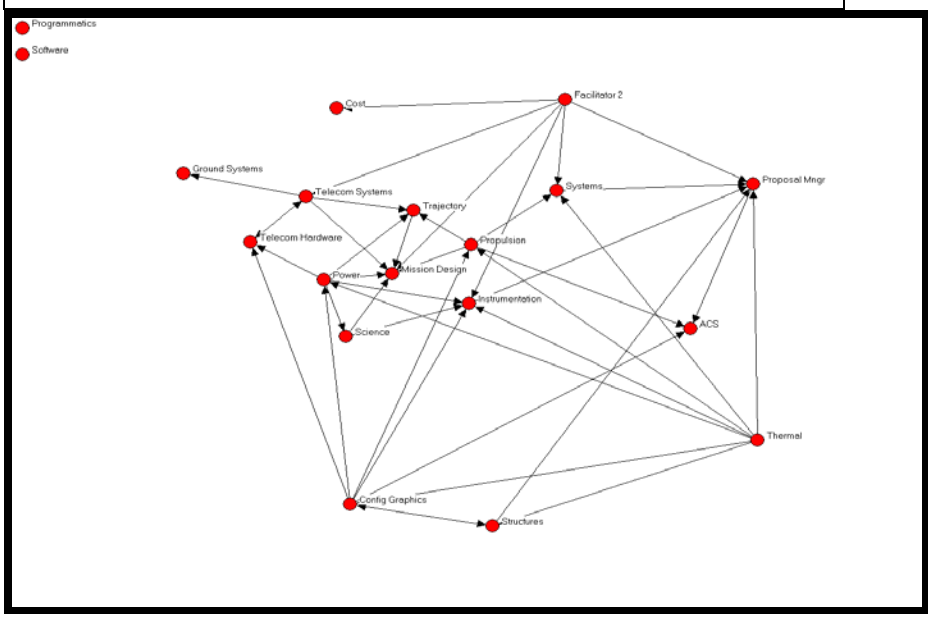


Figure 1 shows that team members have task dependency on facilitator 1 as the ties are directed to him. This demonstrates that facilitator 1 drives the Team X sessions and has a tighter control over the tasks and coordination. Figure 2 shows that facilitator 2 depends more on the team members as ties are directed to the team members. This demonstrates that facilitator 2 opens up the Team X sessions and decentralizes decisions more. The question investigated here is if different leadership styles results in different social structures and organizational performance over time, thus a difference in fostering organizational adaptability and effectiveness.

Modeling Team X

The Team X MetaMatrix

In addition to the task dependency network, the MetaMatrix of structural relations were collected on Team X as shown in Table 1. Two distinct MetaMatrices were made because data was collected on two separate facilitators. The distinctions for these MetaMatrices are other team member's perception of each facilitator and the perceptions each facilitator has of the other team members and the engineering process. Each MetaMatrix represents the team when led by the respective facilitator.

Table 1 – Team X MetaMatrix

	People	**Technology**	**Knowledge**	**Tasks**
People Relation	**Social Network** *Survey question – Communication frequency*	**Technology Network** *Observation and interviews*	**Knowledge Network** *Survey question – Level of knowledge about each position*	**Assignment Network** *Observation and interviews*
Technology Relation		**Operability Network** *Observation and interviews*	**Encoded Network** *Observation and interviews*	**Tool Network** *Observation and interviews*
Knowledge Relation			**Interdependency Network** *Survey question - Interdependencies*	**Needs Network** *Survey question - Interdependencies*
Task Relation				**Precedence Network** *Observation and interviews*

Construct: A multi-agent network model

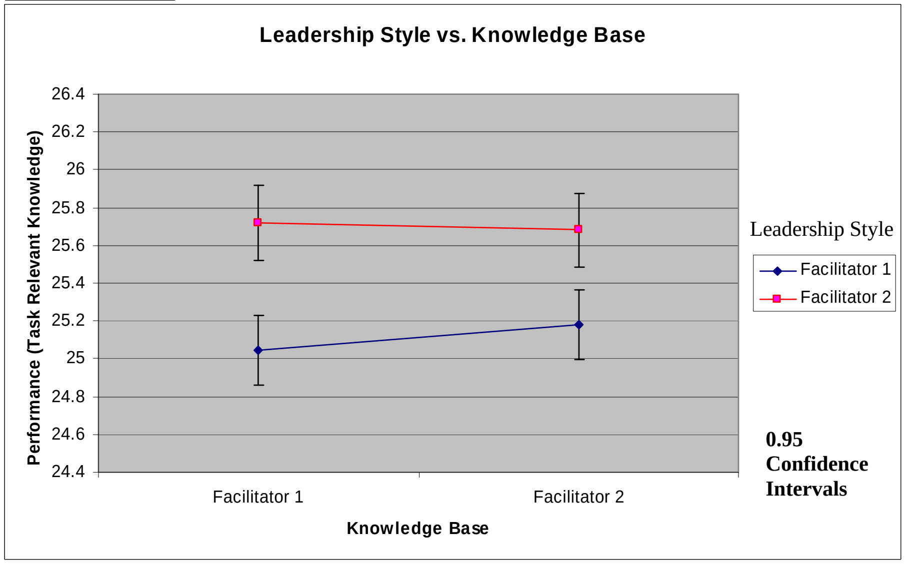
Construct is a multi-agent network model for the co-evolution of agents and socio-technical environments (Carley 1990; Carley 1991a; Carley 1991b; Carley 1995; Carley 1996; Carley 1999a; Carley and Hill 2001; Carley 2002; Schreiber and Carley 2004a; Schreiber and Carley 2004b; Schreiber, Singh and Carley 2004). Agents in Construct are defined as information processing units which interact and communicate through the social processes of homophily (relative similarity) and knowledge-seeking (relative expertise). As agents go through the adaptive process of taking action, learning and altering the network, they perform tasks and the performance accuracy for the team of agents is measured along with the network structure adaptations.

Simulating the structural adaptation and performance of Team X under different facilitators

Relevant networks, such as the knowledge network and the task dependency network from the MetaMatrix were input into Construct. Using the distinct MetaMatrices, we were able to produce a representation of Team X under each facilitator and leadership style, facilitator 1 (directive) and facilitator 2 (participative). Virtual experiments were run to test the effect of each leader on structural integration and team performance. To assure that any significant effects were not due to the particular knowledge base of the leader, another set of conditions were run whereas the knowledge base of each facilitator was used with the other facilitator’s initial network representation. In other words, facilitator 1’s knowledge network was used with facilitator 2’s task dependency network and vice versa.

Figure 3 shows the ending performance results of the virtual experiment. Clearly the team under the direction of facilitator 2 performs better. Also, it is demonstrated that the performance is not due to any difference in the knowledge base of the facilitators. With leadership style established as a factor significantly contributing to performance we now turn to the resulting structure underlying these results.

Figure 3



Figures 4 and 5 show the agent interaction networks at time 100 under facilitator 1 and facilitator 2, respectively. In each figure, the red circle indicates the facilitator and blue circles indicate central agents with at least four ties. Figure 5 shows that in the team led by facilitator 2 there are three central agents. In contrast, figure 4 shows that there are no central agents in the team led by facilitator 1. The participative style of facilitator 2 fosters the emergence of central agents. These agents promote a higher degree of structural integration and greater information flow within the team.

Figure 4 - Interaction network, time 100, Facilitator 2

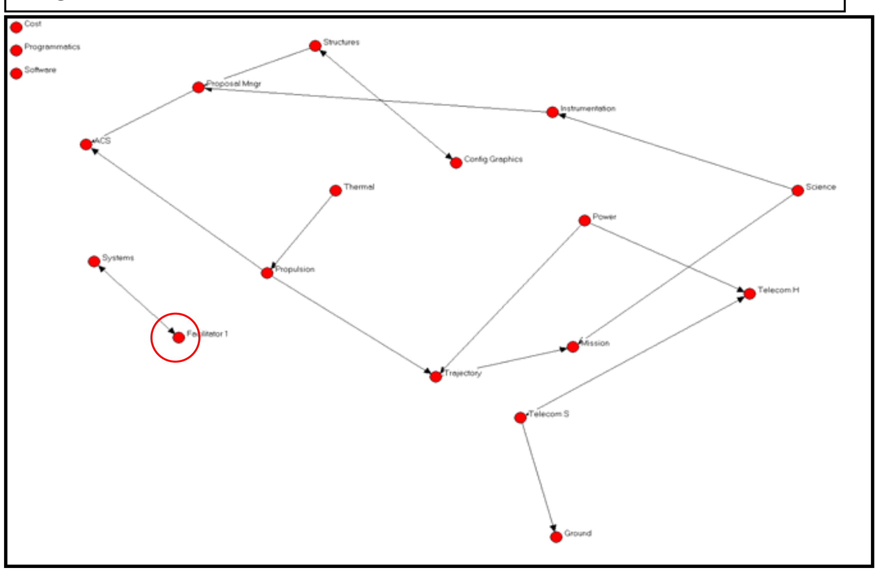
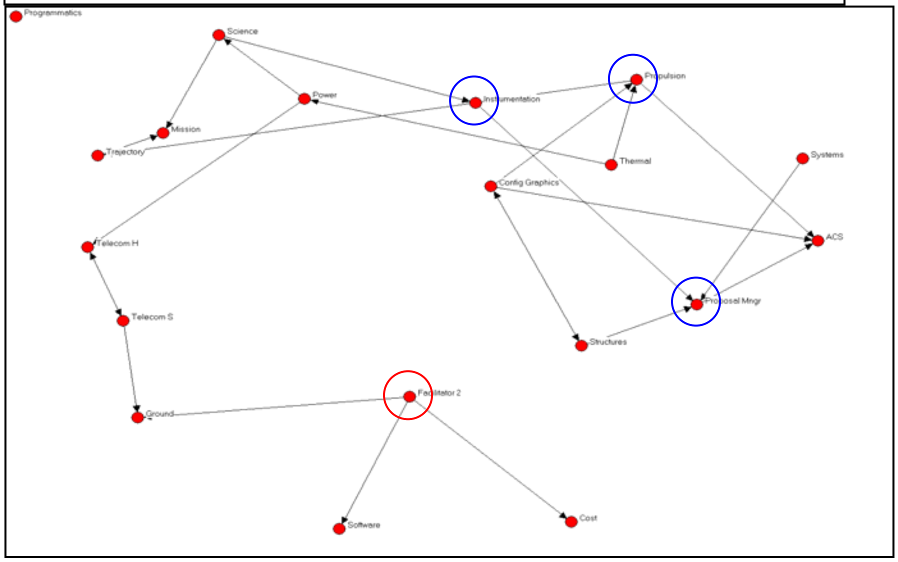


Figure 5 - Interaction network, time 100, Facilitator 2



Similar results were noted for other timeperiods as well. Figure 6 shows the clustering coefficient for each team over time. Figure 7 shows the density of the agent interaction networks for each team over time. In each of these graph level measures, the team under facilitator 2 shows a higher degree of structural integration thus promoting better communication, adaptation and performance. It should be noted that this is not a model of a crisis situation and therefore these results may not hold under such a circumstance.

Figure 6

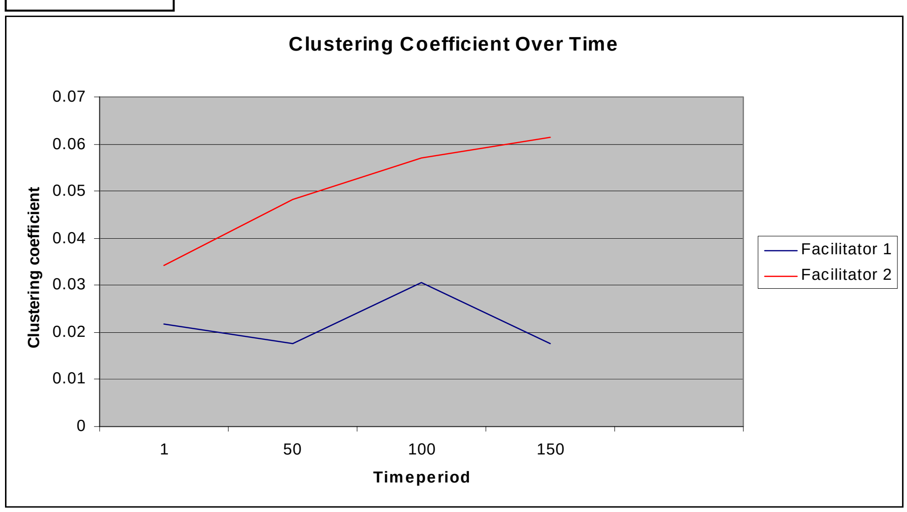
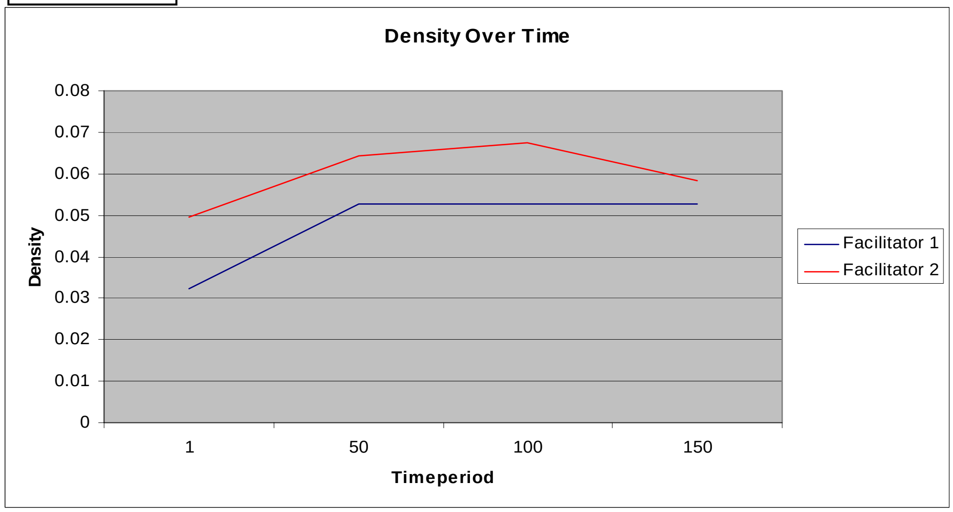


Figure 7



Conclusion

Dynamic network analysis, through multi-level, multi-mode analysis of the interdependent interactions of the socio-technical system, can capture the complexities of NASA structure. The methodology models agents with heterogeneous attributes and can provide analysis for long-standing, complex problems such as structural integration and ineffective leadership.

Participative leadership promotes structural integration and higher levels of organizational performance and adaptation in a dynamic, non-crisis environment

Results of the Team X analysis show that leadership style has an effect on the structural integration of the team. In short, participative leadership encourages the emergence of central team members. These central members provide structural integration which promote more effective communication, information flow, adaptation and performance.

Although the above analysis was at the team level, dynamic network analysis can capture higher levels of complexity and provide insight into this problem at other levels of analysis such as division or organization. Expanding the analysis to larger organizational levels will provide increasing benefit to NASA.

In addition, the analysis can be expanded to other organizational problems that were stated in the CIB report such as barriers to communication and practical drift. Expanding this analysis to include ineffective leadership, structural integration, barriers to communication and practical drift makes intuitive sense because these problems are all related within the organizational system.

Dynamic network analysis can provide complex analysis and innovative solutions for the organizational problems of NASA

For instance, leaders are responsible for ensuring that management decisions are made on solid information and analysis. Solid decisions rely on the structural integration of the differentiated units, NASA centers and independent contractors, through open communication channels which include direct interaction as well as interaction through information technologies and databases. As effective leadership, structural integration and communication wane, formal organizational procedures are impeded and practical drift slowly develops as a means to complete work. Practical drift can also feed the cycle as bypassing formal procedures can exclude information from entering the formal communication system and being passed on to others including management. Therefore, communication and leadership are rendered even more ineffective.

Dynamic network analysis can provide a comprehensive methodology for analyzing complex organizational problems. Through such an analysis, innovative solutions can be found that can improve the ineffective organizational practices that have plagued NASA for many years.

References

Carley, K. M. 1990. "Group stability: A socio-cognitive approach." Pp. 1-44 in *Advances in group processes: Theory & research*, edited by Walker H. Greenwhich, CN: JAI Press.

—. 1991a. "Growing up: The development and acquisition of social knowledge." Pp. 72-105 in *The Self-Society Dynamic: Cognition, Emotion, and Action*, edited by Callero P. Cambridge, England: Cambridge University Press.

—. 1991b. "A theory of group stability." *American Sociological Review* 56:331-354.

—. 1995. "Communication technologies & their effect on cultural homogeneity, consensus, & the diffusion of new ideas." *Sociological Perspectives* 38:547-571.

—. 1996. "Communicating new ideas: The potential impact of information and telecommunication technology." *Technology in Society* 18:219-230.

—. 1999a. "On the evolution of social and organizational networks." Pp. 3-30 in *Special issue of Research in the Sociology of Organizations on Networks In and Around Organizations*, edited by David Knoke. Greenwhich, CN: JAI Press.

Carley, K. M., and V. Hill. 2001. "Structural change and learning within organizations." in *Dynamics of Organizations: Computational Modeling and Organization Theories*, edited by A. Lomi and E. R. Larsen. Menlo Park, CA: MIT Press/AAAI.

Carley, Kathleen M. 1999b. "Organizational change and the digital economy: A computational organization science perspective." in *Understanding the digital economy: Data, tools, research*, edited by Brian Kahin. Cambridge, MA: MIT Press.

—. 2002. "Smart agents and organizations of the future." Pp. 206-220 in *The handbook of new media*, edited by Sonia Livingstone. Thousand Oaks, CA: Sage.

—. 2003. *Dynamic network analysis*. Washington DC: The National Academies Press.

Carley, Kathleen M., and Yuqing Ren. 2001. "Tradeoffs between performance and adaptability for C3I architectures." in *Command and Control Research and Technology Symposium*. Annapolis, MD.

Carley, Kathleen M., Yuqing Ren, and David Krackhardt. 2000. "Measuring and modeling change in C3I architecture." in *Command and control research and technology symposium*. Monterrey, CA.

Columbia, Accident Investigation Board. 2003. "Columbia Accident Investigation Board Report, 6 vols." Washington, D.C.: Columbia Accident Investigation Board.

Krackhardt, David, and Kathleen M. Carley. 1998. "A PCANS model of structure in organization." in *International symposium on command and control research and technology*. Monterrey, CA.

Marion, Russ, and Mary Uhl-Bien. 2001. "Leadership in complex organizations." *The Leadership Quarterly* 12:389-418.

McKelvey, Bill. 2003. "MicroStrategy from MacroLeadership: Distributed jntelligence via new science." in *Mobilizing the self-renewing organization*, edited by A. Y. Lewin and H. Volberda. Armonk, NY: M. E. Sharp.

Perrow, Charles. 1999. *Normal accidents: Living with high-risk technologies*. Princeton, NJ: Princeton University Press.

Presidential, Commission on the Space Shuttle Challenger Accident. 1986. "Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident, 5 vols." Washington, D.C.: Government Printing Office.

Reason, James. 1997. *Managing the risks of organizational accidents*. Aldershot, UK: Ashgate.

Schreiber, C., and K. M. Carley. 2004a. "Going beyond the data: Empirical validation leading to grounded theory." *Computational and Mathematical Organization Theory* 10.

—. 2004b. "Human and organizational risk modeling." Carnegie Mellon University, School of Computer Science, Institute for Software Research, International. Technical Report, CMU-ISRI-04-122.

Schreiber, C., S. Singh, and K. M. Carley. 2004. "Construct - A multi-agent network model for the co-evolution of agents and socio-cultural environments." Carnegie Mellon University, School of Computer Science, Institute for Software Research, International. Technical Report, CMU-ISRI-04-109.

Snook, Scott A. 2000. *Friendly fire: The accidental shootdown of U.S. Black Hawks over Northern Iraq*. Princeton, NJ: Princeton University Press.

Vaughan, Diane. 1996. *The Challenger launch decision: Risky technology, culture and deviance at NASA*. Chicago, IL: The University of Chicago Press.

Weick, Karl E., and Kathleen M. Sutcliffe. 2001. *Managing the unexpected: Assuring high performance in an age of complexity*. San Francisco, CA: Jossey-Bass.