

Human and Organizational Risk Modeling: Critical Personnel and Leadership in Network Organizations

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Abstract

Network organizations offer learning, adaptive and resilient capabilities that are particularly useful in high velocity environments as these capabilities allow the organization to effectively respond to change. The dynamic, evolutionary nature of network organizations affords such advantageous capabilities. Although the advantages of network organizations are well-studied, the risks associated with them are not. Of interest is the study of critical personnel. Understanding criticality within an organization can help improve performance and protect against the risk of loss. But the study of critical personnel has traditionally used static structural representations that do not represent the dynamic nature of network organizations.

This thesis advances the study of critical personnel risks in network organizations by using Dynamic Network Analysis. Dynamic Network analysis is a methodology that incorporates both social network analysis and multi-agent simulation to represent structure and process – the evolutionary nature of network organizations. Advances are made on two fronts. First, theory is developed about three dynamic risks related to critical personnel: intermittent availability, individual redundancy and shifts of critical personnel. These theories are built by using a reasoned computational approach that first validates the multi-agent simulation model and then creates forward grounded theory. Empirical data from two different network organizations are used to validate the model and build theory.

Second, the foundations for a Dynamic Network Analytic Theory of Network Organization Leadership are established. Leadership is a subset of critical personnel and the specific risks of network organization leadership need studied as well. But traditional leadership theory has limited applicability to high velocity contexts and network organizations. Consequently, there has been a call for a paradigm shift in leadership theory. The effective study of risks associated with network organization leadership will require a relevant paradigm and theory. This research developed a relevant paradigmatic framework and provided basic insight for a theory of network organization leadership.

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Chapter 1 : Introduction

1.1. A New World: Change and Adaptation

The world has changed drastically in the last decade, both in terms of business and military context. From a business perspective, the 21st Century knowledge economy is marked by technological revolution and economic globalization (Hitt, 1998) resulting in rapid and continuous change, diminished product lifecycles and the need to turn large amounts of data into useable information (Ireland & Hitt, 1999). This new economy is a rugged and dynamic landscape with considerable uncertainty. Organizations now need to increase the rate of organizational learning and knowledge creation in order to sustain a competitive advantage and to survive in the hypercompetitive environment (Argote & Ingram, 2000; Davenport & Prusak, 1997; Nonaka & Takeuchi, 1995). Faster, productive learning provides an organization with the flexibility and mental agility to quickly identify and exploit emergent opportunities in the ever changing landscape (Ireland et al., 1999).

As such, intellectual assets are now the core competency of modern business organizations (Nonaka et al., 1995; Prusak, 1996). This is quite disparate from the Industrial Age where capital and labor assets were predominately relied upon for gain (Stewart, 1997). The switch is from organizing for control and efficiency (Gulick, 1937) to organizing for learning and adaptability (Baker, 1992; Bettis & Hitt, 1995; Brown & Eisenhardt, 1995; Miles & Snow, 1986)

From a military perspective, current operations are characterized by rapidly changing and uncertain conditions as well. Not only has the nature of warfare changed

through the use of advanced weaponry and the tactics of terrorism but the U.S. military is also increasingly involved in peacekeeping and humanitarian aid responsibilities. Military organizations must be highly adaptable in order to quickly and effectively shift between warfighting, peacekeeping and humanitarian requirements.

In addition, joint and coalition operations are progressively employed to combat terrorism and to perform the various non-combat responsibilities. The military context is now knowledge centric with a premium on cross-functional communication and coordination. These joint and coalition operations provide for interagency cooperation leading to shared intelligence and joint tactical operations – capabilities that are considered essential for quick and effective terrorism response.

The common characteristics of modern business and military contexts are a challenging environment marked by rapid change and uncertainty; an increased dependency on knowledge; a need for fast learning; a need for quick adaptation; and a need for high resiliency. Both contexts deal with information intensive settings that are fueled by technological and environmental change. The operational scene can quickly change from normal to highly stressed. Business and military organizations must quickly respond to volatile conditions.

1.2. Network Organizations: Organizational Design to Match Change

Both business and military organizations have increasingly employed network forms of organizational design in light of the changing and uncertain operating conditions that have fueled the need for learning, adaptability and resiliency (Powell, 1990; Ronfeldt & Arquilla, 2001). Network organizations are characterized by flexibility (Nohria &

Eccles, 1992), decentralization (Arquilla & Ronfeldt, 2001), differentiation (Baker, 1992), diversity (Ibarra, 1992), lateral cross-functional ties (Baker, 1992) and redundancy (Ronfeldt et al., 2001). Thus these organizational forms offer many advantages for surviving and competing in high velocity environments. Advantages include communication speed and richness (Powell, 1990), knowledge transfer (Podolny & Page, 1998), reduction of uncertainty (Powell, 1990), cross-functional collaboration (Baker, 1992), greater collective action (Powell, 1990) and quick and effective decision-making (Kanter & Eccles, 1992).

A particularly relevant goal of a network organization is to be responsive to a highly volatile and uncertain environment. Network organizations, in general, can be learning organizations (Podolny et al., 1998), adaptive organizations (Powell, 1990) and resilient organizations (Arquilla et al., 2001). These responses are what the advantages lead to in network organizations. Communication, knowledge transfer, collaboration, collective action and decision-making advantages can lead to various learning, adaptive and resilient responses. Figure 1.1 shows the conceptual relationship of the characteristics, advantages and desired responses of network organizations. This figure is not intended to be inclusive of all characteristics and advantages of network organizations but it is for conceptual demonstration.

It should be noted that the presence of these characteristics in a network organization does not automatically infer the advantages or preferred responses. It is akin to having a specific intellect or skill for an individual human being. The skill of the individual must be consciously applied in order to gain benefit from it. In the same way, the network organization must make a mindful effort to use the characteristics and gain

the advantages. The advantages, again through mindful effort, can lead to desired responses that meet the dynamic challenges facing the organization.

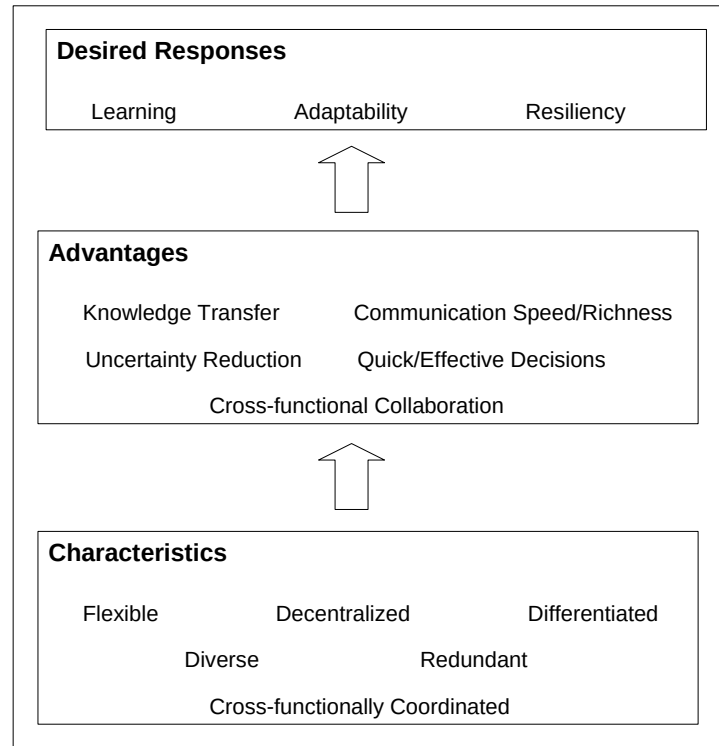


Figure 1.1: Conceptual Relationship of characteristics, advantages and desired responses of network organizations

Initially, the concept of network forms of organization can be traced back to Burns and Stalker's (1961) notion of organic organizations (Nohria, 1992). Network organizations have been described at the societal (Castells, 1996), nation-state (Dertouzos, 1997), industrial (Baker, 1990), small-firm (Perrow, 1992) and single organizational (Baker, 1992) levels.

In this work, I am studying network organizations at the single organizational and team level. There is no single definition of what a network organization is and a definition which may be appropriate for a particular level or context may not be as

appropriate for others (Ronfeldt et al., 2001). I use a definition that follows the lines of Baker (1992) and Ronfeldt and Arquilla (2001) and is appropriate for the organizational and team level of analysis. A network organization is characterized by decentralized control and flexible ties that integrate across formal or functional boundaries. This definition recognizes that there are still formal boundaries in an organization so there can be a degree of hierarchy or centralization that is present within the network form.

1.3. Identification of Critical Personnel and Leadership: A Dynamic View on Risks in Network Organizations

The usefulness of network organizations in highly volatile and uncertain environments – namely the ability to enhance learning, adaptation and resiliency – also creates interesting problems in the identification of critical personnel and in the leadership of such organizations. Particularly, the difficulty lies in the fact that learning, adaptation and resiliency are all dynamic, evolutionary capabilities.

As Kanter and Eccles (1992) point out, networks are contexts for action. The actions of a network organization lead to a dynamic, evolutionary structure. The network is ever-changing and hopefully responsive to the environment.¹ Traditional social network analysis has been the static examination of organizational structure that only provides limited insight into the process of network change and the nature of network organizations. Therefore, process needs to be accounted for in the methodology and added to social network theory (Carley, 2003; Kanter et al., 1992). This work takes a serious view of this need and incorporates process in both methodology and theory. The

¹ Although the author recognizes that organizational action also contains feedback to the environment and contributes to changes there as well, it is not the focus this research and lies outside the bounds of this thesis.

decision to take this route was not only influenced by the academic need for such but also because managers have a real need for process in the practical application of network research (Kanter et al., 1992).

This research explores risks to the effective functioning of network organizations, the nature of leadership in such organizations, and the manner in which risk factors and leadership roles influence each other. First, theory is proposed about several dynamic risks associated with the identification of critical personnel in network organizations. In particular, intermittent availability, individual redundancy and shifts of critical personnel are explored. These risks can potentially constrain the learning, adaptive and resilient responses of network organizations. This research contributes to the literature by theorizing about these risks and the potential dysfunctionality associated with them.

Theory is an explanation of the interactive manner concerning a set of naturally occurring phenomena. Particularly, theory in this thesis is an explanation of how the various risks affect network organizations. Theory was derived computationally in the following way. A simulation model is used to run virtual experiments exploring each of the risks. The simulation model itself is an embodiment of theory. More specifically, the simulation model used in this research is an explanation of how agents in an organization behave communicatively. The simulation model was validated to show that it reasonably explained such behavior.

Next, the various risks were conceptualized verbally and then operationalized as code within the simulation model. Following this, virtual experiments exploring the interactive manner of the risks within the virtual organizations were run. Propositions about the various risks were developed based on the results of the virtual experiments.

These propositions are predictions based upon the simulation model as theory and are thus extensions to the theory.

There have been a few studies concerned with dysfunctionality in network organizations. For instance, the level of embeddedness in a network (Uzzi, 1996) and the amount of experience with network relationships (Powell, Koput, & Smith-Doerr, 1996) have been argued as relating to dysfunctionality. Unfortunately, such studies are under-represented. The functional advantages of network organizations have been studied much more extensively than have the possible dysfunctionalities (Podolny et al., 1998). More attention to dysfunctionality is needed as this can provide balanced insight into factors that can determine the success or failure of network organizations.

Second, issues related to leadership of network organizations are examined because leadership is a subset of critical personnel and traditional leadership theory is limited as to the insight it can provide in a network organizational context. Traditional leadership theory is limited due to an emphasis on efficiency and control within bureaucracies which largely disregards the learning and adaptive needs of modern organizations.

A new paradigmatic framework for network organization leadership is proposed and the foundations for a relevant theory are laid. A network theory of leadership is based on the complex, interactive dynamics that involve the simultaneous enactment of multiple leadership roles within the informal network of an organization. This is a systems view of leadership and influence, both of and within an organization, rather than the traditional dyadic view of influence between a leader and a follower.

A relevant paradigm and theory of leadership are needed before the risks associated with network organization leadership can be appropriately identified and studied. They are needed because the enactment of leadership roles and the risks of network organizations could interact and affect each other. For instance, the enactment of certain leadership roles in particular situations may exacerbate the risks of network organizations. Alternatively, particular risks may interfere with the enactment of certain leadership roles.

The organizations under study, Team X and the Battle Command Group, are both network organizations which represent a business and military context respectively. All organizations are networks and therefore the work of this thesis applies to organizations in general. The use of network organizations is not critical to the analysis of risks or leadership. However, network organizations are useful to study because the informal network is more pronounced or 'dominant' than it typically is in other organizational forms. As such, the informal network is more easily observable and this aids the collection of data and the interpretation of results.

This research is an initial phase of study on organizational risk. The long-range goal is to continue this research stream and to develop a unified theory of organizational risk.

The thesis is subdivided into two sections. The first section discusses the identification of critical personnel in network organizations. In this section, Chapter 2 discusses the problems of intermittent availability, individual redundancy and shifts of critical personnel as well as their relevance to network organizations in general. This chapter contains the verbal conceptualization of the risks. Chapter 3 discusses the

organizations under study and the datasets collected from each. Chapter 4 describes the reasoned computational approach that was used to develop theory. In short, model validation was the first step and grounded forward theory was the second step of the methodological approach. Chapter 5 presents the experimental design and results of the model validation. Chapter 6 presents the experimental design and results of the virtual experiments exploring intermittent availability, individual redundancy and shifts of critical personnel. A description of each risk operationalization within the simulation model is contained in this chapter. A set of proposition are also developed based upon the results of the virtual experiments. These propositions are extensions to the theory that is embodied within the simulation model.

The second section discusses network organization leadership. Chapter 7 addresses the limited relevance of traditional leadership research in the network organizational context. A new complexity theory paradigm of leadership is presented and its relevance to network organizations is discussed. Chapter 8 re-conceptualizes the tenets of the complexity theory approach in the Dynamic Network Analysis framework. This defines network organization leadership in terms of dynamic networks. The Dynamic Network Analysis methodology is also described in whole and the advantages to leadership theory that the paradigmatic framework and methodology provide are presented. Chapter 9 lays the foundation for a Dynamic Network Analytic Theory of Network Organization Leadership. This is a vital link toward the ability to appropriately identify and study leadership risks of network organizations.

Chapter 10 provides a conclusion of the thesis. A summary of the work is presented and the contributions are described.

SECTION 1: CRITICAL PERSONNEL RISKS IN NETWORK ORGANIZATIONS

Chapter 2 : Critical Personnel Risks

2.1. Identification of Critical Personnel

Identifying critical personnel in organizations is a problem that has engendered the interest of practitioners and social network researchers for years. Solutions to the identification problem can be applied both to an organization and its competition. Internal to an organization, solutions have implications such as sustaining or increasing performance and protecting against risk. Externally, solutions have implications such as destabilizing the enemy and decreasing the competition's performance.

Recently, network forms of organizing have become increasingly popular in use. Network organizations offer advantages for dealing with high velocity environments such as the new knowledge economy and modern military operations. Other organizational forms, such as hierarchies, struggle to perform in high velocity environments (Burns et al., 1961; Powell, 1990; Ronfeldt et al., 2001). The advantage for the network organization is a fluid, flexible structure that is decentralized and integrates across functional boundaries. As such, network organizations foster quicker learning and adaptation as well as resiliency.

But this advantage also intensifies the identification of critical personnel problem. With changing environmental conditions and changing organizational structure, critical personnel are now moving targets. In other words, the identification of critical personnel in network organizations is not a static problem but an evolutionary one. For example, organizational structures in the Cold War Era were more stable and identification of important people or leaders in the Russian hierarchy was a relatively stable phenomena.

Now, terrorist organizations are a very adaptable, resilient enemy and identifying critical people or leaders is a much trickier, on-going problem.

In this thesis, I explore and develop theory about several evolutionary risks associated with the critical personnel problem in network organizations. These risks are intermittent availability, individual redundancy and shifts of critical personnel. The following sections describe these risks.

2.2. Intermittent Availability

Intermittent availability is the limited access of a person for task communications. The focus for this thesis is on task-related communications and knowledge transfer and not on morale or other psychological effects. Intermittent availability is proposed as an organizational risk because the insufficient connection of a critical person to the network could serve as a knowledge transfer barrier that slows the rate of organizational learning. For example, a key expert is not as beneficial if they are mostly unavailable and others cannot access them for solutions and advice. A slower rate of learning due to intermittent availability could affect the timeliness of adaptive and resilient responses as well. All these responses – learning, adaptation and resiliency – are important to network organizations and any impediment to them is a risk.

Most social network studies have focused on personnel and knowledge losses in the form of turnover. Turnover has long been recognized as an important organizational problem (Dalton & Todor, 1979; Mobley, 1977; Staw, 1980; Steers & Mowday, 1981). The study of turnover has traditionally looked at voluntary and involuntary separation with voluntary separation being considered the most controllable and reducible (Price,

1977). Voluntary turnover has direct financial costs (Sunoo, 1998) such as those associated with replacement as well as potential indirect costs such as lower employee morale and satisfaction (Krackhardt & Porter, 1985) and knowledge loss. Identifying critical personnel is a vital step towards reducing the voluntary turnover problem as it has been shown that negative impact is largely due to who is leaving, not how many are leaving (Dalton, Krackhardt, & Porter, 1983; Dalton, Krackhardt, & Todor, 1982). Organizations can make better, more efficient use of their retention efforts if they understand who the critical personnel are.

A similar statement can be made for intermittent availability. Organizations can make better, more effective use of their communication networks if they understand who the critical personnel are and what the effects of intermittent availability can be. To this end, comparing the effects of intermittent availability to the effects of turnover may highlight some important characteristics of the intermittent availability risk.

2.3. Individual Redundancy

Individual redundancy is the level of similar knowledge or skill that a person possesses in relation to others in the organization. Network organizations are known for their resiliency due to redundancy (Ronfeldt et al., 2001). As noted by Weick and Sutcliffe (2001) in their work on High Reliability Organizations, elimination of redundant positions sacrifices experience and expertise. Additionally, they go on to say that loss of redundancy “can limit the repertoire of responses available to the organization” (p.169). The limited repertoire means that learning, adaptive and resilient responses are also limited and this lessens the advantages of the network organization. For example, a lack

of individual redundancy can result in needed knowledge or expertise becoming unavailable when the dynamics are fast, task loads are high and people are stretched in multiple directions. Knowledge transfer then becomes constrained and the learning response is limited. This is particularly relevant to network organizations as they are more suited to the useful exchange and transfer of knowledge-based goods which are predominantly tacit in nature (Powell, 1990).

Previously, structural analysis has focused on various measures of uniqueness to determine the criticality of personnel with the centrality of actors and their immediate contacts being the most common (Bavelas & Barrett, 1951; Blau & Alba, 1982; Freeman, 1979; Leavitt, 1951). The power of individual social capital (Bonacich, 1987; Burt, 1992) has also been used as a measure of criticality. The above studies focus mainly on communication, friendship, advice and negotiation networks with the critical personnel being more ‘visible’ to other actors in the network. Unique criticality dimensions based on cognitive, task and knowledge dimensions are less visible or ‘hidden’ to network actors. Carley and Ren (2001b) have shown how cognitive demand² can identify criticality in military teams. Several authors have described or used measures that identify people who are ‘irreplaceable’ due to their unique or specialized task skill and knowledge (Ashworth & Carley, 2006; Brass, 1984; Mechanic, 1962; Pfeffer, 1981). The dimensions listed here, network centrality; power; cognition; knowledge; and task, can all be thought of as critical. The common purpose to all these measures is they attempt to identify personnel who pose an immediate risk if they leave the organization.

² In the original paper, Carley and Ren refer to this as cognitive load. The change in name occurred after the publication.

But the flip side to the traditional view is to identify personnel who can serve as a risk protection; a focus on a more positive aspect of the structure. Sources of individual redundancy may be even more 'hidden' within the organization because these personnel may not be central and the knowledge or skill they hold is not unique. Understanding the risk protection that individual redundancy provides is important as these personnel can pick up the slack when critical others are unavailable or may even emerge as new leaders when critical other's leave.

2.4. Shifts of Criticality

A change of who is critical within an organization over time is what I term shifts of critical personnel. Shifts of critical personnel are adaptive and resilient responses in the face of change. Such realignment of roles and responsibilities may promote learning within the organization as the internal coordination among members brings together varying expertise and knowledge to deal with the dynamic challenges. Given that shifts of critical personnel can occur, it is important to identify who is important when or under what conditions so that risks can be managed.

The identification of critical personnel has been mainly used to identify important people in a static representation of structure. These studies basically applied different measures to simple network structures (Bonacich, 1987; Freeman, 1979) and various real-world contexts such as a high technology firm (Krackhardt, 1987), psychiatric center (Blau et al., 1982) and newspaper firm (Brass, 1984). Although these studies provide meaningful insight to identifying critical personnel at a particular point in time, the cross-sectional nature of the data precludes any attempt to understand how critical personnel

may change over time, especially as the environmental setting and operational conditions change.

There are a few studies that have analyzed networks and critical personnel change over time (Burkhardt & Brass, 1990; Carley, 2003; Johnson, Boster, & Palinkas, 2003; Sampson, 1968). For instance, Burkhardt and Brass (1990) found in their study of a government agency that critical personnel, defined as those who are influential, changed with the introduction of a new technology. Obviously the introduction of technology affords the opportunity for restructuring and it is important to understand the change in critical personnel that may occur. But this and the other studies looking at shifts of critical personnel only study the effect of one factor, such as technological (Burkhardt et al., 1990) or political (Sampson, 1968) change. The partiality of results makes it difficult to develop an overall theory.

2.5. Relevance to Critical Personnel Risks in Network Organizations

The risks of intermittent availability, individual redundancy and shifts of critical personnel relate to the who, why and when of critical personnel identification. Intermittent availability relates to the who and why by identifying persons who may pose risks to learning, adaptability and resiliency. Intermittent availability is probably not readily apparent in static analysis or in immediate impact analysis. Therefore, it should be studied using a longitudinal method that captures the dynamic impact over time. Individual redundancy relates to the why by exploring the protection that expertise redundancy provides for the detrimental effects of personnel unavailability and loss. The risk protection that individual redundancy offers is most evident when agent resources of

the organization are impaired. The effects of individual redundancy need to be studied longitudinally as there is some event, such as turnover, that results in the impairment of agent resources. Shifts of critical personnel relate to the when by exploring the effects that various stressors have upon organizational structure, in particular the individual positions of criticality. Shifts of critical personnel can impact the potential learning, adaptability and resiliency of the organization. These shifts, as apparent, are evolutionary and require dynamic, longitudinal methods of analysis as well.

Each of the risks can have potential impacts on one or more of the desired responses associated with network organizations. As I have argued, network organizations are evolutionary in nature as are each of the risks. Dynamic Network Analysis (Carley, 2003) is an appropriate method for studying these risks because it incorporates network change processes and longitudinally quantifies the structure for analysis and theory building.

Chapter 3 : Organizations

Two different organizational contexts were used in this research. Analytic comparison of the results across these contexts allowed for the development of stronger theory based on commonalities and for understanding how network organizations function idiosyncratically within contexts based on differences. The two different organizations, Team X and the Battle Command Group, and their contexts are described in the following sections.

3.1. Team X

Team X is a first phase conceptual design team located at NASA's Jet Propulsion Laboratory. The mission of the team is to design spacecraft for non-human space flight missions. They incorporate a concurrent engineering approach that is facilitated by collocation in a warroom. The team for this particular design session was composed of nineteen members with one formal leader and the rest of the team being a flat structure. Each member on the team was a functional expert in a particular area of spacecraft design. Each functional expert was responsible for designing their particular subsystem of the spacecraft but the design process required individually designed subsystems to be successfully integrated into one system. The high interdependencies between the subsystems created an inherently complex and uncertain task environment.

Team X is designed to be a network organization due to the specific design task which is performed (Wall, 1999). The design task is exemplary of knowledge work in that it is data intensive, intellectual and integrative with an innovative product outcome.

In addition, the NASA faster, better, cheaper initiative (McCurdy, 2001) influenced the conception of the design task and the team is under extreme time pressure to complete the design. Designing a complex spacecraft in a relatively short period of time requires the team to deal with many unexpected exceptions. There is no formal task structure because each design is unique and problems arise with the evolution of a particular design. So, the team needs to have the ability to form dynamic relations in order to solve problems quickly. The ability of network organizations to support quick adaptation and learning was seen as an advantage and this form of organization was chosen to fit the fast changing task environment.

Team X is funded by outside sources that hire and pay them for their services. Because of this, I consider Team X to be more an example of a business context than a governmental agency context. In fact, Team X had such a good reputation that private aerospace contractors studied and implemented their team design and concept.

Cross-sectional data was collected on the communication, knowledge and task interdependency networks of Team X. The knowledge network was self-reported data on the level of expertise that each member possessed. The knowledge network consisted of fifty-seven knowledge nodes. The task interdependency network is a digraph whereas the tasks of agent i depend on input from agent j . This is agent i 's perception of the tasks that agent j is performing which are important to agent i 's performance. It is perceptual because the task structure is dynamic and contains some uncertainty. The task dependency network is a cognitive network and it consisted of nineteen nodes. Data collection occurred after the Team X design sessions were completed.

In Chapter 1, characteristics of network organizations which are described in the literature were listed. These characteristics include flexibility, decentralization, differentiation, diversity, lateral cross-functional ties and individual redundancy. The network data for Team X was analyzed to determine if these characteristics were present. Table 3.1 presents the empirical social network measures for Team X that relate to the network organization characteristics. Overall, these measures support the qualitative assertion that Team X is a network organization. Based on these measures, Team X has high flexibility potential, low hierarchy, high diversity and existing individual redundancy.

Team X		
<i>Measure</i>	<i>Value</i>	<i>Interpretation</i>
Connectedness	1.0000	The degree of full connectivity; associated with flexibility
Hierarchy	0.1053	The level of status differentiation
Knowledge Diversity	0.9708	The normalized level of knowledge diversity among the agent nodes
Knowledge Redundancy	0.2622	The average amount of redundancy per knowledge node

Table 3.1: Team X Measures of Network Organization Characteristics

Connectedness (Krackhardt, 1994), which is associated with flexibility, measures the degree of full connectivity for a network. This is a normalized value between 0 and 1 with 1 being fully connected. The Team X value of 1 indicates a fully connected network that contained a high degree of flexibility potential. The reasoning is that higher connectivity allows for more agents to be involved in communication and coordination,

even if it is through indirect channels. Agents, therefore, have flexibility in gaining and sending information from and to many other agents.

Hierarchy (Krackhardt, 1994) measures the degree of status differentiation in a network based on a normalized scale between 0 and 1. A 1 indicates a pure hierarchy or high status differentiation. The Team X value of 0.1053 indicates very little status differentiation was present in the informal network. A lower level of status differentiation means there are more cycles in the network and this is an indication of information flow fluidity and faster rework. Higher levels of hierarchy (low number of cycles) are not as 'organic' or characteristic of 'networked' organizations.

Knowledge diversity measures the degree of knowledge diversity among the agent nodes in a network. This is a normalized value between 0 and 1 with 1 being highly diverse. The Team X value of 0.9708 indicates there was diverse knowledge within the Team X network.

Knowledge redundancy (Carley, 2002b) measures the average number of agents who have redundant knowledge based on a normalized scale between 0 and 1 where 1 indicates that all knowledge is completely redundant for every agent. The Team X value of 0.2622 indicates that individual redundancy did exist in the organization. This may provide a backup for risk protection in case a particular expert is unavailable. I am not making any claim as to what level of individual redundancy is good or high, just that individual redundancy is present.

There are two characteristics of network organizations not covered by the above measures: differentiation and lateral cross-functional ties. Differentiation was represented by the unique functional expertise of each member. Even though knowledge

redundancy exists, functional differentiation was still maintained and acknowledged in the organization. Lateral cross-functional ties are best analyzed through visualization. Figure 3.1 shows the communication network of Team X. Each node in the figure is a functional expert and the visualization clearly shows a high degree of cross-functional ties.

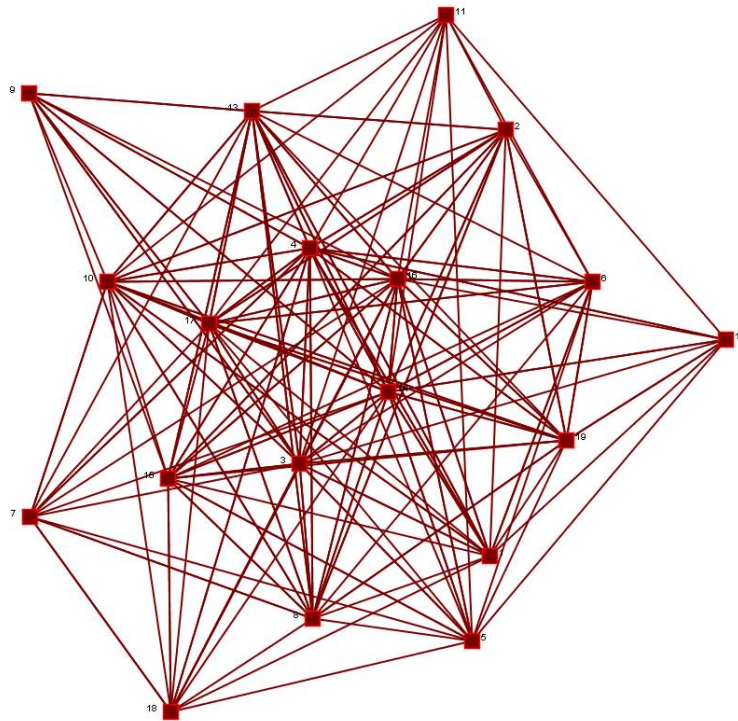


Figure 3.1: Team X Communication Network

3.2. Battle Command Group

The US Army is in the beginning phases of a future force design project aimed at exploring organizational designs which are adaptable to the various demands of military operations. This future force design, the Battle Command Group, is a network-enabled,

knowledge-centric organization performing joint and coalition operations. It is comprised of decentralized, distributed and highly interdependent units.

The Battle Command Group is the military's version of the network organization whereas the organizational structure adapts to environmental conditions. This distributed network structure relies heavily on expertise, information flow and cross-functional collaboration. The Battle Command Group is intended to be a learning organization which can respond quickly to high-velocity changes. It also needs to be highly resilient in the face of change and loss of personnel. The learning, adaptability, and resiliency advantages of network organizations were major factors for exploring the use of this organizational form.

The particular organization studied consisted of one-hundred and fifty-six people. Cross-sectional data was collected on the communication and the task networks of the organization. The task network consisted of fifty-one task nodes. The organization did not afford the opportunity to collect data on the knowledge network. But the task network can be used as a proxy for the knowledge network. This is especially important for later phases of the study when virtual experiments were run and knowledge was a key variable. The task network is an appropriate proxy for the knowledge network because the tasks are actually written products which relay information about the operational environment. Examples of task products include maneuver estimates, intel synchronization plans and support orders. These products relay task-specific knowledge that the agent possesses.

The data collection occurred during the beginning phases of the wargame exercise. People in the wargame were assigned functional roles such as commander or

intelligence officer and the tasks that a person performed were related to the role they played. In addition, the organization was structured into cells such as tactical command and aviation brigade. Each cell contained several of the functional roles and the cells themselves served different operational functions. Cells were expected to functionally collaborate with each other to accomplish the operational mission.

The network data for the Battle Command Group was also analyzed to determine if network organization characteristics were present. Table 3.2 presents the empirical social network measures for the Battle Command Group that relate to network organization characteristics. Overall, these measures support the qualitative assertion that the Battle Command Group is a network organization. Based on these measures, the Battle Command Group has high flexibility potential, moderate hierarchy, high diversity and existing individual redundancy.

Connectedness for the Battle Command Group was valued at 0.8164. Although not fully connected, this organization still had a high degree of connectivity, especially for a large group, and a high degree of flexibility potential. The hierarchy value of 0.4156 indicates a moderate degree of cycles were present in the organizational structure. Cycles (lower hierarchy) are needed for a network organization to produce quicker responses.

The knowledge diversity value of 0.9583 indicates a high level of diversity existed among the agents in the Battle Command Group. Knowledge redundancy, 0.0329, indicates that redundant expertise existed in the organization. Again, individual redundancy may provide a risk protection in case of expert unavailability but I am not making any claim as to what level of individual redundancy is good or high.

Battle Command Group		
<i>Measure</i>	<i>Value</i>	<i>Interpretation</i>
Connectedness	0.8164	The degree of full connectivity; associated with flexibility
Hierarchy	0.4156	The level of status differentiation
Knowledge Diversity	0.9583	The normalized level of knowledge diversity among the agent nodes
Knowledge Redundancy	0.0329	The average amount of redundancy per knowledge node

Table 3.2: Battle Command Group Measures of Network Organization Characteristics

As before, the social network measures do not cover the characteristics of differentiation and cross-functional ties. Differentiation was represented by the cells of the organization. The cells were the dominant categorization in the structure and each cell was responsible for different operational functions. Cross-functional ties should then connect agents in the various cells. Figure 3.2 shows the communication network of the Battle Command Group minus the isolates. The nodes are the individual agents in the organization and the colors represent the particular cell to which the agent was affiliated. In addition, the color of the communication tie indicates source directionality. For instance, a blue line indicates the communication originated from a blue node. Accordingly, ties of one color which are connected to nodes of a different color indicate cross-functional collaboration. The visualization clearly demonstrates the existence of cross-functional ties and collaboration. Agents in different cells are communicating with each other as evidenced by the many colored ties connected to nodes of a different color.

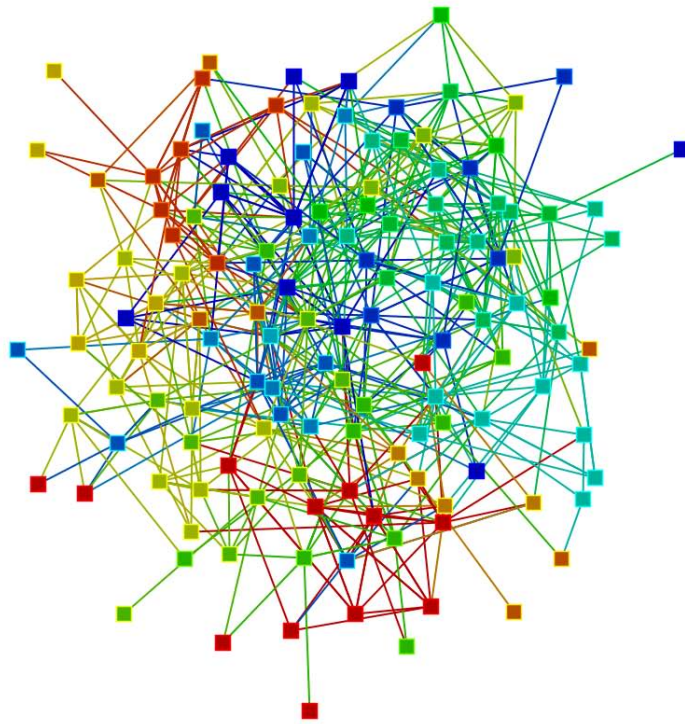


Figure 3.2: Battle Command Group Communication Network by Cell

Chapter 4 : Reasoned Computational Theory using Construct - Grounding Forward Theory through Empirical Validation of Internal Parameters and Processes

4.1. Introduction

The goal for this part of the research was to produce theory about critical personnel risks in network organizations. As previously mentioned, the advantages of network organizations can lead to learning, adaptability and resiliency. But we need dynamic analysis to understand network organizations and the risks associated with them because they are evolutionary in nature. The cross-sectional data that was collected in this research is limited in that it provides a static snapshot of the organization and precludes evolutionary analysis. As an alternative, multi-agent network models allow for reasoning about organizational dynamics over time. The multi-agent network model Construct (Carley, 1990; Schreiber, Singh, & Carley, 2004c) was used in this research to co-evolve organizational networks based on well-founded theories of interaction processes. Network structure and organizational risks can then be analyzed longitudinally and theory can be developed that accounts for the evolutionary nature of network organizations.

There are many benefits to using computation as a means to theory production besides surmounting the limitation of cross-sectional data. Computational analysis can also overcome issues of ethics, cost, timeliness, appropriateness and analytic complexity. But despite the usefulness of multi-agent computational methods, there are many critics of the approach. Often, critics claim that it is unclear whether the agent behaviors are

realistic (Edmonds, 2001). These agent behaviors underlie the global theory produced by multi-agent simulation.

The reasoned computational theory approach used in this research addressed both the empirical data limitations and the critics of theory development employing multi-agent simulation. Using this approach, I first validated the internal mechanisms of the model against empirical cross-sectional data of real-world behaviors. This validation provided confidence concerning the realistic nature of the agents' behaviors in the model. I then evolved the organizational networks using the simulation model initialized with the validated agent behaviors. The resulting evolved networks were then used to reason about critical personnel risks in network organizations. It is reasonable to assume that the outcomes produced from the model could occur in the real-world since the model was grounded in empirically validated behaviors. This evolutionary approach not only overcame the limits of cross-sectional analysis but it also produced forward theory that can be tested with longitudinal empirical studies that collect and analyze structural data on network organizations in similar contexts.

4.2. Producing Reasoned Computational Theory

The process for producing reasoned computational theory consists of two overarching steps, which are shown in detail in Figure 4.1. Step 1 validates agent interactions against cross-sectional communication pattern data collected in the field. First, a network representation of the organization is input into Construct. Organizations are represented in terms of the network relations that exist in the organization, such as the knowledge network or task network. Interaction processes which drive agent interaction

are also varied. There are two interaction processes in Construct, relative similarity and relative expertise. Both the organizational representations and interaction processes are described in more detail in the next chapter. Each combination of organizational representation and interaction process produces a different agent interaction pattern. These interaction patterns are then statistically compared to the empirical communication patterns using QAP. Validation occurs when agent interaction patterns significantly correlate with the real-world communication pattern thus providing an empirical grounding for the model.

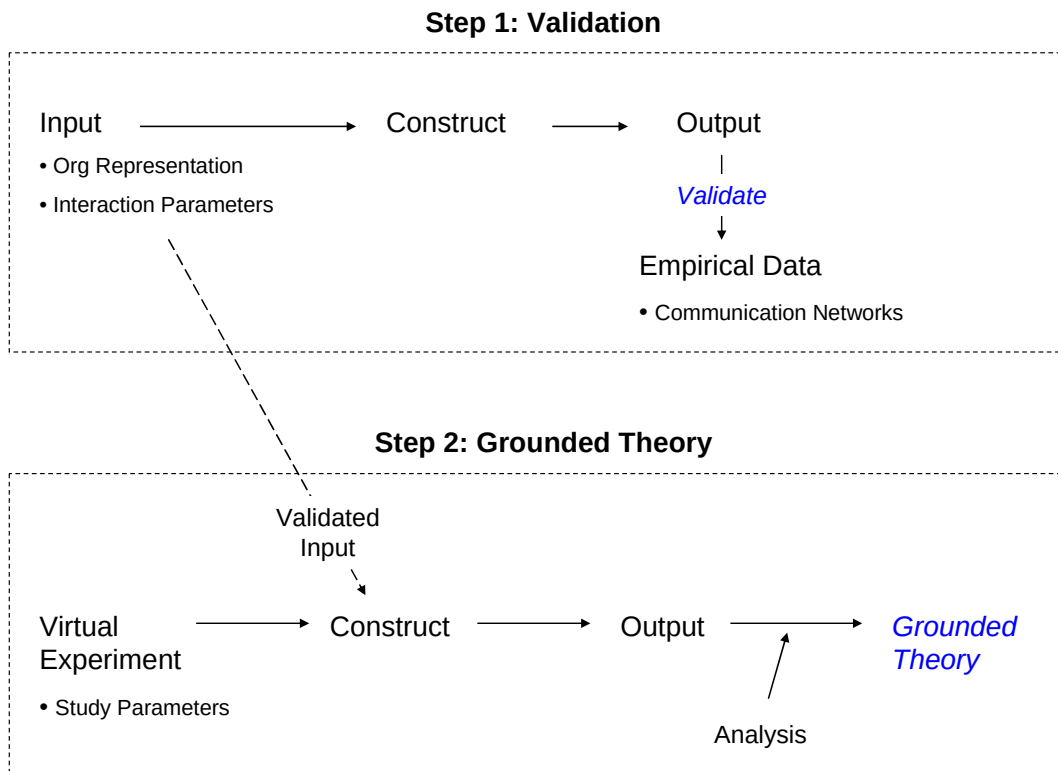


Figure 4.1: Process for Producing Reasoned Computational Theory

Step 2 produces grounded theory. In this step, Construct is first initialized with the validated input – the organizational representation and interaction process from Step 1. Then, virtual experiments are run which vary the independent variables of the study. The evolved networks and outcomes produced from the model are analyzed to produce grounded forward theory. The term ‘grounded theory’ refers to the fact that the theory was developed from a simulation model that was ‘grounded’ with empirically validated input.

4.3. Answering Scientific Questions

There are three basic categories of questions to which research provides answers in organization science: positive, normative and plausible (Burton, 2003). Positive science tests theoretical models of real phenomena to provide explanation. These are questions of ‘what is’. Normative science seeks to provide prescriptions for real-world application. These are questions of ‘what should be’. Plausible science lies in between positive and normative science and seeks to explore what might be possible. These are questions of ‘what might be’.

This research and the process for producing reasoned computational theory relates to all three categories of scientific questions. In terms of ‘what is’, the model is built upon theories of positive science but more importantly the validation is positive in describing the ‘what is’. Through validation, the communication patterns of the organization can be described and understood in terms of a social interaction process that is working within a particular organizational network. For instance, suppose the knowledge network and relative similarity combination validates against the empirical

communication network. Organizational communication can then be understood as being driven by the similarity of knowledge between agents. The empirical data used in the validation is a source for understanding what has happened.

But if we want to explore ‘what might be’ then we need to go beyond the data (Schreiber & Carley, 2004a). Simulation provides a means to create controlled experimental conditions of complex phenomena for answering plausible questions. The virtual experiment will vary the parameters and conditions of the model to explore ‘what might be’ but since it is validated the ‘what might be’ space contains the ‘what is’ space within it. Such experimentation is not only less costly and more timely but is also often more appropriate as manipulating and controlling variables, especially to the extremes, in a real-world setting is not always reasonable or ethical. Theory, which is the main focus of this research, was built from exploring the ‘what might be’ space.

Future positive science questions can also be formulated from the results. This research uses Construct, a multi-agent network model built on theoretical models of positive science to produce plausible theory. The plausible theory is not only grounded in validated empirical behavior but it is also testable for future empirical studies.

In terms of ‘what should be’, model outcomes concerning learning and structural change correspond to the desired outcomes of learning, adaptability and resiliency in network organizations. These desired outcomes were relevant to each organization’s decision to employ the network form of organization. Although not the main focus of this research, normative applications of the results are discussed.

Chapter 5 : Validating Agent Interactions in Construct against Empirical Communication Networks using the Calibrated Grounding Technique

5.1. Introduction

Computational models of organizational systems are developed with the intended purpose of representing the real-world phenomena (Law & Kelton, 2000; Turnley, 1995). Computational models are a means to deal with the complex, dynamic and non-linear functioning of real-world organizations, which often cannot be adequately reduced to an analytic model (Carley & Gasser, 1999; Law et al., 2000; Lee, Schreiber, & Carley, forthcoming). Many useful ends can be obtained from these models such as predictive emulation (Jin & Levitt, 1996; Levitt et al., 1994), normative analysis (Baligh, Burton, & Obel, 1990, 1994), and theory development (Carley, 1990; Schreiber et al., 2004a). But how confident can we be in the ends that are obtained from the model given that the model is only an approximation? In other words, how well does the model represent the real-world phenomena?

Validation is the process of determining how well a computational model matches the organizational system it represents (Balci, 1998; Kleijnen, 1995; Turnley, 1995). Validation is used, first and foremost, to obtain a level of credibility in the model which gives us confidence in the ends that are obtained. But there are many other benefits to the process of validation as it aids in scientific accumulation through an understanding of the strengths as well as the boundaries of the model (Schreiber et al., 2004a). Such

knowledge can provide phenomenal understanding, guidance for application decisions and directions for future research.

This chapter presents a validation study that was performed for Construct, a multi-agent network model for the co-evolution of complex socio-cultural environments. In particular, the focus was on the ability of Construct to produce agent interactions that were representative of communication networks in the two real-world organizations being studied. Validation will provided confidence in the plausible theory and normative guidance that was developed in later phases of the research. I used calibrated grounding to validate Construct. Calibrated grounding is a novel technique that was developed specifically for multi-agent network models.

This chapter is organized as follows. First, an overview of computational model validation approaches is given as well as a description of where the validation performed in this work fits within these approaches. Next, the Construct model and the importance of validating it against real-world communication networks are discussed. Then, the calibrated grounding process used to validate Construct is described. Finally, the results of the study are presented along with the associated benefits.

5.2. Validation

There are three phases of validation for the computational modeling process (adapted from Sargent, 1998): conceptual validation, internal validation, and external validation. Conceptual validation is concerned with the model's assumptions and underlying theories correctly representing the system under study. Conceptual validation usually occurs through an assessment of reasonableness such as subject matter expert

approval. Internal validation is concerned with the representation of the conceptual model in computer code. Internal validation usually occurs through software testing comparing simulation model output to expected outcomes from the conceptual model. External validation is concerned with matching the simulation model output to empirical data collected from the real-world system. External validation occurs through a variety of approaches which are described in the next section on validation types. The validation of Construct falls under the external phase of validation. The other phases are important but have been performed previously and are not within the scope of this study.

5.2.1. Validation types

There are three general types of external validation approaches: grounding, calibration and results verification (Carley, 1996)³. Grounding can involve a qualitative, initialization or evaluation technique. Qualitative grounding is basically a verbal argument as to the reasonableness of a model's limitations, assumptions and scope. This is done to establish the sufficiency of the model in representing the system under study. For example, applying the Social Turing Test (Carley & Newell, 1994) would provide a means for a qualitative argument. In initialization grounding, one sets the initial processes or parameters of a model to match real-world data. This is done so that the system under study has some form of representation in the model. For instance, if we believe that people in an organization interact based on their demographic similarity then we would give agents in the model demographic attributes based on those that people in the organization possess (Carley, 2003). Evaluation grounding establishes that the

³ Carley also describes of fourth general type, harmonization. Since this method is not standard in validating computational models of organizations, it is not described within this paper.

behavior of the model matches the behavior of the real-world system. This is normally done by comparing model output to stylized facts or typical behaviors of the system. An example of evaluation would be showing that an epidemic of infectious disease in the model followed an S-shaped curve (Sterman, 2000).

Calibration is the procedure of tuning a model's processes and parameters so that output matches real-world data within a reasonable tolerance. This is done to demonstrate the feasibility of the model for representing the system under study. Calibration can involve analysis at two levels. At the dependent variable level, the model's outcomes are compared to empirical data on real-world outcomes, see Lee et al. (forthcoming) for an example. At the independent variable level, the model's internal processes and parameters are compared to empirical data on the processes and parameters of the real-world system. Schreiber and Carley (2004a) provides an example of internal calibration.

Results verification is the process of comparing a model's output to real-world data. The comparison is usually performed graphically or statistically (Kleijnen, 1995). This is done to not only gain credibility for the model's assumptions, underlying theory and predictive capability but also to move the model from the theoretical domain to the applied domain. The process of results verification differs from calibration at the dependent variable level in that it does not involve changing the model in any way. Carley (1990) provides an example of results verification.

The validation technique used in this study was a combination of types: initialization grounding and internal calibration (independent variable level). Figure 5.1 shows validations of the computational modeling process and where calibrated grounding

fits within the overall framework discussed so far. The calibrated grounding technique is described in full detail later in this chapter.

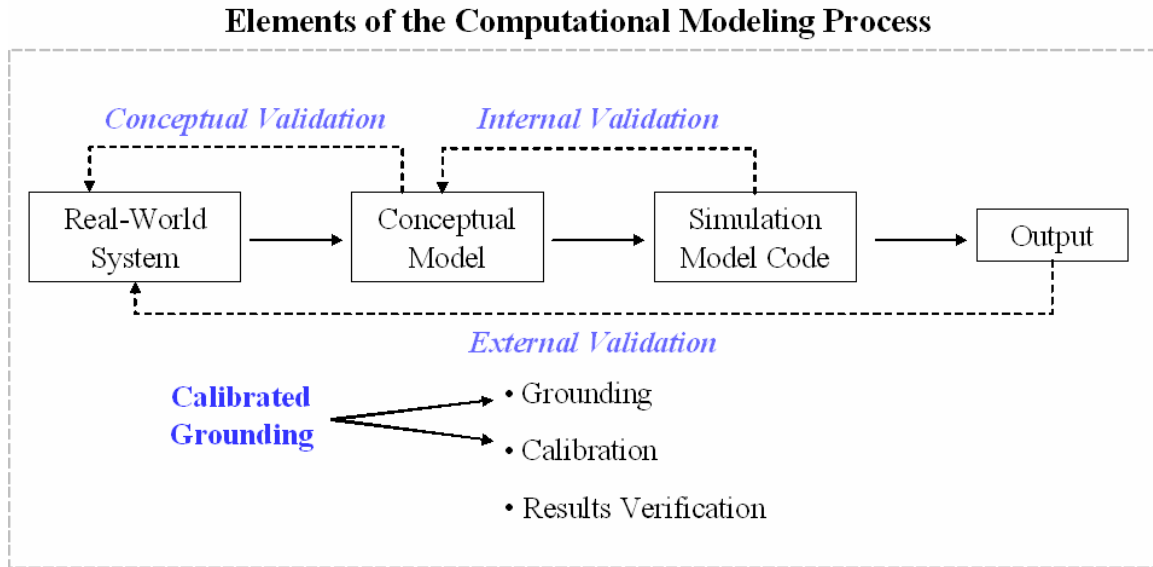


Figure 5.1: The position of calibrated grounding within the phases of computational modeling validation

5.2.2. Validation levels

The process of validation also establishes the degree of model equivalence with the real-world system. There are four kinds of equivalence testing: face validation, numerical equivalence, distributional equivalence and relational equivalence. Face validation uses subject matter experts to conclude if the model’s behavior is representative of the real-world system. The Social Turing test (Carley et al., 1994) would be an example of face validity. Numerical equivalence tests if the model produces results that are numerically identical to data from the real-world system. Stochastic models, such as Construct, are mostly excluded from such an analysis since they produce probabilistic results. Distributional equivalence tests if the model produces a distribution

of results that are statistically indistinguishable from the real-world system. In other words, the shapes of the results match. Schreiber and Carley (2004a), is an example of distributional equivalence. Relational equivalence tests if the model and real-world system produce the same internal relationship among their results. This is a form of pattern validity. Lee et al. (forthcoming) is an example of relational equivalence testing. The calibrated grounding technique as used in this study was distributional equivalence. This will also be described later in this chapter along with calibrated grounding.

5.2.3. A caveat

One important note about validation of computational models in general – validation is only a matter of degree (Law et al., 2000). Models are only approximate representations of the complex systems under study. There cannot be any objective proof of a model's validity (Forrester, 1961). We can only have confidence that a model is a reasonable representation of the system (Greenberger, Crenson, & Crissey, 1976).

5.3. Methodology

5.3.1. Construct

Construct is a multi-agent network model for the co-evolution of the socio-cultural environment (Carley, 1990, 1991, 1999; Carley & Hill, 2001a; Schreiber et al., 2004a; Schreiber & Carley, 2004b; Schreiber et al., 2004c). In the model, agents go through an active, adaptive cycle where they choose interaction partners, communicate, learn knowledge, change their beliefs about the world, and adapt their networks based on

their updated understanding. During this cycle, agents perform tasks based on their current knowledge, and outcome measures such as knowledge diffusion, performance accuracy and consensus are collected. Figure 5.2 shows the Construct action cycle.

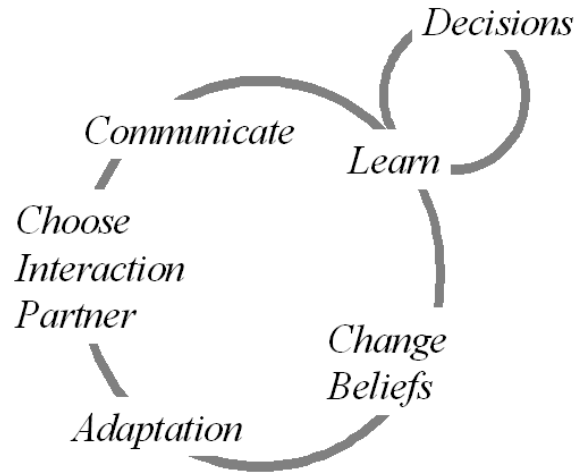


Figure 5.2: Construct action cycle

Agent interactions are the basic foundation on which the output measures depend. These interactions figure prominently in what each agent learns and agent learning determines the values of the outcome measures. Therefore, the first step in validating Construct is to get a reasonable degree of equivalence between agent interactions and real-world communication networks. Such a validation will generate confidence in the model's ability to represent a real-world organization and to originate sound ends, such as theory development. If agent interactions in Construct reasonably represent real-world interactions of a group then we can say that outcomes of the model could reasonably occur in the real-world phenomena.

In Construct, there are two main types of core variables that influence agent interactions: organizational representation parameters and interaction processes. Organizational representations are collected empirically as network data since Construct is a multi-agent network model. This allows for the input of real-world data to initialize the model as a set of individual, heterogeneous agents. Typical networks for which data are collected are the knowledge network, task network and cognitive network. These networks are used because it is believed they influence communication networks. In other words, people will communicate with one another based on the knowledge people possess, the task assignments people have or the perceptions people hold. The knowledge network is ‘who knows what’ in the organization. Knowledge is defined into categories that are relevant to that particular organization. For example, if an organizational simulation group is being studied then data may be collected on knowledge categories such as software development, hardware, organization theory and statistics. The knowledge network then is simply who possesses what level of expertise in each category. The task network is ‘who does what’ task in the organization. This is a straightforward task assignment network.

The cognitive network is the perception of each person as to ‘who knows what’ knowledge or ‘who does what’ task. In other words, it is each person’s perception of the knowledge or task network. The cognitive network is collected because people interact or make choices based on their perceptions of the world, which varies by person. Therefore, it seems that a cognitive perception network would be a good representation to base interactions on in the model. This looks obvious for the cognitive knowledge representation, but in this study data was collected on network forms of organization

where tasks can often be ambiguous and not well defined. In this case, task network perception will vary by person and this could also figure significantly into agent interactions.

One difficulty with cognitive networks is the time commitment required to touch each person in the organization and to get their perception of every other person that they know. This encumbering time commitment often prohibits the actual collection of cognitive network data in many real-world organizations.

The basic interaction processes in Construct, relative similarity and relative expertise, are based on well-known social processes of human interaction. Relative similarity is based on homophily (Lazarsfeld & Merton, 1954); the finding that people tend to interact with those similar to themselves. Arguments supporting homophily include trust, comfort, communicative ease and access. Relative expertise is based on expertise seeking (Cross, Rice, & Parker, 2001b). Arguments supporting expertise seeking are a need for specialized or non-redundant knowledge and knowledge integration.

Each combination of organizational representation and interaction process will result in a different interaction pattern among the agents. For example, a task network and relative similarity will result in agents with common tasks interacting more with each other than with agents who have different tasks. A knowledge network with relative expertise will result in agents with dissimilar knowledge interacting more with each other than with agents who have common knowledge.

I analyzed the ability of various combinations of organizational representation and interaction process to produce valid results by statistically comparing Construct agent

interactions to real-world communication networks. The organizational representations and interaction processes were of interest because these are the core variables influencing agent interactions. Each unique organizational representation and interaction process was considered a different model of the organization. I will refer to these unique organizational representation and interaction process pairs as organizational models from hence forth for word brevity.

5.3.2. Calibrated Grounding

Calibrated grounding is a technique that was developed for validating multi-agent network models against empirical communication networks, see Figure 5.3. Validation occurs when agent interactions are statistically indistinguishable from real-world interactions. This technique is a combination of approaches, specifically initialization grounding and internal calibration. Initialization grounds the model by using empirical data representing the real-world organization. Internal calibration establishes the feasibility of producing validated agent interactions. The idea is that by producing internally valid agent interactions with a model grounded in real-world representation, we can then have reasonable confidence that outcomes produced by the model could occur in the real-world organization. Therefore, ends such as theory development have a sounder basis.

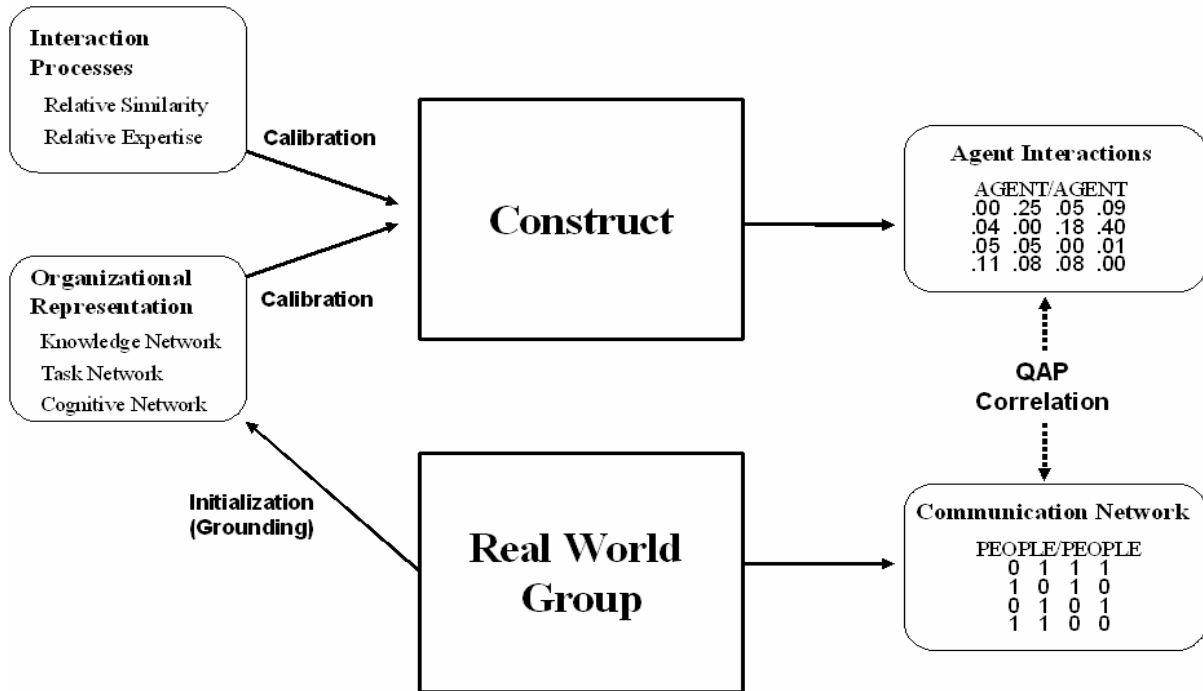


Figure 5.3: The calibrated grounding technique

The process of calibrated grounding has several steps. First, an organizational representation is input into Construct. This representation is a parameter that is believed to influence real-world interactions. Representations include the knowledge network, task network or cognitive network, all previously described. Second, an interaction process that drives agent interactions is chosen. The interaction process will produce an interaction pattern based on the organizational representation. The interaction process choices are relative similarity and relative expertise, also previously described. Third, Construct is run to produce agent interactions. Fourth, the agent interactions are statistically compared to the real-world communication network using QAP correlation. QAP correlation is a non-parametric procedure for comparing relational data. Validation

occurs when significant correlation exists between the simulated and real-world networks. This process is repeated for every organizational model in the dataset.

Calibrated grounding as used in this study was a form of distributional equivalence. I use distributional equivalence because I want the distributions of simulated and real-world interactions to match within a reasonable statistical tolerance⁴. The standard 0.05 significance level is used as the test of reasonable tolerance. Also, calibrated grounding is a form of parameter and process matching, not tuning as in turning knobs and incrementally changing weights to curve fit. The parameter is varied with a set of fixed organizational representations and the interaction processes are varied by two distinctions. Calibrated grounding is a process of how interactions occur. Parameter and process matching is a more meaningful way of validating through calibration (Carley, 1996).

5.3.3. Datasets

For the Team X organizational representation, the knowledge and cognitive task networks were collected. The cognitive task network is the perception of ‘who is working on what’ in the organization. This network was collected because there were no defined task assignments. The tasks that were performed evolved as the design problem was defined and redefined through iterative work cycles. For the Battle Command Group organizational representation, the task network was collected. These different organizational representations were collected as afforded by each respective organization. Communication networks from each organization were collected in addition to the

⁴ Exact matching of the real-world and simulated distributions, as in numerical equivalence, would not occur due to Construct being a stochastic model. Therefore, this form of equivalence is not used.

organizational representations. The communication networks were compared against Construct's agent interactions for validation.

5.4. Results and Discussion

Table 5.1 and 5.2 show the QAP correlation coefficients for each of the organizational models of Team X and the Battle Command Group, respectively. Each statistical test of an organization model for a particular dataset was a separate analysis but they are shown together for analytic clarity.

Team X			
		Organizational Representation	
		Knowledge Network	Cognitive Task Network
Interaction Parameter	Relative Similarity Coefficient	0.174**	0.334**
	Relative Expertise Coefficient	0.057	0.199**

Table 5.1: Team X validation – QAP correlation coefficients
** indicates significance at the 0.01 level

Battle Command Group		
		Organizational Representation
		Task Network
Interaction Parameter	Relative Similarity Coefficient	0.069**
	Relative Expertise Coefficient	0.027**

Table 5.2 : Battle Command Group validation – QAP correlation coefficients
** indicates significance at the 0.01 level

There were three Team X models which validated against the empirical communication network. These models were the knowledge network with relative similarity, the cognitive task network with relative similarity and the cognitive task network with relative expertise. It should be noted that the value of the correlation coefficient does not offer any indication of degree of correlation. QAP correlation is non-linear in this regard. Therefore, it cannot be interpreted that the 0.334 correlation is significantly stronger than the 0.174 correlation. The only indicator of significance is whether or not a particular model passes the statistical test at the 0.05 level of significance.

These results indicate that interactions based on knowledge were predominantly with others who had overlapping expertise. This is not surprising given that members often had obtained some expertise of other functional areas due to the high interdependencies. These results also indicate that interactions based on perceived tasks included members who were performing similar tasks and members who were performing different tasks. Again, high interdependencies forced interactions to occur across different tasks in addition to the obvious common task interactions.

Both of the Battle Command Group models validated against the empirical communication network. These results indicate that there were interactions between members who were performing similar task and members who were performing different tasks. This is not surprising either given the complexity of the battlefield space and the need to build and maintain share situation awareness. Coordination across functions and tasks is crucial in such an environment.

The results showing the significance of the task networks in validating the communication patterns of the agents are expected as others have empirically shown that task networks significantly influence communication networks in organizations (Cross et al., 2001b). Also, the significance of both relative similarity and relative expertise in the validation tests corroborates with similar results by Cross, Borgotti and Parker (2001a) which show the existence of both homophily and knowledge seeking in communication networks.

One benefit of this validation study is the confidence it provides for Construct. Construct reasonably represented the interaction patterns of the real-world groups. The validated organizational models were used in later research phases to produce grounded forward theory about the various critical personnel risks in network organizations. Therefore, there is grounding and confidence about the plausible theories of ‘what might be’. Also, normative implications of the proposed theories are discussed. There is grounding and confidence in the normative suggestions of ‘what should be’.

Only one of the organizational models per each dataset will be used in the production of forward theory and they are all of equal comparison because the level of significance, 0.01, is the same. For Team X, I used the knowledge network since there were more knowledge nodes than cognitive task nodes. This provided more fidelity to the organizational model in terms of evolving the networks. The relative similarity interaction process is used because it validated with the knowledge network whereas the relative expertise interaction process did not. For the Battle Command Group, I used the organizational model represented by relative similarity. This maintained consistency

with the Team X model in terms of interaction process but mainly it was an arbitrary decision.

A second benefit is that this study provided an additional understanding of ‘what is’ from a positive science perspective. The communication networks can now be described in terms of interaction processes within specific organizational representations. In addition, the description of ‘what is’ lends additional quantitative support for these organizations being network forms of organization according to the definition. The relative expertise and task network model for each organization significantly correlated with the respective communication network. This indicates cross-functional coordination – a major characteristic defining a network organization.

Lastly, I want to make a side note about situations when Construct validates with both interaction processes for a given organizational representation. Construct can be set accordingly in terms of the frequency that each interaction process occurs in the organization. In other words, Construct can be set so that agents interact on relative similarity a certain percentage of the time and on relative expertise the remaining percentage. This requires additional information gathering in the organization but would strengthen the representation of the organization in the model. Unfortunately, such information was not feasible to collect in either organization used in this study due to constraints imposed by the organizations on time commitments and survey instruments.

Chapter 6 : Forward Theory – Critical Personnel Risks in Network Organizations

6.1. Introduction

In this chapter, grounded forward theory is developed about the risks of intermittent availability, individual redundancy and shifts of critical personnel as they pertain to network organizations. The previous chapters defined these risks, described their relevance to network organizations and argued that network organizations and the associated risks are evolutionary in nature. Due to this evolutionary nature, a dynamic approach to both methodology and theory is needed.

This work produced theory using Dynamic Network Analysis. Dynamic Network Analysis (Carley, 2003) is a methodology for modeling and analyzing the complex relational qualities and longitudinal dynamics of organizational systems. The techniques of social network analysis and multi-agent simulation are combined in this methodological approach: social network analysis to analyze complex relational qualities and multi-agent simulation to reason about longitudinal dynamics.

Construct, which was described in Chapter 5, was used to evolve the networks for analysis and theory development. The validation of Construct in terms of the communication patterns of the two organizations provided an empirical grounding from which to start the simulations and from which the networks evolved. The longitudinal analysis of the simulated networks produced theory that accounts for the evolutionary nature of network organizations.

This chapter is organized as follows. First, the risks of intermittent availability and individual redundancy are explored. This section begins with the description of the virtual experimental design and followed by the presentation of results, the discussion of the findings and the proposal of theory. Next, shifts of critical personnel are explored. This section begins by explaining the importance of building theory across various operating conditions facing an organization. The stressors that comprise the operating conditions are described as well as their representation in Construct. A main effects experiment is then depicted and followed by the presentation of results that show the efficacy of the stressor representations to the intended purpose. Then, the virtual experimental design for shifts of critical personnel is described and followed by the presentation of the results, the discussion of the findings and the proposal of theory

6.2. Intermittent Availability and Individual Redundancy

Previously, I argued that intermittent availability can pose a risk to the learning responses of network organizations. To test the argument that intermittent availability is an organizational risk, I compared the organizational learning results of intermittent availability to those of turnover⁵. These risks were compared longitudinally to gain an understanding of both the immediate impact and long-term effects of each⁶. This way, I not only determined if and when intermittent availability is a risk but I also gained an understanding of this risk relative to the well-established turnover risk.

⁵ Turnover has long been recognized as an organizational risk in the literature, which I referenced in Chapter 2.

⁶ Earlier, I conjectured that the effects of intermittent availability would most likely be seen in the long-term. In contrast, turnover most likely has an immediate impact. Longitudinal analysis is essential for building theory about the dynamic, evolutionary nature of the risk.

Individual redundancy has been argued as a risk protection against personnel loss or unavailability and which contributes to the resiliency of network organizations⁷. To test this argument, I regressed social network measures of individual redundancy to the organizational learning outcomes of intermittent availability. If individual redundancy is a risk protection then there should be positive correlation between the level of individual redundancy and the organizational learning outcomes associated with intermittent availability. A successful correlation would add quantitative support to the previous arguments.

6.2.1. Experimental Design

The experimental design consisted of three conditions: baseline, turnover without replacement and intermittent availability. Table 6.1 shows the experimental design. The networks were evolved over 250 timeperiods and each result was obtained using a Monte Carlo technique 25 times. Each of the organizations, Team X and the Battle Command Group, were run as separate virtual experiments. Each respective virtual experiment was initialized with the validated organizational model for that organization. The model for Team X is the knowledge network and relative similarity. The model for the Battle Command Group is the task network (used as a proxy for the knowledge network⁸) and relative similarity. The reasoning behind the decision to use these organizational models was explained in Chapter 5.

⁷ These arguments were presented in Chapter 2.

⁸ Note: In Chapter 3 it was explained that the task network is a proxy for the knowledge network. This proxy was used because 1) the products produced in the performance of tasks relate to knowledge about the operation and 2) the organization did not allow the opportunity to collect a knowledge network.

The baseline condition was a single experiment that evolved the networks without any changes in agent loss or availability. The baseline was used to test the statistical significance of the other conditions. Turnover without replacement was a condition that consisted of several experiments equal to the number of agents in the organization. This condition takes one agent out of the organization each experiment and this happened once for each agent in the organization. Therefore, Team X had 19 experiments and the Battle Command Group had 156 experiments. Agent loss occurred at the fifth timeperiod.

Variable	Description	Values
Organization	Organizational model	Team X Battle Command Group
Critical personnel	Baseline network, turnover without replacement for each agent and degrees of intermittent availability for each agent	Baseline <i>(1x per organization)</i> Turnover without replacement <i>(19x for Team X, 156x for Battle Command Group)</i> Intermittent availability <i>(19x for Team X, 156x for Battle Command Group – per each condition)</i> 25% unavailability 50% unavailability 75% unavailability

Table 6.1: Experimental Design for Intermittent Availability and Individual Redundancy

Turnover was modeled in terms of agent loss without replacement because of two reasons. First, the average knowledge per agent in the Battle Command Group empirical data is 3.9%⁹. Replacing lost agents with agents who possess less knowledge would not make much sense in this case. Second, agent loss without replacement models the worst-

⁹ As previously noted, the task network was used as proxy for the knowledge.

case scenario in terms of agent turnover. This scenario should have the largest impact on the simulated organization.

Intermittent availability was a condition that restricted task communications for selected agents and that contained three different sub-conditions. The three sub-conditions vary the intensity of the communication restriction so that the effects of various degrees of intermittent availability could be analyzed. The degrees of intermittent availability were 25%, 50% and 75%. Each percentage corresponds to the average amount of task communication that an agent is unavailable. For instance, 25 % indicates that an agent is unavailable for task communications 25% of the time. A random role of the dice determines whether or not an agent is available for task communications in a given timeperiod.

Intermittent availability experiments were run once for every agent in the organization by sub-condition. For Team X there were 57 experiments and for the Battle Command Group there were 468 experiments. Intermittent availability began at the first timeperiod of each experiment and was active to the ending timeperiod.

Organizational learning was used as the outcome measure for statistical testing. This measure was captured by the knowledge diffusion outcome variable from Constuct. Specifically, knowledge diffusion measures the percent of total knowledge that all the agents have learned on average across the runs. Organizational learning was chosen for several reasons. First, it is a direct proxy for the desired outcome response of overall learning in a network organization. Second, organizational learning can be the foundation for non-structural adaptive responses. An example would be a change in strategic direction based on new information and organizational learning. Third,

maintaining the rate of learning can be considered a resilient response in the face of change, especially when the loss or unavailability of personnel occurs which places stress upon the organization.

The organizational learning measure was used to assess conditions that impact the overall learning achieved within the simulated organization. This measure should not be interpreted as also assessing whether or not the organization was learning the ‘right’ things or if the organization was applying what they learned correctly. Therefore, the results obtained using this measure and the subsequent theory that was developed does not address all possible organizational goals.

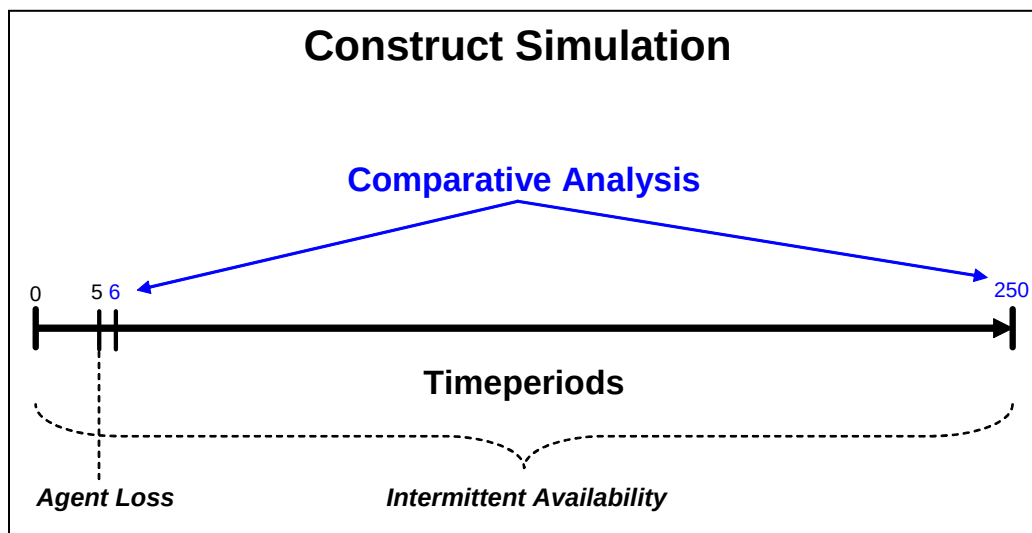


Figure 6.1: Longitudinal Comparative Analysis of Intermittent Availability and Turnover without Replacement

The effects of turnover without replacement and intermittent availability were compared at the sixth timeperiod and the last timeperiod as shown in Figure 6.1. The

sixth timeperiod was used because it captured the immediate impact of both turnover without replacement and intermittent availability. Turnover without replacement occurred at the fifth timeperiod and the analysis at the sixth timeperiod captured the organizational impact right after the agent loss. It also captured the early impact of intermittent availability which began at the first timeperiod. The fifth timeperiod was chosen for agent loss for two reasons. First, it allowed intermittent availability to run for five timeperiods so that the immediate impact was more comparable. This was needed since intermittent availability is determined at random and five timeperiods allowed for unavailability to take place. Second, the agent loss occurred early enough in the simulation run to gauge evolutionary dynamics and long-term effects after the change. This left 245 timeperiods of dynamic evolution.

Confidence interval tests were used to compare each experiment across all conditions to the baseline at the above timeperiods. These tests revealed which and how many agents had a significant impact on organizational learning when the agent was lost or intermittently available. These tests also revealed the relative impact associated with each significant result.

Changes to structural measures could be used to analyze structural learning and adaptation for intermittent availability but this was not chosen due to the use of turnover without replacement. There is undoubtedly a dramatic structural impact and change within the virtual organization when agent loss occurs. Comparing structural measures across conditions where agent loss occurs and conditions where it does not occur is like comparing apples and oranges for the theoretical purposes of this study.

Individual redundancy effects were tested by regressing the social network measure of cognitive similarity to the organizational learning measure. Cognitive similarity (Carley, 2002b) measures the average normalized degree of knowledge redundancy that an agent has to all others in the organization. This measure was calculated on the validated organization representation network which was used to initialize the Construct model. The reasoning for regressing cognitive similarity to organizational learning is that higher levels of knowledge redundancy for an individual agent should result in lessening the impact of loss or unavailability; a risk protection. A significantly positive correlation between cognitive similarity and organizational learning will establish this relationship. Regression was performed for the various experimental conditions which produced mostly significant impacts¹⁰.

The empirical communication network of the organization was also regressed against the organizational learning measure. This adds stringency to the analysis. The validation study determined a significant correlation between the organizational representation network (that was used to initialize Construct) and the empirical communication network. The cognitive similarity measure was calculated on the validated organization representation network. Therefore, the relationship between the communication network and the organizational learning outcomes required testing. This is important for building theory about the effects of individual redundancy.

QAP regression was performed using the Double Dekker Semi-Partialling method with 2,000 random permutations. QAP regression is a non-parametric statistical procedure that accounts for the dependencies which exist among the observations in

¹⁰ Conditions that produced mostly insignificant impacts for intermittent availability and agent loss are uninteresting and ignored for further statistical testing and analysis of individual redundancy.

social network data. Standard statistical analysis is not considered to be valid for this data. A repeated vectors technique was used to perform QAP regression since there is only one vector per outcome measure. This technique uses a square matrix as input into the QAP procedure. The square matrix was built by using the same column vector repeatedly and equal to the number of agents. This was done for both the cognitive similarity and organizational learning measures. The empirical communication network was already a square matrix.

6.2.2. Intermittent Availability – Results and Discussion

The results and discussion starts with the analysis of intermittent availability. This analysis begins with Team X, then the Battle Command Group and followed by the proposal of theory. Next, the analysis of individual redundancy is presented and followed by the proposal of theory.

6.2.2.1. Team X – Intermittent Availability

Table 6.2 presents the results summary for the Team X intermittent availability comparative analysis. This table shows the number of significant results obtained from the confidence interval tests, both in terms of longitude and direction of impact. As expected, intermittent availability does not have an immediate impact but does have a long-range impact. The negative long-term impact to the organization is dramatic as seventeen out of nineteen experiments result in significant decreases to organizational learning. This indeed poses an organizational risk. But surprisingly, this impact is only

in the highest condition of unavailability, 75%. This indicates that intermittent availability is only a risk when interruption to task-related communications is very high.

As expected, turnover without replacement has very little long-term impact. There are a few agents who have a negative long-term impact and this most likely gets back to the notion – it is not the existence of turnover that matters, it is who is leaving that matters (Dalton et al., 1983). In contrast, the immediate impact results are quite unexpected. There are a few agents who result in a negative immediate impact and this is expected. But there are several agents that actually result in an increase to the amount of organizational learning after turnover occurred and this is very unexpected. These increases are curious and need to be explained.

Team X (19 total agents)	Immediate Impact (Timeperiod 6)	Long-term Impact (Timeperiod 250)
Intermittent Availability .25 <i>significant increase</i> <i>significant decrease</i>	-- --	-- --
Intermittent Availability .50 <i>significant increase</i> <i>significant decrease</i>	-- --	-- --
Intermittent Availability .75 <i>significant increase</i> <i>significant decrease</i>	-- --	-- 17
Turnover without Replacement <i>significant increase</i> <i>significant decrease</i>	6 4	-- 3

Table 6.2: Team X - Summary of the Intermittent Availability Comparative Analysis Results

Table 6.3 presents the relationship between agent total knowledge and a significant immediate impact result for turnover without replacement. There is a direct

relationship between the total amount of knowledge an agent possesses and the direction of immediate impact. Agents who are high in total knowledge significantly decrease organizational learning and agents who are low in total knowledge significantly increase organizational learning. Increases are due to how knowledge diffusion is measured. The measure calculates the sum of the percentage of knowledge known per each agent in the organization and divides this by N , the total number of agents. When agent loss occurs, the lost agent and all of their knowledge are taken out of the organization. So not only does knowledge diffusion calculate with less knowledge but also one less agent, $N-1$, which is a different denominator than the baseline comparison of N . In cases where agent loss results in very little knowledge loss, increases occur because the overall organization becomes more efficient in terms of overall organizational learning. But the impact is short-lived as increases in efficiency do not maintain in the long-term and there is no effect whatsoever.

The principal takeaway for these results is the difference between the long-term impacts of intermittent availability and turnover without replacement. There are far more agents whose intermittent availability results in a negative effect to the organization. Of course, this only includes the high unavailability condition. In contrast, turnover without replacement results in relatively few agents whose loss produces a negative impact. The implication is that, in the long-term, network organizations can more easily deal with agent loss than with sustained, high levels of disrupted communication. In this sense, high levels of intermittent availability pose a greater long-term risk than does agent loss.

Team X		
Turnover without replacement Immediate Impact		
<i>Agent</i>	<i>Total Knowledge</i>	<i>Agent Loss Significant Impact</i>
A8	4	Increase
A9	9	Increase
A12	8	Increase
A14	11	Increase
A15	11	Increase
A2	17	Increase
A7	13	--
A5	14	--
A3	17	--
A6	15	--
A10	16	--
A1	18	--
A11	20	--
A17	20	--
A13	20	--
A19	28	Decrease
A4	28	Decrease
A18	30	Decrease
A16	41	Decrease

Table 6.3: Team X - Total Knowledge and Immediate Impact by Agent for Turnover without Replacement

6.2.2.2. Battle Command Group – Intermittent Availability

Table 6.4 presents the results summary for the Battle Command Group intermittent availability comparative analysis. This experiment did not turn out as expected but upon further inspection the results make sense. For intermittent availability, there was a real lack of significant results for the 156 total experiments. The lack of an immediate impact was expected but the general lack of a long-term impact was not. And where there were a few significant long-term impacts, they were in an unexpected direction – positive. These results are due to two factors: group size and training.

First, the Battle Command Group is much larger than Team X and these results indicate that disruption to a single communication link has virtually negligible impact to an organization of this size. In a few cases, the disruption caused a slight but significant increase by reducing the complexity of the overall communication channels and making the organization a bit more efficient in terms of organizational learning. Second, there was very little pre-exercise training for the players in the wargame. This lack of training is evidenced by the low average knowledge per agent, 3.9%. The game was just ramping up and players were just learning the operational scenario. Therefore, the task-level knowledge was in the formative stage. This low level of knowledge per agent also contributed to the low number of significant results for single agent disruption.

Battle Command Group (156 total agents)	Immediate Impact (Timeperiod 6)	Long-term Impact (Timeperiod 250)
Intermittent Availability .25 <i>significant increase</i> <i>significant decrease</i>	-- --	12 --
Intermittent Availability .50 <i>significant increase</i> <i>significant decrease</i>	-- --	3 --
Intermittent Availability .75 <i>significant increase</i> <i>significant decrease</i>	-- --	4 --
Turnover without Replacement <i>significant increase</i> <i>significant decrease</i>	2 --	41 1

Table 6.4: Battle Command Group - Summary of the Intermittent Availability Comparative Analysis Results

The turnover without replacement results follows the same line of reasoning. There was very little immediate impact. The low average knowledge per agent is steady across all agents in the organization with the standard deviation being 0.031318. There was insignificant knowledge loss per agent turnover and the efficiency of the organizational learning measure did not immediately increase even with N-1 in the denominator due to the size of the organization. There were quite a few significant increases in the long-term although overall these account for just a little over one-quarter of the experiments. Those agents with the lowest total knowledge resulted in these increases. Again, the size of the organization is a factor in that the loss of one agent was not detrimental. But in cases where the agent possessed extremely low total knowledge then agent loss caused an increase in organizational learning due to long-term efficiency gains in knowledge diffusion. Basically, there was very little knowledge loss and one less agent to diffuse knowledge to.

6.2.3. Intermittent Availability – Theory

There are a several main points from these results. First, the size of the organization matters. Small network organizations can be susceptible to risks resulting from single agent intermittent availability. Large network organizations can withstand these single agent disruptions to task-related communications as they are minor in relation to the size of the organization. Second, the level of agent unavailability within the small network organization matters. Intermittent availability only had significant negative impacts when task-related communications were highly disrupted. Third, the length of the agent intermittent availability within the small network organization

matters. Intermittent availability had no short-range impacts. It was only after the disruption persisted over time that a significant negative impact was realized. Fourth, the long-term negative impact of intermittent availability for a small network organization was greater than the long term negative impact of agent loss. Negative impacts resulted from 17 agents for intermittent availability as opposed to 3 for turnover. Based on the above results the following theories are proposed:

Proposition 1 – Single agent intermittent availability can pose a risk to small network organizations

Proposition 1a – The disruption to task-related communications must be high and sustained before a risk to the network organization is incurred

Proposition 1b – High, sustained intermittent availability is a long-term risk that is more detrimental to the network organization than turnover

6.2.4. Individual Redundancy - Results, Discussion and Theory

Next, the effects of individual redundancy were tested using the Team X intermittent availability results at the high level of unavailability, 0.75. This experimental condition was chosen because of the prominent level of significant results, 89.5%. All other conditions, whether from the Team X or the Battle Command Group experiments, had low levels of significant results which would discredit the efficacy of the individual redundancy results if used.

In addition, the total knowledge of each agent was added to the regression analysis. This was not a part of the original experimental design but was added because a relationship between total knowledge and organizational learning was shown for Team X in the previous analysis. This relationship was investigated to explain the unexpected

positive results for immediate impact in the turnover without replacement condition. Its addition to the regression determined if this same relationship holds for the long-term impact in the intermittent availability condition. This strengthens the analysis and has a bearing on theory development.

Table 6.5 presents the QAP regression results. Individual redundancy, as measured by cognitive similarity, had a positive and significant correlation with organizational learning. A higher value for cognitive similarity means that an agent had a higher level of individual redundancy. A higher value for organizational learning means that intermittent availability had less of an impact. This significant, positive relationship established individual redundancy as a risk protection.

Team X				
<i>.75 Individual Redundancy</i>				
Regression Coefficients				
<i>Independent Variable</i>	<i>Standardized Coefficient</i>	<i>Significance</i>	<i>Proportion as Large</i>	<i>Proportion as Small</i>
Intercept	0.000000			
Total Knowledge	-0.187362	0.292	0.708	0.292
Communication	0.009651	0.460	0.460	0.540
Cognitive Similarity	0.763623	0.026	0.026	0.974
Model Fit				
<i>R-Square</i>	<i>Adj. R-Square</i>			
0.406	0.390			

Table 6.5: QAP Regression Results for Individual Redundancy

Both the empirical communication and the total knowledge matrices produced insignificant correlations. This strengthened the efficacy of the individual redundancy results since neither of these factors significantly related to the outcome. In addition, the

r-squared is 40%. This also strengthens the results as a fairly large portion of the variance can be explained by individual redundancy. These results provide some quantitative support to the qualitative arguments of several authors who claim individual redundancy is a protection for organizational risks. Based on these results the following theory is proposed:

Proposition 2 – Individual redundancy serves as a risk protection in small network organizations by reducing the detrimental impacts related to agent unavailability

6.3. Shifts of Critical Personnel

Shifts of critical personnel is an important evolutionary problem to understand, especially for a network organization as structural flexibility is one of the primary characteristics that lead to the advantages and desired responses. Network organizations are used in highly volatile environments. They deal with high rates of change and increased uncertainty. Structural flexibility helps the network organization adapt and respond to this volatility.

Change and uncertainty create stress on an organization. Stress is something that all organizations face (Perrow, 1999). The variety and strength of stressors induce a range of operating conditions which confront the organization. It is reasonable to conjecture that the operating conditions affect shifts of critical personnel. More specifically, low stress operating condition may result in fewer shifts whereas high stress operating conditions may result in many shifts. Accordingly, it is meaningful to understand the evolution of critical personnel shifts across the range of operating conditions. The theory built here is in this regard.

6.3.1. Stressors

Lin and Carley (2003) describe three general types of stress that organizations face: external stress, internal stress and time pressure. External stress originates from the external environment. An environment with rapid change and uncertainty is an example of external stress. Network organizations are used in these environments and are considered an advantageous design for dealing with external stress. Internal stress originates from malfunctions in organizational operating conditions. Examples of internal stress are communication barriers, turnover and agent unavailability. In terms of network organizations, this forces sub-optimal conditions for communication and learning. Time pressure constrains rationality. Under time pressure, organizations may communicate and learn based on limited knowledge. This also forces sub-optimal conditions for communication and learning in network organizations. These three stressors can all be simultaneously present in the organization to varying degrees at a given point in time (Lin et al., 2003).

Following their work, I modeled each type of stress as well as the simultaneity of stressors to represent a range of operating conditions. Stressors were modeled at the organizational level and equally affect each agent concurrently within the experiments. The organizational level is the level of interest for this particular study. Individual differences in reactions to stress would represent stress at the individual level and it is assumed that such individual differences would wash-out at the organizational level¹¹.

¹¹ Individual level stress could not be modeled even if this were a level of interest because this data was not available to collect.

6.3.2. Stressor Main Effects: Experiment Design

The purpose of stressing the organization was to create operating conditions which were detrimental to performance. Performance was measured by organizational learning as this is a desired response in network organizations and is consistent within this thesis. Table 6.6 presents the experimental design for the baseline experiment testing the effect of each stressor on organizational learning. The networks were evolved over 250 timeperiods and each result was obtained using a Monte Carlo technique 25 times. Each of the organizations, Team X and the Battle Command Group, were run as separate virtual experiments. Each respective virtual experiment was initialized with the validated organizational model for that organization.

Variable	Description	Values
Organization	Organizational model	Team X Battle Command Group
Stressor	Baseline and type/degree of stress	Normal operations No stressors Dynamic environment 25% rate of change 50% rate of change 75% rate of change Intermittent availability 25% unavailability 50% unavailability 75% unavailability Selective attention 25% selective constraint 50% selective constraint 75% selective constraint

Table 6.6: Experimental Design for Testing the Stressor Effects

External stress was modeled as a dynamic task environment whereas the knowledge an organization needs to learn changes at varying rates¹². In Construct, the external environment represents the task environment of the organization. The agents interacted with the external environment and learned bits of task-related knowledge. The agents then interacted with each other and engaged in task-related communication as described in Chapter 5. Change in the environment occurred by changing the value of the knowledge bits. Agents then had to learn about the change in order to maintain or improve organizational learning. The rate of change in the task environment was probabilistic and occurred at random. For example, when the rate of change was 25% then each knowledge bit had a 25% probability of being changed each timeperiod. A random roll of the dice determined if a particular knowledge bit was changed. The rate of change in the external environment indicated the level of stress. For example, the higher the rate of change the higher the external stress faced by the organization.

Internal stress was modeled as intermittent availability whereas task-related communications are constrained¹³. Intermittent availability was explained earlier in this chapter. Again, this stressor was modeled at the organizational level and affects each agent concurrently. This is unlike the previous virtual experiment where intermittent availability affected only one agent per experiment. The percentage of unavailability indicated the level of stress. For example, the higher the percentage of unavailability the higher the internal stress of the organization.

¹² The external environment is a feature in Construct that is user selected. It is selected to be an active variable for this virtual experiment.

¹³ This is also a user selected option in Construct.

Time pressure was modeled using an information processing approach based on selective attention¹⁴. The following reasoning was applied. Stress causes a rise in arousal (Eysenck, 1967) which then causes selective attention of knowledge (Easterbrook, 1959; Matthews, Davies, Westerman, & Stammers, 2000). Selective attention narrows the amount of knowledge that is considered when communicating. Therefore, learning under the influence of time-pressure is cognitively constrained. This approach is consistent with organizational theorists in that individual stress is the enemy of rationality (Simon, 1947) and reduces the search for alternatives (Staw, Sandelands, & Dutton, 1981). In Construct, agents under time pressure only consider a portion of the overall knowledge they possess when communicating. The portion of knowledge was determined by 1 minus the selective attention effect. In other words, if an agent knows 10 bits of knowledge and they have a selective attention of 20% then the agent only considers 80% or 8 bits of their knowledge when selecting a bit to communicate. A random role of the dice determined the knowledge bits which were selected for consideration. The level of selective attention indicated the level of stress. For example, the higher the level of selective attention the higher the time pressure and cognitive constraint on the knowledge considered for communications.

Three effects were analyzed with this experiment. First, each stressor should decline performance as compared to the baseline. Again, the purpose was to have organizational stressors which have a significant, negative effect upon the organization. Second, each stressor should have an increasing effect as the level of stress goes up. Higher levels of stress need to have a significant, negative effect as compared to the previous level of stress. This ensured that critical personnel changes were analyzed

¹⁴ This is also a user selected option in Construct.

across a range of operational conditions that were different. Third, the effects of the stressors should be comparable. Similar effects by the stressors aid in analyzing shifts of critical personnel by making structural changes more comparable across conditions.

Confidence interval tests were used to test for significant effects. These tests are not interpreted in the traditional way as to whether or not the results were significant but rather to determine that there were a sufficient number of runs to get a good estimate from the model. In other words, increasing N will result in significance. If for some reason increasing N does not result in significance then that means the variable is not having any impact on the model output.

6.3.3. Stressor Main Effects: Results and Discussion

Figure 6.2 graphically shows the main effects and Table 6.7 presents the confidence intervals for the Team X results. The main effects obtained when using the Team X data met the purpose of the study. Each organizational stressor decreased organizational learning significantly. Higher levels of stress within each stressor significantly decreased performance as compared to the next lower stress level. And the effects of each stressor were comparable. The rate of change as the level of stress increased for each stressor, including the baseline, was as follows: dynamic environment, -9.84%; intermittent availability, -11.27%; selective attention, -9.85%.

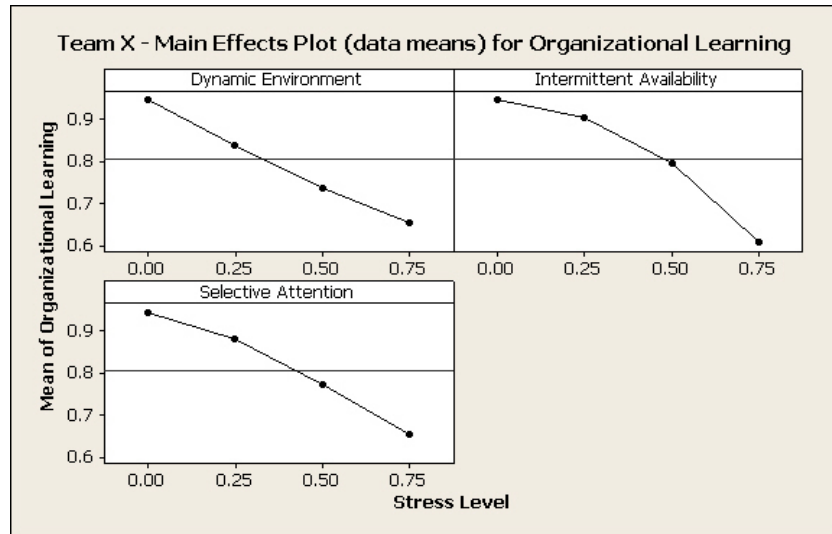


Figure 6.2: Team X - Main Effects for Stressors

Team X		Confidence Interval	
<i>Experiment</i>		<i>Upper Bound</i>	<i>Lower Bound</i>
Baseline		0.952600	0.940106
Dynamic Environment.	- .25	0.858326	0.814804
Dynamic Environment.	- .50	0.756429	0.711899
Dynamic Environment	- .75	0.674328	0.630936
Intermittent. Availability	- .25	0.907822	0.899564
Intermittent Availability	- .50	0.806374	0.783284
Intermittent Availability	- .75	0.616291	0.597745
Selective Attention	- .25	0.897023	0.871213
Selective Attention	- .50	0.800044	0.747324
Selective Attention	- .75	0.693478	0.616032

Table 6.7: Team X - Main Effects Confidence Intervals

Figure 6.3 graphically shows the main effects and Table 6.8 presents the confidence intervals for the Battle Command Group results. The main effects obtained when using the Battle Command Group data met the purpose of the study. Each organizational stressor decreased organizational learning significantly. Higher levels of

stress within each stressor significantly decreased performance as compared to the next lower stress level. And the effects of each stressor were comparable. The rate of change as the stress level increased for each stressor, including the baseline, was as follows: dynamic environment, -7.74%; intermittent availability, -9.02%; selective attention, -9.05%.

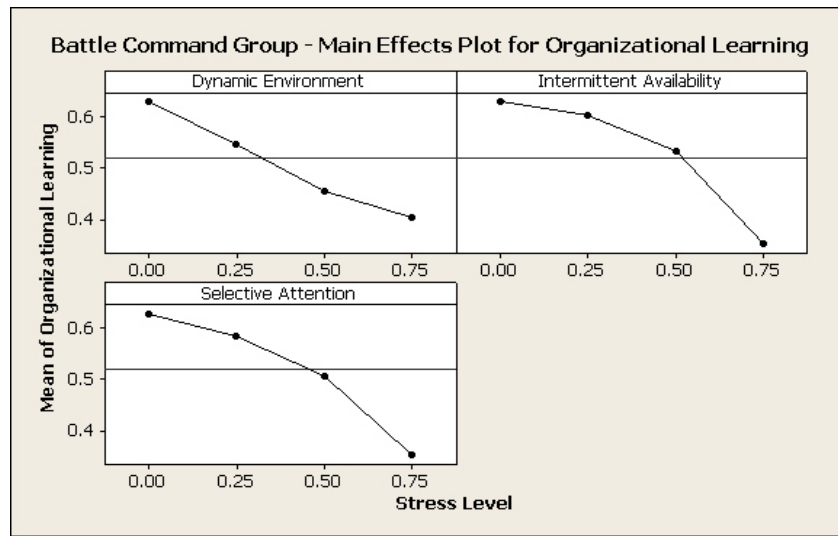


Figure 6.3: Battle Command Group - Main Effects for Stressors

Battle Command Group		Confidence Interval	
Experiment		Upper Bound	Lower Bound
Baseline		0.631697	0.627881
Dynamic Environment.	- .25	0.559863	0.530433
Dynamic Environment.	- .50	0.466492	0.440396
Dynamic Environment	- .75	0.415588	0.388886
Intermittent. Availability	- .25	0.606616	0.599492
Intermittent Availability	- .50	0.535935	0.530707
Intermittent Availability	- .75	0.355841	0.349035
Selective Attention	- .25	0.597914	0.574208
Selective Attention	- .50	0.523379	0.490497
Selective Attention	- .75	0.381319	0.327631

Table 6.8: Battle Command Group - Main Effects Confidence Intervals

The stressors all had similar effects when comparing the results across the organizational datasets. This provided consistency for building theory about shifts of critical personnel based on subsequent virtual experiment results for both organizations. The rates of change were slightly lower for the Battle Command Group due to the lack of training and low average knowledge in the organization. But, this result is intuitive and does not hinder the comparability.

Of particular note is the comparison of the intermittent availability results between this virtual experiment and the intermittent availability virtual experiment. The intermittent availability virtual experiment produced differing results between the organizational datasets in terms of degree and direction of impact. That experiment explored the impact of intermittent availability at the individual level. In contrast, the stressor main effects virtual experiment explored the impact of intermittent availability at the organizational level. The intermittent availability results for the organizational datasets are comparable in terms of degree and direction of impact for this experiment. This lends support to the assumption that individual differences in stress response will wash-out at the organizational level.

6.3.4. Shifts of Critical Personnel: Experimental Design

A virtual experiment exploring shifts of critical personnel was run after determining the stressors were producing the desired effects. Table 6.9 presents the experimental design for the shifts of critical personnel virtual experiment. The networks were evolved over 250 timeperiods and each result was obtained using a Monte Carlo technique 25 times. Each of the organizations, Team X and the Battle Command Group,

were run as separate virtual experiments. Each respective virtual experiment was initialized with the validated organizational model for that organization.

Variable	Description	Values
Organization	Organizational model	Team X Battle Command Group
Dynamic Environment	External Stress	No change 25% rate of change 50% rate of change 75% rate of change
Intermittent availability	Internal Stress	Always available 25% unavailability 50% unavailability 75% unavailability
Selective attention	Time-pressure	No constraint 25% selective constraint 50% selective constraint 75% selective constraint

Table 6.9: Experimental Design for Shifts of Critical Personnel

The focus for this virtual experiment was on the outcome of structural change in terms of critical personnel. Agent interaction patterns produced by Construct were averaged over the Monte Carlo runs and analyzed to determine which agents were critical. The agent interaction patterns correspond to organizational communication networks.

Individual criticality was determined by two factors – social network measures of centrality and measure ranking. Centrality was selected because this family of measures is most commonly used for identifying critical personnel in communication networks. The following centrality measures were calculated: betweenness, eigenvector,

information and total degree. It is customary for these measures to be correlated. Therefore, correlations between the measures were analyzed. If the measures were correlated then only one measure was used to represent criticality, otherwise multiple measure were used.

A preliminary correlation analysis was performed for each organization separately. Centrality measures were calculated using the initialization network of each virtual experiment. Initialization starts at timeperiod 0 and is the agent interaction pattern that validated against the empirical communication network in Chapter 5.

The correlations among the centrality measures at virtual experiment initialization for Team X and the Battle Command Group are presented in Tables 6.10 and 6.11, respectively. All five of the centrality measures were correlated for both organizations. Therefore, only one measure was used in identifying the set of critical agents. Eigenvector centrality was selected because it generally had the highest level of significance among all the correlations but this is mostly arbitrary as any measure would serve the purpose.

Team X			
	<i>Betweenness</i>	<i>Eigenvector</i>	<i>Information</i>
<i>Eigenvector</i>	0.590 0.008		
<i>Information</i>	0.467 0.044	0.859 0.000	
<i>Total Degree</i>	0.506 0.027	0.880 0.000	0.830 0.000
Cell Contents: <i>Pearson correlation</i> <i>P-value</i>			

Table 6.10: Team X - Centrality Measure Correlations at Initialization

Battle Command Group			
	<i>Betweenness</i>	<i>Eigenvector</i>	<i>Information</i>
<i>Eigenvector</i>	0.725 0.000		
<i>Information</i>	0.536 0.000	0.958 0.000	
<i>Total Degree</i>	0.741 0.000	0.988 0.000	0.948 0.000
<i>Cell Contents: Pearson correlation P-value</i>			

Table 6.11: Battle Command Group - Centrality Measure Correlations at Initialization

The second factor in determining individual criticality was measure ranking. The top five agents in terms of highest centrality value were defined as critical. These five agents make up the critical set for each timeperiod. The decision to use five was basically arbitrary as there is no a-priori basis for determining how many agents within a measure are considered critical. Five was chosen because it has been commonly used in the applied work I have done within organizations.

Two types of change in criticality are measured and analyzed, total change and unique change. Total change measures the number of changes that occur to the composition of the critical set over time. This measure was calculated as follows. The critical sets for each adjacent comparison timeperiod were contrasted and a change was recorded for each difference between the sets. For instance, if the sets of agents being compared were {1,2,3,4,5} and {3,4,5,6,7} then two changes would be recorded as there are two differences between the sets. The total number of changes across all comparisons equaled the number of total changes. One note - this measure accounts for the prodigal

son situation. The prodigal son situation is when an agent was in the critical set, fell out of the critical set, and is now back in the critical set. It counts this as a change.

Unique change measures the number of times a new agent enters into the critical set. A new agent is defined as someone who has not previously been in the critical set. This measure was calculated as follows. The critical sets for each comparison timeperiod were joined to make one union set. The difference between the number of agents that comprise the union set and five (the maximum number of critical agents per timeperiod) equaled the number of unique changes. This measure does not count the prodigal son situation as a change.

Both types of change were measured and analyzed to see if operating conditions affected them differently. For instance, it would be reasonable to presume that many different operating conditions induce high amounts of total change but only a few induce high amounts of unique change. Unique change would be particularly interesting to explore as there are many more agents assuming critical roles and this could have important organizational implications.

Comparative analysis for calculating the total change and unique change measures occurred between timeperiods 0, 50, 100, 150, 200 and 250. The knowledge networks for both of the organizational datasets had enough fidelity such that structural changes in Construct needed to evolve over several timeperiods. The above timeperiods were chosen because they allowed enough duration for change to occur between comparisons and because they provided even spacing for calculating change.

The purpose of this study was to build theory about the effects that various operating conditions, as represented by stressors and stress levels, have upon changes in

critical personnel. It was previously determined that there were a sufficient number of runs within the virtual experiment to gain significance and obtain a good estimate of the stressor effects. Therefore, the next step in the analysis was to determine the direction and strength of the relationship between the stressors and structural change. To make this determination, the main effects of the stressors were plotted and multiple regression was performed. The standardized beta coefficients from the multiple regression analysis were used to assess the relative impact of the stressors. These analyses were completed for both total change and unique change.

Next, contour plots were created and hierarchical clustering was run to provide analysis for building theory about the various operating conditions and their effect upon shifts of critical personnel. Contour plots were created and analyzed to gain insight into the interactions between pairs of stressors and the related impacts on structural change. Contour plots allow stress levels to be graphed and highlight peak areas of structural change that exist in the interaction space.

But contour plots use the means of the coordinates to create a continuous surface. This makes classifying the operating conditions more difficult. So a more discrete analysis, hierarchical clustering, was performed to discern how the three factors simultaneously affected shifts of critical personnel and to classify the stressors into operating conditions relating to different degrees of change. To accomplish the discrete classification, the experimental outcomes for total change and unique change were coded into discrete categories.

Three binary factors representing high, medium and low categories of change were created and separately coded for total change and unique change. The categories

were defined based on the range of change outcomes for each organization. This is a context-based approach that acknowledges the different organizational characteristics and situations. What is considered a high degree of change for one particular organizational context may not be considered as a high degree of change for a different context. This approach was especially germane for this analysis because the organizations were of vastly different sizes and represented very different contexts. The exact categorical definitions of change for each organization will be described in the results section.

The binary factors were set according to the categorization of each experimental outcome. For instance, if the change outcome for a particular experiment was determined to be a high degree of change then the high categorization was set to 1 and the medium and low categorizations were both set to 0. Then, the binary change factors and the stress conditions for each experiment were run through the hierarchical clustering procedure. The procedure was run using the average linking method, Pearson correlation distance measure and three partitioning clusters. These parameters were chosen because the objective was to obtain correlated groupings around the high, medium and low categories of change. Total change and unique change clusterings were run separately for each organization.

6.3.5. Shifts of Critical Personnel: Results and Discussion

Team X results are presented and discussed first followed by the Battle Command Group. After that, the results for each organization are compared and theory is proposed based on the findings.

6.3.5.1. Team X – Shifts of Critical Personnel

For Team X, total change ranged from 0–3 and unique change ranging from 0-2 across the experimental conditions. Figure 6.4 shows the Team X main interaction plots for both total change and unique change based on data means. Two trends stand-out. First, higher rates of change in the dynamic environment lead to more shifts of critical personnel. Second, as either intermittent availability or selective attention increase then shifts of critical personnel become constrained. These trends were consistent for both total change and unique change.

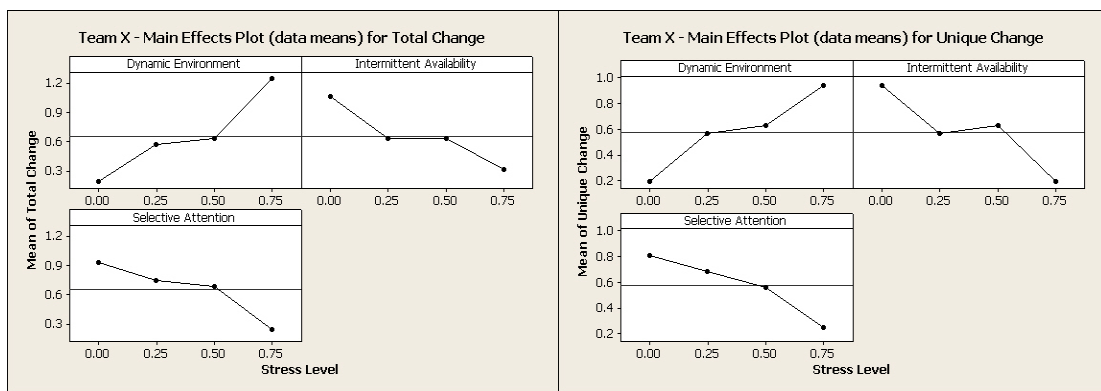


Figure 6.4: Team X - Main Effect Plots for Total Change and Unique Change

Table 6.12 presents the results of separate multiple regression analyses for total change and unique change¹⁵. This table shows that the dynamic environment has a stronger impact on both types of change as compared to the other stressors. It also shows that intermittent availability had a stronger impact on constraining unique change relative to selective attention.

¹⁵ The tables only report the standardized coefficients since the significance of the stressor effects were already established. Again, significance is not interpreted in the normal way. Instead, it is used to show that a good estimate was obtained in the model. The standardized coefficients provide a relative comparison for the stressor effects.

Team X <i>Total Change</i>		Team X <i>Unique Change</i>	
Regression Coefficients		Regression Coefficients	
<i>Variable</i>	<i>Standardized Coefficient</i>	<i>Variable</i>	<i>Standardized Coefficient</i>
Dynamic Environment	0.457	Dynamic Environment	0.394
Intermittent Availability	-0.316	Intermittent Availability	-0.372
Selective Attention	-0.299	Selective Attention	-0.309
Model Fit Adj R-Square – 36.8%		Model Fit Adj R-Square – 35.8%	

Table 6.12: Team X – Standardized Coefficients from the Multiple Regression Analysis for Total Change and Unique Change

In addition, the stressors account for a fair amount of the change experienced in the organization – about 36% for each type of change. It was not expected that the stressors would account for all of the variation as structural change in Construct also happened “naturally” through interactions based on homophily. For example, the baseline condition which had no stressors resulted in one shift of critical personnel for each type of change.

The goal from here was to explore the effects of stressor combinations and to classify operating conditions related to high, medium and low degrees of change. Figure 6.5 shows contour plots of total change. Only total change is presented but the unique change plots resulted in very similar patterns. There are three contour plots – one for each paired combination of stressors. The darker blue regions indicate higher amounts of change whereas the lighter blue regions indicate lower amounts of change. The x-axis and y-axis scales indicate the stress levels for each stressor.

The top left corner shows the contour plot by dynamic environment and intermittent availability. This plot indicates that higher levels of change in the task

environment induced shifts of critical personnel. But this effect was moderated by intermittent availability. Constraints on task-related communications reduced the number of shifts. This moderating effect increased as intermittent availability increased with higher stress levels resulting in fewer shifts of critical personnel.

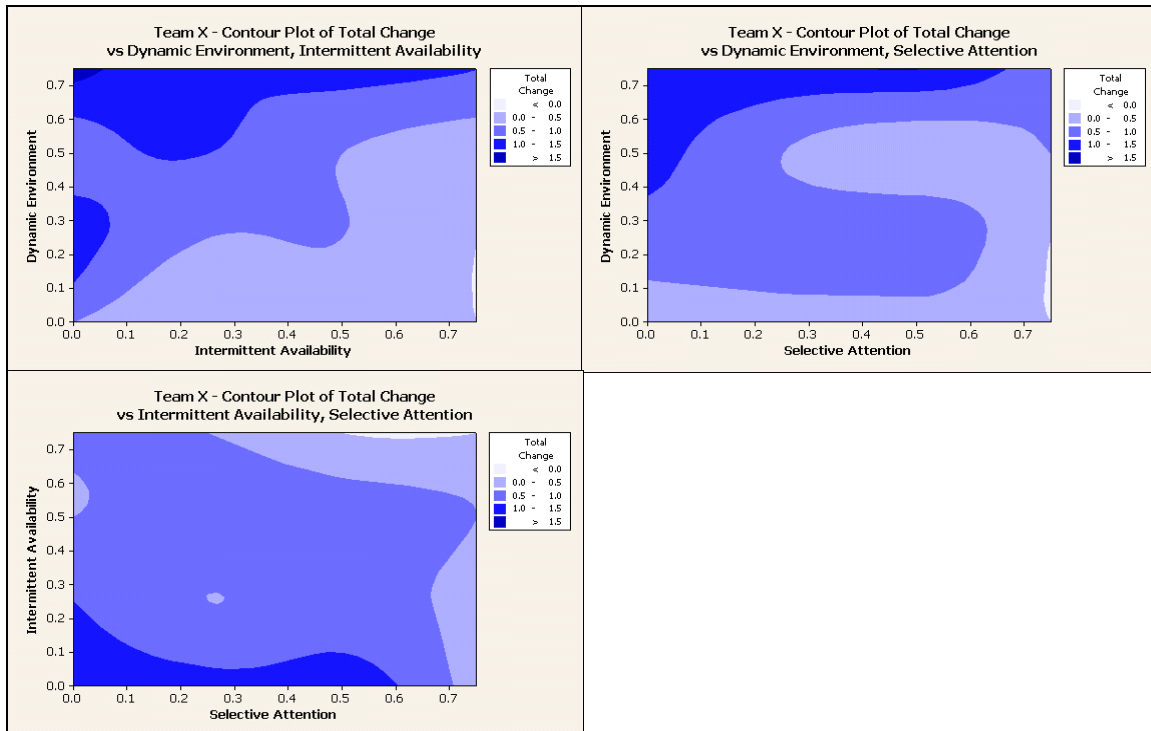


Figure 6.5: Team X - Contour Plots of Total Change by Stressors

The top-right corner shows the contour plot by dynamic environment and selective attention. A similar effect to that of intermittent availability is seen. The dynamic environment effect of inducing shifts of critical personnel was moderated by selective attention. Cognitive constraints on the use of knowledge reduced the number of shifts. The moderating effect for selective attention increased as well with higher stress levels resulting in fewer shifts of critical personnel.

The bottom-left corner shows the contour plot by intermittent availability and selective attention. This plot indicates that the combination of communication and knowledge attention constraints limited the change to moderate and low amounts. The vast majority was in the moderate range.

The next step was to perform hierarchical clustering to classify the stressors into operating conditions related to the three categories of change. The change outcome ranges for Team X were used to determine the specific values defining each category.

Total change had a range of 0-3 and the following categorizations were used: 2,3 – high; 1 – medium; 0 – low. Unique change had a range of 0-2 and the following categorizations were used: 2 – high; 1 – medium; 0 – low. These change ranges and categorizations make sense. Team X is a small-sized organization with a lot of experience and is highly trained in the particular context. There are fewer occasions for change in the simulation model because of the organization size and higher level of overall knowledge. Accordingly, the change categorizations reflect the context. Two shifts of critical personnel can be considered a high level of change for this organization.

Figure 6.6 presents the Team X hierarchical clustering results for unique change. The colored lines represent factors with stronger correlations to a particular change category. The following color schemes were used: blue – low change, green – medium change, and red – high change. The factors on the x-axis correspond as follows:

Prefix

DE = dynamic environment
IA = intermittent availability
SA = selective attention

Suffix

.00 = 0% stress level
.25 = 25% stress level
.50 = 50% stress level
.75 = 75% stress level

Prefix

TC = total change
UC = unique change

Suffix

Low = low amount of change
Med = medium amount of change
High = high amount of change

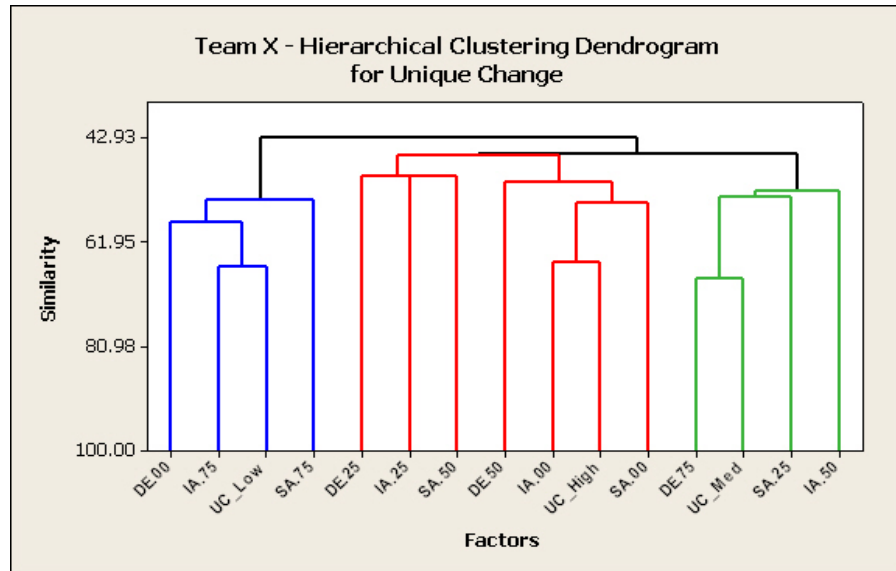


Figure 6.6: Team X - Hierarchical Clustering Dendrogram for Unique Change

There were correlated factors around each change category. Several observations from this figure are notable. First, DE.00, IA.75 and SA.75 were clustered into the low change category. DE.00 is understandable as there is no change for a network organization to respond to. IA.75 and SA.75, as we have already discussed, greatly constrained the network's ability to adapt. Second, IA.00 and SA.00 were prominently correlated with high amounts of change. Although other factors were also correlated with high change, these two factors stand out by degree of correlation. The lack of internal stress and time pressure allowed the network organization to be more adaptive. Third, IA.00 and IA.75 have higher degrees of correlation than does SA.00 and SA.75. This

indicates that the communication structure was slightly more important in determining the degree of change.

The hierarchical clustering results for both total change and unique change were put into a table for comparison. Table 6.13 presents this comparison. The results for both total change and unique change are strikingly similar. This indicates that operating conditions did not affect them differently. Also salient is the pattern for intermittent availability across the change categories. This pattern shows a very consistent and increasingly negative effect. Again, this seems to highlight the importance of the communication network relative to the other stress factors.

Team X <i>Summary of Hierarchical Clustering Results</i>							
		Change Categories					
		High		Medium		Low	
		<i>Total</i>	<i>Unique</i>	<i>Total</i>	<i>Unique</i>	<i>Total</i>	<i>Unique</i>
Stress Levels	DE.00					x	x
	DE.25	x	x				
	DE.50		x	x			
	DE.75	x			x		
	IA.00	x	x				
	IA.25	x	x				
	IA.50			x	x		
	IA.75					x	x
	SA.00	x	x				
	SA.25			x	x		
	SA.50	x	x				
	SA.75					x	x

Table 6.13: Team X - Hierarchical Clustering Results for Total Change and Unique Change

6.3.5.2. Battle Command Group – Shifts of Critical Personnel

The Battle Command Group experiments resulted in a range of 1–9 for total change and a range of 1-6 for unique change. Figure 6.7 shows the Battle Command Group main interaction plots for both total change and unique change based on data means. Several things are notable. First, the dynamic environment lead to more shifts of critical personnel when there were moderate or high rates of environmental change. Second, intermittent availability increasingly constrained the shifts of critical personnel as the stress level went up. Third, selective attention reduced the shifts of critical personnel but levels of stress beyond 25% had less of an effect. These results differ to those of Team X by the plateaus that occur. The low average knowledge per agent in the Battle Command Group, which is due to a lack of scenario training, can explain the plateaus.

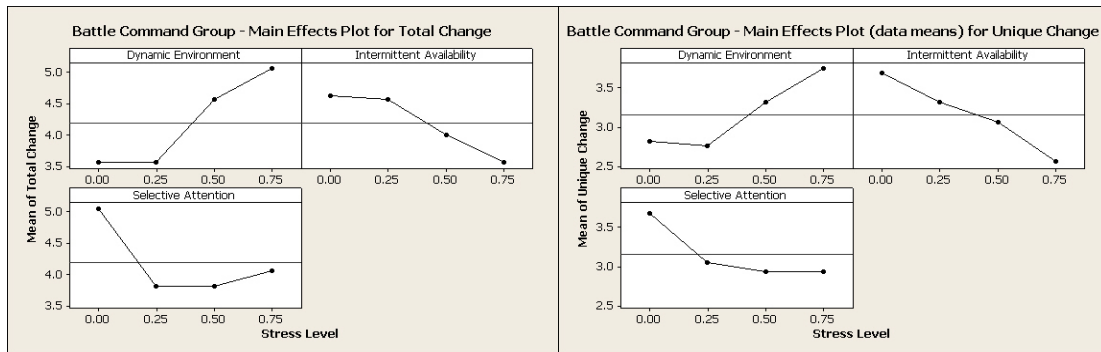


Figure 6.7: Battle Command Group - Main Effect Plots for Total Change and Unique Change

For the dynamic environment condition, the 25% rate of environmental change does not increase shifts of critical personnel over the static environment. The low average knowledge in the organization meant that expertise was just forming. As the

agents learned and began to gain expertise then considerable shifts of critical personnel occurred, even in the baseline condition. The 25% rate of environmental change was not enough change to induce greater shifts of critical personnel over the baseline. It took higher rates of change to do that.

For the selective attention condition, increased stress levels did not further moderate shifts of critical personnel. The lack of training already resulted in low and constrained overall knowledge. Additional cognitive constraint beyond the 25% stress condition had little effect because knowledge was already extensively constrained.

Table 6.14 presents the results of separate multiple regression analyses for total change and unique change. These results show that intermittent availability had a stronger impact on constraining both types of change as compared to selective attention. These results also show that the dynamic environment again had a stronger impact on total change relative to the other stressors. But this is not the case for unique change as the dynamic environment had a similar strength of impact to that of intermittent availability.

Battle Command Group <i>Total Change</i>		Battle Command Group <i>Unique Change</i>	
Regression Coefficients		Regression Coefficients	
<i>Variable</i>	<i>Standardized Coefficient</i>	<i>Variable</i>	<i>Standardized Coefficient</i>
Dynamic Environment	0.333	Dynamic Environment	0.311
Intermittent Availability	-0.227	Intermittent Availability	-0.334
Selective Attention	-0.182	Selective Attention	-0.219
Model Fit Adj R-Square – 15.6%		Model Fit Adj R-Square – 21.8%	

Table 6.14: Battle Command Group – Standardized Coefficients from the Multiple Regression Analyses for Total Change and Unique Change

There is another point to note about these results. The r-square values dropped in comparison to the Team X results. Again, this is due to the lack of training. Many more shifts of critical personnel occurred “naturally” because expertise was just forming. For example, the baseline condition resulted in three critical shifts per type of change for the Battle Command Group as opposed to only one critical shift per type of change for Team X. The stressors accounted for less of the critical personnel changes for the Battle Command Group due to expertise being in the formative stage.

Figure 6.8 shows contour plots of unique change. Only unique change is presented but the total change plots resulted in very similar patterns.

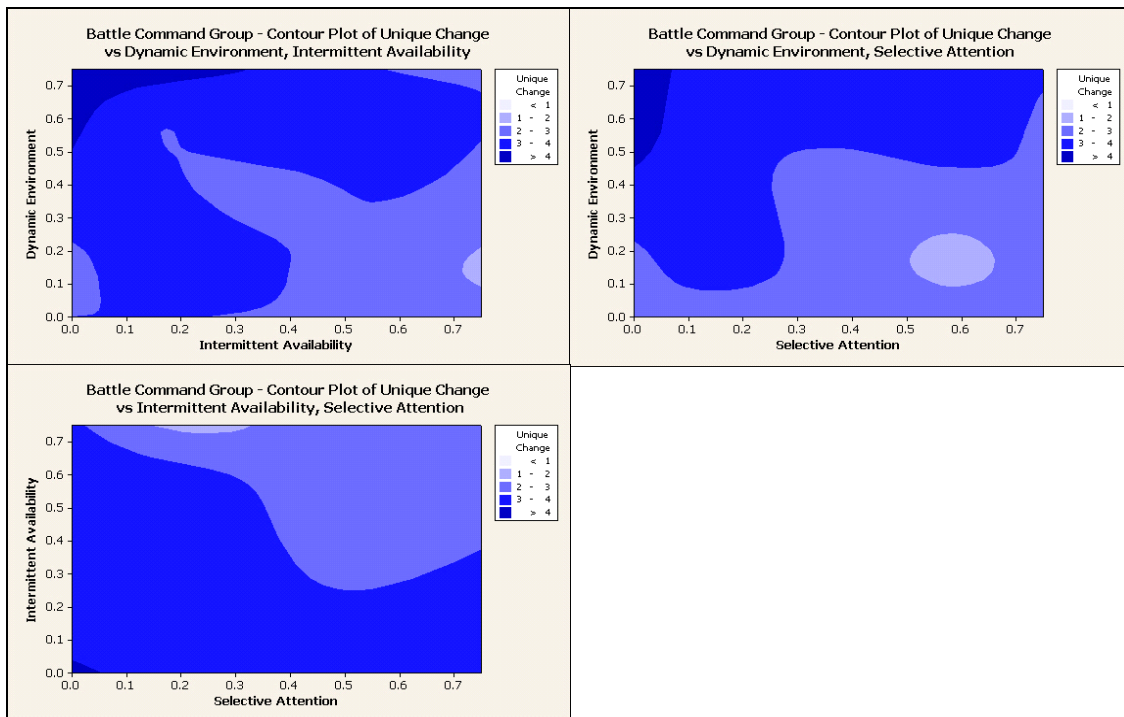


Figure 6.8: Battle Command Group - Contour Plots of Total Change by Stressors

The top-left corner is the contour plot by dynamic environment and intermittent availability and the top-right corner is the contour plot by dynamic environment and selective attention. Both of these plots show that low levels of the dynamic environment stressor had little effect upon the change outcome but that the higher levels induced more change. These plots also highlight the moderating effects for intermittent availability and selective attention.

The bottom-left corner is the contour plot by intermittent availability and selective attention. This plot shows that the combination of communication and knowledge attention constraints limited the change to mostly moderate amounts.

The next step was to perform hierarchical clustering to classify the stressors into operating conditions related to the three categories of change. The change outcome ranges for the Battle Command Group were used to determine the specific values defining each category.

Total change had a range of 1-9 and the following categorizations were used: 7-9 – high; 4-6 – medium; 1-3 – low. Unique change had a range of 1-6 and the following categorizations were used: 5-6 – high; 3-4 – medium; 1-2 – low. These change ranges and categorizations make sense. The Battle Command Group is a large-sized organization with a low average knowledge and low training in the particular scenario. As previously explained, expertise within the organization was just forming and more shifts of critical personnel were likely to occur. The change categorizations again reflect the context.

Table 6.15 presents the Battle Command Group hierarchical clustering results for both total change and unique change¹⁶. Several observations from this figure are notable. First, intermittent availability resulted in a consistent and increasingly negative effect across the change categories. This pattern highlights the importance of the communication network.

Battle Command Group <i>Summary of Hierarchical Clustering Results</i>							
		Change Categories					
		High		Medium		Low	
		Total	Unique	Total	Unique	Total	Unique
Stress Levels	DE.00				x	x	
	DE.25			x			x
	DE.50	x			x		
	DE.75		x	x			
	IA.00	x	x				
	IA.25			x	x		
	IA.50			x	x		
	IA.75					x	x
	SA.00	x	x				
	SA.25			x	x		
	SA.50					x	x
	SA.75			x	x		

Table 6.15: Battle Command Group - Hierarchical Clustering Results for Total Change and Unique Change

Second, the dynamic environment also resulted in a clear pattern, although not as distinct as the intermittent availability pattern. The dynamic environment increasingly

¹⁶ The hierarchical clustering dendograms are not shown for the Battle Command Group because the table presents mostly the same information for easier comparison. The Team X dendogram was a nice illustration of a single analysis but further single illustrations were not considered necessary.

induced shifts of critical personnel with DE.00 and DE.25 resulting in low-to-medium degrees of change and DE.50 and DE.75 resulting in medium-to-high degrees of change. Third, there is no indication that operating conditions affected total change and unique change differently. Obviously intermittent availability had no distinction between the two, but no disparate pattern was discernable for the other two stressors either.

6.3.6. Shifts of Critical Personnel – Theory

Theory is proposed about the shifts of critical personnel in network organizations based on the following comparative analysis between the Team X and the Battle Command Group results. This analysis provided a stronger basis for general theory because it considered organizations of different sizes and contexts. The proposed theories about shifts of critical personnel are additions to the other proposed theories on critical personnel risks in network organizations.

The dynamic environment led to increased shifts of critical personnel as the rate of change in the task intensified. This result was consistent for both organizations. This suggests that re-identification of critical personnel in network organizations should be an on-going activity. A lack of re-identification, especially in volatile conditions, could pose a risk to network organizations. Particularly when strategic decisions such as task assignment, group formation, and personnel retention are made from an offensive perspective or targeting and recruitment are made from a defensive perspective.

The ability of network organizations to exhibit overall structural flexibility in volatile environments is already set in theory. In fact, overall structural flexibility was a key characteristic influencing the use of the network forms by the organizations under

study. This result builds upon existing theory by proposing that critical personnel substructures also exhibit flexibility during times of change.

Proposition 3: Shifts of critical personnel are positively related to the rate of environmental change

Proposition 4: Shifts of critical personnel can pose a risk to network organizations in dynamic environments when re-identification has not occurred and strategic personnel decisions need to be made

Tables 6.16 and 6.17¹⁷ present the results of hierarchical clustering for intermittent availability and selective attention by organization, stress level and degree of change. Table 6.16 is for total change and Table 6.17 is for unique change.

Total Change <i>Summary of Hierarchical Clustering Results</i>									
				Degree of Change					
				High		Medium		Low	
				Stressor		Stressor		Stressor	
				IA	SA	IA	SA	IA	SA
Stress Levels	.00	Org.	TX	x	x				
			BCG	x	x				
	.25	Org.	TX	x			x		
			BCG			x	x		
	.50	Org.	TX		x	x			
			BCG			x			x
	.75	Org.	TX					x	x
			BCG				x	x	

Table 6.16: Total Change – Summary of Hierarchical Clustering Results for Intermittent Availability and Selective Attention

¹⁷ One obvious difference between the clustering results of Team X and the Battle Command Group is the size of the medium and high category clusters. This is particularly evident in Table 6.17. This difference is due to the distribution of the change outcomes into binary categories. Team X had a larger portion of outcomes in the high category whereas the Battle Command Group had a larger portion of outcomes in the medium category

Unique Change									
Summary of Hierarchical Clustering Results									
				Degree of Change					
				High		Medium		Low	
				Stressor		Stressor		Stressor	
				IA	SA	IA	SA	IA	SA
Stress Levels	.00	Org.	TX	x	x				
			BCG	x	x				
	.25	Org.	TX	x			x		
			BCG			x	x		
	.50	Org.	TX			x			
			BCG			x			x
	.75	Org.	TX					x	x
			BCG				x		x

Table 6.17: Unique Change – Summary of Hierarchical Clustering Results for Intermittent Availability and Selective Attention

Both of these tables demonstrate a clear negative effect for these two stressors. (Note: intermittent availability represents communication network constraints and selective attention represents cognitive constraints.) Especially at high levels of stress, these stressors limited the number of shifts that occurred within the critical personnel substructures.

This can pose a risk to a network organization if such flexibility is an advantage for dealing with change. For example, this could slow the integration of diversity or circumvent resiliency. It could slow the integration of diversity when a situation calls for a variety of expertise that is different than previous conditions and those experts do not step up to enact critical roles. It could circumvent resiliency when current critical experts become unavailable or overtaxed and redundant expertise does not shift into the critical role. Moreover, limitations to the number of agents who can assume critical roles, as in

unique change, could pose a risk by restricting the development of expertise. Fewer agents can assume critical roles that give them valuable experience.

Proposition 5: Shifts of critical personnel are negatively related to communication network constraints and cognitive constraints.

Proposition 6: Communication network constraints and cognitive constraints can pose a risk by modifying the number of flexible responses, in terms of critical personnel shifts, exhibited by a network organization in a dynamic environment. This is a risk only when such flexible responses are advantageous and sufficient to dealing with environmental change.

To clarify proposition 6, it is recognized that an occurring shift, even when a shift is needed, is not in and of itself sufficient to ensure an effective response. Shifts could occur that are counter to an organization's intended objective. For example, a situation may be misinterpreted and the wrong agent may assume a critical role. In this case, a necessary shift could be insufficient and result in a risk to the organization.

Intermittent availability had a stronger impact on shifts of critical personnel than did selective attention, as evidenced by the standardized beta coefficients from the multiple regressions. This was consistent for both organizations and for both types of change. This implies that, at the organizational level, communication constraints are a slightly bigger risk to critical personnel shifts than are cognitive constraints.

Proposition 7: Communication network constraints are a slightly larger risk to shifts of critical personnel in network organizations than are cognitive constraints

6.4. Normative Implications

The proposed theories on critical personnel risks have several normative implications for the network organizations under study. The normative implications vary for each organization because of the size and context differences. Some normative implications for each organization are discussed below.

6.4.1. Team X

Team X should have cognitive temperance for time pressure as a factor in personnel selection. Team X is a short-lived but intense organization. Time pressure is high from the beginning to the end of the design process and the selective attention results indicate that cognitive constraints pose a consistent risk for Team X. Not everyone has a predisposition for time pressure, meaning that not everyone is made for Team X. Personnel selection based on cognitive temperance as one the selection factors would better match people to tasks. An additional factor relating to cognitive temperance that can be used for personnel selection is experience. Prior research has shown that experience modifies individual reaction to stress (McGrath, 1976).

Team X should have training for time pressure strategies and communication awareness. As explained above, time pressure presents consistent cognitive risks to Team X. Strategies for dealing with time pressure in fast-changing environments may improve the organization's learning and adaptive responses. This also could expand the pool of personnel with cognitive temperance abilities.

Team X should bring in redundant experts when appropriate. Team X is a small organization collocated in a single room. Therefore, communication networks are dense

and provide low latency response. According to the theory developed in this thesis, intermittent availability would not pose a risk unless an expert is stretched to their limit with a high task load. This situation would result in an expert having high levels of intermittent availability on average as the expert would not be able to communicate with everyone that sought information. When such a situation occurs, the use of a redundant expert would mitigate this risk. But redundant expertise should only be brought in when needed as Team X is also designed for size and efficiency.

6.4.2. Battle Command Group

The Battle Command Group should consider individual redundancy issues when downsizing teams. The Battle Command Group sometimes faces decisions where small teams need to be reduced from 8 to 4 personnel in order to fit into smaller armored vehicles. This reduction obviously reduces expertise redundancy. Since this is concerning a small team within the organization then it is more susceptible to the detrimental effects of agent loss and intermittent availability, especially during combat or covert operations as personnel can often be lost or communications can often become compromised. Selecting small teams that have an adequate level of redundancy among the personnel may reduce the risks of personnel loss or communication constraint. Also, cross-training personnel to acquire broadened expertise may be an option.

The Battle Command Group should re-identify critical personnel often. Observations of this organization during the wargame exercise noted rapid changes to the operational scene when the exercise was in full tilt. The theory developed in this thesis suggests that considerable shifts of critical personnel will occur during these times. Re-

identification will keep the organization current on who is critical. The organization can then make use of these critical personnel in the present situation and this can provide benefits. For instance, critical personnel may improve staff decision-making. Critical personnel who are high in betweenness or degree centrality tend to accumulate knowledge which leads to high situational awareness. Integrating these people into the decision loop can provide the staff with a better understanding of the present situation. In other words, current critical personnel can contribute to the observe and orient processes of the OODA loop. They can also contribute to the decision and action processes as well but in any case their inclusion in the loop may serve to improve decisions.

In addition, critical personnel can be used to improve information flow and the rate of learning in the organization. Observations also noted considerable communication network complexity during times of rapid change. Communication network complexity can slow the rate of learning. Central persons in the communication network serve as focal points or conduits for communications. Commanders can send and receive information through these central agents thereby taking advantage of shorter path lengths and possibly decreasing the number of paths. This serves to reduce communication network complexity and also speed the flow of information. This can also serve to more efficiently integrate the information that is flowing through the organization. Of course, critical personnel can shift during times of rapid change and an awareness of current critical personnel is needed for this strategy to be effective. That is why re-identification is important.

SECTION 2: NETWORK ORGANIZATION

LEADERSHIP

Chapter 7 : Network Organization Leadership

7.1. Introduction

In Chapter 1, I explained that modern business and military organizations are facing highly volatile contexts that are much more dynamic, uncertain and knowledge-driven than the past. Many terms have been used in the literature to refer to this change in context. A partial listing of these terms includes the Knowledge Era (Uhl-Bien, Marion, & McKelvey, 2004), the information revolution (Arquilla et al., 2001), the Information Age (Stewart, 1997) and the new competitive landscape (Hitt, Keats, & DeMarie, 1998). For sake of clarity I will refer to the new context as the Knowledge Era.

The Knowledge Era is in stark contrast to the Industrial Era where the context was considered more stable. In the Industrial Era, bureaucracies were the dominant form of organization. Characteristics of bureaucracies included hierarchical relations, fixed boundaries and top-down control (Child & McGrath, 2001). These characteristics provided a competitive advantage by establishing efficiency and control in a relatively stable context.

But, the Knowledge Era has redefined organizational competitiveness. Competitive advantage is now gained by establishing organizational capabilities geared toward learning and adaptation. Network forms of organization are increasingly used in the Knowledge Era because they can provide the desired learning and adaptive responses. Network organization characteristics such as decentralized control, horizontal structures and flexible boundaries help to promote learning and adaptive responses. In comparison, the characteristics of bureaucracies lead to slower learning and adaptive rigidity (Powell,

1990). Due to this, many have argued that bureaucracies are not a particularly good match for volatile, knowledge-driven contexts (Child et al., 2001).

Unfortunately, leadership theory has not fully embraced the change to leading for learning and adaptation, despite the many discussions about the need for a paradigm shift due to the different context of the Knowledge Era. As Uhl-Bien, et al. (2004) note about the literature, "...we find little explicit discussion of leadership in this work and no explicit models addressing leadership in the connectionist, Knowledge Era" (p. 4). Traditional leadership theories are built upon bureaucratic frameworks and have limited applicability to the Knowledge Era (Streatfield, 2001). To this point, McKelvey (2006) argues that traditional top-down leadership constrains an organization's capacity for learning and adaptation. Leadership theorists are now recognizing that a new leadership paradigm is needed in the Knowledge Era (Davenport, 2001; Marion & Uhl-Bien, 2001; Osborn, Hunt, & Jauch, 2002).

Section 2 is devoted to advancing a new leadership paradigm for network organizations. This was undertaken for two reasons. First, network organizations are increasingly used in the Knowledge Era. This means leadership of network organizations is an increasingly important subject. Two, the risks associated with network organization leadership should be studied within a relevant paradigm. A relevant paradigm is needed to build theory and an appropriate methodology is needed for testing the theory. Leadership theory needs an approach that recognizes and captures the structure and processes of network organizations. The analysis of structure and process will provide understanding of how leadership is enacted in this context. Once network organization leadership is defined in theory, risks can then be identified and appropriately studied.

I argue that the Dynamic Network Analysis approach fills this need both in terms of paradigmatic framework and methodology. The use of Dynamic Network Analysis will lead to the development of network organization leadership theory and the appropriate study of leadership risks. Dynamic Network Analysis provides an exciting and powerful new lens by which network organization leadership can be studied.

The work of this section provides the foundation for studying the risks of network organization leadership. A definition of network organization leadership as well as an understanding of the nature of network organization leadership must first be obtained before risks can be identified and studied. This vital link is put forth in next couple of chapters.

This section is organized as follows. The remainder of this chapter starts with a short background on traditional leadership. Then, a new leadership paradigm based on complexity theory is presented. This is followed by establishing the relevance of this paradigm to network organizations.

Chapter 8 re-conceptualizes the tenets of this paradigm into the Dynamic Network Analysis framework. This is done to better match the predominantly qualitative paradigm with a quantifiable methodology. Then, the theoretical and methodological concerns of network organization leadership are described. The theoretical concerns are for the who, how and when of network organization leadership. The methodological concerns are for a dynamic multi-level analysis that captures the processes and evolutionary structure of network organizations. The tools of Dynamic Network Analysis are subsequently depicted. These tools aid in the collection and analysis of network organization leadership. Lastly, the advantages of using Dynamic Network

Analysis to study network organization leadership are described. A particular advantage of using Dynamic Network Analysis is that the theoretical framework provides a more concrete and understandable interface to the abstract nature of complexity theory.

Chapter 9 is the foundation for a Dynamic Network Analytic Theory of Network Organization Leadership. This work includes a study of network organization leadership for the Battle Command Group. The study presents numerous social network measures that relate to network organization leadership; both at the organizational and individual levels of analysis. Several leadership forms are also introduced and examined. These forms expand the definition of network organization leadership. This study provides insight into the complex contextual nature of network organization leadership and demonstrates how Dynamic Network Analysis can address the theoretical concerns.

7.2. Traditional Leadership Theory

Previous work on leadership has taken trait (Argyris, 1953; Stogdill, 1948), behavioral (Blake & Mouton, 1964; Tannenbaum & Schmidt, 1958), situational (Hersey & Blanchard, 1977; Vroom & Yetton, 1974), transformational (Bass, 1985; Burns, 1978) and leader-member exchange (Graen & Scandura, 1987) approaches to understanding leadership. These approaches concentrate on topics such as leading organizational members toward efficient and effective production (Zaccaro & Klimoski, 2001), motivating members to achieve a goal (House & Mitchell, 1974), inspiring members to commit to a vision (Yammarino, 1994) and developing quality relationships to improve organizational outcomes (Graen, 2003).

Although these approaches all examine leadership from different angles, they also form one dominant paradigm. This dominant paradigm is that leaders influence followers to achieve an objective. A leader influences a follower because of some personal characteristic, behavior or skill. Therefore, the paradigm mostly exudes a single, 'heroic' leader view of leadership. Leadership in this view is a top-down phenomena.

In addition, this paradigm is largely focused on influencing followers in bureaucratic organizations (Zaccaro et al., 2001). The majority of this research is concerned with formal leaders and centralized power in hierarchical structures. Consequently, traditional leadership theory is mainly about leading for efficiency and control in a relatively stable context.

7.3. Complexity Leadership Theory: A New Leadership Paradigm

Several authors are arguing for a complexity theory approach to explaining leadership processes (Marion et al., 2001; McKelvey, 2006; Regine & Lewin, 2000; Wheatley, 1999) due to the limited applicability of traditional leadership theory. The premise is that complexity theory will help explain some of the emergent change processes which are now prevalent in organizations but yet defy explanation according to traditional theories (Smith, 2004).

Although the complexity science approach has been undertaken by several authors, only one has proposed a formal theory that specifically addresses organizations in the Knowledge Era. This theory is Complexity Leadership Theory (Uhl-Bien et al., 2004). Complexity Leadership Theory views learning and adaptation as emergent

outcomes that result from the collective action of agents who are interdependently interacting at the nexus of diverse knowledge. There are several important aspects to this paradigm.

First, learning and adaptability are the result of what people do in an organization; they are the result of collective action. Collective action is necessary to achieving organizational purpose (Zaccaro et al., 2001). The Knowledge Era is a high-velocity environment ripe with change (Hitt et al., 1998) and achieving organizational purpose will depend on the organization's ability to learn and adaptively respond to change.

Second, the co-evolution of human and social capital is at the heart of the collective action process. Collective intelligence is the combination of both human and social capital. Increases to collective intelligence occur when human and social capital co-evolve within the organization (Carley et al., 2001a; McKelvey, 2006). These increases then lead to learning and adaptive responses. This process is synonymous to multi-level learning (Carley et al., 1999; Carley & Svoboda, 1996) where individual agents and teams learn as part of the process by which human capital, organizational structure, social capital, and culture change and evolve. A key factor to increasing collective intelligence is the existence of diverse knowledge. Diverse knowledge provides fertile input into the learning process. In other words, learning is constrained without diverse knowledge.

Third, collective change agents are the competitive source of learning and adaptive responses. Tapping the collective intelligence of the organization's citizenry allows for a quicker response to change. This moves the paradigm away from the single

‘heroic’ leader who has all the answers to one where the responsibility for learning and reasoning about change falls onto the collective organization.

Fourth, collective action needs to be stimulated, not controlled. Productive change occurs by way of interactions among an organization’s citizenry (Bennis & Biederman, 1997). Top-down, command-and-control style leadership can stifle the development of collective intelligence by constraining interactions (Bennis, 1997; McKelvey, 2006). Constrained interactions limit the development of human and social capital (McKelvey, 2006). Quick, adaptive interaction patterns cannot be prescribed by fiat. They are stimulated by conditions such as decentralized decision-making and strong learning cultures.

Lastly, while organizations need to stimulate emergent collective action they also have a bureaucratic nature and a need to control organizational outcomes efficiently for exploitation. This is known as the organizational design paradox (Child et al., 2001). Therefore, Uhl-Bien et al. (2004) have proposed that Knowledge Era leadership is composed of three separate but entangled roles which accommodate the paradox: managerial leadership, adaptive leadership and enabling leadership, see Figure 7.1.

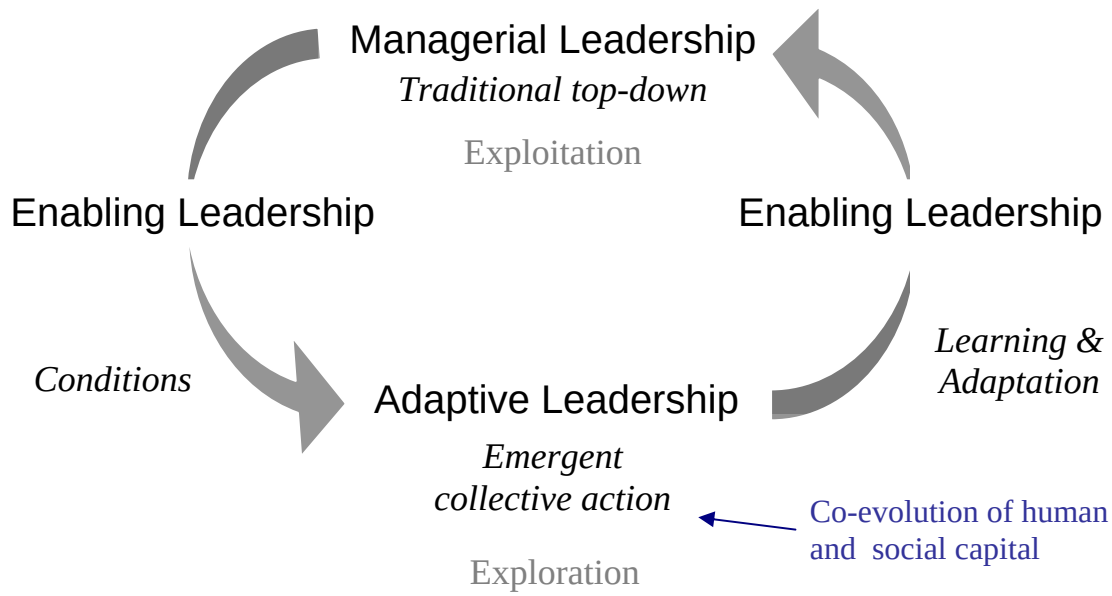


Figure 7.1: The Three Roles of Complexity Leadership Theory

Managerial leadership is concerned with traditional top-down leadership. It is focused more on efficiency, control and the exploitation of responses. Adaptive and enabling leadership are concerned with emergent collective action. Emergent collective action is an exploration process for producing change in response to the dynamic challenges facing the organization. The adaptive and enabling leadership roles are focused on the production and dissemination of learning and adaptive responses. More specifically, adaptive leadership refers to the leadership that occurs within the interdependent interactions of emergent collective action. These leaders are the agents who advance the co-evolution of human and social capital to form collective intelligence.

Enabling leadership serves two functions. First, it creates conditions which stimulate emergent collective action and adaptive leadership. One way it does this is by limiting the top-down controls of traditional leadership, which can inhibit collective

action (Powell, 1990) and stifle the co-evolution of human and social-capital (McKelvey, 2006). Second, it channels productive responses originating in the emergent collective action back up to managerial leadership for strategic planning and exploitation.

7.4. Relevance to Network Organizations

Uhl-Bien et.al. (2004) do not formally address the notion of network organizations in the theory. An indirect link can be drawn between the two because this theory addresses organizational leadership in the Knowledge Era and network organizations are viewed as an organizational form that matches the challenges of this Era. But I will draw a more direct link to show that this theory is clearly relevant to network organizations. This link is drawn by stating how Complexity Leadership Theory relates to the characteristics and advantages of network organizations.

First, Complexity Leadership Theory is focused on leading for learning and adaptation. Learning and adaptation are two of the desired responses for network organizations. Second, collective action results in learning and adaptation. As Powell (1990) notes, network organization are facilitators of collective action. Collective action allows the organization to develop quicker learning and adaptive responses. Third, collective action arises in response to change. Network organizations are responsive to highly volatile environments (Podolny et al., 1998). This responsive capability makes them a good match for the dynamic challenges of the Knowledge Era.

Fourth, collective intelligence is formed by the co-evolution of human and social capital. Network organizations have a flexible social structure that can respond to changes and connect human capital in various ways (Baker, 1992). This capability

increases the rate of learning and human capital co-evolves with changes in social structure. This is considered important for sustaining competitive advantage in the Knowledge Era. Also, diverse knowledge is an essential factor for increasing collective intelligence. Network organizations are characterized by differentiation (Baker, 1992) and diversity (Ibarra, 1992); both of which represent diverse knowledge.

Fifth, collective action needs to be stimulated, not controlled. Network organizations are characterized by decentralization (Arquilla et al., 2001). Decentralization loosens the controls of top-down leadership and stimulates interactions. Sixth, there is a structural duality to account for. Network organizations can contain elements of hierarchy (Arquilla et al., 2001). This is consistent with the network organization definition that I use and has also been demonstrated in the prior analysis on the Battle Command Group.

Chapter 8 : A Dynamic Network Analysis Approach to Network Organization Leadership

In Chapter 7, I argued that the Complexity Leadership Theory paradigm is relevant to network organizations. I have also shown in the previous section of this thesis that Dynamic Network Analysis is an appropriate methodology for studying network organizations. I re-conceptualized the tenets of Complexity Leadership Theory in the Dynamic Network Analysis perspective for two reasons. First, Complexity Leadership Theory is predominantly qualitative at this point. This re-conceptualization puts the paradigm into a quantitative framework suitable for studying network organizations. Second, the tenets of complexity theory are rather abstract. I believe this re-conceptualization is easier to translate into practical application and thereby will reach a broader audience of practitioners. Through this re-conceptualization, Dynamic Network Analysis becomes a paradigmatic framework for network organization leadership.

Overall, this re-conceptualization relates to arguments of several authors who view leadership as embedded in a system of interdependent relationships grounded in an organizational context (Graen & Uhl-Bien, 1995; Sparrowe & Liden, 1997). These same authors also argue that social network analysis can be used to expand our understanding of leadership.

The focus of this re-conceptualization, like that of Complexity Leadership Theory, is on a new paradigm of leadership concerned with learning and adaptation. Managerial leadership is well-studied within the traditional paradigm and is considered

outside the scope of this work. However, managerial leadership is mentioned throughout as the organization design paradox exists and is recognized.

This chapter is organized as follows. First, Complexity Leadership Theory is re-conceptualized in terms of dynamic networks. This is followed by an explanation of the theoretical and methodological concerns of this paradigm. Next, an overview of the Dynamic Network Analysis methodology is given. Lastly, the advantages of using Dynamic Network Analysis to study network organization leadership are described.

8.1. Network Organization Leadership: A Dynamic Network Analysis Perspective of Complexity Theory

The complexity theory approach to leadership emphasizes two elements that are important to producing learning and adaptation: context and process. Organizational context refers to the conditions which not only allow for emergent collective action but also guide the system toward productive learning and adaptation through the use of internal and external tensions¹⁸. The process of learning refers to 1) the interdependent interactions between agents which lead to increases in collective intelligence and to the production of learning and adaptive responses, and 2) interfacing the formal and informal structures for exploitation of the responses.

Accordingly, network organization leadership entails two types of leadership: leadership of context and leadership in process. *Leadership of context* enables organizational conditions that allow for productive collective action to emerge in

¹⁸ From a complexity theory perspective, collective action is not controlled in the traditional sense of top-down command and control, but in the sense of guiding the system toward productive outcomes. Guiding the system is needed when emergent behaviors emanating from systems of free association go off in directions that are nonproductive in terms of innovation and adaptability (Uhl-Bien et al., 2004).

response to a changing environment. In Complexity Leadership Theory, this is the first enabling leadership function – creating conditions. *Leadership in process* facilitates learning and adaptation through the emergent interactions and informal dynamics which form collective action. It also channels the learning and adaptive responses to formal management for exploitation. In Complexity Leadership Theory, this is adaptive leadership as well as the second enabling leadership function – interfacing responses.

In the Knowledge Era, organizational context must change in response to environmental volatility in order to support an adaptable learning environment. Changes in organizational context enable learning and learning, in turn, enables change in the organizational context. The Knowledge Era is a learning era and the process of learning and changes in organizational context are intimately intertwined.

8.1.1. Leadership of context

One aim of the complexity science approach is to propose organizational contexts in which collective action can emerge in response to change. Collective action is necessary to increase information processing speed and to learn at a faster rate. Faster learning is needed to sustain superior performance for organizations in the Knowledge Era (Child et al., 2001). The organizational context referred to is the nature of the network within which informal dynamics occur. Therefore, the context from which collective action emerges is the informal structure, the sets of nodes and relationships, of the organization.

Contexts which promote learning will have both internal and external tensions that foster interactions and introduce interdependence. The combination of interactions

and interdependence then enables learning; interactions induce knowledge flow and interdependence pressures agents to act on knowledge. Examples of strategies that induce interactions are self-forming teams, deference to expertise and sensitivity to operations. Examples of strategies that induce interdependence are heterogeneous workgroups, role/expertise familiarity and decentralized problem-solving.

Two key characteristics of organizational context which relate to interdependent interactions and the production of learning and adaptation are requisite variety (Ashby, 1960) and relational coupling (Kauffman, 1993). Requisite variety, the matching of internal complexity to environmental complexity, is associated with exploration (March, 1996) which involves the search for new knowledge (McGrath, 2001). In other words, requisite variety is a necessary component for the process of learning in organizations. Relational coupling, the degree of interdependent relations within a system, has been theorized as being relevant to productive outcomes (Kauffman, 1993). More specifically, moderate coupling is posited as being important to the process of learning (Uhl-Bien et al., 2004).

8.1.2. Leadership in process

Another aim of the complexity science approach is to propose leadership activities that improve collective intelligence within the informal dynamics. Learning occurs via interactions among agents in an organizational system. Interdependent interactions between agents lead to the diffusion and combination of knowledge and results in learning and adaptability. As agent interactions evolve in an organizational

system, changes to both ‘what’ an agent knows and ‘who’ an agent interacts with will occur (Carley et al., 2001a).

McKelvey (2006) refers to this as the co-evolution of human and social capital. This process is akin to neural network theory of how the brain functions and learns. Neural networks learn by neurons making dynamic connections to themselves through synaptic links. Organizations learn by human capital nodes making dynamic connections to themselves through social capital relations. Human capital appreciation accumulates energy in the form of knowledge. Energy flow in the informal network is knowledge flow through social interactions that are actuated by tensions originating in the organizational context. These social interactions are fluid and can change in response to changes in knowledge and tension. Change in social interactions can affect where, in the network, knowledge accumulates and builds upon itself and therefore where learning occurs. Analyzing the co-evolution of human and social capital can give us insights into the effects that organizational contexts have on learning and adaptive responses.

Leadership in the learning process supports learning and adaptability through activities which foster knowledge flows, enhance interactions, advocate contextual change (structuration) and facilitate aggregation. For instance, agents who are high in degree centrality¹⁹ are influential in terms of knowledge flow within the network. The communication activities of degree central agents can have significant effects throughout the organization as these agents have the ability to enhance learning by accumulating knowledge and diffusing it to numerous others through their populous interactions.

¹⁹ Degree centrality is the normalized total number of relations for an agent. In other words, the number of others they are connected to.

In addition, Uhl-Bien et al. (2004) describe the process of interactively interfacing the productive learning outcomes of collective action with the formal system. Recognizing that organizations are also bureaucratic or formal systems is important to the reality of organizing. Interfacing informal outcomes with formal structure allows organizations to diffuse learning outcomes through the formal system (Uhl-Bien et al., 2004) and to better exploit (March, 1996) learning and adaptation. The process of interfacing the informal and formal systems is also considered a part of leadership in process.

Two caveats to the process of learning are important to note. First is the cascading effect of change. Since the organizational system is a network, learning in a particular part of the structure can have cascading effects to other parts and eventually influence overall system behavior. Such cascading effects can be dramatic or trivial. Second is the subsystem rate of evolution. Human capital and social capital are interdependent but different subsystems. Although these subsystems co-evolve, the respective rates of evolution can be different. Patterns of collective action, which generate learning and adaptation, are a function of these relative evolution rates.

8.1.3. Theoretical and methodological needs

The previous discussion explained the what and why of network organization leadership. In short, network organization leadership is leadership of change which enables emergent collective action and promotes learning that fosters productive responses to volatility. The theoretical concerns of network organization leadership are for understanding *who*, *how* and *when*.

To understand *who* is a leader, including multiple *who*'s, we need to examine the dynamic changes to the broad organizational context in which leadership is embedded. Network organization leaders are not necessarily those in appointed or authority positions. Leadership is embedded in context and network organization leaders emerge due to the need for learning and adaptation. Regardless of whether it is leadership of context or leadership in process, anyone could emerge as a leader. Identifying who is a leader becomes an important task that is non-trivial due to the complexity of the organizational context.

In addition, shifts in leadership make identifying leaders difficult. The dynamic landscape of the Knowledge Era results in changing needs for learning and adaptation. As the organization learns and adapts to the environmental changes, new leaders can emerge and previous leaders could be performing non-leadership roles (Ireland et al., 1999). As the organizational context changes so can the leader. The shifts of critical personnel results from Chapter 6 speak to this very point.

Leadership is also not necessarily enacted by a single individual. Since the organizational context is a network, leadership may result from the activities of more than one person during a particular event or period in time. Network organization leaders can be dispersed throughout the organization and these leaders can act and coordinate without centralized control (Ronfeldt et al., 2001). Therefore, network organization leadership also includes concepts such as distributed (Gronn, 2002) and shared (Pierce & Conger, 2003) leadership.

To understand *how* and *when* leaders lead we need to understand both the natural evolutionary processes in organizations and the strategic interventions that leaders use to

induce and guide change. Learning processes, such as the multi-level learning in a network organization, are natural evolutionary processes which may result in the desired responses of learning and adaptation. But in order to get the desired responses, the organizational context has to not only be conducive to decentralized, interdependent interactions but also guide these interactions in productive directions. This is where strategic interventions come into play.

Network organization leaders use strategic interventions to foster productive collective action. For example, strategic interventions may be used to inject diversity or change the evolutionary rate of learning. Such strategic interventions are intended to influence natural evolutionary processes; processes that cannot be controlled but can possibly be stimulated and guided. It is therefore necessary to understand the effects that strategic interventions have upon natural evolutionary processes. This will provide reasoning about *how* leaders lead. It is also necessary to understand natural evolutionary processes such as learning and the direction in which the organization is headed. As per the example above, when the system lacks diversity and learning is constrained then strategic intervention is needed. Understanding the natural evolutionary process will provide insight into *when* leaders should lead.

Methodologically, there is a clear need for longitudinal, multi-level analysis which permeates the theoretical concern for the *who*, *how* and *when* of network organization leadership. Complex interdependent interactions form aggregates or sub-groups of agents (Holland, 1995). These sub-groups can form larger sub-groups among themselves and so on such that there are multiple levels of aggregation within the organizational context. As previously noted, learning can cause cascading effects

throughout an organization and this includes effects across aggregate levels. Also, leadership can occur simultaneously and at multiple levels within a network organization. There can be individuals leading as well as teams of people leading and who is leading a network organization can shift over time. Longitudinal, multi-level analysis will offer insight into *who* is leading, *how* strategic interventions affect multiple levels of organizing and *when* strategic interventions need to be invoked.

Rapid change is a hallmark of the Knowledge Era and leadership of change is an important process within network organizations. When change occurs, it is not a static state - it is a dynamic state. To understand network organization leadership and develop theory, we need a dynamic methodology that analyzes both change of context and change in process at multiple levels of analysis.

8.2. *Dynamic Network Analysis*

Dynamic Network Analysis (Carley, 2003) is a new field of science which entails the theory and design of complex, dynamic networks and the study of emergent phenomena which is enabled and/or constrained by such networks. Dynamic Network Analysis extends the reasoning about social networks to large-scale, dynamic socio-technical systems which have multiple co-evolving networks. The co-evolution of human and social capital is an example of the type of simultaneous analysis afforded by Dynamic Network Analysis (Carley et al., 2001a). Applied to network organization leadership, Dynamic Network Analysis is a methodology and a theory for understanding changes of context and changes in process, both over time and at multiple levels of analysis.

8.2.1. Context: The MetaMatrix and Structural Measures

The MetaMatrix is a theoretical framework for representing the complex nexus of interdependent relationships of organizations (Carley, 2002a; Krackhardt & Carley, 1998). Organizations are composed of a plurality of nodes types (multi-mode) and relations (multi-plex) forming a complex meta-network. Typical node types include people, technologies, events, knowledge and organizations. Typical relations include friendship, advice, resource-access, task-assignment and participation. Any two node types can have multiple existing relations and each unique node type pair and distinct relation connecting them form a network.

Figure 8.1 shows an illustrative MetaMatrix for an organization. The MetaMatrix is an extensible framework where node types and relations are defined by the researcher or practitioner according to the appropriate context of the organization.

	People/ Agents	Knowledge/ Resources	Tasks/ Events	Groups/ Organizations
People/ Agents	Social Network	Knowledge/ Resource Network	Assignment Network	Membership Network
Knowledge/ Resources		Information/ Substitutes Network	Needs Network	Core Capabilities
Tasks/ Events			Precedence Ordering	Institutional Relations
Groups/ Organizations				Inter- Organizational Network

Figure 8.1: Illustrative MetaMatrix

Measures of context are calculated based on the various networks of the MetaMatrix. These measures range from traditional Social Network measures, like degree centrality, which are based on a single network to more complex measures, such as cognitive demand²⁰, which are based on several networks. The advantage of the complex measures is that they capture the relations within and among networks.

In an organization, networks do not exist in isolation. They are inter-related. For example, the social network (social capital) and knowledge network (human capital) co-evolve in the following manner. Agents interact through their social relations and learn or create knowledge, thus updating their understanding which changes the knowledge network. This new updated understanding can subsequently influence who the agent interacts with in the future, thus changing the social network.

The complex measures capture more of the complex, interdependent realities of organizational life by taking into account the relations between networks. Ongoing research is being conducted for developing new measures which are appropriate for describing and contrasting networks. Although the development of complex measures is nascent to the field, research has shown that such measures can provide useful insight. An example is cognitive demand which has been used to predict emergent leadership (Carley et al., 2001b).

²⁰ Cognitive demand measures the effort an individual spends in performing their tasks and is based on the agent's various communication, knowledge, resource and task networks

8.2.2. Change Processes

In Dynamic Network Analysis, the process of change involves the addition and deletion of nodes and relations. Table 8.1 shows illustrative real-world change processes for nodes. This list is not intended to be inclusive of all change processes. As an example of change, innovation would lead to the addition of knowledge and/or resources nodes. This change could lead to changes in other networks as research has shown that the adoption of innovation can be an occasion for the restructuring of social relations and roles (Barley, 1986). Turnover is a different example of change where people and/or knowledge nodes are lost. Turnover can potentially have negative effects on an organization (Krackhardt & Porter, 1986).

People/ Agents	Knowledge/ Resources	Tasks/ Events	Organizations
Promotion Mobility Recruitment Downsizing Turnover	Innovation Discovery Re-distribution Training Forgetting Consumption	Goal Change Re-engineering Development of new technology Stop usage of technology	Organizational birth Organizational death New Markets Alliances Mergers Acquisitions Divestment Legislation of new entity

Table 8.1: Illustrative Real-World Change Processes for Nodes

Table 8.2 shows illustrative real-world change processes for relations. Again, this list is not intended to be inclusive of all possible change processes. An example of change in relations is learning. Learning involves the addition of a relation between a

person and knowledge (Carley et al., 2001a). As previously described, learning can lead to subsequent changes in other networks, such as the social network. Another example of change is adaptation through task re-assignment. Task re-assignment results in the addition and deletion of relations between a person and various tasks. It should be noted that the deletion of nodes also results in the deletion of all relations tied to that node.

	People/ Agents	Knowledge/ Resources	Tasks/ Events	Organizations
People/ Agents	Motivating interactions Creating interdependency Boundary spanning Adaptation	Learning Innovation Enhancing knowledge flows	Creating interdependency Adaptation	Motivating interactions Creating interdependency Boundary spanning Adaptation
Knowledge/ Resources		Learning Innovation Enhancing knowledge flows	Learning Innovation	Learning Innovation Enhancing knowledge flows
Tasks/ Events			Creating interdependency Adaptation	Creating interdependency Adaptation
Organizations				Motivating interactions Creating interdependency Boundary spanning Adaptation

Table 8.2: Illustrative Real-World Change Processes for Relations

8.2.3. Interactions, Learning and Adaptation

A limitation of traditional social network analysis is that it does not represent agents as actively interacting and learning and thus altering their networks.

Interpretations of behavior and potential outcomes were drawn from static network representations. Prediction of learning and adaptive responses across various levels of aggregation is extremely difficult as it requires the ability to think through the co-evolution of networks in multiple complex dimensions.

Simulation provides a means for reasoning about complex network changes as a result of both natural evolutionary processes and strategic interventions. Through simulation, the network organization is modeled as a complex adaptive system (Carley et al., 1999). Complex adaptive systems are a complexity theory approach to modeling organizational systems as it models the informal network interactions among heterogeneous agents. Learning and adaptation, or the lacks thereof, are the products of agent interactions not the specific acts of individuals.

For example, Construct is a multi-agent simulation model for reasoning about dynamic network change. Construct was described in Chapter 5. Natural evolutionary processes such as multi-level learning are represented in Construct. As the agents go through the interaction cycle they learn new knowledge and also reposition themselves in the network. Strategic interventions in the simulation are represented by purposeful change of the network. Such interventions could include the proximal placement of human agents as an attempt to infuse a hot group or the addition of organizational capabilities as an attempt to integrate diversity to spur learning and adaptation. Simulation allows for what-if scenarios of strategic interventions.

Modeling natural evolutionary processes and strategic interventions allows for reasoning about how the organizational context supports learning and adaptive responses. It also allows for reasoning about when strategic interventions need to take place. This is

a continual process as learning changes the context of the organization – networks are constantly evolving and emerging. As noted previously, context and learning are intimately intertwined.

8.2.4. Tool Chain

The CMU Dynamic Network Analysis tool chain was developed to aid in the extraction, visualization, analysis and reasoning about complex, dynamic network data (Carley, Diesner, Reminga, & Tsvetovat, 2004). This tool chain is both interoperable and extensible. Figure 8.2 shows the tool chain along with some illustrative analytic outcomes related to network organization leadership. The tools consist of:

- DyNetML, an XML based interchange language for representing MetaMatrix relational data (Tsvetovat, Reminga, & Carley, 2004).
- AutoMap, a tool for the semi-automated extraction of network data from texts (Diesner & Carley, 2004).
- ORA, a statistical tool for the analysis of dynamic network data (Carley & Kamneva, 2004; Carley & Reminga, 2004).
- Construct, a multi-agent network simulation model for reasoning about network change (Schreiber et al., 2004c).
- Social Insight, a network visualization tool

Both ORA and Construct were used in this research and were great aids to the analysis. Social Insight is embedded in the ORA tool and was used to create the visualizations contained herein. Although other tools such as AutoMap were not needed for this research, they can provide benefit to an analysis when a large corpus of texts need analyzed.

8.3. Advantages for Leadership Theory

An obvious and prodigious advantage to using Dynamic Network Analysis is that the theoretical framework provides an understandable interface to the abstract nature of complexity theory. Practitioners can struggle with the connection of complexity theory to real-world application. The categories of nodes and relations in Dynamic Network Analysis are based on organizational context. The practitioner is familiar with node types such as people, tasks, resources, etc. Accordingly, it is easy to understand that people have relations to one another, that people are assigned to tasks, and so on. Also, the real-world change processes listed above are enacted as the addition and deletion of nodes and relations. This representation of change within the theoretical framework is easily comprehensible.

In addition, at times, the networks can be visually depicted. The reasonableness of visual depiction depends on the size and complexity of the networks. Information is not easily conveyed when the networks are too large or too complex. But when networks either naturally lend themselves to depiction or are able to be reduced then this can expedite comprehension by illuminating contextual nature, change effects and possible strategic interventions.

Besides providing an understandable interface, there are several other advantages that Dynamic Network Analysis (DNA) offers leadership theory because it is an integrated analytical framework spanning context and people. These advantages include:

- Representing organizations as multi-mode, multi-plex entities with many networks captures more of the realistic nature and complexity of organizational life.
- Various categories of measures exist and provide insight for understanding the relational qualities of organizational context. Categories of measures include:

- relational coupling, variety, individual/shared/aggregate points of influence, emergent leadership, human capital and social capital (collective action), informal subgroup and topology identification.
- Various measures of leadership forms exist and enable the user to capture leadership in process. These leadership forms include: creating interactions and interdependencies, enhancing knowledge flows, maintaining relational coupling, increasing the speed of learning, communicating new knowledge.
 - Identification, measurement and analysis of leadership events can be accomplished.
 - Contextual changes and leadership events over time, both within and between organizations and events, can be compared and contrasted
 - Using DNA tools, the researcher or manager can analyze and reason about, in a systematic fashion, the complex interactive collective action process within a specified organizational context.
 - Using DNA tools, the researcher or manager can analyze and reason about organizational outcomes such as learning and adaptive responses.
 - Multi-level analysis ranging from the individual agent level to inter-organizational level can be done concurrently.

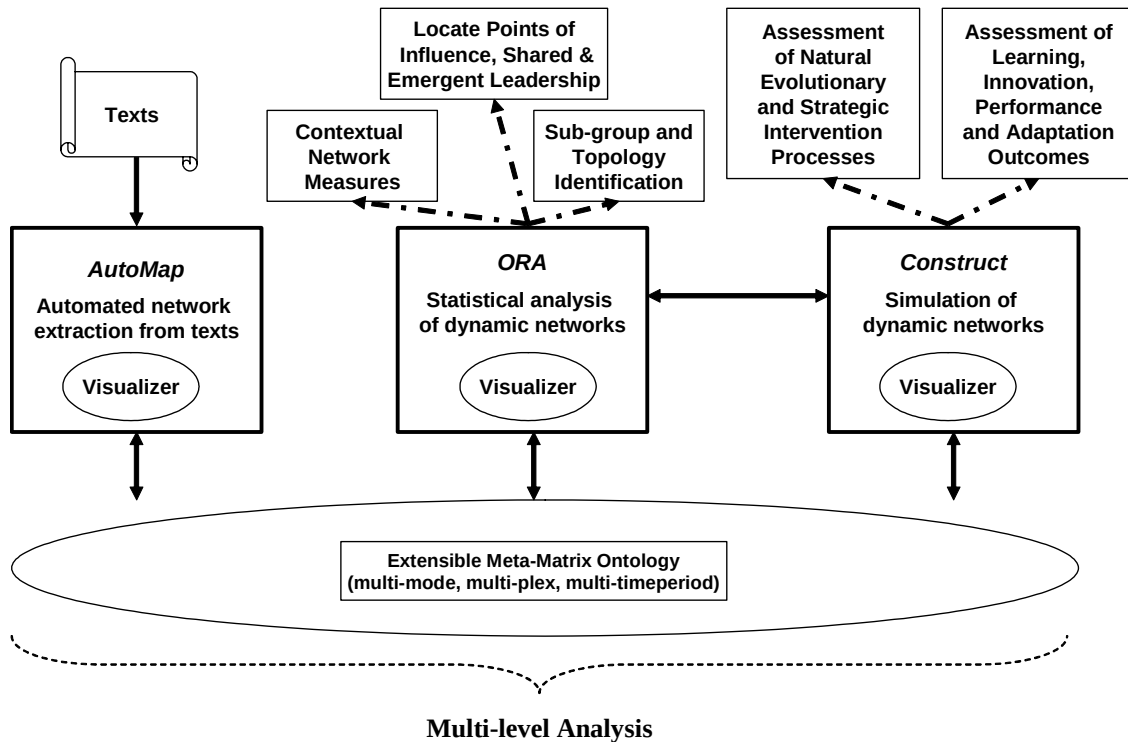


Figure 8.2: CMU Dynamic Network Analysis Tool Chain for Reasoning about Network Organization Leadership

Chapter 9 : Toward a Dynamic Network Analytic Theory of Network Organization Leadership

In this chapter, I provide an understanding about the nature of network organization leadership through the use of Dynamic Network Analysis. An analysis of the Battle Command Group was performed and fresh insights from this analysis are highlighted. This analysis is the capstone to advancing the network organization leadership paradigm and the beginning to developing a Dynamic Network Analytic Theory of Network Organization Leadership.

This chapter is organized as follows. First, leadership of context is presented. Social network measures which relate to complexity theory concepts of context are described and then used to analyze the Battle Command Group. The results of this analysis are presented and discussed. Next, leadership in process is presented. I first expand the definition of leadership in process by proposing that leadership in network organizations takes many forms. These different forms of leadership are represented by various social network measures. These social network measures are used to analyze the Battle Command Group. The results of this analysis are then presented and discussed. This analysis provided insight into the complex dynamic of leadership activities that are enacted in a network organization. Next, an immediate impact analysis of top leaders in the Battle Command Group is presented. This analysis illustrated the process and context link. It also provided understanding about the impact that different leaders and forms of leadership had on the network organization. Lastly, I discuss what this work means to network organization leadership.

The analysis of the Battle Command Group was performed using ORA. First, the empirical networks collected from this organization were input into ORA. These networks were described in Chapter 3. Then, statistical network analysis was run. I used the All Measures report in ORA and only the relevant measures were selected for output. These measures were used to characterize organizational context and to identify influential agents in the leadership process. Next, ORA was used to reason about the relative impact of different leaders in process. Each top leader for a leadership form, determined by the relevant measure, was separately taken out of the organization by isolating them in ORA using the Key Set Selector. Isolation deletes the agent node as well as all relations connected to that agent. New context measures were computed and compared to the original context measures. This happened five times, once for each leader. The comparison provided an assessment of each leader's impact on the organization by analyzing the changes to the network in their absence.

9.1. Leadership of Context: Measures of Context

Table 9.1 shows the ORA graph level measures which characterize the context of the Battle Command Group at the organizational level. The analysis is broken down into categories of measures relevant to the organization and to the complexity science perspective: relational coupling, variety, organizational form and stress.

Complexity Context Category	Social Network Measure	Value	Description
Relational Coupling	Density	0.0286	The ratio of existing relations over all possible relations
	Connectedness	0.8164	The degree to which each agent can reach every other agent
	Average Speed	0.2809	The average inverse of all pairs of shortest paths
Variety	Capacity for Learning	0.7721	The networks learning potential based on human and social cap.
Organizational Form	Hierarchy	0.4156	The degree of status differentiation present in a network
	Upper Boundedness	0.9957	The degree to which agent pairs have a common superior
Stress	Cognitive Demand	0.0338	The average amount of effort for agents to complete tasks
	Knowledge Load	0.0390	The average knowledge per agent

Table 9.1: Measures of Organizational Context

Relational coupling

Relational coupling is the degree of interdependent relations within a complex system. Moderate coupling has been theorized as being the most conducive to producing learning and adaptive responses. Low coupling does not generate enough interactive activity and high coupling causes information overload. The following social network

measures provide insight into the degree of interdependent relations in a network organization: density, connectedness and average speed.

Density (Wasserman & Faust, 1994) is a standard social network measure of the ratio of existing relations over all possible relations, ranging from 0 to 1. The 0.0286 density is not surprising for an organization of this size. Unfortunately, density tends to go down as organizational size increases. Consequently, its main use is for comparing organizations that are similar in size. In general, for organizations of relatively the same size, the organization with the higher density is more tightly coupled. Of course, a mid-range number would indicate the theoretically desired moderate coupling of complexity theory.

Connectedness (Krackhardt, 1994) is the degree to which each agent can reach every other agent in the network, ranging from 0 to 1. The 0.8164 connectedness indicates that this is a highly connected organization; although there are some isolates (a 1.0 would indicate a fully connected graph). High connectedness is needed for dealing with complex and changing environments. The connectedness provides a structure - a relational coupling - that is at least essential for the collective to produce learning and adaptive responses.

Average speed (Carley, 2002b) is the average of the inverse of all shortest paths among each pair of agents in the network, ranging from 0 to 1. The 0.2809 average speed indicates that this organization has some degree of loose coupling. Knowledge does not travel that quickly in this network (a 1.0 would be the fastest speed) as there are long paths between pairs of agents. As noted in the Chapter 6 normative implications, focusing communications through central agents can reduce the longer paths to shorter

ones. This strategy is relevant here as well. In effect, the relational coupling and communication speed of the network will be increased by making better use of central agents. This can serve to improve the learning and adaptive responses of the organization.

Variety

Variety is the degree of internal complexity that exists in the system. This refers to knowledge diversity in the network organization leadership paradigm. Knowledge diversity is essential to the process of learning

A new measure, learning capacity, is introduced into the MetaMatrix family to assess variety. Learning capacity is a transformative measure which assesses a network's potential increase for organizational learning. It is based on the existing knowledge network (human capital) and social network (social capital). Learning capacity is used as a measure of variety because leadership of variety is related to organizational learning and adaptation (Hazy, 2004, under review; Hazy & Tivnan, 2004). Learning capacity is calculated as follows. First, the maximum possible knowledge diffusion that could be achieved by the organization is obtained by multiplying the inverse of the reachability graph, obtained from the social network, with the knowledge network. The reachability graph takes into account the direction of ties in the social network which means that a full diffusion of knowledge may not result²¹. Next, the learning potential of the network is obtained by subtracting the original knowledge network from the maximum possible knowledge diffusion. This subtraction ensures that the original knowledge an agent possesses is not counted as potential

²¹ A disconnected graph could also result in knowledge diffusion that is less than full.

learning. This step captures the highest level of learning that could occur in the organization given the current constraints of the networks. Next, the learning capacity is calculated as a ratio. This step divides the learning potential by the maximum possible knowledge diffusion. The measure ranges from 0 to <1 with a zero indicating there is no capacity for learning and a number close to one indicating there is a large capacity for learning.

Learning capacity is an indicator of complexity, more specifically to the amount of existing knowledge variety which could potentially be combined through existing relations. Changes to knowledge, people and relations would change the measure. It should be noted that this indicator gives us a sense of complexity and that full learning potential in a network would unlikely be reached.

The 0.7721 learning capacity indicates a large capacity for learning in this organization. Injecting non-redundant knowledge or adding non-redundant relations may increase the capacity. But given the current capacity, such strategic interventions may only be marginal or needed in the event of changing conditions. By virtue of the average speed measure above, an applicable strategic intervention maybe shortening the paths lengths between agents by focusing communications through central agents as this organization has a large capacity to learn but a slow rate of learning.

Organizational Form

For purposes of the network organization paradigm, organizational form refers to the degree of status differentiation or cycles within the informal structure. Higher numbers of cycles are an important characteristic of network organizations as they are indicators of information flow fluidity and rapid rework. Cycles can lead to quicker

production of learning and adaptive responses. The social network measures of hierarchy and least upper boundedness provide insight about an organization's form.

Hierarchy (Krackhardt, 1994) is the degree of status differentiation or cycles that are present in the informal structure, ranging from 0 to 1. The 0.4156 hierarchy indicates that the informal network has a moderate amount of cycles. (a 1 for this measure would indicate an absence of cycles.).

Least upper boundedness (Krackhardt, 1994) is the degree to which agent pairs have a common superior. The 0.9957 least upper boundedness also indicates the existence of hierarchy as practically every node has a common superior for conflict resolution. This is not surprising either as conflict resolution is an emphasis in military functioning.

These measures do not necessarily indicate that the organization will lack a learning or adaptive response. Work on high-reliability organizations has shown that the structure of reliable organizations can change to fit the situation (Weick et al., 2001). This means that the level of cycles within the informal structure can fluctuate in response to the situation. These measures of organizational form indicate that the Battle Command Group may also possess this ability whereas they have fewer cycles in normal operations but more cycles in rapidly changing and critical situations. In fact, given the stress analysis below this may be the case.

Stress

Stress is an indicator of tension in a system. The social network measures of average cognitive demand and knowledge load provide insight about the existing stress of a network organization. These measures do not distinguish between external or internal

sources of stress. Rather, they are indicators of overall stress. It should be noted that stress (tension) is needed to improve the process of learning but oversteering is counterproductive.

Average cognitive demand (Carley, 2002b) is the average amount of effort all agents exert in the course of interacting and doing work in the organization, ranging from 0 to 1. The 0.0338 cognitive demand indicates a very low amount of stress on the overall organization. (a 1.0 would indicate a highly stressed organization.) Agents have a great deal of slack mental resource at this time. This makes sense as the data was collected at the beginning of the experiment when the battle lab exercise was just starting.

Knowledge load (Carley, 2002b) is the average knowledge each agent currently uses. This is a normalized value ranging from 0 to 1 where 1 indicates that all knowledge is used by every agent. The 0.0390 indicates a very low knowledge load as there are 51 knowledge categories in this organization. Again, agents are not stressed at this time and have slack cognitive resources.

These measures may account for the existence of moderate hierarchy in the organization. From a complexity theory perspective these measures indicate the need for tension in the organization. As cognitive demand and knowledge load increase, interactions and knowledge flow should also increase as agents work on complex tasks and try to reduce the tension in the organization.

9.2. Leadership in Process: Identification of Influential Agents

Leaders in process are those that shape communication flows and foster productive learning and adaptive responses. Accordingly, I propose that there are several

forms of leadership in network organizations that shape communication flows in various ways and that provide benefits toward productive responses. These leadership forms are based upon social network measures at the individual agent level and include: creating interactions and interdependencies, enhancing knowledge flows, maintaining relational coupling, increasing the speed of learning, and communicating new knowledge. The measures for each leadership form are:

<i>Measure</i>	<i>Leadership Form</i>
Cognitive demand	Creating interactions and interdependencies
Degree centrality	Enhancing knowledge flows
Boundary spanner	Maintaining relational coupling
Closeness centrality	Increasing the speed of learning
Effective network size	Communicating new knowledge

The leadership forms are not necessarily inclusive of all possible forms of leadership in process. Ongoing research into the formation process of emergent collective action will most likely identify other forms of leadership in process and new measures for identification.

These leadership forms are additions to the definition of leadership in process that was previously discussed. Because of this, I discuss each leadership form and related social network measure in more detail below.

Creating interactions and interdependencies

Cognitive demand is the amount of effort an agent exerts in the course of interacting and doing work in the organization, ranging from 0 to 1. This is the measure that was previously averaged to produce information about organizational context at the

graph level. Agents high in cognitive demand are likely to be emergent leaders (Carley et al., 2001b). The larger workload and sphere of interaction of these agents give them a better, more complex understanding of the situation. This can push them into a position where they often need to direct others in order to complete tasks and obtain the objective. Agents high in cognitive demand will provide interactive direction and establish interdependencies as they coordinate task assignments with others.

Enhancing knowledge flows

Degree centrality (Wasserman et al., 1994) is the normalized total number of relations for an agent, ranging from 0 to 1. This measure identifies agents who are likely to have the most interactions and therefore are likely to learn the most knowledge. It is a powerful measure of influence. Agents high in degree centrality will facilitate knowledge flows through the network due to their accumulation of knowledge and high degree of interactions.

Maintaining relational coupling

Boundary spanner (Cormen, Leiserson, & Rivest, 2001) is the normalized component betweenness of an agent, ranging from 0 to 1. In effect, it measures agents as gatekeepers. Boundary spanner identifies agents who most likely connect otherwise disjoint groups in an organization. Boundary spanner agents will facilitate knowledge flows to parts of the organization that are normally hard to reach. These agents tend to overcome organizational barriers that prevent interactions and thus can play an important role in the complex functioning and dynamics of the informal network.

Increasing the speed of learning

Closeness centrality (Freeman, 1979) is the normalized average closeness in path length of an agent to all other agents in the organization, ranging from 0 to 1. This measure identifies agents who can most quickly communicate knowledge to the organization as a whole. These agents will provide speed of knowledge flow. This will be important for diffusing knowledge that is critical about the changing conditions in the environment. Closeness centrality agents can support faster learning and quicker adaptive response.

Communicating new knowledge

Effective network size (Burt, 1992) is the number of non-redundant ties in an agent's ego network. In other words, it measures the structural hole that an agent fills. Effective network size identifies agents who are most likely to communicate new knowledge. These agents will interact with other agents who are largely not connected to one another and this facilitates the communication of non-redundant knowledge. Agents with large effective networks will increase the interactive complexity by channeling new knowledge through the network. This helps the collective to learn and adapt.

Analysis Results and Discussion

Table 9.2 presents the influential agents of leadership in process by leadership form. The top five agents in each leadership form are listed²². An inspection of the table shows that, by and large, different agents performed different forms of leadership. This finding lends support to the notion that collective change agents are the source of

²² Closeness centrality lists six agents as the Intel and Coalition Center LNO had identical scores for the fifth spot.

competitive advantage in network organizations. The collective intelligence of the organization's citizenry was being tapped in many ways by various leaders who were enacting diverse forms of leadership. In other words, learning and adaptive responses were being developed through a collective dynamic.

This finding also lends support to the notion of shared leadership within network organizations. Obviously, leadership in the informal dynamic was being performed by many agents. This means communication was being shaped by a collection of leaders. This shared leadership dynamic occurred across and within various leadership forms. For instance, the top leader in each form was different and leadership across forms was shared. In addition, there was clearly a shared leadership dynamic within forms which did not have a distinct top leader. An example is closeness centrality where the range among the top five was 0.0028.

It can also be the case that agents enact multiple forms of leadership in process. For example, Plans, AVN provided leadership by creating interactions and interdependencies and by maintaining relational coupling.

There is also evidence of distinctive leadership as these leaders stood-out in comparison to everyone else. As an illustration, Figure 9.1 presents a plot of degree centrality against effective network size. Here we can see the distinctive leaders as they are outliers to the rest of the organization. The leaders shown are FEC1, TAC CP1, who enhances knowledge flow through his central position and Effects NCO, HBCT1, who communicates new knowledge through non-redundant relations.

Measure	Agent	Value	Description
Cognitive Demand	Effects, HBCT1	0.0716	Agent who is most likely to induce interactions and establish interdependencies
	Fires & Effects, AVN	0.0716	
	Fires NCO, Fires BDE	0.0716	
	Plans, AVN	0.0716	
	Commander, HBCT3	0.0716	
Degree Centrality	FEC1, TAC CP1	0.0935	Agent who is most likely to have the most interactions and to learn more knowledge
	ACOFs G3, TAC CP1	0.0710	
	ACOFs G2, Uex Main	0.0710	
	Chief of Staff, Uex Main	0.0677	
	Effects, Fires BDE	0.0677	
Boundary Spanner	Plans, Maneuver	0.0295	Agent who most likely connects otherwise disjoint groups
	G3 COO, TAC CP2	0.0275	
	A2C2, TAC CP2	0.0241	
	MP, Maneuver	0.0234	
	Plans, AVN	0.0221	
Closeness Centrality	Comm. Officer, Maneuver	0.0397	Agent who can most quickly communicate to the organization at large
	TNC G6, Uey	0.0391	
	Network Eng., Uex Main	0.0388	
	C4/G6, TAC CP1	0.0373	
	Intel, Uey	0.0369	
	Coalition Center LNO, Uex Main	0.0369	
Effective Network Size	Effects NCO, HBCT1	11.0556	Agent who is most likely to communicate new knowledge
	G3 COO, TAC CP2	6.7000	
	Commander, Maneuver	6.5833	
	A2C2, TAC CP2	6.5714	
	Plans, Maneuver	6.3929	

Table 9.2: Leaders in Process by Leadership Form

In network organizations, leadership in process is itself a complex dynamic which is made up of a variety of leadership forms. Leadership can be distinctive and it can be shared, both within and between forms. Individual leaders can also exhibit leadership

within multiple leadership forms. All this happens concurrently within the complex dynamic.

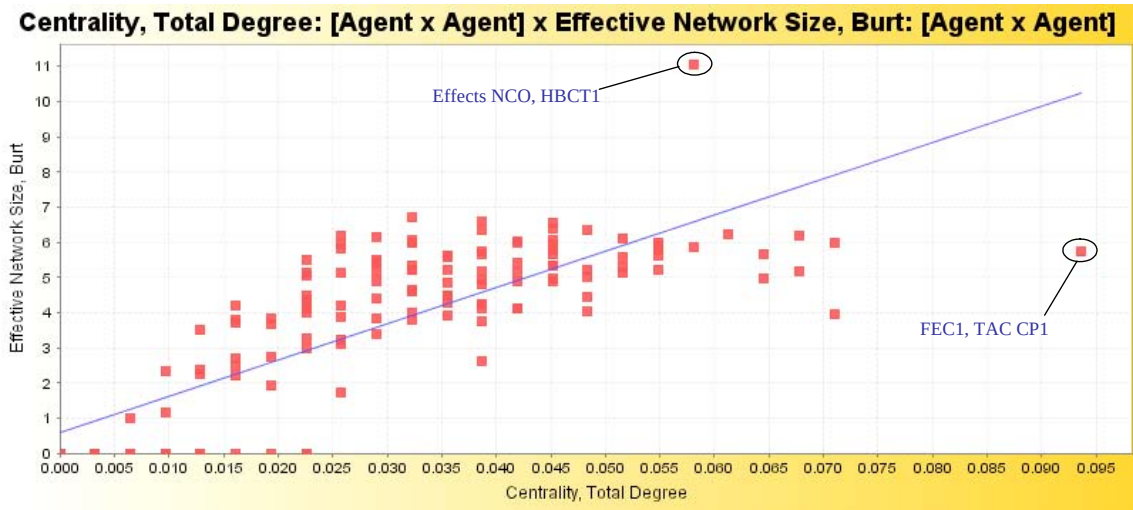


Figure 9.1: Plot of the Degree Centrality and Effective Network Size Measures at the Agent Level

9.3. Reasoning about the Nature of Network Organization Leadership through Immediate Impact Analysis

The following question was asked to gain an understanding of the impact that the different leaders have on the network organization: “What would happen, immediately, were this leader not present?” Each top leader for a leadership form, determined by highest value, was separately taken out of the organization and the context measures recomputed. The new context measures were then compared to the original context measures that represent the presence of that leader. There were five immediate impact analyses, one for each leader. This analysis provides an understanding of the benefit that each leader provided while enacting their leadership role during the situation at the time of data collection. This is insight into the contextual nature of leadership in process

within the network organization. It illustrates the process and context link; the tightly intertwined dynamics of leadership in process and leadership of context.

Two interesting results are highlighted from this analysis. The first result is the impact of each leader in process on the capacity for learning measure. Figure 9.2 presents a bar chart of these results. There were five separate analyses by leadership form but they are shown together for analytic clarity and comparison.

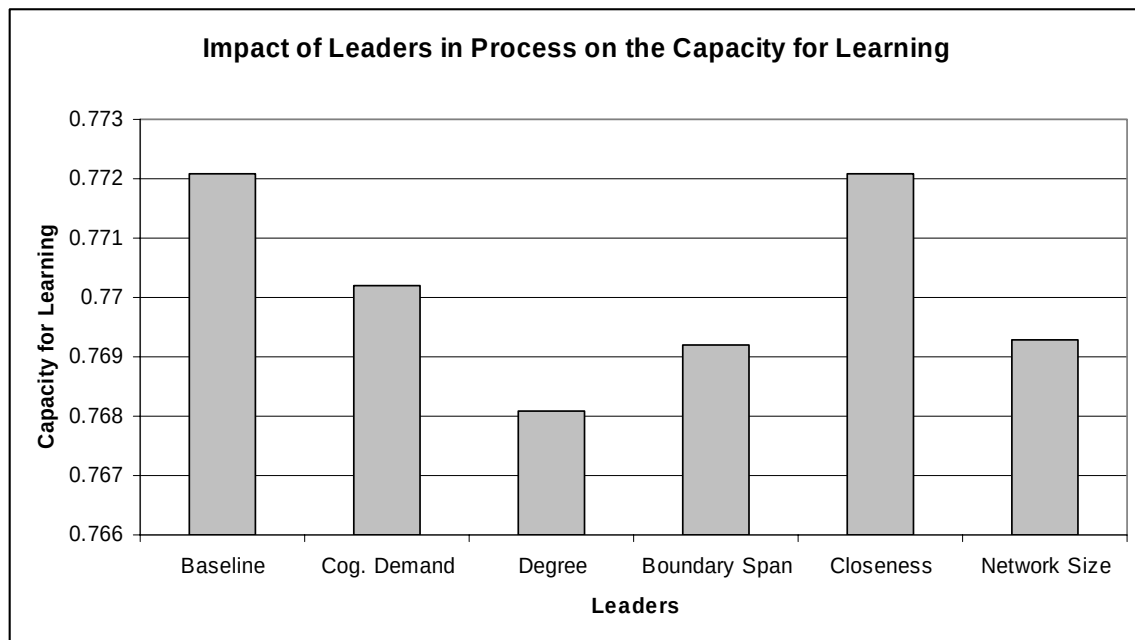


Figure 9.2: The Impact of Leaders in Process on the Capacity for Learning

The degree centrality, boundary spanner and effective network size leaders all positively affect the organization's capacity for learning considerably. The degree centrality leader has the greatest impact. This result indicates that these leaders, especially degree centrality, are all important to the informal interdependent interactions

of the collective. They all provide a type of benefit to the social capital structure that produces collective action and collective intelligence. As previously noted, there is low average knowledge per agent in the Battle Command Group data and this is consistent across agents. These results are due more to the structural role of the leader rather than the loss of knowledge in their absence.

The cognitive demand leader is also important but to a more moderate degree. In fairness, this analysis is during a time of non-stress in the organization and cognitive demand leaders emerge during times of stress. Therefore, these results may not be fully representative of the impact of cognitive demand leaders.

Another noticeable result is the lack of any impact on the capacity for learning by the closeness centrality leader. This is not all that surprising since the main benefit of closeness centrality leaders is speed of learning which the learning capacity measure does not capture.

The second result is the impact of each leader in process on the level of hierarchy in the organization. Figure 9.3 presents a bar chart of these results. All five immediate impact analyses are shown together for analytic clarity and comparison.

The degree centrality and cognitive demand leader have very little impact. The equalizing effect on the hierarchy measure during the absence of the degree central leader suggests that this leader has ties to both formal leadership and the informal network. It also suggests that this leader is a natural interface between the informal dynamics and top management. The same can be said for the cognitive demand leader. But caution should be noted as this analysis may not represent the proper context in which cognitive demand leaders are important.

The boundary spanner and closeness centrality leaders provide some level of hierarchy in the organization as we see the level goes down in their absence. This is due to their ties to the Chief of Staff and Uey top-level command group, respectively. These leaders are good candidates for interfacing the productive outcomes of the informal network with top management. But care should be taken with these leaders, along with the degree central leader, as they could also be conduits of top-down control.

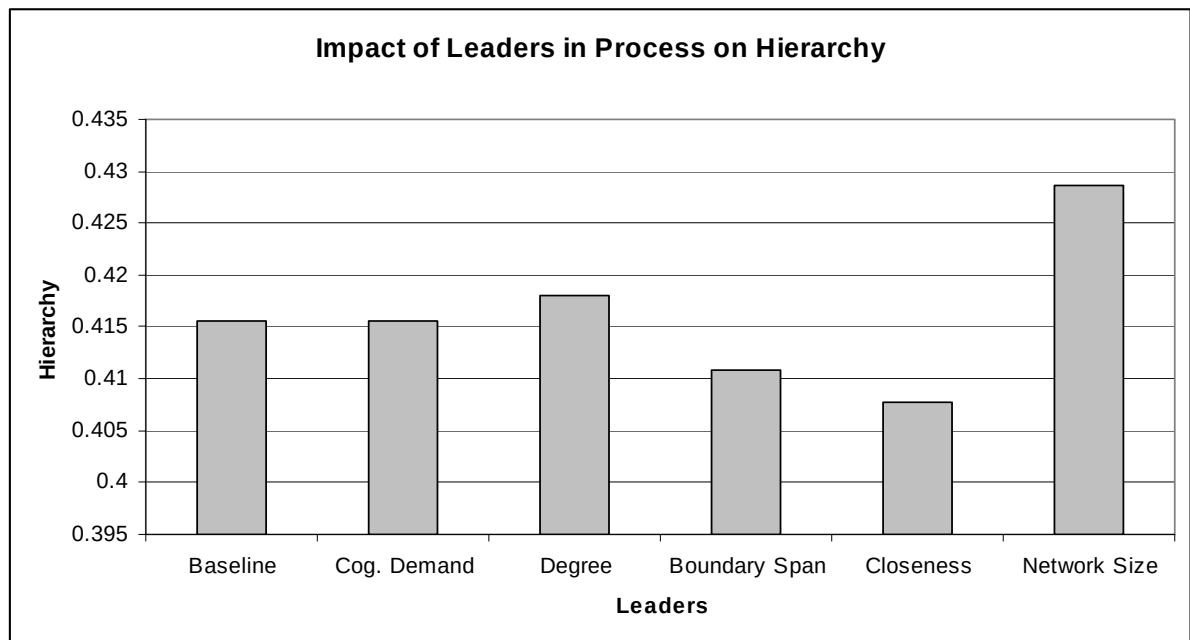


Figure 9.3: The Impact of Leaders in Process on Hierarchy

Lastly, an interesting result occurs with the effective network size leader. This leader is very important to the informal interactions in the collective as the hierarchy measure increases considerably when he/she is not in the organization. This leader's ability to supply non-redundant ties to many people, as evidenced by the 11.0556 value

for effective network size, has a definite impact on the emergent complex functioning within the organization. The effective network size leader provides critical social structure that promotes higher levels of cycles within the informal structure. This certainly can have a positive effect on the timely production of learning and adaptive responses.

9.4. Network Organization Leadership

This chapter is the foundation for building a Dynamic Network Analytic Theory of Network Organization Leadership. The above work presented structural measures that characterize the contextual nature of the organization, introduced forms of leadership in process that are enacted by leaders, presented structural measures that identify leadership in process, illuminated the complex dynamic of leadership in process, and demonstrated the contextual nature of leadership whereas context and process are intimately intertwined.

This analysis also showed the efficacy of the methodological approach for addressing the theoretical needs of network organization leadership. The *who* of network organization leadership was addressed by identifying leaders in process. For instance, the analysis showed that leadership in process was comprised of distinct leaders as well as leaders whose contributions were part of a shared dynamic. The *how* of network organization leadership was addressed by defining various leadership forms and showing the benefits that various forms provide. For instance, degree centrality leaders contribute significantly to the organization's learning capacity by providing social capital structure and enhancing knowledge flows. The *when* of network organization leadership was

addressed by demonstrating the contextual nature of leadership. For instance, cognitive demand leaders do not need to contribute as much in low stress contexts.

There is undoubtedly more to the nature of network organization leadership than was shown in this analysis. But this is an initial step toward developing theory. A full theory will need to explain the complex interplay between the various forms of leadership in process. I have demonstrated the concurrent existence of these leadership forms and described individual contributions for each. But the obviously complex dynamics between them need to be better understood as there can be significant implications. A full theory will also need to expand on the intricate link between context and process. I have argued that this is an important link in the functioning of network organizations as changes in one affect changes in the other. More research is needed to provide a better understanding of interactions between various leadership processes and contextual variables. A more complete theory of network organization leadership will establish the ability to appropriately identify and study leadership risks of network organizations.

CONCLUSION

Chapter 10 : Conclusion

Network organizations are increasingly used in today's high velocity business and military environments. Network organizations are advantageous in high velocity environments because they are conducive to producing many desired responses to change. These responses include learning, adaptation and resiliency. The functional ability of network organizations to effectively respond to change lies in their dynamic, evolutionary structure.

These functional advantages as well as the successes of network organizations have been a popular topic in the literature. Unfortunately, the dysfunctionalities or risks associated with network organizations have not garnered as much attention (Podolny et al., 1998). Understanding risks can provide balanced insight into the reasons why network organizations not only succeed but also fail.

But the evolutionary nature of network organizations makes the study of risks particularly difficult. Traditional social network analysis has been the study of static structural representations (Carley, 2003). This can only provide limited insight about network organizations because of their evolutionary nature (Kanter et al., 1992). Process needs to be studied in conjunction with structure to advance the study of network organizations and the risks associated with them.

This thesis advances the study of risks in network organizations by using Dynamic Network Analysis, a methodology that incorporates both structure and process. The particular focus of this research was on critical personnel risks and leadership in network organizations. Advances were made on two fronts.

First, theory was developed about three evolutionary risks related to critical personnel in network organizations: intermittent availability, individual redundancy and shifts of critical personnel. These risk factors can all lead to dysfunctionality by constraining the learning, adaptive and resilient responses of network organizations. Theory about these risks was developed by analyzing the results of virtual experiments that evolved the networks of two real-world organizations, Team X and the Battle Command Group.

Intermittent availability is the limited access of a person for task communications. Intermittent availability poses a risk because insufficient integration of critical personnel can slow the rate of learning as well as limit the timeliness of adaptive and resilient responses. Turnover was used as a comparison risk in order to get a sense of the relative impact of intermittent availability. Turnover is also concerned with agent and knowledge unavailability but on a permanent basis instead. In addition, turnover is a well-studied risk with known negative consequences (Dalton et al., 1983). The following theories were proposed based on the simulation results and comparative analysis:

Intermittent Availability

Proposition 1: Single agent intermittent availability can pose a risk to small network organizations

Proposition 1a: The disruption to task-related communications must be high and sustained before a risk to the network organization is incurred

Proposition 1b: High, sustained intermittent availability is a long-term risk that is more detrimental to the network organization than turnover

Individual redundancy is the level of similar knowledge or skill that a person possesses in relation to others in the organization. Individual redundancy has been qualitatively cited as providing resiliency (Ronfeldt et al., 2001) and expanding the available responses (Weick et al., 2001) for organizations in volatile environments. This is a form of risk protection. Traditional social network analysis has focused on critical personnel that pose a risk based on some measure of uniqueness (Burt, 1992; Pfeffer, 1981). This work performed a quantitative analysis of the individual redundancy effects on intermittent availability risks in small network organizations. This analysis supported the qualitative observations and expanded the notion of criticality in social networks to include non-uniqueness.

Individual Redundancy

Proposition 2: Individual redundancy serves as a risk protection in small network organizations by reducing the detrimental impacts related to agent unavailability

Shifts of critical personnel are changes to who is critical within an organization over time. Shifts of critical personnel are adaptive and resilient responses in the face of change. Such responses can also impact learning. It is important to identify who is critical when, or under what conditions, so that organizations can effectively manage risks. Most social network research has studied critical personnel in static structure (Freeman, 1979). Only a few social network studies have examined critical personnel longitudinally, such as Burkhardt and Brass (1990). But none propose a theory about how different conditions facing an organization affect shifts of critical personnel. This

work proposed such a theory. This theory provides guidance about when re-identification of critical personnel should occur.

Shifts of Critical Personnel

Proposition 3: Shifts of critical personnel are positively related to the rate of environmental change

Proposition 4: Shifts of critical personnel can pose a risk to network organizations in dynamic environment when re-identification has not occurred and strategic personnel decisions need to be made

Proposition 5: Shifts of critical personnel are negatively related to communication network constraints and cognitive constraints.

Proposition 6: Communication network constraints and cognitive constraints can pose a risk by modifying the number of flexible responses, in terms of critical personnel shifts, exhibited by a network organization in a dynamic environment. This is a risk only when such flexible responses are advantageous and sufficient to dealing with environmental change.

Proposition 7: Communication network constraints are a slightly larger risk to shifts of critical personnel than are cognitive constraints

In addition, normative applications were furthered. Practitioners need to account for process in the practical application of network research (Kanter et al., 1992). Understanding the change that occurs in a network organization is just as important to a manager as is a comprehension of the structure at a particular point in time. A more complete picture allows the manager to be more strategic in interventions aimed at influencing change and mitigating risks.

Normative implications for the real-world organizations were discussed based on the proposed theories. These normative implications include cognitive temperance

qualification for personnel selection, training for time-pressure strategies, the effective use of redundant expertise and the re-identification of critical personnel during times of rapid change.

The second advance was made by establishing the foundations for a Dynamic Network Analytic Theory of Network Organization Leadership. The Knowledge Era has ushered in a knowledge-driven environment that is highly dynamic and uncertain (Hitt et al., 1998). Traditional leadership theory has limited applicability in this context (Streatfield, 2001) and a new paradigm is needed (Marion et al., 2001; Osborn et al., 2002). Leadership is a subset of critical personnel and the development of a theory of network organization leadership is important for two reasons. First, network organizations are increasingly used in the Knowledge Era. Therefore, leadership of network organizations is an important subject. Second, the effective study of risks associated with network organization leadership will require a relevant paradigm and theory. Existing theories have limited applicability in this context.

A new paradigmatic framework for network organization leadership that accounts for both structure and process was presented. This paradigmatic framework is based on complexity theory but provides normative application by representing the structure and processes of network organization leadership in practical terms using Dynamic Network Analysis. The network organization leadership paradigm involves two types of change leadership: leadership of context and leadership in process.

Leadership of context enables organizational processes that allow for productive collective action to emerge in response to a changing environment. The Dynamic Network Analysis framework allows for the quantification of complexity science

concepts. The following social network measures were proposed as representing complexity science concepts relating to organizational context. These measures will inform the researcher or practitioner and provide a means for quantitative analysis.

<i>Complexity Science Context</i>	<i>Social Network Measure</i>
Relational Coupling	Density Connectedness Average Speed
Variety	Learning Capacity
Organizational Form	Hierarchy Least Upper Boundedness
Stress	Cognitive Demand Knowledge Load

Leadership in process facilitates learning and adaptation through the emergent interactions and informal dynamics which form collective action. This leadership type also channels the learning and adaptive responses to formal management for exploitation. Leaders in process are those agents that shape communications. Therefore, it was proposed that leadership in process contains several forms of leadership that shape the communication network in various ways. These forms can be defined in terms of social network measures. These measures also inform the researcher or practitioner and provide a means for quantitative analysis. The following list is each leadership form and associated social network measure:

<i>Leadership Form</i>	<i>Social Network Measure</i>
Creating interactions and interdependencies	Cognitive demand
Enhancing knowledge flows	Degree centrality
Maintaining relational coupling	Boundary spanner
Increasing the speed of learning	Closeness centrality
Communicating new knowledge	Effective network size

Then an analysis of the Battle Command Group was performed that focused on the enactment of the various leadership forms within the organization. This analysis produced the following insights into the nature of leadership in network organizations.

Network organization leadership contains distinct leaders, leaders who enact multiple forms of leadership and shared leadership - both across and within forms of leadership. Network organization leadership is therefore a complex, interactive dynamic where many leaders are enacting several forms of leadership simultaneously. The simultaneous enactment of diverse leadership forms serves to shape the overall communications of the organization and to tap the collective intelligence of the organization's citizenry in many ways. Therefore, learning and adaptive responses are developed through a collective dynamic. Consequently, this analysis supports a paradigm shift for leadership whereas the impetus of change falls on the collective and is not the actions of a single 'heroic' leader.

The foundation for a theory of network organization leadership was laid by defining leadership in terms of the Dynamic Network Analysis paradigmatic framework and by providing insights into the nature of leadership. Additional research into the complex interplay between the various forms of leadership in process and into the intricate link between context and process will build upon this foundation to develop a full theory of network organization leadership. The development of a full theory is a vital link leading to the effective study of risks associated with network organization leadership.

The relationship between the critical personnel risks and the enactment of leadership in process is shown in Table 10.1. This relationship also highlights the context

and process link as the risks relate to the overall context of the organization and leadership enactment is in the process of collective action.

Leadership and Risks				
		Leadership Enactment		
		<i>Distinct</i>	<i>Shared</i>	<i>Multiple</i>
Critical Personnel Risk	<i>Intermittent Availability</i>	Higher association	Lower association	Higher association
	<i>Individual Redundancy</i>	Higher association	Lower association	Higher association
	<i>Shifts of Critical Personnel</i>	More identifiable	Less identifiable	More identifiable

Table 10.1: The Relationship between Critical Personnel Risks and Leadership Enactment

Distinct leadership as well as the enactment of multiple forms of leadership by a single leader should have a higher association with the intermittent availability and individual redundancy risks. In contrast, shared leadership should have a lower association with both of these risks. For example, a distinct leader who is intermittently available would exacerbate the effects of intermittent availability because these leaders provide a much larger benefit to the shape of communications than the others enacting a similar form. The intermittent availability of a shared leader would not have as much of an effect as there are others who also provide a benefit and who can help to maintain the level of communications. The association between leadership enactment and individual redundancy follows the same reasoning. There are likely fewer others who are in a position to fill the role of a distinct leader whereas there are several others who can take up the slack for an unavailable shared leader.

The re-identification of critical personnel concerning leaders in process is another issue. Shifts of distinct or multiple enacted leadership will be more easily observable and identifiable because they are much more pronounced. On the other hand, shared leadership is a more complex dynamic and shifts that occur within this dynamic may be more subtle and less noticeable. This poses a more difficult problem for the re-identification of critical personnel. It also may pose a problem for the enactment of shared leadership as numerous shifts could cause coordination problems in the shared dynamic.

New metrics are needed to further the study of leadership and risk. For instance, the degree of linkage between the various forms of leadership as well as the relative positions of each form of leadership needs to be measured. Such measures would provide insight into the complex interactive dynamic of leadership in process that shapes the overall communications of the organization. These measures may also need to be valued in order to provide a granularity that captures the subtleties of the bottom-up dynamic. The same types of measures are needed for leadership of context as well. It is obvious that the context of the organization is made up of various interdependent characteristics.

In addition, measures are needed that combine the various forms with assessments of collaborative activity. Collaborative activity can be measured by reciprocal, cooperative or trustworthy ties. Each leadership form could pose a risk to the organization if enacted in an opportunistic way because the collective dynamic and timely responses rely upon collaborative behavior. As an example, agents high in effective network size fill a structural hole. Such agents can opportunistically decide to

withhold new knowledge and exploit it for personal power and gain. Such behavior will restrict the flow of new knowledge in the organization and work counter to the quicker production of learning and adaptive responses. Thus such enactment of the leadership role is counter to the goals of the organization and is a risk. These measures are needed to identify the opportunistic enactment risks of leadership roles.

There are several implications of this work for network organizations. One implication is that the size of the network organization matters. Obviously, smaller network organizations are more susceptible to risks affected by a single critical agent whereas larger network organizations are more concerned with risks that affect a larger portion of the organization's functioning. This goes along with the line of reasoning that it is easier to disrupt a terrorist cell than it is to disrupt the terrorist organization. But the more novel results of this research suggest that the critical personnel substructures of small network organizations are more stable than those of larger ones. There seems to be a couple of reasons for this. The first is that the size of the network constrains the occasion for shifts of critical personnel. The second is that smaller network organizations are designed more for specialized functions. As such these organizations have a higher concentration of expertise, deal with a scaled down scope of operations and have an element of efficiency in addition to adaptability. The re-identification of critical personnel is less of an issue for small network organizations than it is for large ones.

Another implication is that leadership in large network organizations is a very complex dynamic. Not only is leadership enacted through multiple processual forms that create a distributed and shared dynamic but leadership also shifts considerably. This makes leadership within the organization obscure. Re-identification is a highly important

task in order to make strategic use of the current leadership that is being enacted in the organization. Further, this new paradigm of network organization leadership may prove to be important for understanding adaptable enemies such as terrorist organizations. Targeting leadership using a tradition paradigm has proven to be ineffective. It is possible that new, effective strategies can be derived from this paradigm. Especially as more research provides a better understanding into the interactions between the various leadership forms and the context and process link.

Although this research studied two specific network organizations, the theories and findings apply to organizations in general as networks are integral to all organizations. Network organizations were studied because the informal networks are typically more pronounced and dominant than in other forms. This not only helped in the collection of quantitative data but also in the qualitative observation of network dynamics which made the interpretation of results easier to accomplish and the normative implications easier to discern.

This work also has implications for Dynamic Network Analysis. First, a validated model was provided. This validation gives confidence for the results and moves the Construct model toward the applied realm. Additional work that uses relational equivalence and validates the internal mechanisms and outputs of Construct against longitudinal data will further Construct as a fully-applied model. Second, additional functionality related to organizational stressors was established in Construct. These stressors include the intermittent availability of agents, the selective attention of agents and a dynamic task environment. This functionality adds realism to the model as all of these stressors are present in organizations. It also greatly expands the model's

capabilities. For instance, Construct can now be used to explore organizational problems related to changing environmental conditions because the dynamic environment represents a non-static base of knowledge.

Third, a Dynamic Network Analysis operationalization of risk measures was provided. This research explored the effects of intermittent availability, individual redundancy and shifts of critical personnel. Although this research was focused on network organizations, this operationalization can now be used to study the effects of these risks in other organizational forms and contexts. Fourth, a Dynamic Network Analysis operationalization of complexity science concepts was provided. The leadership of context and leadership in process measures support the quantification of these complex concepts. These measures not only give insight to researchers and practitioners but they are also essential to the development of a full theory of network organization leadership.

This work does have its limitations. For one, the agents in Construct are modeled as cooperative agents. It is recognized that organizations do have competitive and opportunistic behaviors which are not accounted for in the model. Network organizations are no different in that they will contain non-cooperative behaviors. But this is only a minor limitation in the network organization context. Trust has been identified as essential to the effective functioning of network organizations (Perrow, 1992; Podolny et al., 1998; Powell, 1990; Ronfeldt et al., 2001; Uzzi, 1997). There is cooperation, solidarity, reliability and a norm of reciprocity in these contexts. Such trust and cooperation allow the network to respond quicker to change by eliminating the need for formal procedures such as the restructuring of contractual agreements. While purely

cooperative agents are a limitation, this research is very relevant to the context of network organizations.

Another limitation is that theory was developed by analyzing only two organizations. The theory was strengthened by the fact that the organizations were different in terms of size, organizational composition and setting. But it is recognized that much more research is needed to extend and confirm these theories. Replication within these settings as well as the study of additional settings is necessary. For example, additional studies can extend the research to medium sized network organizations. This may show that medium sized network organizations function a bit differently than either large or small ones and that they are better suited for particular settings.

Testing of these theories is also necessary and can be accomplished through computational or empirical analysis. The theories proposed in this research are empirically testable. For instance, a longitudinal study of the effects of communication and cognitive constraints on learning outcomes within network organizations is empirically feasible. In fact, empirical testing is most desirable and is considered the best test for confirming the theories.

The long-term goal of this research agenda is to develop a unified theory of organizational risk. This work has developed theory about three critical personnel risks and has laid the foundation for developing theory about leadership risks. Continued research will build upon this basis toward the goal of a unified theory. This goal will be obtained through a building block approach. Additional organizational risk factors will be studied and theory developed. For instance, study of the complex interplay between the various forms of leadership in process will lead to the identification of risks that are

subsequently studied for theory development. As this happens the overall theory of organizational risk becomes more holistic.

In addition, the next step for validation will be to establish relational equivalence for Construct. This will involve collecting empirical longitudinal data, both in terms of social structure and organizational performance. This data will be used to validate the internal mechanisms and outputs of Construct using relational equivalence, which will further move the model into the applied realm.

References

- Argote, L., & Ingram, P. 2000. Knowledge transfer: A basis for competitive advantage of firms. *Organizational Behavior and Human Decision Processes*, 82: 150-169.
- Argyris, C. 1953. Some characteristics of successful executives. *Personnel Journal*, 32: 50-63.
- Arquilla, J., & Ronfeldt, D. 2001. The advent of netwar (revisited). In D. Ronfeldt (Ed.), *Networks and netwars: The future of terror, crime and militancy*: 1-24. Santa Monica, CA: Rand Corporation.
- Ashby, W. R. 1960. *Design for a brain* (2nd ed.). New York, NY: Wiley.
- Ashworth, M., & Carley, K. M. 2006. Who you know vs. what you know: The impact of social position and knowledge on team performance. *Journal of Mathematical Sociology*, 30(1): 43-75.
- Baker, W. E. 1990. Market networks and corporate behavior. *American Journal of Sociology*, 96: 589-625.
- Baker, W. E. 1992. The network organization in theory and practice. In R. C. Eccles (Ed.), *Networks and organizations: Structure, form and action*: 397-429. Boston, MA: Harvard Business School Press.
- Balci, O. 1998. *Verification, validation and accreditation*. Paper presented at the 1998 Winter Simulation Conference, Washington, D.C.
- Baligh, H. H., Burton, R. M., & Obel, B. 1990. Devising expert systems in organizational theory: The organizational consultant. In M. Masuch (Ed.), *Organization, management and expert systems*: 35-57. Berlin: Walter De Gruyter.
- Baligh, H. H., Burton, R. M., & Obel, B. 1994. Validating the organizational consultant on the fly. In M. J. Prietula (Ed.), *Computational organization theory*: 179-194. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Barley, S. R. 1986. Technology as an occasion for structuring: Evidence from observations of CT scanners and the social order of radiology departments. *Administrative Science Quarterly*, 21: 78-108.
- Bass, B. M. 1985. *Leadership and performance beyond expectations*. New York, NY: Free Press.
- Bavelas, A., & Barrett, D. 1951. An experimental approach to organizational communication. *Personnel*, 27: 366-371.
- Bennis, W. 1997. Cultivating creative genius, *Industry Week*: 84-88.
- Bennis, W., & Biederman, P. W. 1997. *Organizing genius: The secrets of creative collaboration*. Reading, MA: Addison-Wesley.
- Bettis, R. A., & Hitt, M. A. 1995. The new competitive landscape. *Strategic Management Journal*, 7(13): 7-19.
- Blake, R. R., & Mouton, J. S. 1964. *The managerial grid*. Houston, TX: Gulf.
- Blau, J., & Alba, R. 1982. Empowering nets of participation. *Administrative Science Quarterly*, 27: 363-379.
- Bonacich, P. 1987. Power and centrality: A family of measures. *American Journal of Sociology*, 92: 1170-1182.

- Brass, D. J. 1984. Being in the right place: A structural analysis of individual influence in an organization. *Administrative Science Quarterly*, 29: 518-539.
- Brown, S. L., & Eisenhardt, K. M. 1995. Product development: Past research, present findings and future directions. *Academy of Management Review*, 20: 343-378.
- Burkhardt, M. E., & Brass, D. J. 1990. Changing patterns or patterns of change: The effects of a change in technology on social network structure and power. *Administrative Science Quarterly*, 35: 104-127.
- Burns, J. M. 1978. *Leadership*. New York, NY: Harper and Row.
- Burns, T., & Stalker, G. M. 1961. *The management of innovation*. London: Tavistock.
- Burt, R. S. 1992. *Structural holes*. Boston, MA: Harvard University Press.
- Burton, R. M. 2003. Computational laboratories for organization science: Questions, validity and docking. *Computational and Mathematical Organization Theory*, 9(2): 91-108.
- Carley, K. M. 1990. Group stability: A socio-cognitive approach. In H. Walker (Ed.), *Advances in group processes: Theory & research*, Vol. VII: 1-44. Greenwich, CN: JAI Press.
- Carley, K. M. 1991. A theory of group stability. *American Sociological Review*, 56(3): 331-354.
- Carley, K. M. 1996. Validating computational models: Carnegie Mellon University.
- Carley, K. M. 1999. On the evolution of social and organizational networks. In D. Knoke (Ed.), *Special issue of Research in the sociology of organizations on networks in and around organizations*, Vol. 16: 3-30. Greenwich, CN: JAI Press.
- Carley, K. M. 2002a. Smart agents and organizations of the future. In S. Livingstone (Ed.), *The handbook of new media*: 206-220. Thousand Oaks, CA: Sage.
- Carley, K. M. 2002b. Summary of key network measures for characterizing organizational architectures: Working paper, Carnegie Mellon University.
- Carley, K. M. 2003. Dynamic network analysis. In P. Pattison (Ed.), *Dynamic social network analysis: Workshop summary and papers*: 133-145. Washington D.C.: The National Academies Press.
- Carley, K. M., Diesner, J., Reminga, J., & Tsvetovat, M. 2004. Interoperability of dynamic network analysis software: CASOS Working Paper.
- Carley, K. M., & Gasser, L. 1999. Computational organization theory. In G. Weiss (Ed.), *Multiagent systems: A modern approach to distributed artificial intelligence*: 299-330. Cambridge, MA: The MIT Press.
- Carley, K. M., & Hill, V. 2001a. Structural change and learning within organizations. In E. R. Larsen (Ed.), *Dynamics of Organizations: Computational Modeling and Organization Theories*. Menlo Park, CA: MIT Press/AAAI.
- Carley, K. M., & Kamneva, N. 2004. A network optimization approach for improving organizational design: Carnegie Mellon University, School of Computer Science, Institute for Software Research, International. Technical Report, CMU-ISRI-04-102.
- Carley, K. M., & Newell, A. 1994. The nature of the social agent. *Journal of Mathematical Sociology*, 19(4): 221-262.
- Carley, K. M., & Reminga, J. 2004. ORA: Organizational risk analyzer: Carnegie Mellon University, School of Computer Science, Institute for Software Research, International. Technical Report, CMU-ISRI-04-101.

- Carley, K. M., & Ren, Y. 2001b. **Tradeoffs between performance and adaptability for C3I architectures**. Paper presented at the Command and Control Research and Technology Symposium, Annapolis, MD.
- Carley, K. M., & Svoboda, D. M. 1996. Modeling organizational adaptation as a simulated annealing process. *Sociological Methods and Research*, 25(1): 138-168.
- Castells, M. 1996. The information age: Economy, society and culture, **Volume I: The rise of the network society**, Vol. I. Malden, MA: Blackwell.
- Child, J., & McGrath, R. G. 2001. Organizations unfettered: Organizational form in an information-intensive economy. *Academy of Management Journal*, 44(6): 1135-1148.
- Cormen, T. H., Leiserson, C. E., & Rivest, R. L. 2001. **Introduction to algorithms** (2nd ed.). Cambridge, MA: MIT Press.
- Cross, R., Borgotti, S., & Parker, A. 2001a. Beyond information: Relational content of the advice network. *Social Networks*, 23(3).
- Cross, R., Rice, R., & Parker, A. 2001b. Information seeking in social context: Structural influences and receipt of informational benefits. *IEEE Transactions on Systems, Man and Cybernetics, Part C: Applications and Reviews*, 31(4): 438-448.
- Dalton, D. R., Krackhardt, D. M., & Porter, L. W. 1983. The impact of teller turnover in banking: First appearances are deceiving. *Journal of Bank Research*, 14(3): 184-192.
- Dalton, D. R., Krackhardt, D. M., & Todor, W. D. 1982. Turnover overstated: The functional taxonomy. *Academy of Management Review*, 7(1): 117-123.
- Dalton, D. R., & Todor, W. D. 1979. Turnover turned over: An expanded and positive perspective. *Academy of Management Review*, 4: 225-236.
- Davenport, T. H. 2001. Knowledge work and the future of management. In W. G. Bennis, G. M. Spreitzer, & T. G. Cummings (Eds.), **The future of leadership: Today's top leadership thinkers speak to tomorrow's leaders**: 41-58. San Francisco, CA: Jossey-Bass.
- Davenport, T. H., & Prusak, L. 1997. **Working knowledge: How organizations manage what they know**. Boston, MA: Harvard Business School Press.
- Dertouzos, M. 1997. **What will be: How the new world of information will change our lives**. San Francisco, CA: HarperCollins.
- Diesner, J., & Carley, K. M. 2004. AutoMap1.2 - Extract, analyze, represent, and compare mental models from texts: Carnegie Mellon University, School of Computer Science, Institute for Software Research International, Technical Report CMU-ISRI-04-100.
- Easterbrook, J. A. 1959. The effect of emotion on cue utilization and the organization of behavior. *Psychological Review*, 66: 183-201.
- Edmonds, B. 2001. Against: a priori theory, For: descriptively adequate computational modelling. *Post_Autistic Economics Review*, December(10, December, Article 2).
- Eysenck, H. J. 1967. **The biological basis of personality**. Springfield, IL: Charles C. Thomas.
- Forrester, J. W. 1961. **Industrial dynamics**. Cambridge, MA: MIT Press.

- Freeman, L. C. 1979. Centrality in social networks: I. Conceptual clarification. ***Social Networks***, 1: 215-223.
- Graen, G., & Uhl-Bien, M. 1995. Relationship based approach to leadership: Development of leader-member exchange (LMX) theory of leadership over 25 years: Applying a multi-level, multi-domain approach. ***The Leadership Quarterly***, 6(2): 219-247.
- Graen, G. B. 2003. Role making onto the starting work team using LMX leadership: Diversity as an asset. In G. B. Graen (Ed.), ***Dealing with diversity: LMX leadership: the series***, Vol. 1: 1-28. Greenwich, CT: Information Age.
- Graen, G. B., & Scandura, T. 1987. Toward a psychology of dyadic organizing. In B. Staw, & L. L. Cummings (Eds.), ***Research in organizational behavior***, Vol. 9: 175-208. Greenwich, CT: JAI Press.
- Greenberger, M., Crenson, M., & Crissey, B. 1976. ***Models in the policy process***. New York, NY: Russell Sage Foundation.
- Gronn, P. 2002. Distributed leadership as a unit of analysis. ***Leadership Quarterly***, 13: 423-451.
- Gulick, L. 1937. Notes on the theory of organization. In L. Urwick (Ed.), ***Papers on the science of administration***: 3-13. New York, NY: Institute of Public Administration.
- Hazy, J. K. 2004. ***A leadership and capabilities framework for organizational change: Simulating the emergence of leadership as an organizational meta-capability***. Unpublished dissertation, The George Washington University, Washington, D.C.
- Hazy, J. K. under review. Measuring leadership effectiveness in complex social systems. ***Emergence: Complexity and Organization***.
- Hazy, J. K., & Tivnan, B. F. 2004. ***On building an organizationally realistic agent-based model of local interaction and emergent network structure***. Paper presented at the 2004 Winter Simulation Conference, Washington D.C.
- Hersey, P., & Blanchard, K. H. 1977. ***Management of organizational behavior: Utilizing human resources***. Englewood Cliffs, NJ: Prentice-Hall.
- Hitt, M. A. 1998. Twenty-first-century organizations: Business firms, business schools and the academy. ***Academy of Management Review***, 23(2): 218-224.
- Hitt, M. A., Keats, B. W., & DeMarie, S. M. 1998. Navigating in the new competitive landscape: Building strategic flexibility and competitive advantage in the 21st century. ***Academy of Management Executive***, 12(4): 22-42.
- Holland, J. H. 1995. ***Hidden order***. Reading, MA: Addison-Wesley.
- House, R. J., & Mitchell, T. R. 1974. Path-goal theory of leadership. ***Journal of Contemporary Business***, 3: 81-97.
- Ibarra, H. 1992. Structural alignments, individual strategies, and managerial action: Elements toward a network theory of getting things done. In R. G. Eccles (Ed.), ***Networks and organizations: Structure, form and action***: 165-188. Boston, MA: Harvard Business School Press.
- Ireland, R. D., & Hitt, M. A. 1999. Achieving and maintaining strategic competitiveness in the 21st century: The role of strategic leadership. ***Academy of Management Executive***, 13(1): 43-57.

- Jin, Y., & Levitt, R. E. 1996. The Virtual Design Team: A computational model of project organizations. *Computational and Mathematical Organization Theory*, 2(3): 171-196.
- Johnson, J. C., Boster, J. S., & Palinkas, L. 2003. The evolution of networks in extreme and isolated environments. In P. Pattison (Ed.), *Dynamic Social Network Modeling and Analysis: Workshop Summary and Papers*. Washington D.C.: National Academies Press.
- Kanter, R. M., & Eccles, R. G. 1992. Making network research relevant to practice. In R. G. Eccles (Ed.), *Networks and organizations: Structure, form and action*: 521-527. Boston, MA: Harvard Business School Press.
- Kauffman, S. 1993. *The origins of order*. New York, NY: Oxford University Press.
- Kleijnen, J. P. C. 1995. Verification and validation of simulation models. *European Journal of Operational Research*, 82: 145-162.
- Krackhardt, D. 1987. Cognitive social structures. *Social Networks*, 9: 109-134.
- Krackhardt, D. 1994. Graph theoretical dimensions of informal organizations. In M. Prietula (Ed.), *Computational organizational theory*: 89-111. Hillsdale, NJ: Lawrence Erlbaum.
- Krackhardt, D., & Carley, K. M. 1998. *A PCANS model of structure in organization*. Paper presented at the International symposium on command and control research and technology, Monterrey, CA.
- Krackhardt, D., & Porter, L. W. 1986. The snowball effect: Turnover embedded in social networks. *Journal of Applied Psychology*, 71(1): 50-55.
- Krackhardt, D. M., & Porter, L. W. 1985. When friends leave: A structural analysis of the relationship between turnover and stayers' attitudes. *Administrative Science Quarterly*, 30: 242-261.
- Law, A. M., & Kelton, W. D. 2000. *Simulation modeling and analysis* (3rd ed.). Boston: McGraw-Hill.
- Lazarsfeld, P., & Merton, R. 1954. Friendship as a social process: A substantive and methodological analysis. In C. Page (Ed.), *Freedom and control in modern society*. New York: Octagon.
- Leavitt, H. J. 1951. Some effects of certain communication patterns on group performance. *Journal of Abnormal and Social Psychology*, 46: 38-50.
- Lee, J.-S., Schreiber, C., & Carley, K. M. forthcoming. Validation and docking of two organizational simulations using dynamic team performance data. In H. A. H. Handley (Ed.), *Team design and analysis: The adaptive architectures project*. Boston, MA: Kluwer Academic Publishers.
- Levitt, R. E., Cohen, G. P., Kunz, J. C., Nass, C. I., Christiansen, T., & Jin, Y. 1994. The 'Virtual Design Team': Simulating how organization structure and information processing tools affect team performance. In M. J. Prietula (Ed.), *Computational organization theory*: 1-18. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Lin, Z., & Carley, K. M. 2003. *Designing stress resistant organizations: Computational theorizing and crisis applications*. Boston, MA: Kluwer Academic Publishers.
- March, J. G. 1996. Exploration and exploitation in organizational learning. In L. S. Sproull (Ed.), *Organizational learning*. Thousand Oaks, CA: Sage.
- Marion, R., & Uhl-Bien, M. 2001. Leadership in complex organizations. *The Leadership Quarterly*, 12(4): 389-418.

- Matthews, G., Davies, D. R., Westerman, S. J., & Stammers, R. B. 2000. ***Human performance: Cognition, stress and individual differences***. East Sussex, UK: Psychology Press.
- McCurdy, H. E. 2001. ***Faster, better, cheaper: Low-cost innovation in the U.S. space program***. Baltimore, MD: The Johns Hopkins University Press.
- McGrath, J. E. 1976. Stress and behavior in organizations. In M. D. Dunnette (Ed.), ***Handbook of industrial and organizational psychology***: 1351-1395. Chicago, IL: Rand McNally.
- McGrath, R. G. 2001. Exploratory learning, innovative capacity, and managerial oversight. ***Academy of Management Journal***, 44(1): 118-131.
- McKelvey, B. 2006. MicroStrategy from MacroLeadership: Distributed intelligence via new science. In A. Y. Lewin, & H. Volberda (Eds.), ***Mobilizing the self-renewing organization***. Armonk, NY: M. E. Sharp.
- Mechanic, D. 1962. Sources of power of lower participants in complex organizations. ***Administrative Science Quarterly***, 7: 349-364.
- Miles, R. E., & Snow, C. C. 1986. Network organizations: New concepts for new forms. ***California Management Review***, 28: 62--73.
- Mobley, W. H. 1977. Intermediate linkages in the relationship between job satisfaction and employee turnover. ***Journal of Applied Psychology***, 62: 237-240.
- Nohria, N. 1992. Is a network perspective a useful way of studying organizations? In R. G. Eccles (Ed.), ***Networks and organizations: Structure, form and action***: 1-22. Boston, MA: Harvard Business School Press.
- Nohria, N., & Eccles, R. G. 1992. Face-to-face: Making network organizations work. In R. G. Eccles (Ed.), ***Networks and organizations: Structure, form and action***: 288-308. Boston, MA: Harvard Business School Press.
- Nonaka, I., & Takeuchi, H. 1995. ***The knowledge creating company: How Japanese companies create the dynamics of innovation***. New York, NY: Oxford University Press.
- Osborn, R. N., Hunt, H. G., & Jauch, L. R. 2002. Toward a contextual theory of leadership. ***Leadership Quarterly***, 13: 797-837.
- Perrow, C. 1992. Small-firm networks. In R. C. Eccles (Ed.), ***Networks and organizations: Structure, form and action***: 445-470. Boston, MA: Harvard Business School Press.
- Perrow, C. 1999. ***Normal accidents: Living with high-risk technologies***. Princeton, NJ: Princeton University Press.
- Pfeffer, J. 1981. ***Power in Organizations***. Marshfield, MA: Pitman.
- Pierce, C. L., & Conger, J. A. 2003. All those years ago: The historical underpinnings of shared leadership. In C. L. Pierce, & J. A. Conger (Eds.), ***Shared leadership: Reframing the hows and whys of leadership***: 1-18. Thousand Oaks, CA: Sage.
- Podolny, J. M., & Page, K. L. 1998. Network forms of organization. ***Annual Review of Sociology***, 24: 57-76.
- Powell, W. W. 1990. Neither market nor hierarchy: Network forms of organization. In L. L. Cummings (Ed.), ***Research in Organizational Behavior***, Vol. 12: 295-336. Greenwich, CT: JAI.

- Powell, W. W., Koput, K. W., & Smith-Doerr, L. 1996. Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly*, 41(1): 116-145.
- Price, J. L. 1977. *The study of turnover*. Ames, Iowa: The Iowa State University Press.
- Prusak, L. 1996. The knowledge advantage. *Strategy and Leadership*, 24: 6-8.
- Regine, B., & Lewin, R. 2000. Leading at the edge: How leaders influence complex systems. *Emergence: A Journal of Complexity Issues in Organizations and Management*, 2(2): 5-23.
- Ronfeldt, D., & Arquilla, J. 2001. Networks, netwars and the fight for the future. *First Monday*, 6(10).
- Sampson, F. 1968. *A novitiate in a period of change: An experimental and case study of social relationships*. Unpublished Doctoral dissertation, Cornell University.
- Sargent, R. G. 1998. *Verification and validation of simulation models*. Paper presented at the 1998 Winter Simulation Conference, Washington, D. C.
- Schreiber, C., & Carley, K. M. 2004a. Going beyond the data: Empirical validation leading to grounded theory. *Computational and Mathematical Organization Theory*, 10(2): 155-164.
- Schreiber, C., & Carley, K. M. 2004b. *Key Personnel: Identification and assessment of turnover risk*. Paper presented at the 2004 NAACSOS conference proceedings, Pittsburgh, PA.
- Schreiber, C., Singh, S., & Carley, K. M. 2004c. 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.
- Simon, H. A. 1947. *Administrative behavior*. New York, NY: Free Press.
- Smith, A. T. 2004. Complexity theory and change management in sport organizations. *Emergence: Complexity & Organization*, 6(1-2): 70-79.
- Sparrowe, R. T., & Liden, R. C. 1997. Process and structure in leader-member exchange. *Academy of Management Review*, 22: 522-552.
- Staw, B. M. 1980. The consequences of turnover. *Journal of Occupational Behavior*, 1: 253-273.
- Staw, B. M., Sandelands, L. E., & Dutton, J. E. 1981. Threat rigidity effects in organizational behavior: A multilevel analysis. *Administrative Science Quarterly*, 26(4): 501-524.
- Steers, R. M., & Mowday, R. T. 1981. Employee turnover and post-decision accommodation processes. In B. M. Staw (Ed.), *Research in organizational behavior*, Vol. 3: 235-282. Greenwich, CT: JAI Press.
- Sterman, J. D. 2000. *Business dynamics: Systems thinking and modeling for a complex world*. Boston, MA: Irwin McGraw-Hill.
- Stewart, T. A. 1997. *Intellectual capital: The new wealth of organizations*. New York, NY: Doubleday.
- Stogdill, R. M. 1948. Personal factors associated with leadership: A survey of the literature. *Journal of Psychology*, 25: 35-71.
- Streatfield, P. J. 2001. *The paradox of control in organizations*. London: Routledge.
- Sunoo, B. P. 1998. Employee turnover is expensive. *Workforce*, 77(7): 19.

- Tannenbaum, R., & Schmidt, W. H. 1958. How to choose a leadership pattern. **Harvard Business Review**, 36(2): 95-101.
- Tsvetovat, M., Reminga, J., & Carley, K. M. 2004. DyNetML: Interchange format for rich social network data: Carnegie Mellon University, School of Computer Science, Institute for Software Research International, Technical Report CMU-ISRI-04-105.
- Turnley, J. G. 1995. **Validation issues in computational social simulations**. Paper presented at the 3rd Lake Arrowhead Conference on Human Complex Systems, Lake Arrowhead, CA.
- Uhl-Bien, M., Marion, R., & McKelvey, B. 2004. Complexity leadership theory: Shifting leadership from the Industrial Age to the Knowledge Era. New Orleans, LA: Presentation at the *Academy of Management*.
- Uzzi, B. 1996. The sources and consequences of embeddedness for the economic performance of organizations: The network effect. **American Sociological Review**, 61(4): 674-698.
- Uzzi, B. 1997. Networks and the paradox of embeddedness. **Administrative Science Quarterly**, 42: 35-67.
- Vroom, V. H., & Yetton, P. W. 1974. **Leadership and decision-making**. New York: Wiley.
- Wall, S. D. 1999. Reinventing the design process: Teams and models: NASA, Jet Propulsion Lab. Technical Report 99-0379.
- Wasserman, S., & Faust, K. 1994. **Social network analysis: Methods and applications**. Cambridge, UK: Cambridge University Press.
- Weick, K. E., & Sutcliffe, K. M. 2001. **Managing the unexpected: Assuring high performance in an age of complexity**. San Francisco, CA: Jossey-Bass.
- Wheatley, M. J. 1999. **Leadership and the new science** (2nd ed.). San Francisco, CA: Berrett-Koehler.
- Yammarino, F. J. 1994. Indirect leadership: Transformational leadership at a distance. In B. M. Bass, & B. J. Avolio (Eds.), **Improving organizational effectiveness through transformational leadership**: 26-47. Thousand Oaks, CA: Sage.
- Zaccaro, S. J., & Klimoski, R. J. 2001. The nature of organizational leadership: An introduction. In S. J. Zaccaro, & R. J. Klimoski (Eds.), **The nature of organizational leadership: Understanding the performance imperatives confronting today's leaders**: 3-41. San Francisco, CA: Jossey-Bass.