Building Bridges: A Study of Coordination in Projects

by

Libby Marie Hemphill

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Information)
in The University of Michigan
2009

Doctoral Committee:

Research Associate Professor Stephanie D. Teasley, Chair
Professor Michael D. Cohen
Associate Professor Barry J. Fishman
Associate Professor Curtis D. LeBaron, Brigham Young University

Dedication

To my family, for everything

Acknowledgements

It took a village to raise this dissertation, and I am indebted to my colleagues, friends, and family for their help and support.

My dissertation committee members have been crucial to my training. Since our first phone call about research at the School of Information more than seven years ago, Stephanie Teasley has encouraged and mentored me. She provides an excellent model of a balanced woman in academia, and I am grateful for her continued support. Michael Cohen has inspired me as both a scholar and a teacher (I don't mean to put scholarship and teaching at odds, but rather to single them each out for recognition), and I am lucky to have received his guidance and attention. He challenges me to be more clear and careful, and my work is better for it. Curtis LeBaron taught me to see data in new ways and to appreciate my own writing style. His incredibly supportive and encouraging correspondence during the writing of this dissertation was invaluable. Barry Fishman has been showing me that scholarship can be both fun and rigorous since my first year at SI. I am indebted to him for helping me stay grounded and accountable to the field of Information.

I am honored to have worked with the members of the WAB Project. They welcomed my curiosity and spent hours answering my questions and showing me their work. I especially thank "Mark" who introduced me to other project members and took all of my calls and questions. His enthusiasm for ECC is contagious, and I wish him the best. The National Science Foundation made their work and mine possible, and I appreciate the hard work the NSF officers endure so that we may continue our research. Interviews with engineers outside the WAB Project were crucial to my understanding of construction projects, and I am grateful to those participants for their time and attention.

To the Bleary Theorists, I owe my sanity and some of the good ideas in this dissertation. They allowed me to avoid struggling in silence, and their insights about my work were valuable and quite welcome. To Eric Cook, Jude Yew, Emilee Rader, Rick Wash, and Jenn Thom-Santelli especially, my sincerest thanks – for reading my drafts, for writing jams, for breaks, fried food, laughter, and beer. This endeavor would have been nearly impossible without them. Brian Hilligoss is a recent addition to the Bleary Theorists, and I appreciated his help interviewing for this study. Special thanks also go to Dr. David Ribes and Jina Huh for their help analyzing the email data thread in section 4. B. 1.

I have been lucky to be surrounded by wonderful, smart, fun friends throughout this project. To my friends from Spencer who have remained close and some of whom are also writing their dissertations, to the Thetas who encourage me even at my nerdiest, and to the Chicagoans who provide an escape and the most entertaining email a girl could receive, thank you. My friends in Ann Arbor have provided an incredibly safe and happy a place for me to live and work, and I am indebted to them for helping me stay grounded throughout this ordeal. I am particularly grateful to Jolie Valentine for reading this whole thing and providing helpful comments and encouragement. My kind, understanding, and entertaining roommates, Molly Kleinman and Jason Young, also deserve special thanks for living with me through the roughest patches of my dissertation. I could not have asked for a better home during the final push. I was also fortunate to have Naomi Goldberg's support and care; thank you for believing in me and helping take care of the non-dissertation parts of my life.

My family has never wavered in their support. I am blessed to have such loving and helpful parents, Don and Judy, and Ben, the most reassuring big brother. You have always given me the freedom and means to explore the world and to satisfy my curiosity. Who knew I'd take it this far? For listening to me ramble as I figured out just what I was studying, for taking me on vacation, for being proud of me, thank you. I am also grateful to my grandmothers, Virginia and Doris, and my extended family for their supportive letters and laughter and for always believing I could do it.

Finally, thank you to the many reference librarians who have helped me via "Ask Us" and the reference desk. May all researchers be lucky enough to find and to trust you; you ease much of the pain from research and writing.

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

In the fall of 2005, drivers began crossing over Interstate 94 on a new kind of bridge. The bridge beneath them looked nearly the same as other bridges that carried city streets over the Interstate, but this bridge could bend. It couldn't bend like Gumby, but it could bend like steel. Building the deck of this bendable bridge – the Woods Avenue Bridge (WAB) – involved a state department of transportation, a university research lab, and several private contractors. This dissertation uses the project to build this bridge as a case study to explore coordination in collaborative projects; it explains how the team managed to collaborate with new colleagues and to build a bridge with a remarkable new kind of deck.

We take the products of construction projects for granted – e.g., bridges, roads, sidewalks, and office buildings. The work required to build a bridge, besides that which we can witness while driving by a construction site, goes largely unseen. The materials used in bridge construction seem mundane – steel, concrete, water. A bridge construction project can be understood to involve the integration of materials, expertise, and effort from many different areas. In the case of the WAB, engineers, contractors, designers, inspectors, and suppliers worked for over two years to produce a bridge with a novel deck. The seemingly mundane materials and unseen work produced a bridge that can withstand years of heavy traffic and extreme temperature changes.

I had the opportunity to study the WAB Project after its completion. I was able to read and analyze documents the project team created during and after the project and to interview members of the project team. This dissertation is situated in the context of bridge construction research, but the behaviors I observed relate to a broader range of collaborative activity. In this dissertation I do not report on the entire process of designing and building the WAB. Instead, I use the context of my broader observations to inform a better understanding of the work involved in coordinating collaborative endeavors.

At its heart, the team that built the WAB was a project – a temporary collaborative arrangement undertaken to build a specific product (see Duncan, 1996; C. Jones & Lichtenstein, 2008). I use data from the WAB Project to further develop the concept of "adaptive capacity." Adaptive capacity refers to the accumulated abilities of a group to adjust their work to manage uncertain and unpredictable changes in their environment (see Parsons, 1964; Staber & Sydow, 2002). The WAB Project involved changes in materials and personnel, and, according to Annie, an experienced crew chief[1], all construction projects encounter a number of unexpected changes that demand coordination work (Annie, 05/09).

The term "projects" refers to temporary endeavors to create a product or service (Duncan, 1996). Multiple organizations collaborate for a limited time in interorganizational projects (C. Jones & Lichtenstein, 2008), and such arrangements are used in construction (Bryman, Bresnen, Beardsworth, Ford, & Keil, 1987; Eccles, 1981), biomedical research (Teasley, Schleyer, Hemphill, & Cook, 2008), engineering (Birnholtz, 2007), and film (Bechky, 2006; C. Jones, Lichtenstein, Borgatti, Hesterly, & Tallman, 1998), among other industries. The WAB Project was a construction project with a twist – the materials used in the

[1] Crew chiefs are MDOT or county employees who are responsible for surveys and survey-related tasks during construction. For instance, crew chiefs oversee the staking of site layouts. Crew chiefs may be involved with many sites at once, and they interact with contractors and site supervisors at each site.

bridge’s deck had never been used in a production scale structure in the United States. The WAB’s deck is made, in part, of engineered cementitious composite (ECC), a material specially designed to afford ductility in concrete.

ECC is an umbrella term for many types of fiber-reinforced concrete that are micro-mechanically engineered and contain short, randomly distributed fibers. Concrete typically includes four ingredients – water, sand, stone, and cement. Fiber reinforcement in concrete is not a new idea. For instance, on any drive during road construction season we can see crews building steel-reinforced concrete roads. Asbestos was a popular concrete reinforcement fiber used in the early 1900’s; horse hair and mud combinations predated even asbestos. ECC differs from other fiber reinforcement approaches by specifying all elements of the concrete mix – fiber, matrix, and interface. Fiber specifies the type, size, and concentration of fibers in the mix. Matrix refers to the crystalline matrix that cement and water create and that holds together the sand and stone. Interface refers to the point of contact between the fiber and the matrix – where the fiber “sticks.” ECC mixes specify particular kinds of fiber, matrix, and interface to be used, and they rely on micro-mechanical models that relate properties of the elements of the mix to responses of the final product. Dr. Wang, the director of the MRL and inventor of ECC, describes this as “relating constituent properties to composite response” (Dr. Wang, 11/08).

The properties of ECC that make it desirable – mainly its durability and ductility – result from the dispersion of material components throughout the final mix. The theories underlying bendable concrete assume various distributions of mix components, and mix recipes are finely tuned to produce desired levels of ductility and durability. The ECC link slab in the WAB replaced a mechanical joint in the WAB, and the result is a jointless bridge deck. Jointless bridges last longer, require less maintenance, are less expensive to build, and perform better than traditional bridges (Kalousdian, 2006). However, because the climate where the bridge was built has such a pronounced freeze-thaw cycle, jointless bridges are not popular there – bridges in the Midwest need to be able to expand and contract with the weather, and jointless bridges of traditional concrete suffer fatal cracking under such conditions.

The WAB project involved members of the Michigan Department of Transportation (MDOT), a state government's transportation department; academic researchers from a materials research lab (MRL) at a large public research university; and a variety of construction contractors and material suppliers. Those who worked on the WAB Project had varying degrees of familiarity and experience with the materials, processes, and personnel involved in the project. The project included experts in construction research management, concrete mixing, form building, contract bidding, materials research, structural engineering, construction project management, and the list goes on. When the project began, no one knew whether any of the people or new technologies being employed would be used again.

Because projects are an increasingly common organizational structure (T. W. Malone, 2004), it would be useful for us to better understand how they work. Earlier research on projects and other collaborations emphasizes the importance of coordination in ensuring success (Cummings & Kiesler, 2003). The WAB Project provides an opportunity to examine coordination more closely. Literature suggests that connections among actors (e.g., Dourish & Bly, 1992; C. Jones & Lichtenstein, 2008; W. Powell, White, Koput, & Owen-Smith, 2005) and communication (e.g., Al-Ani & Edwards, 2008; Fussell et al., 1998; Hinds & Mortensen, 2005) are important for coordination. What's missing are explanations of *how* connections and communication matter – what coordination work they afford. I propose that *adaptive capacity* is a useful way to understand the set of abilities groups develop by building connections and communicating; adaptive capacity tells us how those connections and communications help us accomplish coordination – by giving groups the ability to adapt.

Successful coordination is crucial for successful collaboration (Cummings & Kiesler, 2005; Sonnenwald, 2007). In construction, for instance, the work demands that the right equipment (e.g., concrete mixing truck) carrying the proper materials (e.g., ECC) be available during a small window of time (e.g., before the ECC gets too dry to pour). Meanwhile, that same equipment is used on other jobs in other locations. The personnel involved in the WAB Project were multitasking as well: the researchers were continuing their laboratory studies of advanced ECC materials; MDOT was overseeing a season of road repair; and each contractor was responsible for at least one other project at the same time.

Existing literature tells us that coordination is important and difficult (Sonnenwald, 2007) but does not explain how coordination work is accomplished. Coordination models fail to account for contingencies in collaborative activity (March & Simon, 1993). This dissertation builds on this earlier research and enhances our understanding of coordination work by explaining how interactions in face-to-face meetings, contractual documents, and positive affect may have helped the WAB Project team develop the ability to adapt to changes in its environment. I call this set of abilities to make adjustments *adaptive capacity*, and the concept helps understand what about teams enables them to successfully make the adjustments necessary to accomplish their coordinative work. Though I rely here on data from a single case of collaborative activity, the concept of adaptive capacity is useful more generally in helping us understand what capabilities teams develop that enable them to work together effectively.

In order to develop the concept of adaptive capacity, I use data from WAB Project meeting notes and minutes and interviews with WAB Project members and other engineers. Before discussing the WAB Project data, I review literatures on projects, collaboration, and practice that suggest a number of challenging aspects of collaborative projects. I employ related research on social networks and social capital to discuss information flow and social relationships within collaborations and how those flows influence coordination. I then use those literatures and data from the WAB Project to further develop the concept of adaptive capacity so that we may better understand how coordination work is accomplished in collaborative projects.

1. A. Why Collaborate at All?

We collaborate because some problems are too big for a single organization to solve, and some problems require knowledge that a single organization does not possess. For example, microbiologists do not study the human body and so may not know how a certain microbe will affect it. Similarly, immunologists may not know about a particular microbe's properties or ways to manipulate it. When microbiologists, who know how to manipulate microbes, work with immunologists, who know about how the body reacts, the two disciplines can create a collaboration with complementary expertise that enables them to address the problem of terrorists' use of anthrax by creating a vaccine that protects human bodies from infection. However, successful collaboration requires compromise and presents challenges of communication and coordination not found in individual work (Sonnenwald, 2007). Prior research has examined the influence of factors such as face-to-face interaction (J. S. Olson, Teasley, Covi, & Olson, 2002; Schunn, Crowley, & Okada, 2002), collaborative technology (Ackerman, 1998; G. M. Olson & Olson, 2000), organizational structure (Bryman et al., 1987; Corley, Boardman, & Bozeman, 2006), motivation to collaborate (Birnholtz, 2007; Teasley & Wolinsky, 2001), and coordination efforts (Bechky, 2006; Cummings & Kiesler, 2005; Sonnenwald, 2007) on collaborations.

Interorganizational collaborations of varying sizes and durations have been employed to address a number of contemporary problems including terrorists' use of anthrax and the U.S. banking crisis of 2008. These collaborations bring together experts from a number of fields (e.g. immunology and microbiology) or firms (e.g. the Department of Treasury and JPMorgan Chase) to solve a specific problem or to provide some strategic advantage over single discipline or single firm offerings. Interorganizational collaborations, including projects, often involve entities that possess different expertise. A better understanding of how project-based collaborations among different kinds of experts can be successful would enable us to develop effective collaborative structures and strategies.

Small and medium enterprises are often engaged in subcontracting relationships that mirror the structure of familiar projects such as films and bridges; networked relationships allow organizations to enter niche markets and join cooperative ventures (Castells, 2000) that they cannot reach on their own. Especially as the number of projects in organizations increases, understanding the work involved in successful projects is important.

In summary, individuals and organizations collaborate to tackle problems too large for a single individual or team and to leverage expertise outside their own (W. W. Powell, Koput, & Smith-Doerr, 1996).

1. B. Why Study Projects?

Loosely-coupled, short-term endeavors are increasingly common in many organizations. Projects produce films, houses, concept cars, and many other new products. Project structures vary across organizations but share a few common elements; for instance, they are temporary and collaborative. Prior studies of projects tell us how they impact individuals' careers (C. Jones, 1996), how organizations pursue remarkably new products (Obstfeld, 2009), and how struggles for power and responsibility influence our ability to get new things done (M. Loosemore, 1999). Projects are becoming increasingly important to the growth and competitiveness of firms and other organizations (Davies & Hobday, 2005; T. W. Malone, 2004). The WAB Project provides an opportunity to explore a collaborative project in detail.

1. C. Using and Contributing to an Information Perspective

Within the field of information, many of our studies of collaboration focus on the technologies used to facilitate collaboration (e.g., Finholt, 2002; G. M. Olson & Olson, 2000), but we also explore the social aspects of collaborative work (e.g., Lee, Dourish, & Mark, 2006; Palen & Grudin, 2002). Regardless of the primary focus, though, information studies of collaboration explore both social and technical aspects of collaborative work. My dissertation fits within the larger field of information because of (1) the methods I employ – analysis of information artifacts and participant interviews – and (2) the phenomenon I endeavor to understand – collaborative work.

We in information are promiscuous in the areas in which we study collaboration, whether in biomedical research (Teasley et al., 2008), high-energy physics (Birnholtz, 2007), software engineering (Fussell et al., 1998), or, now, construction. Conducting research in so many different areas helps us to develop concepts that cross disciplinary and practice boundaries – such as "coordination." Our findings inform the design of information systems, use and re-use of information artifacts, and structure and policies in collaborative arrangements.

My dissertation continues the line of information research on collaboration, and my findings contribute to our understanding of the work involved in supporting collaboration. My findings will be useful for designing both collaborations and, potentially, the technologies that support them. In this document, I will focus primarily on the social aspects of collaboration and will save a more technical discussion for my future work.

I. D. Terms Used Through this Document

Before I proceed to describe the WAB Project and the study I conducted, I wish to define a number of terms that will be used throughout this document. I have approached the project from specific theoretical backgrounds that use seemingly familiar terms such as "work" in very specific ways; I define my use of those terms to allow for a more precise discussion and to eliminate potential confusion. Important threads in these definitions are the ideas of agency and process; my study looks at activity and necessarily focuses on the changing nature of the work under examination. The definitions I use for these words imply an emphasis on processes and change.

I. D. I. Work

Work is both a noun and a verb, and I will use it both ways: some*thing* that was done and to *do* something. This definition is intentionally vague. It is impossible for me to know *a priori* what in the WAB Project counts as work. In fact, one of the main goals of this dissertation is to describe what "somethings" were done in that project. Work is the product of an actor's agency; actors do work. Work also implies effort – work requires that some entity expend effort to achieve a purpose. I will be able to identify work by tracing actors in networks.

1. D. 2. Collaboration

Like work, *collaboration* will take on a number of meanings. Collaboration is especially tricky because the "-tion" ending can signal both a process and a product. In this dissertation, collaboration will refer both to the process of collaborating and the product of collaborative activities. When talking about processes, I focus on collaborations in which participants are oriented toward the production of a common outcome.

1. D. 3. Coordination

When I refer to coordination, I mean "the organization of different elements of a complex body or activity so as to enable them to work together effectively" (Oxford English Dictionary, 1996). Malone and Crowston (1994) offer an inclusive definition of coordination – "coordination is managing dependencies between activities" (p. 90) – and a long list of other similar definitions. So, when literature uses the term "coordination," it generally refers to management that enables effective work.

1. D. 4. Adaptive Capacity

Researchers who study climate change and other external stresses on ecosystems use the concept of adaptive capacity to indicate a system's relative vulnerabilities (e.g., Yohe & Tol, 2002). Similarly, research on organizations uses the concept to describe an organization's abilities to respond to external stresses such as market pressure (e.g., Staber & Sydow, 2002). Throughout this document, I will further develop the concept of adaptive capacity to refer to the capabilities a team develops that allows them to adjust to both internal and external changes. My use of the concept extends both the ecological and organizational uses by emphasizing the team's agency and including internal changes in its purview.

1. E. Research Context

The WAB Project was the second of three projects that involved the research arm of MDOT and the Materials Research Lab (MRL) group of academic researchers. Beginning in 2001, MDOT and MRL conducted a laboratory research project to develop a theoretical design of a structure that would incorporate ECC. The major deliverables of that first project were the calculations necessary for the design of a production scale bridge deck and a 1:5 scale model bridge deck.

MDOT and MRL agreed in 2004 to conduct a research demonstration project to replace an aging bridge deck with an ECC deck. This research demonstration project became the WAB Project and is the focus of this dissertation. During the first year of the WAB Project, the team focused on site selection and deck redesign, and the bridge deck construction was completed in the fall of 2005. Data collected from tests conducted on the finished deck revealed small problems with the material, and MDOT and MRL conducted a third research project to reduce early-age cracking in ECC. The eventual goal of these research projects is to find ways to include ECC in MDOT's regular contracts and structures.

My involvement with the WAB Project came after the bridge deck was completed. Beginning in the fall of 2007, I was a graduate student research assistant on a grant where investigators on the WAB Project and my advisors in the School of Information were Co-PIs. Through that grant, I was introduced to the academic researchers who invented ECC, and my dissertation grew out of my repeated interactions with those researchers. I was originally interested in how ECC would influence the practices of bridge designers and builders. However, my initial interviews revealed that while designers were excited about the affordances ECC provides, they did not claim that working with the material required radical changes in their practice. Those interviews did highlight the surprises participants encountered when collaborating with people whose work differed dramatically from their own. For instance, a civil engineering researcher recounted the new considerations a concrete contractor made him address about using bendable concrete: a researcher needn't worry about how bendable concrete affects the mechanics of a concrete truck because concrete trucks are not part of his normal practice. For a concrete contractor, how a material interacts with his truck is a $300,000 question – if the material damages his truck, he may have to spend that much to replace it. My early interview participants were curious about how the WAB Project managed to address these varying concerns and differing goals; I shared their curiosity and used this dissertation as an opportunity to explore coordination in the WAB Project.

My interview participants and literature on construction projects repeatedly emphasized that unexpected events happen often in construction projects. Because I am interested in coordination – how groups cope with unexpected events (T. W. Malone & Crowston, 1994) – studying a construction project offered me a chance to study many unexpected events within a single project. Construction project participants knowingly and actively engage in coordination often, and this dissertation explores how the WAB Project members accomplished coordination effectively enough to build their bridge.

1. F. Summary

This dissertation is organized into seven chapters. In this chapter, I introduced the WAB Project and the concepts of adaptive capacity and coordination. I explained that the WAB Project gives us an opportunity to explore many moments of coordination in order to understand how it is accomplished in collaborative projects. As we increasingly engage in collaborative activities to address large problems and develop new products and technologies, it will behoove us to understand how to work together more effectively. Coordination is just one piece of effective collaborative work, and the rest of this dissertation will help us better understand coordination as it happened in the WAB Project and what we can learn from that project.

In chapter 2, I review related literature about projects, collaboration, innovations, and coordination. In chapter 3, I describe the methods of data collection and analysis I used to study the WAB Project. Chapter 4 explores the documents and meetings that the WAB Project team created and attended during the project. In chapter 5, I present data from interviews with WAB Project participants and other engineers conducted after the bridge was completed. Chapter 6 develops the concept of adaptive capacity to describe how social and adaptive aspects of a project enable coordination. In chapter 7, I summarize my findings, their implications, and provide some ideas for future research.

The goal of this dissertation is to understand how one project managed the tensions between collaborators, the challenges of using innovative materials, and effectively coordinated its work. Data from the WAB Project informs a theoretical concept for interpreting the work involved in coordinating collaborative activities – *adaptive capacity* – a concept that can be applied in other examinations of collaboration and collaborative projects to help us understand how those collaborative teams coordinate their work.

Chapter 2

Related Literature

Prior studies of projects focus on how projects are structured, how frequently projects occur, and propose factors that influence projects' effectiveness. Collaboration literature indicates that professional boundaries, coordination of group work, and social capital influence collaborative activity. In construction, literature suggests that procurement and project management are the major factors that influence the success of projects. Here I review these independent literatures and identify a subset of factors that are common among these literatures and that potentially impact collaborative projects.

Besides the obviously related literature on construction projects, I include discussions of communities of practice, collaboratories, and interorganizational collaborations because those literatures provide insight into the WAB Project as well. Even though the WAB Project was temporary and established new relationships, the people involved are all members of communities of practice and enter projects with their own community of practice "baggage," such as routines and values. Collaboratory research helps us understand how scientists are able to collaborate beyond the walls of their laboratory; the civil engineering researchers in the WAB Project were central members of the project, and understanding their work requires that we look to studies of science and research rather than only to studies of industrial activity. Interorganizational collaboration literature tells us something about the organizational contexts in which projects happen; for instance, understanding how organizations make choices about what goals to pursue may help us understand why MDOT would work with academics in the first place.

2. A. Adaptive Capacity and Perspectives on Organizational Adaptation

The concept of adaptive capacity provides a new way of thinking about how organizations, especially collaborative projects, accomplish coordination work. Adaptation and adjustment have always been necessarily in collaborative endeavors. Failure in projects is, at some level, the inability to appropriately adapt to an unfamiliar or unexpected scenario. Successful projects recognize and adapt to surprises.

Prior research on adaptive capacity in organizations emphasizes the continued development and application of new knowledge in order to compete (e.g., Hanssen-Bauer & Snow, 1996). The capacity to adapt is a theme in discussions of organizational change, but it is often subsumed by a discussion of strategy or management more broadly. For instance, when reporting on a study of a learning network established to help small- and medium-sized firms increase their management and adaptive capacity, Hanssen-Bauer and Snow (1996) quickly drop "adaptive" from their discussion and focus only on "management capacity." Like Hanssen-Bauer and Snow, other discussions of adaptation and adaptive capacity emphasize the strategic impacts of adaptive capacity in firms (Chakravarthy, 1982; Staber & Sydow, 2002). In this literature, adaptive capacity is described as an approach to management and contrasted with "adaptation."

Literature on sustainability and the natural environment uses the term "adaptive capacity" differently – to refer to a property of social-ecological systems. For instance, Folk and colleagues (2002) discuss adaptive capacity in terms of a system's ability to adjust. They use examples from the Everglades and the Grand Canyon to describe how actively managing water resources influenced the ability of these social-ecological systems to adapt to changes in the ecosystem such as habitat loss. In this social-ecological literature, as in organizational literature, discussions of adaptive capacity are wrapped in broader discussions of management generally. These literatures suggest that adaptive capacity is something for which managers and management should aim.

In the Report of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the authors list six features of communities that determine their adaptive capacity: economic wealth, technology, information and skills, infrastructure, institutions, and equity (Smit et al., 2001). Communities "with limited economic resources, low levels of technology, poor information and skills, poor infrastructure, unstable or weak institutions, and inequitable empowerment and access to resources have little capacity to adapt" (Smit et al., 2001, p. 879). The IPCC report is about the adaptability of communities to climate change, but their discussion of adaptive capacity may have broader relevance for us as we try to understand what features of a project afford it adaptive capacity. In climate studies, adaptive capacity usually refers to "systems' abilities to handle external stress" (Yohe & Tol, 2002, p. 25). Organizational literature was similarly outward-facing – focusing on stresses from beyond the boundaries of the organization. When I discuss adaptive capacity, I will mean a group's ability to adjust to changes both within and beyond its boundaries.

Another concept that is related to adaptive capacity is *resilience*, the maintenance of positive adjustment under challenging conditions (Hollnagel, Woods, & Leveson, 2006, pp. 3-4). Resilience comes from a positive approach to studying organizations – instead of focusing on failure and rigidity, resilience emphasizes the ability of organizations to bounce back when battered by external stresses. Just as the ecological and organizational literature referenced earlier was outward-facing, so is resilience. These approaches emphasize how organizations respond to pressures beyond their boundaries and often use competitive imagery such as "threat," "danger," and "bounce back" to describe the organization's environment and goals. These discussions conjure up an image of an organization as soldier, avoiding threats from his enemies, bravely bouncing back when injured. These concepts emphasize the ability of an organization to successfully compete with other organizations and to continue to exist.

2. A. 1. Building on Adaptive Capacity

Adaptive capacity offers an alternative perspective on coordination and collaboration that is especially useful for projects. Projects, unlike other organizational structures, are temporary. They are not meant to last forever. Because projects are temporary, whether or not a project team completed the service or product it set out to produce is a better measure of the project's success than is its survival.

Focusing on the external environment also limits the usefulness of an adaptation perspective for projects. This perspective assumes that the internal struggles of an organization are familiar or expected and that only the external environment presents challenges. For projects, and likely for new organizations, the internal/external divide is unclear at best. Projects bring together new constellations of actors who may or may not have worked together before. For projects, many scenarios are unfamiliar or unexpected because the people and work involved are unfamiliar.

An adaptive capacity perspective, as I develop it, is useful for thinking about how project teams develop the abilities to work together despite the fuzzy divide between internal and external environment, despite their temporary nature. This perspective emphasizes the agency exercised by the project team in adjusting to their new, unfamiliar colleagues and tasks. Adaptive capacity is not about competing or bouncing back but about adjusting and adapting to move toward a goal. Using an adaptive capacity perspective allows us to escape the language of battle so frequently used to discuss organizational behavior. Instead of "dangers," we can think of "opportunities to adjust;" instead of "bouncing back," we can think of "moving forward." An adaptive capacity perspective treats all scenarios that require change or adjustment the same, whether the reason for the change comes from within or outside the project. Adaptive capacity serves as a conceptual tool for understanding how coordination is accomplished in

Table 2-1. Labels for various kinds of assemblages of workers

Label or concept to denote a particular kind of collaboration	Definitions and sources
Community of practice	"an activity system about which participants share understanding concerning what they are doing and what that means in their lives and for their community. Thus, they are united in both action and in the meaning that that action has, both for themselves, and for the larger collective" (Lave & Wenger, 1991, p.98)
Network of practice	a network in which people share the same practice but have little need to coordinate their work (Brown & Duguid, 1991; Brown & Duguid, 2001)
Interorganizational collaboration	a broad term to denote various types of interfirm alliances including, but not limited to, research and development partnerships, equity joint ventures, collaborative manufacturing, and complex co-marketing arrangements (W. W. Powell et al., 1996)
Collaboratory	a computer-supported system that allows scientists to work with each other, facilities, and databases without regard to geographical location (Finholt, 2003)
Project	"temporary endeavor undertaken to create a unique product or service" (Adler & Obstfeld, 2007, p. 29; Duncan, 1996, p. 4; see also C. Jones & Lichtenstein, 2008)
Creative project	"a form of interdependent action, conceptually distinct from, but closely related to, both stable and more adaptive depictions of routines. Creative projects are exploratory ventures that offer one means by which organizations and their routines change" (Obstfeld, 2009, p. 9)
Team	"small groups of interdependent individuals who share responsibility for outcomes for their organizations" (Sundstrom, de Meuse, & Futrell, 1990, p. 120)

collaborative work, and the rest of this chapter reviews literature on collaboration work more broadly.

2. B. Kinds of collaborative arrangements

I identified myriad terms from literature for labeling different kinds of collaborative endeavors and summarize those terms in Table 2-1. I explored literatures on each type of collaboration in order to develop a better understanding of what kind of collaboration the WAB Project most closely resembles.

Collaborative endeavors differ from one another along a number of dimensions: who is involved, how long the endeavor is intended to last, how the work in the endeavor relates to the other work a person or organization does, and what the endeavor should produce. Some terms used to describe collaborative endeavors, such as "community of practice" (CoP), refer not to organizational entities but to social arrangements that span organizational boundaries.

2. B. 1. Communities and Networks of Practice

Communities and networks of practice describe collections of individuals based on their professional activities. Lave and Wenger (1991) define a CoP as

> "an activity system about which participants share understanding concerning what they are doing and what that means in their lives and for their community. Thus, they are united in both action and in the meaning that that action has, both for themselves, and for the larger collective." (p. 98)

Their definition emphasizes participation and self-awareness; members of CoPs are members through their actions and know that they are members. Members of CoPs become members by engaging in a shared activity system. Wenger (1999) uses the example of insurance claims processors to illustrate CoP concepts. The claims processors' work can be described in individual terms – one person handles a claim from the time it comes in until it is resolved – but the processors work together to accomplish their tasks. For instance, when a processor wonders how to handle incomplete claim forms, she asks her co-workers what they would do. The answer she gets becomes the way incomplete forms get handled because co-workers keep sharing their practices with one another (see Vignette 1 in Wenger, 1999).

CoPs are informal communities that result from shared activities; they are not "built" or "designed" but emergent. Brown and Duguid (1991) use Orr's (1986) study of copy machine repair technicians to illustrate the informal development of a CoP. The technicians Orr studied shared stories with one another about machines they worked on; these stories were a mechanism for developing technicians' expertise in diagnosing machine problems. These stories, shared informally during breaks or on service calls, rather than in the official repair manuals, helped technicians adapt to solve problems they hadn't seen before (Orr, 1986).

The term “network of practice” (NoP) describes a network in which people share the same practice but have little need to coordinate their work (Brown & Duguid, 2000/2002; Duguid, 2005); an NoP “designates the collective of all practitioners of a particular practice” (Duguid, 2005, p. 10). A network of practice differs from a community of practice in its distributed nature but maintains the “similar practice” aspect. Individuals join CoP locally, and their membership in a CoP makes them members of the larger, distributed NoP. Software engineers from different companies are an example of a NoP (Fischer, Rohde, & Wulf, 2007); they do not work on the same project but struggle with similar sets of problems.

Because they are informal, CoPs and NoPs may not be recognized by the organizations in which their members reside, and they may span organizational boundaries (Brown & Duguid, 2000/2002; Duguid, 2005; Fischer et al., 2007). Institutional boundaries do not define communities of practice, nor do CoPs reduce to institutions (Wenger, 1999). I avoid using the term “NoP” in the rest of this document because its name is ambiguous – it is not immediately clear whether the network is of many people who share practice or the network is of many practices shared by people.

CoP’s focus on a single set of work practices limits its ability to explain activities in collaborations involving multiple CoPs. Lave’s (1991) example of tailors illustrates this aspect of the concept of CoP. She describes a tailor’s apprentice who is learning to mimic the senior tailor’s practices so that he may develop the same expertise. In a CoP, everyone possesses (or is training to possess) *similar* expertise. In projects like the WAB Project, expertise is intentionally *varied* rather than similar.

The WAB Project and other collaborations that involve individuals from more than one CoP are networks of practice in another sense; rather than a loosely-connected network of people with similar expertise, these collaborations are a tightly-coupled network of people with differing expertise. Because the resulting network of people from many practices may be relevant, I avoid using Brown and Duguid’s ambiguous term – “network of practice.”

A number of CoPs are potentially relevant in the WAB Project. Perhaps the most relevant CoP is civil engineering – people who develop materials and design civil infrastructure. They must work with professionals in other CoPs including construction contractors, public officials, and architects. ECC offers these engineers, and their associated CoPs, a radically different tool for building civil infrastructure and may influence the ways in which they collaborate.

The connections these informal communities establish within and across organizational boundaries serve as conduits for innovative views (Brown & Duguid, 2001). However, the CoP and NoP concepts alone do not explain how these informal connections are created and used. In Section 2. D. 2. I will introduce another discussion of networks – social networks.

2. B. 2. Interorganizational Collaborations

Interorganizational collaborations come in many types as varied as collaborative manufacturing and co-marketing arrangements (W. W. Powell et al., 1996). In these collaborations, organizations engage one another in lasting, strategic arrangements. For example, if you use Tide detergent, you'll notice a note on the side of the box about how best to use Tide in a Whirlpool washing machine. Those messages are part of a co-marketing arrangement between Tide and Whirlpool. Putting a message about Whirlpool on its packaging has little, if any, impact on Tide's core business – making laundry detergent – but it provides reciprocal advertising for Tide from Whirlpool. Collaborative manufacturing refers to a general approach to manufacturing that involves sharing business process information with external supply chain partners (McClellan, 2003). The goal of collaborative manufacturing is to provide everyone in the group the same information so that the group as a whole will be more efficient and better positioned to leverage that efficiency for profit. The core business of each company involved in a collaborative manufacturing arrangement remains unchanged; suppliers continue to supply materials but do so armed with more information. Co-marketing arrangements and collaborative manufacturing are examples of how organizations collaborate with one another at high levels that have little influence on the core practice or business of any of the organizations involved. Interorganizational collaboration literature focuses on high-level arrangements and is minimally useful for analyzing work at the WAB Project level.

2. B. 3. Collaboratories

Most generally, collaboratories are "center[s] without walls, in which researchers can perform their research without regard to physical location" (Wulf, 1993, p. 19). The phrase, first proposed by scientists and computer scientists, implicitly includes notions of computer-supported work that relies on internet technologies to allow scientists to work without regard to physical location. Some definitions of collaboratory refer to the technical infrastructure that supports such work (Finholt & Olson, 1997; Finholt, 2002; Finholt, 2003); others use the word to refer to a virtual scientific organization supported by collaboration technology (Teasley et al., 2008).

Research on collaboratories explores how they are funded (Corley et al., 2006), how they are managed (G. M. Olson, 2004), what motivates participation in them (Birnholtz, 2007), and how to encourage their success (Birnholtz & Bietz, 2003; Corley et al., 2006). Olson (2004) notes that collaboration readiness, technical readiness, incentives compatibility, and management are issues central to collaboratories' success. Management issues are central because collaboratories are often established by federal science funding, and management falls to domain scientists rather than to trained managers. Corley, et al., (2006) argue that inter-institutional collaboratories' success relies on epistemic development of the domains involved and organizational structure of the collaboration. They claim that collaborations involving highly developed domains and those with highly developed organizational structures will be more successful than less-developed domains and organizations.

Studies of collaboratories provide a term for organizations that conduct scientific research and tell us something about why people engage in those collaborations and how their management influences their success. Individuals join collaborations when doing so advances their research goals (Birnholtz, 2007). Their involvement in research collaborations impacts their scientific and human capital (Bozeman, Dietz, & Gaughan, 2001; Bozeman & Corley, 2004) which, in turn, impacts their ability to enter other collaborations that further their research goals.

2. B. 4. Projects

Projects differ from other interorganizational collaborations because they are temporary and focus on producing a specific product or meeting a specific goal (Duncan, 1996; C. Jones & Lichtenstein, 2008). Temporality is a crucial component of projects. The temporary nature of projects influences the ways in which they manage coordination and uncertainty. For instance, deadlines and milestones serve as coordination mechanisms, helping project members know when some aspect of work is completed and when to move forward to the next stage (Davies & Hobday, 2005). Projects are also often characterized by flatter hierarchies than other interorganizational collaborations (Davies & Hobday, 2005). These flatter hierarchies allow for different communication and information flows and enable local adaptations (Gann & Salter, 2000). Projects often involve members from multiple communities or networks of practice. In order to produce a new product, projects bring together team members with differing expertise. Because projects are temporary and situated outside the regular structure of organizations, it is difficult to ensure learning across projects (Anderson, 2004; Gann & Salter, 2000).

2. B. 5. Creative Projects

Creative projects are a special kind of project where the aim is to do something more exploratory than in traditional routines or projects (Obstfeld, 2009). Obstfeld and Adler (2007; 2009) describe characteristics of creative projects in the automotive industry. They argue that affect provides the “motivational underpinnings of … creative projects” (Adler & Obstfeld, 2007, p. 19). They use the concept “affect” to explain how organizations are able to maintain the level of commitment required for successful research and development (R&D) and situate projects as the central organizational arrangement for R&D. Adler and Obstfeld use Dewey’s (1922/2002) notion of "impulse" to argue that affect is an essential component of motivation. Affect provides direction, intensity, and persistence in activity; positive affect encourages people to tackle problems rather than to avoid them (Seo, Barrett, & Bartunek, 2004).

2. B. 6. Summary

Literature on various kinds of collaborative structures suggests that the duration, structure, communication patterns, and coordination of the collaboration have the strongest effects on the work the group accomplishes. Longer collaborations, such as joint ventures, have different paces and communication patterns than short-term projects. Similarly, formal interorganizational collaborations often have semi-rigid hierarchal structures that mediate communication while projects with flatter hierarchies show broader communication. Coordination mechanisms such as milestones and meetings impact how members of collaborations know what work is happening and what comes next.

All the types of collaboration reviewed here shared a common idea of awareness – members of these arrangements know they are members, and outsiders also recognize those memberships. While this notion of membership may seem straightforward, research has shown that membership is not so clear cut (Lee et al., 2006). The WAB Project involved multiple organizations and different constellations of human actors during various stages of the project. These fuzzy memberships and changing arrangements were not necessarily problematic; Lee, et al., (2006) also argue that work can be accomplished with only a partial view of membership.

The WAB Project shares characteristics with many different kinds of collaborative arrangements. It was temporary and goal-oriented, like many other projects, especially construction projects. It relied foremost on the work of research scientists (those who invented ECC) working with people outside their lab, like collaboratories. It also established formal relationships, governed by legal contracts, among various firms, like interorganizational collaborations. Members of the WAB Project come from many different communities of practice, each characterized by a set of common approaches to problems, to work, and to collaboration.

2. C. Procurement, Project Management, and Other Challenges in Construction Projects

Work in construction differs from work in other firms in a number of potentially important ways. First, the project orientation of construction projects creates a constellation of actors that continually changes. Each project brings together a group of firms and individuals who may not have worked together before and who may never work together again. Second, much of the work in construction is governed by standards. These standards help produce a strong community of practice (Dubois & Gadde, 2002) and allow firms to manage uncertainty (Kadefors, 1995). Construction projects are incredibly complex (Dubois & Gadde, 2002); so complex that some researchers wonder at "the informal and adaptive systems, that is, those unremarkable processes that enable the construction process to function at all" (Shammas-Toma, Seymour, & Clark, 1998, p. 178). Dubois and Gadde (2002) use Weick's (1976) concept of "loose coupling" to discuss complexity, productivity, and innovation in construction.

Weick (1976) characterizes loose couplings as those in which coupled events have their own identities and some physical or logical separateness from other events; meanwhile, the events are responsive to other events. The potential effects of loose coupling include localized adaptation, buffering mechanisms, sensing mechanisms, identity preservation, and a sense of efficacy (Dubois & Gadde, 2002; Weick, 1976). Localized adaptation is possible in loosely coupled systems because of the physical and/or logical independence of events; adjustments in one event do not necessarily affect the rest of the system. Similarly, loose couplings buffer events from adverse conditions in other events. The localized adaptation possible in loose couplings also provides a sensing mechanism; loosely coupled systems interact with their environments at many different points and may therefore provide a better picture of the environment.

The separateness of loosely coupled events allows each event to preserve its identity. The separateness of events also provides room for self-determination than can lead to a higher sense of efficacy in a loosely coupled system than in tightly coupled systems in which individuals have limited discretion.

Thinking of construction projects as loosely coupled systems provides language and concepts for understanding coordination and innovation within and among projects. The short-term, temporary nature of projects implies that teams are recombined for each project. This continual recombining complicates coordination. Temporary projects lack the past experience that eases coordination and the common future that can justify coordination costs. Other industries manage uncertainty and interdependence through tight couplings (Dubois & Gadde, 2002). The inter-firm adaptations that manage that uncertainty are uncommon in construction projects. Instead, construction projects rely on standards and localized control to handle situations requiring adaptations and adjustments.

Because anomalies are managed locally, information about adaptations or adjustments made is also localized. The distributed, localized nature of the control in construction projects allows for flexibility within a project but complicates information transfer among projects and even parts of single projects. Construction projects are organized in order to reduce dependence on a single entity; meanwhile the parts of projects and technically interdependent. The concrete deck of a bridge cannot be poured before the frame is in place, for example; the order in which work must be done produces dependencies that flow down the chain.

Standards are one mechanism that helps reduce dependency on a single provider. By developing and adopting standards, consumers and producers of construction make the work output, rather than relationships among firms, the measure of construction. Standards such as the State Department of Transportation’s (MDOT) *Standard Specifications for Construction* supply the “basic requirements governing the material, equipment, and methods used in construction contracts administered by [MDOT].”

Fairclough (2002) conducted a review of the United Kingdom's construction industry with an eye toward determining what the role of government should be in supporting construction research. Fairclough interviewed members of government, construction industry firms, and other researchers; he also reviewed documents from those groups. He claims that challenges for collaborative projects between industry and government suffer from loose coupling among organizations, fragmentation in the construction industry, and a lack of long-term strategy on the part of either government or industry. Fairclough further argues that because the construction industry and the government agencies that could support construction research are loosely coupled, they may be prone to animosity. Animosity presents significant challenges to collaborations, especially where projects are informal configurations that are only temporary. Each project reassembles a group of people who are members of different organizations. These projects construct informal ties between the organizations represented, but the informality and temporary nature of those ties means that the kind of work required to overcome animosity is difficult. Overcoming animosity takes time and repeated interactions (Cohen & Bailey, 1997).

Fairclough also claims that collaborations between industry and academy suffer because funding fails to work as a significant motivator for academics to conduct industry-focused research and because privatization and competition operate as disincentives to project formation. He notes that academic research and the construction industry are poorly coupled, and that in the UK, industry views academic research warily. Funding aimed at bridging the gap between academia and industry by creating partnerships has not been successful.

Fairclough and SPRU (a center for Science and Technology Policy Research at the University of Sussex) attribute the decline in collaboration among research bodies to, in part, privatization and competition. They claim that the realities of privatization and competition make it less likely that firms will collaborate with one another and that rebalancing of funding mechanisms could encourage collaboration to increase.

A number of researchers identified similar kinds of challenges; for instance, Anderson (2004) discussed the short-term orientation of projects and that orientation's negative impact on long-term learning. The kinds of challenges that emerged from this literature on construction include

1. Short-term project orientation limits long-term learning;
2. Funding doesn't work as a motivator for academic researchers, and the outcome is research that is not tightly coupled to industry needs;
3. Strong institutional forces in construction industry limit the ability of any one actor to induce significant change;
4. Loose coupling among actors in a project limits the learning and information sharing that occurs among actors;
5. Procurement processes encourage builders and clients to see one another as adversaries; and
6. The regulatory environment's influences on innovative construction projects are poorly understood, or existing regulations stifle innovation.

In summary, construction literature suggests that procurement methods and aligning goals present challenges to construction projects. Successful construction projects are able to leverage the advantages of loose coupling to limit the impact of local changes on the broader project.

2. D. Factors that Influence Collaboration Success[2]

Many of these challenges literature suggests for collaborations relate to coordination within the project, the impacts of crossing professional boundaries, and the balance of social capital.

---

[2] I use the phrases "factors that influence" and "challenges" almost interchangeably – not all factors that influence collaborations present challenges for those collaborations. However, the goal of this study is to understand, using data from the WAB Project, what influences collaborators' abilities to achieve their goals. Whether we call those things that do the influencing "factors" or "challenges" does not change the mission of this project. I am interested in the stuff of collaboration, and engaging in a debate about whether something is an influencing factor or a challenge threatens my focus. On a related note, I could write another complete dissertation on what "success" means for collaborations. Throughout this document I use the term success to indicate the achievement of goals or the approval of the individuals involved – the WAB Project was a success because the bridge exists and because the people involved consider it a success.

Sonnenwald (2007) argues that different factors influence scientific collaborations at different stages of the collaboration's development. At the outset, scientific, political, socio-economic issues; resource accessibility; and social networks stand out as the most influential factors. Later in a collaboration's development, issues of leadership, communication, research goals, and organizational structure have greater influence. Kraut and Streeter (1995) similarly suggest that clear structure and roles improve collaboration; their study focuses on software developers. Jones's (1996; C. Jones & Lichtenstein, 2008) studies of film projects suggest that interpersonal skills and industry socialization have strong impacts within projects; they argue that temporal and social embeddedness provide mechanisms for managing uncertainty and facilitating collaboration. The collaborations studied and reviewed by Sonnenwald, Kraut and Streeter, and Jones differ dramatically in their goals, their domains, even their structures; however, issues of interpersonal engagement (e.g. communication, social networks, and organizational structure) and an ability to handle uncertainty are identified as important in each. That these issues crop up in diverse types of collaborations suggest that they may be common in most collaborations.

2. D. 1. Crossing or Permeating Professional and Organizational Boundaries

While communities of practice may facilitate flows of innovation *within* communities, they may impede diffusion *across* communities (Brown & Duguid, 2001). Projects experience similar in-group and out-group communication dynamics – information may flow freely within the flat hierarchy of a project, but because projects are loosely coupled to other activities, information does not flow easily across multiple projects or back to the parent organizations or communities involved (Anderson, 2004; Gann & Salter, 2000). Innovations, through their novelty, necessarily disrupt established work practices. Switching costs and lack of exposure to outside ideas in established communities of practices may pose problems for innovations, such as ECC, that span communities.

Knowing something about how professions, and their associated communities of practice, develop can help us understand how professions influence communication patterns. Abbot (1988) argues that it is important to examine not only the form but also the content of professions; he characterizes the establishment of a profession as the struggle for control of a content jurisdiction. Professions assert themselves by saying something like, “We own this area, and here is the line between your jurisdiction and ours.”[3]

Through our repeated engagement with a particular CoP or profession, we develop expertise that enables us to work smoothly with others like us. Our shared values and practices help us coordinate our work. When we work with people whose expertise differs from ours (i.e., from other CoPs), we cannot leverage the same resources of shared practices and values. Instead, we must rely on other coordination mechanisms to enable us to work together. The next section explores the concepts of social capital and networks as ways in which we can trace participation, and in turn, the development of shared understanding and the work of coordinating.

2. D. 2. Balancing Bridging and Bonding Social Capital

Social capital has often been used to explain success in a number of areas related to organizations (see Adler & Kwoon, 2000 for a review). For instance, Baker (1990) proposes a way to understand interorganizational relationships by examining market ties (exchanges of goods, services, etc.). His results indicate that market ties result from deliberate management; specifically, firms make efforts to reduce interdependence and to exploit their power in relationships (see also Pfeffer, 1987). By deliberately managing market ties, actors create and extract social capital from those relationships. In Baker’s study, those actors are members of the corporate and financial communities.

Social capital has developed into an umbrella term (Adler & Kwoon, 2000); some of the most common definitions are

[3] This us-them boundary can be identified through social network analysis, and I will return to this point shortly.

- "the sum of the resources, actual or virtual, that accrue to an individual or a group by virtue of possessing a durable network or more or less institutionalized relationships of mutual acquaintance and recognition" (Bourdieu & Wacquant, 1992, p. 119);

- "the structure of individuals' contact networks – the pattern of interconnection among the various people with whom each person is tied" (Raider & Burt, 1996, p. 187);

- "the web of social relationships that influences individual behavior" (Pennar, 1997, p. 154); and

- "the information, trust, and norms of reciprocity inhering in one's social networks" (Woolcock, 1998, p. 153);

- "resources embedded in a social structure which are accessed and/or mobilized in purposive actions" (Lin, 2001, p. 12).

These definitions of social capital emphasize that resources individuals and groups possess influence the way they behave and relate to other individuals and groups; these definitions also include a network component. The term *resource,* in the context of social capital, often refers to valued resources such as wealth, status, and power.

Kraatz (1998) explains how social network ties and social capital mitigate uncertainty and promote social learning[4]. He studied the program offerings of 230 colleges over 16 years and found that members of small consortia tended to imitate other successful colleges within their consortium. For example, liberal arts colleges in small consortia adapted professional programs. Kraatz's study explains how strong social ties influence organizational behavior, leading to more imitation and less uncertainty.

Rogers (1995) discusses the role of social networks in innovation diffusion similarly. He uses the term "communication channel" to label the network tie

---

[4] Kraatz uses a definition of "social learning" that considers imitation of adaptive responses *learning* (see Rogers, 1995). Rather than enter a debate about what "learning" ought to mean, I will refer to the kind of learning Kraatz and Rogers discuss as "imitation" or "change" in order to distinguish it from the learning referenced by Lave and other practice researchers. Lave and Wenger (1991) writes about learning as a process of acquiring skills and gaining membership in a community.

established between two individuals when they exchange messages. The communication channel plays a crucial role in innovation diffusion:

> The nature of the information exchange relationship between a pair of individuals determines the conditions under which a source will or will not transmit the innovation to the receiver and the effect of such a transfer. (Rogers, 1995, p. 18)

In other words, the nature of the tie between two individuals determines when and with whom a person will share information about an innovation.

One explanation may be that the kind of social capital involved in the relationship impacts how information in the relationship is shared. The distinction between *bridging* (or inclusive) and *bonding* (or exclusive) social capital[5], for instance, may help explain that nature of relationships to which Rogers refers. *Bridging* social capital results from links to external resources. Putnam (2001) uses the civil rights movement and ecumenical religious organizations as examples of networks with high bridging social capital. *Bonding* social capital results from internal connections; examples of bonding networks are close-knit offices or book groups. Bridging social capital provides access to resources that lay in other networks; it fills structural holes and extends networks. Bonding social capital increases the strength of internal network ties, bolstering individual rather than network identities. As Putnam (2001) points out, “Bonding social capital, by creating strong in-group loyalty, may also create strong out-group antagonism” (p. 23). This potential out-group antagonism affects the connections established between communities. “Bonding social capital” provides a label for the characteristics that impact the flow of information from one group (e.g. a community of practice) to another group (e.g. another community of practice). Without high bridging social capital to connect the two groups, the level of bonding social capital within groups may impede the flow of information between groups.

If the relative amount of bridging and bonding social capital may explain part of information diffusion, knowing those amounts could be useful. Lin (2001) outlines two ways to measure social capital: embedded resources and network

---

[5] From Putnam (2001), who gives credit for coining the terms to Gittel & Vidal (1998).

location. The first approach, embedded resources, measures social capital based on the value of wealth, power, and status available within a network. The resources measurement approach is usually applied when considering specific actions such as a job hunt; this approach emphasizes the possession and valuation of resources. The second measurement approach, network location, was proposed by Granovetter (1973) and later formalized by Burt (1992) to measure social capital based on an individual's position within a network. The network location measurement approach emphasizes the value of bridges (i.e. connections between individuals in a network) or the access to information and resources afforded by bridges, rather than the explicit possession of those resources.

Measuring and Analyzing Social Capital

Studying social networks' structures and attributes can help us understand micro-behavioral processes. For instance, Carpenter and Westphal (2001) studied the impact of shared membership on boards of directors on strategic business decisions. They found that understanding the social context in which a board was embedded helped explain some of the board's strategic behavior. In another study using social network analysis (SNA) to understand project outcomes, Jones, et. al, (C. Jones et al., 1998) used network analysis to study how human capital influences film projects' success.

Combining social network data in matrices and graphs with qualitative data from interviews and observations helps us understand how social ties and networks impact behavior. For example, in order to understand the purposes of friendship, Belloti (2008) interviewed single heterosexuals and used that data to construct social network datasets. She used the structure of social networks to identify interesting characteristics about which to ask her interview subjects and found that friendship styles depend, at least in part, on differences in gender and social class (Bellotti, 2008).

SNA's tools for making connections among indiviudals apparent are useful for studies of collaborations. SNA helps us identify connections, or the lack thereof, that enable information flow and establish interpersonal connections. SNA lets us get at the development of scientific and human capital that influence collaborative behavior (Bozeman & Corley, 2004) and the social embeddedness that helps collaborators manage uncertainty (C. Jones & Lichtenstein, 2008).

2. D. 3. Mechanisms for Success

While the literature discussed above points out that innovations present challenges for collaborations, and SNA shows loose coupling and disconnected networks make it harder for information to travel, other literature suggests mechanisms for improving projects' chances for success.

Social embeddedness – the frequency, duration and pattern of dyadic interactions for an individual or organization (Granovetter, 1985) – refers to the structural relations of individuals or organizations within a network and enables groups of actors to reduce uncertainty and develop shared understandings. Empirical studies reveal that relational embeddedness – a kind of social embeddedness developed through repeated dyadic interactions – reduces uncertainty (see C. Jones & Lichtenstein, 2008 for a review). Structural embeddedness – another social embeddedness measure that refers to how connected one's connections are to each other (Granovetter, 1992) – facilitates the development of shared understandings (C. Jones & Lichtenstein, 2008). Shared understandings establish a "macroculture" which serves as a toolkit (Swidler, 1986) that actors use to do coordination work (C. Jones, Hesterly, & Borgatti, 1997).

In construction, closely aligned goals have proven effective at ensuring project success (Fairclough, 2002). Closely aligned goals reduce the negative effects of competition and develop incentives for accommodating one another. Adler and Obstfeld (2007) argue that affect – as used in psychology, referring to feelings or emotions – plays a strong role in projects. Emotions provide the impetus to care about the work involved in a project, motivating us to face problems rather than to avoid them. Similarly, Latour (1996) suggests that interest encourages coordination. Lastly, a combination of informal and formal communication helps reduce uncertainty and improve coordination (Kraut & Streeter, 1995).

2. D. 4. Coordination

When literature uses the term "coordination," it generally refers to the management of resources. It is not surprising, then, that effortful coordination increases collaboration success (Cummings & Kiesler, 2003). As Malone and Crowston point out, coordination is not limited to the management of human activities; it may also refer to management of technical resources such as processors and memory (T. W. Malone & Crowston, 1994, p. 112). In this study, I focus on coordination related to researchers, contractors, and construction equipment and materials.

Crowston (1997) uses data from a study of software engineering to explore the insights coordination theory provides to organizational processes. Coordination theory suggests that tasks can be divided into those necessary to achieve the stated goal and those that manage dependencies among resources and activities. Much of the discussion of "coordination theory" emphasizes formal models and coordination in computing systems (see Durfee, Lesser, & Corkill, 1990; T. W. Malone & Crowston, 1994) and a task-level analysis of activities (e.g., Crowston, 1997). March and Simon (1993) recognize that formal models do not account for "the contingent character of activities" (p. 46). The emphasis on "tasks" that permeates discussions of coordination emphasizes a different level of analysis than the one I have chosen in this study. In analyzing the WAB Project, I have not done a task-level analysis of the team's work. Instead, I have focused on the activities the project team used to enable them to coordinate their work, regardless of the specific nature of their individual tasks.

The following sections review coordination mechanisms – tools we use to organize our activities so we may work together effectively – and adaptive capacity – a term used to describe the abilities of systems and structures to adjust to changes in their surroundings.

Coordination Mechanisms

Organizational literature introduces three categories of coordination mechanisms: *direct supervision*, where one actor is responsible for coordinating activities; *mutual adjustment*, where actors make ongoing adjustments to one another; and *standardization*, where existing or determined norms govern activities (March & Simon, 1993; Mintzberg, 1979).

Cummings and Kiesler (2003) list 10 different coordination mechanisms such as "supervision by a faculty" and "at least monthly in-person meetings" used in distributed scientific research projects. They go on to claim that coordination is important but fail to explain why "supervision by a faculty" differs from "supervision by a graduate student" or how "at least monthly in-person meetings" accomplish more coordination than do "at least monthly phone calls and email."

Communication and shared understandings are also resources for accomplishing coordination. Many ethnographic studies document the significance of material artifacts on the development of shared understandings across communities (e.g., Lutters & Ackerman, 2002; S. L. Star & Griesemer, 1989). The concept of boundary objects has sparked debate as mechanisms that contributed to successful collaboration (see S. L. Star & Griesemer, 1989) and as a concept whose overuse masks the important disorderly processes in collaboration (Lee, 2007) and underestimates the importance of human actors in making boundary objects useful (LeBaron & Thompson, in preparation). Boundary objects "inhabit several intersecting social worlds…and satisfy the informational requirements of each" (S. L. Star & Griesemer, 1989, p. 393). At their heart, discussions about boundary objects are discussions about how artifacts serve as resources to coordinate perspectives across communities (Wenger, 1999).

Researchers often invoke the concept of "common ground" as another tool for developing shared understandings. Common ground – "mutual knowledge, mutual beliefs, and mutual assumptions" (Clark & Brennan, 1991, p. 127) – is a confusing metaphor. The presence of "ground" in the phrase invokes a sense of place and physicality, when, unlike physical space, common ground cannot be measured or possessed (Koschmann & LeBaron, 2003). By using the phrase "common ground," we assume the development of mutual knowledge, leaving out any discussion of how that mutual knowledge develops in the first place.

CoP literature suggests that we develop this mutual knowledge by engaging in similar practices, tackling similar problems. We learn what the community knows through our participation. Similarly, Abbott's (1988) work on the development of professions suggests that we gain mutual beliefs through claiming and enacting membership in a profession that shares some of our existing individual beliefs.

Shared artifacts, participation, and membership are mechanisms through which we develop mutual knowledge, and this mutual knowledge, combined with regular communication, does the work of coordination. Analyzing artifacts, participation, and membership, then, allows us to study that coordination.

Understandings of *how* these coordination mechanisms work are missing from their discussions – how is direct faculty supervision effective? How does mutual adjustment happen? I will return to these questions in Chapters 4 and 5 when I discuss the roles of coordination mechanisms in the WAB Project. The next section introduces a concept – *adaptive capacity* – that I will expand in Chapter 6 when I discuss how coordination could have been accomplished in the WAB Project.

2. E. Summary

In this chapter, I identified a variety of collaborative arrangements that shared traits with the WAB Project. From literatures on those various kinds of collaborations, I identified common aspects that influence collaborations' success:

- Competing interests, goals, and practices of organizations and industries involved;
- Imbalance between bonding and bridging social capital within and across groups involved in the project;
- Procurement, project management, the regulatory environment, and a tension between change vs. tradition within the construction industry;
- Coordination problems common in collaborations.

I also reviewed literature about the development and affordances of social capital and on mechanisms that enable coordination. Finally, I reviewed literature on coordination and adaptive capacity. Together, these literatures suggest that

- Coordination significantly impacts a collaboration's success,
- Successful coordination manages task dependencies appropriately, and
- Social interactions and communication are resources for coordination.

These literatures fail to explain how projects cope with their dynamic environments, how social interactions and communication afford coordination. A more complete understanding of how projects adjust to changes in their environment would include explanations of

- How shared understandings develop,
- How communication moves throughout the team,
- How relationships develop,
- How the quality of a relationship impacts coordination work, and
- How motivation develops.

Adaptive capacity as a concept provides a useful way of talking about the set of capabilities that enable a team to coordinate its collaborative activities. Those capabilities include the abilities to (1) develop shared understandings and to (2) negotiate dependencies. The remainder of this dissertation uses data from a particular construction research project to identify the components of adaptive capacity, how it is developed, and what it helps us understand about coordination in projects. The next chapter will explain the research context and methods I used to investigate the relationships among social interaction, coordination, and adaptive capacity in the WAB Project.

Chapter 3

Methods of data collection and analysis

3. A. Selecting the WAB Project for Study

I had a broad research goal of investigating the relationships and work in a collaboration among individuals from multiple areas of expertise. My earlier work in large-scale collaborations provided some experience negotiating access to collaborative projects. I was especially interested in how collaborations coordinate their many goals and activities. I first encountered members of the WAB Project during an all-hands meeting for an NSF grant team on which I was invited to serve as a graduate student research assistant. While explaining the design and development of ECC, Dr. Wang's former students introduced me to the WAB Project.

The WAB Project involved an innovation that was difficult to use and understand and required that members of state agencies, academic research labs, and construction industry companies to work together. Construction projects require a great deal of coordination among contractors, clients, and the building environment. Annie, a crew chief I interviewed, mentioned, "We did a lot of redesigning in the field that, on things that wouldn't work that were on the paper" (Annie, 5/09) – she was pointing out that some of the coordination that must happen occurs quite quickly and in the messy environment of a construction field site. The WAB Project was an interesting site in which to study coordination because it involved so many different groups of people, a new material, and many activities to coordinate, as in any construction project – this project provided many opportunities for me to notice and analyze coordination work.

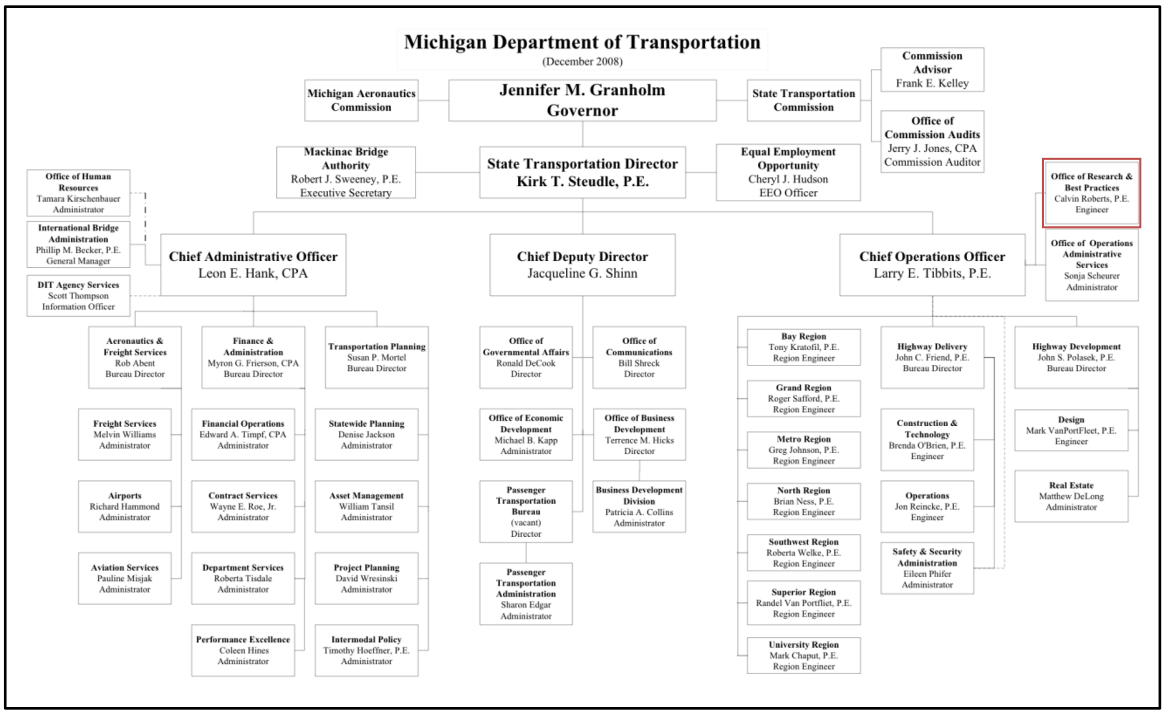
The WAB Project was completed in 2005, and my research began shortly thereafter. Because my research commenced after the bridge was complete, my methods are necessarily historical. A number of significant events affecting other bridges and civil structures occurred between the completion of the Woods Avenue Bridge and my research on the project and may have impacted the information I gained from interviews and observations. For instance, a bridge over the Mississippi River on Interstate 35W in Minneapolis, Minnesota failed on August 1, 2007. The I-35W Bridge carries over 140,000 cars per day, and its collapse brought renewed attention to the condition of our civil infrastructure. I did not speak directly with my participants about the I-35W bridge failure, but it is reasonable for us to assume that as designers and developers of infrastructure, such a high profile failure influenced their responses to my questions about other bridge structures. Such bridge failures also speak to the potential impact of projects like mine that explore how we are able to successfully build innovative structures. ECC and other new technologies have the potential to reduce the costs, both monetary and social, of infrastructure development and maintenance.

3. B. A Note on Levels of Analysis

Studying collaborations necessarily involves making decisions about on which level or levels of analysis to focus (D.M. Obstfeld, personal communication, Jan. 28. 2009). A collaborative project is likely to have both parent and constituent projects and routines, and collaborations involving members of many organizations sit in a gray area organizationally. They are not owned or defined by any single organization but have varying relationships to an organization's regular work and goals. MDOT has managed some of the gray area by creating a separate organization – the Department of Research and Best

Practices (DRBP) – within the larger Department (see Figure 3-1). This arrangement allows the DRBP to have different measures of success, different routines, and a different chain of command than other areas of MDOT such as "Design" where practices are more standardized and routinized than in research. MDOT builds many bridges, and DRBP conducts many transportation research projects. The particular bridge that I studied has component projects such as the ECC link slab and the sidewalk that may be considered subprojects of the bridge. I focus on the ECC link slab because it required the kind of collaboration among people with different expertise that I wanted to understand.

Figure 3-1. MDOT Organization Chart



3. C. A Qualitative Approach

I chose a qualitative approach because it most appropriately prepared me to illuminate and develop abstract concepts such as “boundary object” and “positive relational engagement.” A qualitative approach allows categories to inductively emerge from the data (Creswell, 2003). The inductive nature of a qualitative approach enables me to identify patterns in the data and to develop theoretical concepts to understand or explain those patterns.

Actor-network theory informed my approach to analysis. Though actor-network theory (ANT) contains the word “theory” in its name, I used it more as a method. ANT insists on (1) treating human and non-human actors symmetrically and (2) getting a detailed description of what is happening in an interaction through identifying major actors. Such a detailed description can be especially useful when analyzing sociotechnical systems such as the Woods Avenue Bridge. I refer to the Bridge itself and the WAB Project as *sociotechnical systems* because the term *sociotechnical* indicates an emphasis on interdependencies and technological components. “Not all social systems are socio-technical” and the term sociotechnical indicates that a system is “directly dependent on [its] material means and resources” (Trist, 1981). The WAB Project depends explicity on the material means of designing, mixing, and building with ECC – a material technology. Understanding the WAB Project team as a sociotechnical system and my study as an exploration of a *primary work system* (see Trist, 1981) situates my study among literatures about systems, organizational design and management, and social interaction while engaging the nonhuman aspects of projects that may also influence their activities.

I relied on my participants’ words and actions and the documents they produced to identify and trace potential actors. These potential actors indicate what aspects of the project the participants thought were important. Tracing actors through interviews and documents allows me to uncover the negotations project participants conducted in defining the important features of their interactions. For instance, I asked each participant to describe who they worked with, either through diagramming or listing people. These diagrams and lists enumerated possible human actors. I identified non-human actors such as the fibers in ECC by examining how my participants described the fibers and their importance to other members of the project. For instance, the ECC special provision, a legally binding document included in the construction bid packet, enumerates the aspects of ECC mixing that require special attention. I consider those aspects named in the ECC special provision actors. However, ANT does not define methods of inquiry, and I rely on ethnographic traditions to conduct my interviews and document analysis. The aim of actor-network theory is to describe actors (both human and non-human) tethered in networks built and maintained in the pursuit of a particular end (Stalder, 1997). Here, I use ANT to describe the actors and networks built and maintained in the pursuit of the successful completion of the Woods Avenue Bridge.

The purpose of the ANT descriptions of the WAB Project is to provide the rich data necessary for theory development. The qualitative methods I employed provide this data:

> Theory building seems to require rich description, the richness that comes from anecdote. We uncover all kinds of relationships in our 'hard' data, but it is only through the use of this 'soft' data that we are able to 'explain' them, and explanations are, of course, the purpose of research. (Mintzberg, 1979, p. 587)

In order to develop theoretical concepts, I used the constant comparative method. The constant comparative method's primary concerns are generating categories, properties, and hypotheses about general problems (Glaser & Strauss, 1999). The goal is not necessarily to develop causal arguments or hypotheses but rather to delineate a theory that serves as a reasonably accurate statement of the matters studied. Because the constant comparative method requires that one stay close to the data, it builds appropriately on the descriptions developed when using actor-network theory. Previous research on collaboration in science (Finholt, 2003; G. M. Olson, Zimmerman, & Bos, 2008), practice (Brown & Duguid, 1991; Wenger, 1999), standards and infrastructure development (Bowker & Star, 1997; S. L. Star, 1999), and legitimation of professional work (Abbott, 1988) provided additional theoretical categories for consideration and helped ground my theory in existing work. Exploring perspectives from other fields exposed me to metaphors that challenge one another; I am able to contribute to our understandings of collaborative projects by using data from my project to extend and combine theories from multiple fields.

3. D. Data Collection

Analyzing documents and artifacts related to the ECC project increased my understanding of the nature of the constraints and goals of the bridge project. For example, legal codes governing the development of civil infrastructure play a large role in governing the work of transportation engineers and designers. These documents contain controlled vocabularies, describe standard operating procedures, and set the rules for designing infrastructure. Training documents for designers and researchers potentially shed light on the skills and processes that are central to professional practice. Such documents can tell us what skills are considered paramount to a given profession and help us understand how practitioners think about themselves. These documents inform our understanding of the nonhuman agents such as standards that impacted the development of the bridge deck. When quoting or referencing documents, I use the identifiers listed in Table 3-1 and a number or date if the document contains one – e.g. (Progress meeting minutes, 8/4/05) for the minutes from a progress meeting held on August 4, 2005.

Much of my analysis focuses on minutes from progress meetings held during the project. Those minutes, produced by the contractors overseeing the project, provide data about the interactions among project participants and issues the team encountered.

I used data from interviews with 12 people and three days of observations with professionals involved in the Woods Avenue bridge deck project. These professionals included civil engineering researchers; Michigan Department of Transportation engineers, managers, and bridge designers; construction firm personnel; and policy makers. During some interviews, I asked participants to draw a number of diagrams including a social network graph of the collaboration (i.e., with whom do they collaborate and on what) and a diagram of the processes in which they engage (e.g., how proposed legislation resulted in a federal law). Not all participants were comfortable diagramming, and I did not press those who expressed their preference not to draw. Guided diagramming served two purposes: 1) as an interviewing prompt to help elicit information from interviewees and 2) to identify what potential actors to turn to next in data collection. Because the bridge project was already completed when my project began, I was not able to directly observe the project as it unfolded. I was given access to videos taken by engineering researchers during the project and used those videos during interviews as prompts to help participants describe the work they did on the project.

Interviews and guided diagramming provided data about what actors participants thought were important, about their perceptions of the work and of others', and provided insight about the project in general. When I refer to data gathered during interviews, I will provide a pseudonym or generic title for the person interviewed and an approximate date of the interview – e.g. (Todd, 10/05) for an interview with "Todd" in October of 2005. Mark, a doctoral student from the materials research lab, conducted 4 of the interviews from which I use data; the interviews he conducted are marked with an * in Table 3-2. Brian Hilligoss, another doctoral student in my program, also conducted two interviews, and those are marked with a ^.

I conducted observations within the lab that developed ECC to gather data about their non-declarative practices, tacit understandings, and physical procedures. I was able to observe the members of the lab training new people how to mix ECC and to witness their regular work. Before my project began, the difficulty of training new people to mix and use ECC was identified by the inventing lab as a significant problem. Data from my observations help me understand where people unfamiliar with ECC struggle in learning how to work with the material. I will refer to this data by the location and date the observation took place. For example, data from my observations at the concrete plant will be marked "(Concrete plant, 6/07)" after the discussion.

3. E. Data Sources

Table 3-1. Archival Materials

Document Identifier	Document or Materials	Information the Data Provide(s)
Prog. meeting minutes, date	Progress meeting minutes	Meeting attendees, topics, and contractor's advice
Info meeting, date	Informational meeting minutes	Meeting attendees, topics, and questions before work got underway
Special provision	ECC Special provision	Guide for using ECC in structure
Research report #	MDOT Research Reports	Meeting notes from informational meetings Parties' concerns before and during construction Negotiations about materials and design
Email #	Emails with questions about ECC	Points of struggle Interaction patterns
NIIA	National Infrastructure Improvement Act	Establishes national commission on infrastructure – political priorities
Slides, date	Presentations about ECC to other groups	How do researchers communicate about ECC outside their field
Patent	Sprayable ECC patent	Prior art – how is ECC different?
Protocol, date	Testing protocols and results	Identify points where the technology changes Inferences about how the data get used Inferences about what collaborators are willing to share
History	History of Roads in Michigan	Historical perspective on highway building
SSC	Standard Specifications for Construction	Standards governing construction in Michigan
MRL Website	MRL website about WAB Project	Official story of the project from the researchers' perspective

Table 3-2. Interview Participants

Interview Participant Pseudonym	Project institution	Project Role	Summary of duties
Dr. Wang	MRL	Director of research lab	Oversee research aspects of projects, invented the ECC being used, wrote MDOT research reports
Mark	MRL	Graduate student	Designed link slab, wrote ECC special provision, attended project meetings, coordinated work between MRL and MDOT, wrote MDOT research reports
Mei	MRL	Graduate student	Involved in two MDOT research projects, wrote MDOT research reports
Chen	MRL	Graduate student	Involved in follow-up MDOT research projects, wrote MDOT research report
Brad*	Great Lakes Civil Engineering (GLCE); subcontracting firm	Project manager	Oversees contractors and agreements, manages a number of projects at once
Seth*	GLCE	Project superintendent	Works for project manager, manages one project at a time, works on-site
Todd*	BTNH; general contracting firm	Senior inspector	Employee of BTNH, in charge of on-site inspections
Tim*	BTNH	Senior Project Engineer	Employee of BTNH, oversees projects as general contractor for MDOT
Jason	MDOT	MDOT research officer	MDOT's representatives in research projects, wrote reviews of ECC literature for MDOT
Annie	County DOT	Crew chief	Not involved in WAB Project; responsible for survey work on multiple road construction projects
Karen^	Private engineering firm	Inspector, design engineer	Not involved in WAB Project; develop construction plans from concept to contract; inspect projects underway
Medha^	Government organizations, contractors	Design engineer	Not involved in WAB Project; design plans for large scale structures (e.g. roads, bridges)

3. F. Data Analysis

I analyzed my data by coding and cross-coding my field notes, interview transcripts, and documents to identify themes and actors in the bridge project. I used Microsoft Office OneNote to organize and code my data. My analysis was ongoing. I had the opportunity to interview some of my participants multiple times, and I was able to ask follow up questions and to gather more relevant data by analyzing data between meetings. These multiple meetings also provided informal validation of my findings; I was able to discuss my impressions and interpretations with my participants. Their feedback provided me a deeper and more nuanced view of my own continuing analysis.

I also used social network analysis techniques to analyze data about social relationships. For instance, I used social network analysis to construct matrices and graphs of data about participation in progress meetings during construction. I developed a 2-mode person *x* meeting matrix in order to get a sense of the social structure of meetings. Then I converted that matrix into a 1-mode person *x* person matrix in order to see who had strong meeting proximity; that 1-mode matrix indicates how often two individuals participated in the same meeting. I used these and similar social network datasets from documents and interviews to identify questions to ask my participants and to formally evaluate my participants' theories about what made the WAB Project successful.

3. G. Summary

This chapter described the methods, data sources, and data analysis approaches I used to study the WAB Project. Qualitative data gathering included interviews with nine members of the project team, three interviews with other construction and engineering professionals, and approximately 500 pages of documents produced for and about the project. These data informed the analysis in the following chapters.

Chapter 4

Results from Documents and Meeting Minutes

This chapter and the next report results from my study of the WAB Project. I have organized the results into sections that correspond to components of adaptive capacity. In this chapter, I discuss how the WAB Project established roles and responsibilities, developed shared understandings about their work, and built social capital within the project team. Other literatures suggest that understanding each of these activities individually is central to understanding collaborative work. I argue that considering each activity independently focuses our inquiry too narrowly. Instead, we should analyze how each narrow activity interacts with other activities and how those interactions enable the team to develop the capacity to adapt when working collaboratively.

During the WAB Project, MDOT and MRL developed documents including design plans for the ECC link slab and special provisions for contractors to follow in the bidding and construction processes. MDOT worked with MRL, a bridge design consulting firm, and a number of general contractors to legally approve the bridge deck design documents and to secure funding and construction for the project. The general contractor who won the bid worked with subcontractors, including a concrete supplier in southeast Michigan, to complete the bridge deck in stages. Table 4-1 provides a timeline of the WAB Project.

Table 4-1. Bridge Project Timeline

Date	Who	Did what
2001	MRL, MDOT	Worked on theoretical design
2004	MRL, MDOT	Agreed to do a research demonstration project with ECC
	MDOT	Chose Woods Ave. Bridge
	MRL	Mark designed link slab
	MDOT	Gave Mark's design to bridge design consulting group
	General Contractor, MDOT	"Stamped" Mark's link slab design documents, making them legal and official
	MRL	Drafted special provision describing ECC use and testing for contractors
	MDOT	Released general contract (including special provision) and project plans
	MDOT	Sent project out for bid (as part of a larger set)
	MRL, Materials Contractor	Evaluated ECC material changes
May 2005	MDOT, MRL, General Contractor	Informational meetings
	Materials Contractor	Submitted equals
	MRL	Approved equal
	Materials Contractor	Demonstration mixes
July 2005	MDOT, Contractors, MRL	Biweekly progress meetings begin
September 2005	Contractors	Cast first phase of the link slab
September 2005	MRL	Tested material for compressive and tensile response
September 2005	Contractors	Cast second phase of the link slab
November 2005	MDOT, Contractors, MRL	Biweekly progress meetings end

The rest of this chapter provides data from documents produced and used during the project; I focus on a section of the construction contract called a "special provision" and the minutes of progress meetings held during the project. These data suggest that the WAB Project used these documents and meetings to share knowledge across communities of practice and to develop social ties and social capital. The concepts of timing/scheduling, communication, and proactivity appeared frequently in meeting minutes, suggesting that these were important considerations for the project team.

My analysis of these documents suggests that the WAB Project team was able to build shared understandings and reduce uncertainty through specific discussions of ECC mixing practice. Their regular progress meetings provided opportunities for strong social ties to develop, potentially facilitating communication within the project. The meeting minutes indicate that the team specifically addressed scheduling and communication issues by discussing them as a group. Lastly, the social network that emerged from progress meeting participation suggests that communication could flow easily among project team members. Shared understandings, reduced uncertainty, and strong social ties are aspects of adaptive capacity. The data presented in this chapter illustrates how those aspects of adaptive capacity could have developed in the WAB Project team.

4. A. Establishing Roles and Responsibilities through Shared Documents

Literature suggests that the lack of common understandings among communities of practice (Brown & Duguid, 1991) and the strong connections within those communities (Putnam, 2001) may inhibit collaboration across communities. Information artifacts can help individuals and organizations share information and to build shared understandings (S. L. Star & Griesemer, 1989). Latour (1988) uses the term "immutable mobiles" to refer to entities that can travel without suffering distortion, loss, or corruption. Immutable mobiles can be used to help people to convince others to go out of their way (Latour, 1990) by providing the information someone has gathered into a presentable, readable, and combinable package. Star and Griesemer (1989) offer the concept of "boundary object" as another way to describe artifacts that help cross institutional boundaries. They characterize boundary objects as "objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites"

(S. L. Star & Griesemer, 1989). They emphasize that creating and managing boundary objects is a key part of the process of developing relationships across intersecting social structures. Boundary objects coordinate perspectives of many communities of practice (Lee, 2007; Wenger, 1999). The concept of boundary object helps understand how groups who lack standardized rules for engagement are able to begin working together.

The WAB Project employed a number of artifacts to facilitate work that spanned organizational boundaries. The construction contract, for instance, includes both textual and graphic inscriptions of MRL's and MDOT's ideas and rules. Prior research has discussed contracts as boundary objects in more detail (e.g., Carlile, 2002; Koskinen & Mäkinen, 2009); here I will focus on just one section of the contract and the work it did in the WAB Project. My participants identified the ECC special provision as a key component of the construction contract.

MDOT has an extensive set of standard specifications that govern the material, equipment, and methods used in construction contracts – the Standard Specifications for Construction, nicknamed "The Construction Bible" (Jason, 12/08). Special provisions are amendments or additions to MDOT's standards. Special provisions govern the material, equipment, and methods used in an individual contract or for an individual material not covered in the Standard Specifications. Contractors use special provisions to understand how to work with non-standard materials or procedures. Special provisions explain materials, procedures, procurement, and pricing information.

In early 2005, members of the MRL authored a special provision for ECC in bridge deck link slabs[6]. The ECC special provision uses language, materials, tests, and pricing guidelines similar to other concrete standards. Contractors who work with concrete can use the ECC special provision to understand how working with ECC differs from working with standard concrete. The special

[6] A "link slab" is literally a slab of material that is used in place of an expandable mechanical joint in a bridge deck. Bridge decks commonly deteriorate around their joints, and link slabs are a way to reduce the need for joints. See the introduction and http://www.acppubs.com/article/CA6316928.html for more information.

Table 4-2. Human Actors in the ECC Special Provision

Human Actor(s) specified	Human Actor's role(s)
The Contractor	Notify Engineer before batching Adjust mix for appropriate aggregate absorption and specific gravity Produce link slab that meets specifications outlined in the special provision
The Engineer	Approve use of High Range Water Reducer Approve ECC material supplier Approve batching sequence Judge proper fiber dispersion and rheology of the mix Approve hand held vibration equipment Designate testing organization
Contractor's technical representative	Batch and mix ECC Be present at the trial batch to make recommendations and adjustments Be present at the first placement of ECC to make recommendations and adjustments
MRL	Write special provision Oversee quality assurance testing
Silica Corp[7]	Supply fine aggregates
Fiber America	Supply PVA fibers
R.W. Knight and Company	Supply admixtures
MDOT personnel or designated MDOT representatives	Provide ECC batching, mixing, and placement training

provision also names a number of human actors and their responsibilities. Table 4-2 provides a summary of those actors and their responsibilities.

The ECC bridge deck link slab special provision is a five-page document written for construction contractors by the developers of ECC material. The special provision tells contractors what materials they need to purchase to mix ECC, the procedure for mixing ECC, how to assess and eventually test the mix,

[7] Names of specific institutions, even within public documents, have been changed to protect the privacy of participants.

and how to price their work and materials for the ECC bridge deck link slab. For example, one paragraph of the "Materials" section of the special provision[8] reads:

> Fine aggregates used for ECC material must be virgin silica sand consisting of a gradation curve with 50% particles finer than 0.04 mils and a maximum grain size of 12 mils. Fine aggregates meeting this requirement are available from the following manufacturer under the trade name "F-110 Foundry Silica Sand." Approved equal will be accepted.

The other paragraphs of the Materials section are structured similarly. First, the special provision labels a kind of material, here "fine aggregates." Then, the provision describes the properties the material must possess, here "virgin silica sand consisting of a gradation curve with 50% particles finer than 0.04 mils and a maximum grain size of 12 mils." Then, the provision tells contractors where to procure the material, here "the following manufacturer under the trade name 'F-110 Foundry Silica Sand.'" Lastly, the paragraph indicates whether or not an approved equal will be accepted. In this case, an approved equal for the listed fine aggregates will be accepted.

The structure of the prose in the special provision outlines the immutable aspects of ECC and bounds the aspects of ECC that are flexible. The special provision carries MRL's knowledge of ECC and how ECC is both similar to and different from standard concrete to entities used to working with standard concrete. By being both rigid, e.g., "Fine aggregates … must be virgin silica sand…," and flexible, e.g., "Approved equal will be accepted," the special provision provides both advice and agency to the concrete supplier.

"Approved equals" are materials that do not exactly match the specifications in a standards document or special provision but that are acceptable as substitutes for the listed material. For instance, the paragraph above lists a specific fine aggregate, "F-110 Foundry Silica Sand," that is available from a specific manufacturer. Contractors may use the first sentence of the provision paragraph, the one describing the properties the fine aggregate used must possess, to find a different material from another manufacturer. If the

[8] Documents will be referenced by their nicknames. I have made efforts to include some context about a document when referring to it and refer readers to Table 3-1. Archival Materials on page 46 for a full list of documents and their contents.

contractor does so, he must submit the alternative material for approval as an "approved equal." By including the last sentence of the paragraph, MRL indicates that "F-110 Foundry Silica Sand" may not be the only available fine aggregate that meets the specifications required of a fine aggregate in ECC. The authors provide enough information in the special provision that contractors may seek other material suppliers. Similar paragraphs describe the other materials necessary for mixing ECC, including fibers, water reducing admixture, and retarding admixture. In this special provision, approved equals are allowed for each material.

When discussing approved equals, the special provision is serving the informational needs of both the researchers' and the contractors' communities. Boundary objects are useful, in part, because of their ability to fulfill the different information needs of different communities (S. L. Star & Griesemer, 1989).

The next section of the special provision describes the procedure for mixing ECC. This section of the special provision describes properties the mix must possess and the amount of each material to be used in the mix. This part of the provision outlines how ECC material suppliers and contractors gain approval from MDOT to use ECC. The section reads, in part:

> The ECC mixture requirements are shown in [Table 4-3]. For the mixture proportions listed, fine aggregate weight is assumed to have a dry bulk density of 2.60. The Contractor will adjust the mix design for aggregate absorption (assumed Moisture Content = 0.1%, Absorption Capacity = 9.0%, Specific Gravity = 2.65), and for specific gravity if it differs by more than 0.02 from the assumed value. At the site, additional High Range Water Reducer (HRWR) may be added to the mix to adjust the workability of the mix with onsite approval of the Engineer. Water additions are not allowed at the bridge site or in transit.
>
> …
>
> The ECC material supplier must be approved by the Engineer and should be familiar and experienced with batching, mixing, and placement of ECC material. Adequate experience with ECC batching, mixing, and placement techniques is achieved after participating in ECC batching, mixing, and placement training to be arranged with MDOT personnel (or designated MDOT representatives) prior to the Contractor's first project using ECC material.

Table 4-3. ECC Mix Design Parameters

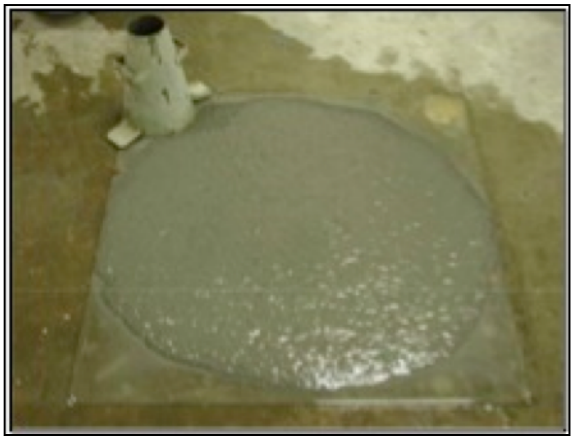
ECC Mix Design Parameter	Value
Mix Water (net)	544 lb/cyd
Portland Cement, Type I	973 lb/cyd
Fly Ash, Type F	1167 lb/cyd
Fine Aggregate, Dry	778 lb/cyd
High Range Water Reduced (HRWR)	14.6 lb/cyd
Poly-vinyl-alcohol Fibers	43.8 lb/cyd
Retarding Admixture	Optional

This section of the special provision explains what the mixing process includes and who can approve the material for use ("the Engineer"). It also explains how those mixing the material can tell if the mix is right. For instance, another paragraph reads:

> Adequate workability of the ECC mixture can be verified using a standard slump cone. Workability testing should be performed on a flat Plexiglas or glass surface upon discharging of the ECC mixture at the site. Upon removal of the cone, the resulting pancake of ECC material which is formed must be greater than 30 inches in average diameter and less than 90 inches. No check on air content is necessary.

A "standard slump cone" is piece of equipment used in a slump test (see Figure 4-1). In a slump test, fresh concrete is poured into a standard slump cone, testing personnel pull the cone up, and then measure how far from the center of the cone the concrete ends up. Basically, a slump test makes a pancake of concrete and measures its radius or diameter. The results of a slump test tell one something about how "workable" the concrete is – how easily one can place it in a structure or form. A slump test also tells one how cohesive the mix is. By including the standard slump cone and slump test, the ECC special provision meets the concrete supplier on familiar territory. Slump tests are a common, standard test for workability and cohesiveness of concrete. This section of the

Figure 4-1. Result of a Slump Test



provision explains how ECC is different from other materials but uses familiar terms and procedures to explain those differences.

Typically, concrete is tested for compressive strength. ECC is designed to withstand both compressive and tensile strain; therefore, it is tested using both compressive and tensile tests[9]. The special provision includes the strength values a mix must meet. Strength is measured in pounds per square inch in both compressive and tensile tests. The mix must meet minimum measurements in three areas of strength: compressive, tensile (uniaxial), and ultimate tensile strain capacity. Compressive and tensile (uniaxial) tests must be performed at intervals 7, 14, and 28 days after the ECC is poured. Table 4-4 shows the minimum strength requirements for each test at each interval.

Here again the ECC special provision uses measures and concepts familiar to the audience – concrete suppliers and contractors – to introduce a new material and its properties. The special provision communicates across the

Table 4-4. ECC Strength Requirements

Minimum Strength of ECC Material	7 day	14 day	28 day
Compressive	3200 psi	4000 psi	4500 psi
Tensile (Uniaxial)	500 psi	500 psi	500 psi
Ultimate Tensile Strain Capacity	2% (uniaxial tension)		

[9] Tensile tests measure the ductility of materials; during such tests, the material is bent until it fails, and sensors measure the load the material can withstand throughout the test.

boundary between the MRL research lab and the construction industry by using familiar language and providing its readers agency to identify and produce acceptable substitutes based on an unchanging set of properties. We can understand the ECC special provision as a boundary object because it spans material research, construction contracting, and legal communities and satisfies the informational requirements of each (see S. L. Star & Griesemer, 1989).

The special provision makes clear the connections between the communities' familiar territory – e.g., mixing standard concrete – and the new territory of working with ECC. It represents the knowledge MRL researchers have about ECC and how to prepare and mix the material. Contracts, especially related to new projects, are boundary objects used to accomplish knowledge sharing across communities (Carlile, 2002). The special provision, like the email thread in section 4. B. 1. , is an attempt to develop a shared understanding between the inventors of ECC and those trying to mix it for the first time. Material artifacts can have significant impact on the development of shared understandings within and across groups (Lutters & Ackerman, 2002; S. L. Star & Griesemer, 1989).

4. A. 1. Limitations of Boundary Objects

The concept "boundary object" or "immutable mobile" gives us language to talk about the translational work that a document such as the ECC special provision can do. The special provision translates from the research lab to the concrete supplier by explaining how ECC differs from traditional concrete and what properties the components of ECC must contain. Boundary objects cannot do all the work of translation on their own though, and they are made meaningful through their relationships to the material and social surround (LeBaron & Thompson, in preparation).

LeBaron and Thompson (in preparation) argue that people play an important role in making boundary objects locally meaningful and introduce the notion of "boundary agents"; boundary agents are people who bring boundary objects to life. Lee (2007) cautions that not all objects which move between communities should be called boundary objects and argues that nonstandardized artifacts play important roles in collaborations. We must be careful to think about what work boundary objects do and not to refer to all objects that exist at or cross institutional boundaries as "boundary objects."

Understanding the ECC special provision as a boundary object helps us understand what work the document was facilitating. To be sure, the special provision did not exist in a vacuum – its meaning and use depended on the people who authored and used it. Its very existence is social – the law requires that it be written by one community and followed by another. Special provisions are a class of standard document, and the ECC special provision is one instance of that class. Its structure conforms to the standards of special provisions – a standard that requires that the prose indicate what is different or unique about a material or method and that a special provision contain enough information for a contractor to use it to complete a bid and eventually a task.

Users of the special provision had questions about the material and its production that the document did not answer. For instance, during an informational meeting between MRL and contractors, Nancy, an inspector for the general contractor, asked, "why people want the large deformation of ECC" (Info Meeting Minutes, 5/31/05). When talking about concrete, "deformation" refers to how much the material can bend or stretch. Dr. Wang answered that, "high strain capacity of ECC material is needed to accommodate the tensile strain" (Info Meeting Minutes, 5/31/05) the bridge deck would experience; Dr. Wang was explaining that ECC accommodates strain by stretching or deforming. He acted as a boundary agent, giving meaning to the requirements set forth in the special provision.

In the same meeting, Todd, a supervising engineer, asked, "what kind of other application the ECC material has been used for" (Info Meeting Minutes, 5/31/05). The answer to his question requires information that is beyond the scope of the special provision. Dr. Wang provided five examples of other construction projects that used ECC in both the U.S.A. and Japan. In his answer, Dr. Wang included information about how the ECC had performed in one of those structures: "Under very heavily loaded 11-axle trucks, and almost three full winter freeze-thaw cycles, the ECC patch exhibits very tiny cracks, with crack width around 50 μm. In contrast, the maximum crack width in the surrounding concrete is significantly higher at the same age, which is about 3.8mm" (Info Meeting Minutes, 5/31/05). The additional information in Dr. Wang's answer does some convincing work; he is reassuring Todd that ECC can outperform concrete and that the WAB Project won't be the first place where that is true. The special provision alone was not able to answer Nancy's question about deformation nor Todd's about where else ECC had been used.

The special provision and informational meeting accomplished some of the work of increasing affect and relational embeddedness which increase motivation (Adler & Obstfeld, 2007) and reduce uncertainty (C. Jones & Lichtenstein, 2008) in collective work. The boundary object – the special provision – accomplished some of the formal communication work that eases coordination in large projects (Kraut & Streeter, 1995). The informational meeting between MRL, MDOT, and contractors was an occasion for MRL members to serve as boundary agents, bringing meaning to the "cool" special provision. The meeting also served as an opportunity for MRL to reduce the contractors' uncertainty by directly answering their specific questions. The next section analyzes other meetings that served as occasions for the development of additional social ties.

4. B. Developing Shared Understandings through Repeated Communication

Prior work suggests that shared understandings provide a toolkit that actors can use to coordinate their work (Swidler, 1986). Jones and her colleagues (1998; 2008) argue that shared understandings develop through repeated interaction, but repeated interaction is not the whole story. Not all repeated interactions produce shared understandings; for instance, frequent shouting matches are not likely to do so. The email thread discussed below provides an opportunity for us to analyze the content of the interactions and to watch the shared understanding develop.

So far, mixing ECC has proven so complicated and precise a process that the engineers who invented it have struggled to develop a description of the process that can be useful on its own. Much like Collins (1982) found when studying TEA lasers, success in mixing the concrete has occurred only when personnel from the original lab move to new labs. MRL could not mix concrete for a bridge deck because MRL is not an approved materials provider for the state department of transportation, and MRL does not have the capacity to produce the required amount of ECC. In order for the concrete innovation to spread, it will need to be more scalable – the engineers seek to make it possible to recreate the bendable concrete in different locations without having to have an already experienced researcher at the site. One of the goals of the research project under which the WAB Project was funded was to train new materials suppliers in the mixing and pouring processes of ECC. In order to illustrate how complicated the ECC mixing process is and to demonstrate how MRL researchers interact with others trying to learn how to mix ECC, I provide data and analysis from an email thread between two ECC researchers[10]. Analyzing this email thread also allows us to trace the development of a shared understanding among the four researchers about what matters in the ECC mixing process.

The recipe for ECC is quite precise, and other labs and concrete suppliers have regularly had difficulty when trying to mix it. The only way researchers at MRL have been able to help other labs be successful is to send personnel, usually a post doc, to teach the new lab. In this case, the director of the Civil Engineering Research lab (CER) at another university, Susan, visited MRL to learn how to mix the concrete, then returned to her lab and tried to replicate the process. In analyzing this email thread, I traced potential actors as engineers learned what had to be conveyed in order to learn this process over a distance.

---

[10] This email exchange took place after the completion of the WAB Project and is included here to illustrate the complexity of ECC's mixing process. Success in the WAB Project required that MRL be able to teach another institution, Midwest Concrete, how to mix the ECC. I did not have access to primary data from that training, and I offer this illustration of complexity and training in its place.

4. B. 1. Analysis of an email thread

In this analysis, researchers from MRL are corresponding with researchers in another lab, CER, which has not successfully mixed ECC on its own. The email thread began with Susan (CER) emailing Dr. Wang, the director of MRL, asking for help troubleshooting their mixing process. “We tried to mix the M45 mix in our new Zyklos mixer yesterday and we had to bail out (!)," she wrote. In subsequent emails, Wang and Susan added their students Chen (MRL) and Nick (CER) to the thread. The four researchers introduced and discussed a number of possible variables in the mixing process. In Susan's original email, she suggested ‘*order*’ of the mixing sequence (line 1), ‘*scale*’ of the materials to be mixed (line 3), *mixer type* (lines 3-4), or *brand* (line 3), and *timing* (line 7) as possible variables influencing the mix by writing,

1 I believe it was because of the order in which we were
2 putting the constituents in the mixer. It was done in a
3 way that worked in our small Hobart mixer - but it
4 seemed to be too much stress in the Zyklos. I was
5 wondering if you or one of your students could let me
6 know what order you add the constituents (and what
7 the mixing times are) that you have found to be
8 successful.

At this point, these four variables – *order*, *scale*, *mixer*, and *timing* – are only potential actors, as suggested by Susan herself. We now have a starting point for following the actors. By carefully following the variables in the upcoming emails we will come to understand the data in greater detail, and be able to trace as the participants identify the actors.

Wang responded to Susan and vaguely agreed that *order* and *mixer* may be important, saying, “The adding sequence can be important, and may depend on the type of mixer," and deferred further questions to Chen, the “local expert." Thus, *order* and *mixer* have become stronger candidates for being actors, but the assertion remains tentative, as Chen, the “local expert” has not said anything about the variables yet.

In her next email, Susan thanked Wang and Chen for their help and introduced Nick as “in charge of mixing" in her lab. When Chen responded, in the message below (lines 9 – 25), he explained the successful procedure they use in Wang's lab, emphasizing *order* (line 9), *timing* (lines 12, 14, and 16), and *texture* (lines 17 and 22) as important variables:

> The mixing procedure we used for the Hobart and Zyklos type mixers is:
>
> 1. Solid ingredients, including cement, fly ash, and sand, were first mixed for a couple of minutes.
> 2. Water was added into the dry mixture and mixed for three minutes.
> 3. Superplasticizer was then added into the mixture and mixed for another three minutes. The liquefied fresh mortar matrix should reach a consistent and uniform state before adding fibers.
> 4. After examining the mortar matrix and making sure there is no clump in the bottom of the mixer, PVA fibers were added into the mortar matrix and mixed until all fibers are evenly distributed.
>
> Based on our experience, this procedure works fine for the Hobart and Zyklos type mixers. Please let me know if you have further questions.

Chen dismissed *mixer* as an important variable (line 23-24), saying the procedure should work in either kind of mixer being discussed. Thus the variable *mixer* we have been following as a strong potential actor is now less significant. Rather, other variables – namely *order* and *timing* – have been emphasized, and a new variable, *texture*, was introduced.

In the email above (lines 9 – 25), Chen explained that an even distribution of fibers is desired. In the following email (lines 26 – 32), Susan responded by describing their mixing procedure, identifying a point of failure in the process, and asking a number of questions about what might have gone wrong:

26 1. What does the mix look like when you are about to
27 add the super?
28 2. Have you ever added the super to the water? If so,
29 with what results?
30 3. Could you let us know what the largest volume of
31 ECC (batch) was that you have made in your Zyklos
32 mixer (I believe your mixer is 150L)?

Susan included details about the *order*, *timing*, and *texture* in her description of their process. She asked about *texture* (line 26), *order* (line 28), *volume of mix* (line 30), *mixer* (line 31), and *mixer size* (line 32) in her follow up questions.

This message marks the first introduction of *mixer size* as a potential variable. Before this message, only the broader category of mixer type or the brand name of a mixer was used. In order to understand the variable *mixer* I followed up with an interview and learned that *mixer* may subsume variables such as size, angle, shape, height, speed, and lining that are potentially influential aspects of mixers. Notably, of these possible variables, only the *mixer size* was selected by the researchers as a potential actor. This message treated *mixer* as less important variable, and I then needed to consider the relationship between *mixer* and *mixer size*.

Susan asked about the mixer's brand, its size, and the volume of mix created with it. Chen responded, and his treatment of mixer brand and size is vague:

33 2. Yes, we try (sic) that in the Hobart mixer and the
34 result looks the same but we have never try (sic) that in
35 the Zyklos type mixer.
36 3. The Zyklos type mixer we used has a capacity of
37 27L. The largest batch of ECC we ever mixed was 25L.
38 We have no experience in using the larger Zyklos mixer
39 you mentioned in producing ECC.

In the above message (lines 33 – 39), Chen provided details about the mixer sizes with which he has experience; he neither confirmed nor disconfirmed that size could matter.

This short email thread shows how the researchers negotiated the significance of a number of variables in their mixing procedures. They did so by introducing the variables in their descriptions of the process or in specific questions. Others signaled the importance they placed on specific variables through the way they discussed them in email (e.g., dismissing them, asking specific questions). Carefully analyzing the way in which researchers discuss these variables helped identify a subset of all possible variables for special consideration – namely *order*, *scale*, *texture*, and *timing*.

The range of variables in ECC mixing that may matter is vast. For example, the possible number of configurations for mixers is quite large; there are two brands of mixers – Hobart and Zyklos – and mixers can differ in the kind and shape of their bowls, the angle at which they mix, and the power of their motors. Given the many ways in which the mixers differ, there are literally scores of potential configurations. By following the actors carefully, as the engineers themselves introduce and debate likely actors, the range of possiblities is greatly narrowed. For example, as we saw the email thread dismisses mixer as an important variable but leaves open the prospect that a mixer's characteristics, such as size, may be significant. Following from the email data I interviewed both Dr. Wang and Chen and they mentioned that the lining of the mixer (whether it is wet or dry) and the speed at which it mixes may also be relevant but dismissed other mixer aspects as unimportant.

In the email thread above, we are able to trace the development of a shared understanding about what matters in mixing ECC. By the end of the thread, the four researchers share an understanding of the important components of the ECC mixing process and how those components may be influencing the mix at CER. Throughout these repeated email interactions, they negotiated possible important aspects of the process until they settled on four key aspects. Prior work suggests that shared understandings serve as a resource for coordination but fails to account for the processes through which those understandings develop. Analyzing this email thread provided the opportunity to trace the development of such an understanding. The next section reports results from my analyses of progress meeting minutes; those results provide insight into the development of social capital, another resource for coordination, within the WAB Project team.

4. C. Building Social Capital in Progress Meetings

The temporary nature of projects does not typically provide an environment in which long-term, stable relationships develop (Munns, 1996; Beyer & Holtzblatt, 1998). Relationships, though, are important for cooperation. In this section, I use data from progress meeting minutes to trace how relationships among members of the WAB Project team could have developed and discuss how the social capital they developed contributed to their development of adaptive capacity.

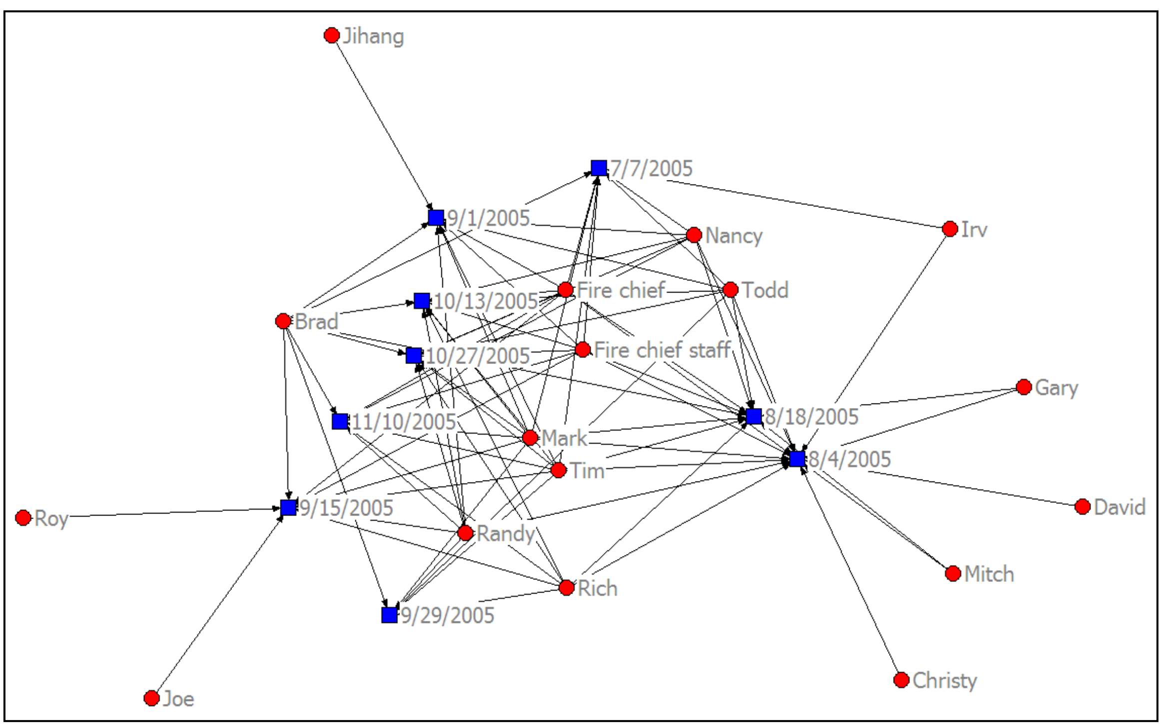
TheWAB Project team held biweekly meetings to discuss progress and concerns about the project. Tim, the senior project engineer recorded detailed minutes for each meeting. He made the minutes available to all members of the project team and interested supervisors, and they were also included in MDOT research reports related to the projects. Each set of meeting minutes follows a similar structure: the minutes begin with the time and location of the meetings and continue with comments from the fire chief, engineer issues, contractor issues, and miscellaneous. “Engineer issues” and “contractor issues” take up most of each set of minutes. Engineer issues are raised by MRL members and BTNH employees. Contractor issues are raised by employees of the subcontractors, e.g. the site inspector.

The WAB Project is one piece of a larger contract with MDOT to repair a number of bridges and on ramps. The engineers and contractors who attend these meetings are working on different parts of the larger contract. The fire chief or his employees attend every meeting, usually to discuss lane closures and rerouting plans; meetings were almost always held at the fire chief's local station. The WAB Project was discussed in meetings between July and November 2005. I analyzed these meetings minutes because 1) literature argues that meetings are effective coordination mechanisms (Cummings & Kiesler, 2003; G. M. Olson & Olson, 2000) and 2) my participants referred to the meetings as important (Mark, 12/08). In the next section I use social network analysis measures to describe the relationships that resulted from participation these meetings. Section 4. C. 3. describes the content of the minutes.

4. C. 1. Meeting Participation

Tim, a manager at BTNH, was ultimately responsible for the WAB Project, and all the other projects awarded under the same bid. He was the person in charge of construction engineering and employed by BTNH, the firm MDOT hired

Figure 4-2. Affiliation network: meeting participation



“to manage the engineering on the project and basically act on MDOT’s behalf during the course of the project” (Mark, 12/08). Tim was the highest-level manager and was responsible for the hiring and oversight of the all subcontractors, and he recorded the minutes for each progress meetings.

The first set of social network analyses I performed focused on participation in progress meetings. In this section I use “participated” to mean “spoke or provided information.” I coded participation in each meeting by tracing whose contributions were noted in the meeting minutes. I do not have access to the attendance records, and it is possible that individuals attended the meetings but were not noted in the minutes. It is also possible that individuals who were at meetings but were not noted in the minutes affected the conversations, interactions, and development of relationships. My claims about participation and embeddedness rely on the strict definition of participation that means a person was mentioned in the meeting minutes; a person’s influence may not necessarily correlate with how often they spoke, but my data contains information only about what was said. Individuals are included in the graphs and matrices if the meeting minutes mention them as speakers or indicate that they provided information during a meeting.

Figure 4-2 is a bipartite graph of the participants in the nine progress meetings during which the WAB Project was discussed. Figure 4-2 represents the affiliation network that resulted from participation in those nine meetings. Affiliation networks are a kind of two-mode network that represents the connections between a set of actors (e.g. meeting participants) and a set of events (e.g. meetings) (Wasserman & Faust, 1994). Such networks are also referred to as *membership networks* (Breiger, 1974). Researchers have used affiliation networks to study the theoretical implications of individual affiliations with groups, sometimes called “social circles” (Simmel, 1950), and to argue that “overlap in group memberships allows for the flow of information between groups, and perhaps coordination of the groups’ actions” (Wasserman & Faust, 1994, p. 293). I use an affiliate network here to understand what opportunities the WAB Project members had to interact with one another and to develop pair wise ties (i.e. ties between two people). The presence of links between individuals is central to social capital theory and will be discussed further in the next section.

In Figure 4-2, red circles represent individuals, and blue squares represent meetings. Distance between nodes indicates dissimilarity in participation. Nodes representing individuals are far apart because they participated in different meetings; meeting nodes are far apart when their participants differ. The two meetings in the cluster on the right had the highest attendance and included a different constellation of participants than the cluster on the left. The eight individuals between the two clusters of meetings participated in seven or more of the nine meetings.

The arrangement of actors in Figure 4-2 indicates at a number of differences among meetings and meeting participants. First, there are the individuals in the center, between the two clusters of meetings, who seem different from the individuals around the outside of the graph. To determine whether these individuals are different from the others in the graph, I conducted structural holes analysis (see tables 4.5 – 4.7) to determine the density and redundancy of their ego networks and to measure the constraint of connections (Burt, 1992). High dyadic redundancy shows high embeddedness in networks with few structural holes (Hanneman & Riddle, 2005, ch. 9). High dyadic constraint measures indicate that one actor has some control over another actor's connections, and eventually to another actor's access to information. Jones and her colleagues (2008) and Sonquist and Koenig (1975) argue that embeddedness in networks reduces uncertainty and improves coordination in social networks formed during projects.

Tables 4.5 – 4.7 illustrate that, throughout the network of meeting participants,

1. dyadic redundancy is generally high (mean = 0.68; median = 0.85),
2. dyadic constraints are quite low and similar (mean = 0.02; median = 0.02), and
3. structural hole constraints are low and similar (range = 0.23 – 0.28).

These measures tell us that most of the actors in the meeting affiliation network are highly embedded in the network. None of the actors in the network significantly constrain any other actors; there are no “gatekeepers” in this network. Additionally, none of the actors is highly constrained in the network – they have a variety of connections and many independent sources of information.

In the progress meeting network, high dyadic redundancy and low constraint measures indicate that the network has high embeddedness and that actors have freedom to interact with a variety of other actors. The progress meeting networks indicate that progress meetings allowed participants to develop ties that improve coordination within the team. I will use the content of the meeting minutes (Section 4. C. 3.) and data from interviews with project team members (Chapter 5) to determine whether and how the progress meetings actually improved coordination.

	Christy	Fire chief staff	Fire chief	David	Brad	Irv	Gary	Jihang	Joe	Mitch	Mark	Nancy	Roy	Randy	Rich	Todd	Tim
Christy	-	0.92	0.92	0.92	0.00	0.92	0.92	0.00	0.00	0.92	0.92	0.92	0.00	0.92	0.92	0.92	0.92
Fire chief staff	0.69	-	0.94	0.69	0.81	0.75	0.75	0.44	0.44	0.75	0.94	0.81	0.44	0.94	0.88	0.81	0.94
Fire chief	0.69	0.94	-	0.69	0.81	0.75	0.75	0.44	0.44	0.75	0.94	0.81	0.44	0.94	0.88	0.81	0.94
David	0.92	0.92	0.92	-	0.00	0.92	0.92	0.00	0.00	0.92	0.92	0.92	0.00	0.92	0.92	0.92	0.92
Brad	0.00	0.93	0.93	0.00	-	0.71	0.71	0.50	0.50	0.71	0.93	0.79	0.50	0.93	0.86	0.79	0.93
Irv	0.85	0.92	0.92	0.85	0.77	-	0.92	0.00	0.00	0.92	0.92	0.92	0.00	0.92	0.92	0.92	0.92
Gary	0.85	0.92	0.92	0.85	0.77	0.92	-	0.00	0.00	0.92	0.92	0.92	0.00	0.92	0.92	0.92	0.92
Jihang	0.00	0.88	0.88	0.00	0.88	0.00	0.00	-	0.00	0.00	0.88	0.88	0.00	0.88	0.00	0.88	0.88
Joe	0.00	0.88	0.88	0.00	0.88	0.00	0.00	0.00	-	0.00	0.88	0.00	0.88	0.88	0.88	0.00	0.88
Mitch	0.85	0.92	0.92	0.85	0.77	0.92	0.92	0.00	0.00	-	0.92	0.92	0.00	0.92	0.92	0.92	0.92
Mark	0.69	0.94	0.94	0.69	0.81	0.75	0.75	0.44	0.44	0.75	-	0.81	0.44	0.94	0.88	0.81	0.94
Nancy	0.79	0.93	0.93	0.79	0.79	0.86	0.86	0.50	0.00	0.86	0.93	-	0.00	0.93	0.86	0.93	0.93
Roy	0.00	0.88	0.88	0.00	0.88	0.00	0.00	0.00	0.88	0.00	0.88	0.00	-	0.88	0.88	0.00	0.88
Randy	0.69	0.94	0.94	0.69	0.81	0.75	0.75	0.44	0.44	0.75	0.94	0.81	0.44	-	0.88	0.81	0.94
Rich	0.73	0.93	0.93	0.73	0.80	0.80	0.80	0.00	0.47	0.80	0.93	0.80	0.47	0.93	-	0.80	0.93
Todd	0.79	0.93	0.93	0.79	0.79	0.86	0.86	0.50	0.00	0.86	0.93	0.93	0.00	0.93	0.86	-	0.93
Tim	0.69	0.94	0.94	0.69	0.81	0.75	0.75	0.44	0.44	0.75	0.94	0.81	0.44	0.94	0.88	0.81	-

Mean = 0.68; median = 0.85

Table 4-5. Dyadic Redundancy: High dyadic redundancy indicates high embeddedness

Table 4-6. Dyadic Constraint: High constraint indicates that an actor constrains another's relationships, effectively limited independent sources of information

	Christy	Fire chief staff	Fire chief	David	Brad	Irv	Gary	Jihang	Joe	Mitch	Mark	Nancy	Roy	Randy	Rich	Todd	Tim
Christy	-	0.02	0.02	0.02	0.00	0.02	0.02	0.00	0.00	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.02
Fire chief staff	0.01	-	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02
Fire chief	0.01	0.02	-	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02
David	0.02	0.02	0.02	-	0.00	0.02	0.02	0.00	0.00	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.02
Brad	0.00	0.02	0.02	0.00	-	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02
Irv	0.02	0.02	0.02	0.02	0.02	-	0.02	0.00	0.00	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.02
Gary	0.02	0.02	0.02	0.02	0.02	0.02	-	0.00	0.00	0.02	0.02	0.02	0.00	0.02	0.02	0.02	0.02
Jihang	0.00	0.03	0.03	0.00	0.03	0.00	0.00	-	0.00	0.00	0.03	0.03	0.00	0.03	0.00	0.03	0.03
Joe	0.00	0.04	0.04	0.00	0.04	0.00	0.00	0.00	-	0.00	0.04	0.00	0.03	0.04	0.04	0.00	0.04
Mitch	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	-	0.02	0.02	0.00	0.02	0.02	0.02	0.02
Mark	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	-	0.02	0.01	0.02	0.02	0.02	0.02
Nancy	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.00	0.02	0.02	-	0.00	0.02	0.02	0.02	0.02
Roy	0.00	0.04	0.04	0.00	0.04	0.00	0.00	0.00	0.03	0.00	0.04	0.00	-	0.04	0.04	0.00	0.04
Randy	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	-	0.02	0.02	0.02
Rich	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.00	0.01	0.02	0.02	0.02	0.01	0.02	-	0.02	0.02
Todd	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.00	0.02	0.02	0.02	0.00	0.02	0.02	-	0.02
Tim	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	-

Mean = 0.02; median = 0.02

	Effective Size	Efficiency	Constraint	Hierarchy	Indirects
Christy	1.00	0.08	0.26	0.00	0.77
Fire chief staff	4.00	0.25	0.23	0.01	0.92
Fire chief	4.00	0.25	0.23	0.01	0.92
David	1.00	0.08	0.26	0.00	0.77
Brad	3.29	0.23	0.24	0.01	0.81
Irv	1.31	0.10	0.25	0.00	0.82
Gary	1.31	0.10	0.25	0.00	0.82
Jihang	1.00	0.13	0.27	0.00	0.46
Joe	1.00	0.13	0.28	0.00	0.50
Mitch	1.31	0.10	0.25	0.00	0.82
Mark	4.00	0.25	0.23	0.01	0.92
Nancy	2.14	0.15	0.25	0.00	0.86
Roy	1.00	0.13	0.28	0.00	0.50
Randy	4.00	0.25	0.23	0.01	0.92
Rich	3.13	0.21	0.24	0.01	0.89
Todd	2.14	0.15	0.25	0.00	0.86
Tim	4.00	0.25	0.23	0.01	0.92

Table 4-7. Structural holes: High constraint measures indicate that one's connections are connected to each other

Figure 4-3. Meeting Co-participation

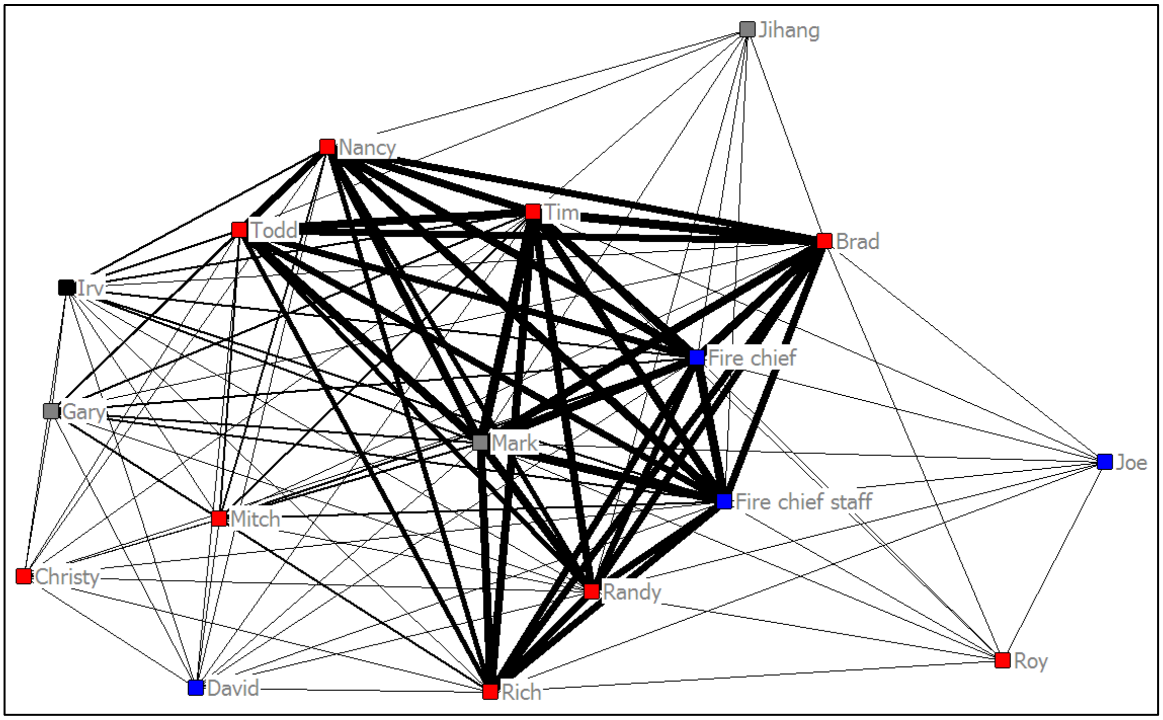


Figure 4-3 provides another graph view of the network that resulted from progress meeting participation. Figure 4-3 is a one-mode network of co-participation in the progress meetings. By co-participation I mean that two individuals participated in the same meeting. All nodes are human actors, and all lines represent how often two individuals participated in the same progress meetings. Heavier connecting lines indicate more co-participation. For instance, Tim and Mark both participated in all nine meetings. They are the only two people for whom this is true, and the line that connects them is the heaviest.

Node color indicates the kind of institution of which the individual is a member. Gray nodes are members of universities; blue nodes are employees of DOT, and red nodes are contractors and subcontractors. Black represents the lone materials supplier. The view of the social network shows us that ties developed among participants from different organizations. Literature suggests that bonding social capital – the kind developed among similar individuals like members of the same community of practice – can lead to out-group antagonism (Putnam, 2001). One way to limit the negative impacts of high bonding social capital is to develop more bridging social capital – to reduce the disparity between bonding and bridging capital by increasing connections *across* boundaries. The social network that developed during progress meetings indicates that bridging social capital should be available for the WAB Project team. Their frequent interactions during meetings could have helped them develop the kind of connections among organizations and between communities of practice that limit the influence of out-group antagonism.

Literature on construction projects suggests that the strong occupational stereotypes different communities of practice have about each other can act as barriers to communication in construction (M. Loosemore & Tan, 2000); reducing the influence of these stereotypes can reduce uncertainty and conflict within construction project teams. The short-term and seemingly random nature of the combinations of organizations involved in construction projects also contributes to the potential for conflict and poor communication (Munns, 1996). The network that resulted from the progress meetings indicates that the WAB Project team was able to develop (1) high bridging social capital that may reduce the negative impacts of stereotypes and (2) high relational embeddedness that should improve communication throughout the team. Social capital and embeddedness tell us something about the network as a whole. The single-mode co-participation network, also shows us something about individuals within the network.

The data underlying Figure 4-3 is shown in Table 4-8. I've placed the diagonal in bold to make it easier to see how many meetings an individual attended. Red text indicates the maximum number of meetings – notice that only two people, Mark and Tim, participated in all nine meetings.

	Christy	Fire chief staff	Fire chief	David	Brad	Irv	Gary	Jihang	Joe	Mitch	Mark	Nancy	Roy	Randy	Rich	Todd	Tim
Christy	1	1	1	1	0	1	1	0	0	1	1	1	0	1	1	1	1
Fire chief staff	1	8	8	1	7	2	2	1	1	2	8	7	1	6	6	6	8
Fire chief	1	8	8	1	7	2	2	1	1	2	8	7	1	6	6	6	8
David	1	1	1	1	0	1	1	0	0	1	1	1	0	1	1	1	1
Brad	0	7	7	0	8	1	1	1	1	1	8	6	1	6	6	6	8
Irv	1	2	2	1	1	2	1	0	0	1	2	2	0	1	1	2	2
Gary	1	2	2	1	1	1	2	0	0	2	2	2	0	1	2	2	2
Jihang	0	1	1	0	1	0	0	1	0	0	1	1	0	1	0	1	1
Joe	0	1	1	0	1	0	0	0	1	0	1	0	1	1	1	0	1
Mitch	1	2	2	1	1	1	2	0	0	2	2	2	0	1	2	2	2
Mark	1	8	8	1	8	2	2	1	1	2	9	7	1	7	7	7	9
Nancy	1	7	7	1	6	2	2	1	0	2	7	7	0	5	5	6	7
Roy	0	1	1	0	1	0	0	0	1	0	1	0	1	1	1	0	1
Randy	1	6	6	1	6	1	1	1	1	1	7	5	1	7	6	5	7
Rich	1	6	6	1	6	1	2	0	1	2	7	5	1	6	7	5	7
Todd	1	6	6	1	6	2	2	1	0	2	7	6	0	5	5	7	7
Tim	1	8	8	1	8	2	2	1	1	2	9	7	1	7	7	7	9

Table 4-8. Progress meeting co-participation

Actors with high co-participation measures potentially developed high relational embeddedness – they interacted with each other frequently. The actors around the edges of Figure 4-2 did not interact as frequently and are therefore not as embedded in the network of meeting participants. For instance, Mark and Tim attended nine meetings together, and Gary attended only two meetings. This suggests that Mark and Tim were more likely to develop ties with one another, and ties suggest information flow (Wasserman & Faust, 1994, p. 291) and the development of social capital (C. Jones et al., 1998). Chapter 5 uses interview data to explore whether those ties developed and includes a discussion of the sidewalk problem to illustrate how Mark and Tim used their social ties to complete the WAB Project successfully.

The strong ties evident in Figure 4-3 and Table 4-8 indicate that information could flow easily among organizations and that shared understandings could have been developed (C. Jones & Lichtenstein, 2008). The density of networks like this one that develop during short-term construction projects permit participants to learn about each other's practices (Eccles, 1981) and to establish routines for working together (Bryman et al., 1987) – both of which potentially improve coordination.

4. C. 2. A Note on Informational Meetings

The month before the WAB Project team joined the regular progress meetings, they held two additional "informational" meetings – the same meetings I referred to earlier when discussing Dr. Wang acting as a boundary agent. These meetings were held to

> introduce the various parties involved with the link slab project to the development of ECC material, the theory behind the link slab replacement of expansion joints, and to answer any general questions they might have before the construction work began. Those in attendance, in addition to [materials research lab] personnel, were MDOT, [BTNH] Engineers, Inc. (project managers), [HTN] Consultants, Ltd. (consultant), Construction Technology Laboratories, Inc. (CTL) (testing consultants), [Great Lakes Civil Engineering] (bridge contractor), and [Midwest] Concrete (concrete material supplier). (Research report #1471)

Minutes from only one of these meetings were available – those for May 31, 2005. Those minutes recorded who was present at the meeting, the questions that were asked, and the answers that were provided. ECC's properties and how to work with the material were the main topics of the informational meeting. Only the employees of BTNH attended both the informational meeting and any progress meeting. Mark, the MRL member who attended every progress meeting, was not available for the informational meeting on May 31, 2005. Because the networks of attendees at the informational meeting and the progress meetings had little overlap, and the purposes and structures of the meetings were very different, I did not include the informational meeting in the graphs and calculations above.

4. C. 3. Meeting Minutes Content

Communication, timing, and proactivity were the most common concepts in the meeting minutes. The rest of this section uses excerpts from the progress meeting minutes to illustrate the repeated reference to those three concepts.

Tim marked progress meetings as important communication mechanisms and "encouraged [team members] to attend" to receive "more definite information" than in other forms of communication (Progress meeting minutes, 08/04/05). Each set of minutes begins with comments from the fire chief and his staff. In six of the nine meetings, the first paragraph reads, "[The fire chief] and his staff stated that they had no pressing issues and were please with all communication to date" (Progress meeting minutes, 07/06/05) or another sentence with nearly the same phrasing. In the other three sets of minutes, Tim notes that the fire chief is seeking information about lane closures. "Communication" is the only topic Tim's minutes emphasize in sections pertaining to the fire chief and his staff.

Tim also emphasizes communication and timing by using bold text for the following excerpt: "Applicable testing staff should be notified of the trial batch!" (Progress meeting minutes, 07/06/05) He marks notification as an important task for the team. He also actively encouraged informal, proactive, and timely communication. For example, during one discussion about timing researchers' involvement, the meeting minutes read

> They need to be notified in advance of the actual pour in order that they can attach their strain gauges to the reinforcing steel once it is in place. They were also encouraged to contact the [power company] as soon as possible if they wish to explore the possibility of using their electric power. (Progress meeting minutes, 8/4/05)

By recording instructions such as "in advance" and "as soon as possible," the notes indicate that the team is proactive about planning. The WAB Project manager signals his efforts to plan ahead by using "as soon as possible" in his recorded instructions. He also mentions, "It is not too soon to start be pro-active (*sic*)" (Progress meeting minutes, 08/18/05). He again uses the "as soon as possible" marker when discussing the possible change in materials for the second stage of the link slab pour:

> …if a decision is made concerning additional usage of ECC material for Stage II construction this information must be made known ASAP in order that [Midwest Concrete] can insure that they have available materials on hand. (Progress meeting minutes, 09/15/05)

Annie, a crew chief who did not work on the WAB Project, pointed out, "Timing in Michigan and with contractors and scheduling [is challenging]," and "I think the coordination is probably --- probably the hardest [thing in construction projects]" (Annie, 5/09). Tim's minutes explicitly mark timeliness as something worth noting. After a subcontractor requested contract extensions, the minutes read:

> This has been discussed with the MDOT and it does not appear as though [the requests] will be given much consideration. However, it will be noted that they were received in a timely manner. (Progress meeting minutes, 08/04/05)

During each meeting, a large part of the minutes is devoted to updating the subcontracting schedules. For instance, in minutes from 08/18/05, 09/01/05, and 09/15/05, the team discusses delays and rescheduling activities for the actual pouring of the ECC link slab. The pour was originally scheduled to occur in two stages – one for each lane of traffic. The first stage was scheduled for 08/31/05, was eventually rescheduled twice, and occurred on 09/03/05. The second stage occurred in October of 2005, after the team had solved the sidewalk problem. I use the sidewalk problem to illustrate "adaptive capacity" in Chapter 5.

4. C. 4. Two Central Meetings

As shown in Figure 4-2, two meetings were more central to the social network of the project than the test – 08/04/05 and 08/18/05 (see also Table 4-9). The language of SNA can be slippery; for instance, when I say the meetings were “central,” I mean that those meetings had higher quantitative measures of their position in the network. “Central” in social network terms does not necessarily mean “important” or “essential” in a qualitative way. Those two meetings had the highest degree centrality (c = 0.77 and c = 0.59), and their centrality measures were different enough from the other meetings to matter. The graph layout in Figure shows that these two meetings are more similar to each other than they are to any of the other meetings; the algorithm used to determine the graph layout is based on geodesic distances – the shortest paths between nodes. The information in Figure 4-2 is richer than the table below because it uses more measures to determine the layout of the graph; the centrality measures reported in the table may not appear significantly different, but the graph layout tells us that they are. An actor with high degree centrality “is ‘where the action is’ in the network” (Wasserman & Faust, 1994, p. 179, quotes in original). Their high centrality measures make these meetings interesting – but not necessarily important – and by examining the minutes for these meetings, we can learn about what might have made them so central to the network and help us understand whether their content was in fact important.

Meeting participants discussed scheduling and lane closures, but those topics were not unique to these two meetings. The unique topics of those meetings were

1. the first trial batch of ECC,
2. attaching sensors to reinforcing steel, and
3. the first mention of the sidewalk problem.

Table 4-9. 2-mode centrality measures for progress meetings

	Degree	Closeness	Betweenness
7/7/05	0.47	0.65	0.05
8/4/05	0.77	0.81	0.29
8/18/05	0.59	0.70	0.09
9/1/05	0.53	0.67	0.10
9/15/05	0.53	0.67	0.18
9/29/05	0.35	0.60	0.01
10/13/05	0.53	0.67	0.03
10/27/05	0.53	0.67	0.03
11/10/05	0.47	0.65	0.02

The minutes for 08/04/05 introduce the test batch of ECC saying,

> The trial batch of the ECC mixture, which was performed on July 23, 2005 appears to have been successful. Satisfactory strength results are being obtained. (Progress meeting minutes, 08/04/05)

Members of MRL often express concern about whether others will be able to properly mix ECC (see section 4. B.). It is not surprising, then, that the first trial batch mixed by Midwest Concrete would warrant discussion in a progress meeting. The minutes read, in part,

> [Mark] presented additional data pertaining to the trail ECC mixture. All results are very positive. He also presented [Irv (Midwest Concrete)] with several suggestions that should help with the field application of the ECC mixture. (Progress meeting minutes, 08/04/05)

At first, MDOT and Midwest Concrete wondered "whether more suppliers were available and whether the raw materials could be substituted" (Info meeting minutes, 05/31/05). These questions do not resurface in the progress meetings, and the attention shifted to "field application" rather than ECC raw materials:

> These suggestions pertained to amount of mixing water, desired slump measurements, mixing time required after the addition of fibers, possible screeding technique and texturing techniques. (Progress meeting minutes, 08/04/05)

As we saw in the email thread in section 4. B. when teaching others to mix ECC, MRL members focus on just a few of the many variables that could matter in ECC mixing. After observing the test batch Midwest Concrete conducted, Mark (from MRL) targeted his suggestions toward just a few variables – water, slump, mixing time, and finishing techniques. He included these suggestions not just in the test batch meeting but also in a progress meeting where they were recorded and archived. These variables are absent in other project documents; for instance, they were not addressed in the ECC special provision (see section 4. A. . Boundary objects alone could not train Midwest Concrete how to successfully mix ECC, and Mark's suggestions warranted recording once they were delivered.

One of the other projects included in the package bid of which the WAB Project as a part included another research project with another university. That university was outfitting various steel reinforcement structure with sensors so that they may study structures' properties in real time (Progress meeting minutes, 08/04/05). Topic #2 – attaching sensors – relates to that project. The third unique topic of the central meetings was the sidewalk problem. The sidewalk problem was introduced on August 18, 2005:

> The issue being addressed is the combination of the ECC link slab being poured in conjunction with a concrete sidewalk and concrete railing. (Progress meeting minutes, 08/18/05)

The problem with pouring the ECC link slab in combination with a concrete sidewalk is that connecting ECC to concrete restricts ECC's ductility. The theoretical design for an ECC link slab did not include sidewalk on either side and limited the interfaces between ECC and other materials. The disparity between the theoretical design and the requirements of the Woods Avenue Bridge required that the link slab be redesigned before the scheduled pour in September 2005. The sidewalk problem and its resolution are discussed in greater detail in 5. D. Tracing topics through these central meeting minutes revealed the importance of mixing ECC and of limiting ECC's interfaces with other materials. These minutes also illustrate how the WAB Project fits within the larger bid – as one of many projects whose needs are all discussed in the meetings.

4. D. Summary

In this chapter, I focused on the data available from documents related to the WAB Project, especially the ECC special provision and the minutes recorded during progress meetings. The ECC special provision served as a boundary object for the WAB Project team, translating the MRL's research work into language appropriate for concrete contractors and bridge engineers.

Data from the ECC special provision and emails about ECC's mixing procedure illustrate how shared information artifacts helped facilitate the development of shared understandings and to negotiate roles and responsibilities in the project. Both shared understandings and negotiation are important components of adaptive capacity.

The progress meeting minutes describe the development of relationships among members of the WAB Project team. Social network analyses of the participation in progress meetings indicate that the WAB Project team could have had good communication flow and effective coordination, potentially reducing the uncertainty and conflict that often characterize construction projects. The network analysis suggests that bridging social capital and high relational embeddedness could contribute to the WAB Project team's abilities to effectively work together, but network analysis cannot tell us about the content or quality of those interactions. For example, repeated fighting and repeated play can look the same in network graphs.

In order to understand the quality of those relationships, I analyzed content from the meeting minutes and interviewed members of the WAB Project team. My analysis of the meeting minutes' content suggests that the management of the WAB Project was proactive and that communication and timeliness were important to the team. Analysis of minutes from two central meetings suggested that trying out a batch of ECC and designing ECC's interface with other materials were important events for the WAB Project.

The next chapter describes data from interviews with WAB Project team members and illustrates how the team developed quality within their relationships. Chapter 6 further develops the concept of adaptive capacity and explains how the WAB team developed the capabilities to adjust their activities to accommodate or capitalize on work done by others.

Chapter 5

Results from Interviews

Chapter 4 provided data from documents created and used during the WAB Project. It also addressed ways in which documents help develop shared understanding and accomplish some parts of negotiation, both aspects of adaptive capacity. In this chapter, I focus on data from interviews with project team members and other civil engineers. I use data from these interviews to identify social resources the WAB Project team used to facilitate their work. My participants indicated that perspective-taking, multimembership (or brokering), and affect were present and significant in the WAB Project. I introduce the term “relational engagement” to refer to the collection of social resources the team leveraged to interact and communicate during the Project. Positive relational engagement is another important component of adaptive capacity. Positive relationships enable negotiation and compromise.

5. A. Developing Positive Relationships through Perspective Taking

Perspective-taking is a concept found in psychology literature (e.g., Gehlbach, 2004; Johnson, 1975). Perspective taking refers to the ability to put oneself in the place of another and to recognize that others may have views different from one’s own (Johnson, 1975). Most studies of perspective taking employ experiments or surveys and aim at measuring either a person’s propensity or ability to take another's perspective. Results of these studies are expressed in correlations between propensity or ability for perspective taking and something like conflict resolution (e.g., Corcoran & Mallinckrodt, 2000). A related concept – "social language" – is a term linguists use to refer to "language that indicates an awareness of other people" (Pennebaker, 2008). Social language is the kind of language we use when demonstrating our perspective-taking abilities.

Members of the WAB Project indicate their perspective taking abilities when they make comments such as

> I would think that if you guys got involved with maybe [a community college], They have a concrete technology program up there. You could get a lot of free help with a lot of experiments up there, and they're more than willing to work with concrete and do labs and anything you guys don't like doing. (Todd, 10/05)[11]

By saying, "I would think," Todd indicates awareness that someone else might think something else. He implies that there is more than one idea about what the listener ("you guys") might want to do. After the WAB Project was completed, Mark, one of the doctoral students in the MRL, conducted a series of short interviews with people who had worked on the project. In the quote above, Todd is responding to Mark's last question, "Any other thoughts?"

When Mark asked Brad, an engineering project manager, "What advice would you give somebody else using this on a project?" Brad answered,

> If you can find a local materials supplier, you can reduce the cost. And reducing the cost you also want to pour it during the daytime hours. It makes it easy finishing. Number one is cost in the construction business. If you can reduce the cost, you can sell the product. (Brad, 10/05)

Above, Brad gives advice about how to sell the material. The question suggested an audience of "somebody else using [ECC] on a project," but his complete answer was geared to an audience of people trying to sell ECC. Brad's answer started as a general comment – "If you can find a local materials supplier, you can reduce the cost." Then he goes on to explain other ways to reduce cost – "pour it during daytime hours" – and eventually why reducing costs matters – "If you can reduce the cost, you can sell the product."

[11] Interviews will be referenced by participant name and approximate date. I have made efforts to identify participants by their role and refer readers to Table 3-2 on page 47 for a full list of interview participants and a summary of their duties.

Later in the same conversation, when asked if he had any other thoughts about the project or ECC, Brad expresses other concerns about the material, besides cost, that relate to how the material impacts the pouring procedure on other structures:

> In the small area that we just poured with (sic), it was very easy to finish it. In doing an entire bridge deck, when you have to use a roller and a screen to finish it, if you have to maintain a crown, that would be a concern. With this material being as elastic as it was, could you maintain a crown? You have to have some degree of slump with it. So I'd be curious about that. (Brad, 10/05)

His comments show that Brad thinks about more than just cost. His earlier comments were aimed at teaching the student something about the construction industry and how to sell a newly developed material; his later comments showed that he wondered about how the material would pour in other structures.

Conversations between project members are not the only place where perspective taking can be observed. Project team members also indicate their ability to recognize other perspectives when talking *about* one another, not just *to* one another. For instance, in an interview with me long after the project was completed, Dr. Wang, the director of MRL, had this to say about the MDOT program manager for the project:

> [Program managers] don't get much recognition for a successful program; [I'm] not sure he gains a lot by sticking his head out. Whenever you talk about a new technology there are many risks; [he] had to take a guess that it works, and if it works they don't get much. (Dr. Wang, 11/08)

His comment indicates his understanding of the program manager's work environment and reward structure. Dr. Wang understands that the program manager had to take risks with unclear or small rewards, that the program manager was taking a chance on Dr. Wang's material. The accuracy of Dr. Wang's understanding of the program manager's responsibilities is less important than that Dr. Wang thinks about them at all. His comment shows that Dr. Wang considers what might matter for the program manager, what risks he may be taking, and whether or not he will be recognized if his risks pay off.

Mark and I talked about the WAB Project a number of times, and during each interview he mentioned the importance of attending progress meetings and forming relationships during those meetings:

> But the fact that I went to all those meetings and was there to hear all that stuff and showed that, “Yes, I am very aware of all the other things that go on,” and appreciate the fact that there are other things they’re worrying than my research project. I went a long way with getting them to want to cooperate with us as well. It formed a really good relationship with the contractors just because I made the effort. Tom appreciated that as well. Plus, I had a chance to actually get a seat at the table, at the table, when decisions were made. (Mark, 12/08)

Mark’s comments reveal his understanding that his research project is not the only thing the group cares about. He also marks the “good relationship” his efforts to demonstrate that understanding afforded. Lastly, he marks his “seat at the table” as the outcome of his effort and the development of those good relationships. Mark’s comments reveal his ability to recognize that other people have different perspectives and illustrate his understanding of how making an effort to see those perspectives help him work with the team.

Todd, Brad, Dr. Wang, and Mark made comments that revealed their recognition of multiple perspectives in the project. The ability to take another’s perspective, or at least to recognize that yours is not the only perspective, may help reduce conflict in collaboration. Another way to reduce conflict is to effectively broker collaborative arrangements. The next section focuses on brokering through multimembership in communities.

5. B. Leveraging Social Knowledge through Multimembership

Membership in many communities of practice – *multimembership*– allows us to transfer elements of practice between them – a process Wenger (Wenger, 1999) calls *brokering*. Brokering among communities of practice helps align the different perspectives each has. Wenger describes this process as “brokers press into service … the possibilities for negotiation inherent in practice” (p. 109). This idea of negotiation was crucial in solving the sidewalk problem (see section 5. D.) and in helping the WAB Project team adjust to unfamiliar practices.

The project team held two informational meetings four months before the scheduled ECC pour in order to alleviate concerns and share knowledge about working with the material. MDOT employees and subcontractors had a number of questions about how working with ECC was different from working with traditional concrete, and during those meetings, subcontractors asked questions such as, “How [should we] finish the surface of the ECC link slab after casting?” (Info meeting, 05/31/05). “Finishing” refers to steps to adjust the surface of the concrete after it has been poured (Jason, 01/09); most often finishing work is done on concrete that will be visible. The question about finishing the surface of the ECC came after a lengthy discussion of the importance of even fiber distribution in ECC and the flowability (e.g. how easily it pours) of the ECC. Often in finishing, rakes and brushes are used that could potentially change the distribution of the fibers throughout the poured material. The informational meeting provided an opportunity for Midwest Concrete to learn about ECC and how using it would require them to adjust their normal practices – in this case, Dr. Wang taught them how to finish the material without affecting fiber distribution.

Concrete contractors were not the only group who needed to adjust their normal work during the WAB Project. MRL researchers were used to working in a very controlled environment within their research lab (Mark, 12/08), while in construction, on the other hand,

> out on a job, people are swearing and smoking and chewing tobacco and talking about girls and dirty things and, you know, what they did the night before and then you go back into the office and it’s like, I am in a suit again and try not to swear because you have been swearing for six months in the field and it’s -- it’s a really dirty job, always filthy, like physically filthy. (Annie, 5/09)

Mark, a member of MRL, had worked both in the lab and on construction sites. He expressed concern about MRL researchers’ ability to handle work on real construction sites:

> So having worked on a construction site and knowing what that’s like … I knew what it was gonna be like as far as scheduling goes and how things can change minute to minute on a construction site. If something doesn’t work, all of a sudden, a pour gets pushed off two or three days, whatever… Then having worked in [the MRL] lab for a while, I was personally concerned about our ability to work with that. (Mark, 12/08)

Because he had worked in construction before and was then a senior student in the MRL lab, Mark could inhabit both the research and construction communities of practice. He understood that the preparation for a concrete pour, for instance, was very different in the lab than in the field:

> I mean, for us [at MRL], it was, okay, getting ramped up for a pour on ECC was a big deal. For these guys [in construction], pouring concrete is something you do every day. So for them to push a concrete pour back three days isn't a big deal … For us, it was weeks of getting everything put together and getting everybody lined up schedule wise and all this other stuff. (Mark, 12/08)

The MRL experiences pours differently in part because they do so few of them. Most of the work in their lab uses small pieces of ECC, about the size of two bathroom tiles (see the stack of ECC specimens in the background of Figure 5-1). These pieces are used in tensile and strength tests. Only rarely does the lab pour an ECC structure that requires more material than will fit in a seven-quart Kitchenaid blender (see Figure 5-1). Pouring any larger structure requires that they rent a concrete mixer, build a form to hold the concrete in place while it cures, and find a time when all the students in the lab are available (Mei, 11/07). Because the pours are so rare, it's important that the students be there so that by the time they graduate, they have participated in many ECC pours; each pour is an opportunity for senior students to teach newer students about the complicated mixing process (Chen, 11/07).

Figure 5-1. Blender used to mix most of MRL's ECC batches

As Mark points out, pouring concrete is a daily activity for many construction crews, especially crews that work on roads and bridges. Concrete suppliers have the capacity to mix on demand and do not usually require special equipment as the MRL does. Construction crews also work on many projects at once and can work on something else if a pour is delayed (Annie, 05/09); MRL pours only when they need structures and therefore may have to stop work until a pour can be completed. Mark was able to leverage his multimembership in construction and research communities to help ease concerns about MRL researchers working with construction workers. Preparation and delays are experienced differently in the lab than in the field. The next section focuses on one difference between these experiences – the presence of affect in the MRL researchers' comments.

5. C. Providing Motivation through Affect

Mark and the other MRL members had an emotional investment in the WAB Project that the construction workers did not. For instance, he indicated that schedule changes could have an emotional effect on the MRL researchers, using the term "devastating" to describe their potential response: "putting [an ECC pour] off a couple days was devastating, right" (Mark, 12/08). Mark preferred to manage the emotional aspects of the project through active engagement:

> The way that I tried to manage [my concerns about our lab working in the field] as best we could was, while I wasn't required to, I did attend every project meeting that was held once kind of this phase of the project started. (Mark, 12/08)

Mark's comments make it clear that MRL researchers experience ECC affectively – schedule changes are "devastating" – and that at least Mark saw value in actively working to manage his concerns about MRL's work. Adler and Obstfeld (2007) argue that affect plays a large motivational role in projects. They argue that the affect (their word for Dewey's "impulse") and projects are tightly linked and use a discussion of the Latin roots of the word "project" and Dewey's own discussion of the connections between impulse and projects:

> Impulses are the pivots on which the re-organization of activities turn,they are agencies of deviation, for giving new directions to old habits their quality. Consequently, whenever we are concerned withunderstanding social transition and flux or with*projects*forreform,personal and collective, our study must go to analysis of nativetendencies. (Dewey, 1922/2002, p. 93, emphasis added)

This argument suggests that the WAB Project was able to use the affect/impulse provided by the MRL researchers as a resource for completing the Project.

5. D. Solving the Sidewalk Problem

In this section I use data from a specific incident during the WAB Project to illustrate adaptive capacity and to discuss how it could have developed in the WAB Project. I use this example to illustrate what perspective taking, multimembership, and affect enable.

Figure 5-2. Sidewalk Reinforcing Bars

Solving the sidewalk problem required that the project team redesign the sidewalk in the field; these kinds of redesigns are common in construction (Annie, 05/09). Normally, sidewalks attach to the bridge decks on both sides. The interface between ECC and any other material is a tricky area because the material is so carefully engineered. A steel rod or a traditional concrete interface changes the way the ECC is able to respond – it cannot bend as much when connected to rigid materials. Joint interfaces and gaps are a major reason MDOT wanted to try ECC in the first place – repairing joints between sections of concrete and fixing rubber joints are incredibly expensive parts of road maintenance (Jason, 12/08). By removing the need for joints, ECC greatly reduces the cost of maintenance (Dr. Wang, 11/08; Mark, 02/07). However, ECC still has to interface with materials on the bridge deck and now with the sidewalk; anywhere two materials meet is an opportunity for failure.

One of the graduate students in the WAB Project first told me about the sidewalk problem by saying, “there was [*sic*] definite concerns back and forth regarding sidewalk. Sidewalk was a big hanging point for this project,” and “Who would have thought a sidewalk was going to be our Achilles' heel? I didn't see that coming. This is a bridge" (Mark, 02/07). Basically, MRL's original theoretical design for an ECC link slab had not accounted for a sidewalk, but the Woods Avenue Bridge had one. So, the contractor, researchers, and MDOT had to redesign the sidewalk and the interface between the sidewalk and the bridge deck on the fly in order to avoid costly downtime during construction.

Mark, the doctoral student, described the sidewalk problem this way while pointing at a bridge design diagram and photographs of the WAB Project underway:

> Here we've got the, and this is actually something we had written in the design. So, we've got steel girders here, concrete slab here, down here. The way that it had been designed and like I said we totally missed this – was that the sidewalk was made of regular concrete and would run [along the edge of the ECC link slab]. Okay. Like this, with the railing up here and they had a two-inch belt expansion joint [between the deck and the sidewalk]. Okay.
>
> Okay, which, would work really well if you worked this previous system with a little two-inch gap, and also the sidewalk is connected to the, um, to the deck. [sidewalk reinforcing bars would be] good for the concrete section, but then they were also [using reinforcing bars] with … the link slab. And so basically, what it

Figure 5-3. Transition Zone between Concrete and ECC

> was doing was taking this very ductile material and tying that down, tie it down to this sidewalk, yeah. And we said, “Ohhhhh, noooo. You can’t do that.” (Mark, 02/07)

Figure 5-2 shows the sidewalk reinforcing bars to which Mark referred. These steel bars connect sidewalk to adjacent materials. As Mark says, the bars “loop into the sidewalk;” looping steel through ECC and concrete sidewalk would have the effect of “tying [ECC] down.” Figure 5-3 shows the formwork where the deck of the bridge with transition from traditional concrete to ECC. ECC was placed left of the wooden markers. The deep red area contains shear connectors – steel that holds down the deck. Regular concrete has these shear connectors underneath it, but only the edges of the ECC link slab have shear connectors underneath them. Note that the shear connectors stop near the bottom left part of the photograph. Most of the ECC link slab was poured over the black material (roofing paper) where shear connectors are absent and where the ECC will not be tied down. ECC was not be held down by shear connectors. The shear connectors are similar to sidewalk reinforcement bars – they are both steel forms designed to couple adjacent materials. ECC is designed to work with minimal connections though, and the problem with the sidewalk was that it had more steel connectors than the link slab areas, limiting the very flexibility for which ECC was designed.

In his comments above, Mark is introducing the sidewalk problem. He points out that attaching ECC to a less ductile material changes the way the ECC behaves. He continued, describing the alternatives the team offered for pouring the sidewalk without “tying” the ECC down to a rigid material:

> And so we had come up with, well one option was just to say okay, this section of the sidewalk also has to be ECC. That would have been okay. They said, “We can’t do that. We can’t afford to do that. That’s another pour. It’s another day. It means emptying our bins again at the, because we had to empty the bins at the ready-mix plant in order to get material out in the first place.” So, they didn’t want to do that at all. And so we said, “Okay. What we can do is put another layer of roofing paper there, kind of to decouple the [ECC and the sidewalk] and make sure there’s no rebar going between them.” That would have worked as well. (Mark, 02/07)

Pouring the whole sidewalk in ECC and using roofing paper to decouple the concrete sidewalk and the ECC deck were the first two options presented for solving the sidewalk problem. The "bins" to which Mark refers are the large silo-like bins that concrete suppliers use to store the raw materials. When production scale concrete suppliers mix concrete, they do so by adding the raw materials directly to the mixing truck, usually by pouring from raised bins (see Figure) into the top of the mixing truck. Because ECC uses different raw materials, the supplier had to empty the bins and fill them with ECC raw materials for each day of pouring (Mark, 02/07; Jim, 06/07). When Mark says, "That's another pour," he's referring to the process of emptying and filling bins at the plant (see Figure 5-4). The "ECC sidewalk" option was too expensive in time and money to be viable.

Mark described the resolution of the sidewalk problem by discussing apprehension within the team and explaining how he and an onsite engineer were able to redesign the sidewalk in the field:

> They were very apprehensive to [decouple the materials] because MDOT had a

Figure 5-4. Concrete mixing plant bins

> lot of experience … with water running into [the gap] and kind of working its way in between these two [materials] and they said, "Mm-mm, decoupling this is not a good idea." There was even talk of rather than using concrete here in this section, we would switch over to a "thriving" which is kind of like those metal guardrails … Leave no sidewalk here and put a steel plate with an expansion joint here and here to kind of complete the sidewalk.
>
> It would have looked odd, to say the least, but it would work. And so we went through all these things with the engineer onsite, his name was, [Tim]. He would be an engineer with [BTNH]. They were the construction engineer on the project. So, we went through all these things and all these options. But, finally, what we ended up deciding was at this particular joint, the way this joint is designed there's not a whole lot of movement at this particular joint, on this particular bridge. There are two other expansion joints [in other parts of the same bridge] that in a full ECC link slab bridge you would replace those with link slabs as well. We only wanted to do one demonstration at this point. (Mark, 02/07)

Instead of decoupling the deck and the sidewalk using roofing paper, they decided to pour the sidewalk on top of ECC (Progress meeting minutes; 09/01/05). Lastly, Mark notes the tradeoffs the team was making by choosing that alternative design. He also explains that the end result will not be exactly how ECC was intended to work:

> And it was decided that a little bit of restriction from the sidewalk would not detrimentally damage the link slab for a number of reasons. Now number one was the amount of movement. Number two was it's only the edge of the bridge where this is going to impact [the ECC]. We still have the entire field where [restriction is] not going to be a problem. So, while we might see some heavy cracking and maybe some cracking in the concrete [where the slab meets the sidewalk], that's a little more than we want, it wouldn't, you know, totally, it wouldn't be detrimental to the overall construction. Okay.
>
> So, we decided all right, go ahead with this plan. It's okay, but if we really want to make this system work, as it's intended to work in the future, this cannot happen. So, it was kind of a give and take between the contractor, MDOT and us. (Mark, 02/07)

Mark's descriptions include the multiple options the team discussed for solving it. First, they considered pouring the sidewalk with ECC, but that option was expensive in materials and in the time and effort required to do an additional ECC pour. Then, they offered to decouple the deck and sidewalk using roofing paper. Because water can get into the space roofing paper creates, decoupling was not a preferred method. Lastly, the group considered connecting the deck and the sidewalk by pouring concrete on top of ECC. This is eventually the route they took, and Mark notes that the process of solving the sidewalk problem required "give and take" and that it resulted in a solution that was not ideal from

MRL's perspective. His comments show that MRL was willing to make compromises because they "really want[ed] to make this system to work."

Mark first mentioned the sidewalk problem in a progress meeting on August 18, 2005 (Progress meeting minutes, 08/26/05). He and other MRL researchers then met with Tim, from BTNH, and Randy from MDOT, on August 26, 2005 and redesigned the interface between the ECC link slab and the sidewalk (Progress meeting minutes, 09/01/05). Mark and Tim finalized the redesign at the construction site. The original theoretical design of the ECC link slab took just over two years – November 1, 2001 - November 16, 2003 (Research report #1438), and the redesign to solve the sidewalk problem took three meetings over one week. As Annie, the crew chief, notes, redesigning on the construction site is a common activity. However, Annie also noted that in her experience, redesigns were not problematic because communication on her crew was easy. She explained,

> Once they worked for you for a while, [you team members] know exactly what you want and when you want it. All the way down to my guy that I had on my crew forever [Cal] had extra pens, had extra everything that I always need. If I drop a pen in the water working on a bridge or just something I mean, he was always like (pulls a pen out), you know, it was great … you got to the point where you didn't even have to ask them to do things or [show] where to set up … If you had a good crew you really didn't have to talk much. (Annie, 5/09)

The WAB Project team didn't have nearly as much shared experience as Annie and Cal, but they were able to develop the trust that Medha, another bridge engineer, marked as most important: "Number one is [to] provide, [create] trust – that's number one, you know, so as to avoid all these miscommunications later" (Medha, 5/09).

By the time they encountered the sidewalk problem, Mark and Tim had attended 2 progress meetings and 2 informational meetings together to talk about the WAB Project, and they had worked onsite together for one full day. Tim had asked Mark questions about the material itself, about his background in construction, about the theory behind ECC, and he had reviewed all of Mark's calculations. He and Mark established a social tie strong enough to enable them to adapt on site and to redesign the sidewalk together. Mark describes the importance of those interactions this way:

> By having been in all these meetings of when somebody said, "Well, you know, we're not sure exactly what to do." "Well, we can call [Mark]," right. It wasn't so hard to pick up the phone and call me and ask my opinion on something because I had sat in on all the meetings and people who knew who I was – and then when the day came to pour, I wasn't some stranger showing up on site saying, "Look, let's do it this way."
>
> That went a long way to kind of bringing everybody here down a couple notches. Not to say that weren't concerns, I mean, there [were] concerns on everybody's behalf. But we tried to take care of those the best we can. It actually … it went pretty smoothly. I think they were expecting a lot more hiccups too because I don't think they expected me to come to all the meetings and understand what their – what all of their concerns were. (Mark, 12/08)

Mark identifies "knowing" him as something that allowed other people on the team to work together "smoothly." Mark continues, labeling "effort" as something he did and "understanding" as something that resulted from the shared meetings:

> Yeah. So you probably don't need to go to all the meetings I went to. But I would definitely suggest you got to make an effort at understanding what the other concerns people are dealing with so that you don't come in and say, "Look, my little" – you have to understand. You're just a little piece of this whole – and that your little piece isn't necessarily the most important part to everybody. (Mark, 12/08)

Literature and research participants often mention trust as a crucial component of successful collaborations; they mark it as a mechanism for communication as Medha did. But trust also helps with less explicit tasks – trust enables the moment by moment coordination required to redesign a bridge while it is being built. Social network analysis often uses "trust" as a term to describe a resource afforded by social ties and repeated interaction (Burt, 2001; Woolcock, 1998). "Social capital" is a broader term that refers to all the resources afforded by such social connections (Bourdieu & Wacquant, 1992; Lin, 2001). Interacting repeatedly during meetings enabled Mark and Tim to build social capital, and Mark describes the use of this capital when he says, "That went a long way to kind of bringing everybody here down a couple notches." The social capital he built with Tim afforded calmness and understanding among Mark's lab mates and the construction contractors.

The adaptive capacity present in the WAB Project team resulted from their repeated positive interactions during progress meetings. They leveraged this adaptive capacity to solve the sidewalk problem – generating alternatives and eventually an acceptable compromise that limited the restriction of ECC and kept the total cost of construction low.

Adaptive capacity refers to the capabilities of both individuals and groups to adjust their activities to accommodate or capitalize on work done by others. The ability of constituent roles to adjust to changing conditions contributed to the WAB Project's success. In order to solve the sidewalk problem, Mark needed to take on the role of researcher and designer. Mark represented the interests of the researchers who wanted a demonstration link slab designed as close to their laboratory specifications as possible. Similarly, Tim took the role of supervising engineering, designer, and MDOT proxy. He represented the interests of the construction contractors and the financial backer of the project. They were able to inhabit these roles because they had developed knowledge of others' concerns and had built social capital through repeated positive interactions. Mark and Tim knew that others had different perspectives on the project and had interacted enough to be willing to work together on a redesign. Mark indicated his understanding of someone else's perspective when he took on the voice of the contractors:

> They said, "We can't do that. We can't afford to do that. That's another pour. It's another day. It means emptying our bins again at the, because we had to empty the bins at the ready-mix plant in order to get material out in the first place." So, they didn't want to do that at all. (Mark, 02/07)

Obstfeld (2001, p. 154-155) uses the term "riffing" to describe this particular kind of perspective taking where one portrays the voice of another. Tim marked his awareness of multiple perspectives and adaptations during his post-project interview with Mark:

> [I thought] effective coordination and communication [would be the biggest problems]. I was a little bit concerned about initially with working with a group of people that were not fully cognizant of the cost and time constraints that the contactor had to adhere to and just making sure that the research project was going to be compatible with the contractor's progress schedule. … It turned out excellent. Cooperation was just great. I think there was (sic) more concessions

> made on the university's part than on the contractor's part because his schedule really was never affected. (Tim, 10/05)

Tim labeled "cognizance" and "concessions" as keys to avoiding the problems he thought the project would encounter. He was answering the question, "What were your biggest concerns before [the WAB Project] started?" His comments illustrate that Tim was concerned about whether project team members would be able to think about each other's needs (i.e. would have positive relational engagement). He then acknowledges that he witnessed adaptation – "more concessions made" – during the project. Tim, Mark, and their descriptions of the project and the sidewalk problem illustrate the work adaptive capacity enables.

In order to solve the sidewalk problem, the WAB Project team needed to consider their alternatives and to negotiate a solution that met each constituency's goals. MDOT and the contractors wanted to keep costs down and to limit the exposure of materials to water and its potential to damage them. The MRL researchers wanted to test their material in the field and to control the interfaces between ECC and other, less rigid materials. In the end, the team was able to redesign the sidewalk and its connection to the deck on the fly. The resources the team developed and that were discussed in this chapter under the term "relational engagement" – perspective taking, brokering, and affect – enabled the team to adapt during the Project.

5. E. Summary

In this chapter, I provided results from interviews conducted between 2005 and 2009. These data indicate that WAB Project members understood that other people had different perspectives on the project. They also made efforts to bridge the distance between multiple perspectives by participating in group meetings or by providing advice related to another team member's goals.

I identified three resources the WAB Project team used to support its work – perspective taking, multimembership, and affect. Perspective-taking, social language, brokering, and affect are markers of something I refer to as "positive relational engagement." Positive relational engagement (PRE) labels the processes through which teams develop the trust and communication that my participants labeled as crucial to the success of the WAB Project. PRE is marked by perspective-taking and affect, especially; perspective-taking provides some resources for interacting with teammates, and affect provides the motivation to do so. Relational engagement is not necessarily about accurate understandings of different perspectives; rather, collaborators' abilities to recognize the existence of and the willingness to try to understand other perspectives are the activities that make up positive relational engagement. Trust and communication matter because they provide resources for accomplishing coordination – the central and enduring problem for collaborative activities.

I used data from a specific incident during the WAB construction – the sidewalk problem – to illustrate the kind of adjustments adaptive capacity enables teams to accomplish. In the next chapter, I further develop the term "adaptive capacity" in order to understand how coordination is achieved in projects.

Chapter 6

Discussion: Developing Adaptive Capacity

Chapters 4 and 5 reported data from information artifacts the project team created, the meetings they held, and interviews my colleagues and I conducted. My analysis of those data indicates that the WAB Project was characterized by explicit roles and responsibilities, a network structure that enabled communication flow, perspective taking, multimembership, and positive affect. In this chapter I propose that those attributes of the WAB Project are some of the capabilities that enabled them to coordinate their work effectively. I introduced "adaptive capacity" as a term to describe the property these attributes afford a collaborative project, and in this chapter I further develop the concept.

Adaptive capacity tells us how aspects of a collaboration – especially its relational engagement and social flexibility – enable coordination work – by enabling a team to adjust. Adaptive capacity does not replace coordination as a set of activities important in projects but rather explains how coordination work is made possible and what it involves. We know from prior work that adaptive capacity is the product of active management (Folke et al., 2002; Staber & Sydow, 2002).

My goal here is to look beyond the terms "coordination" and "project management" and to understand how we accomplish those activities and ensure success within projects. It is not enough to group all communication activities under the umbrella of "coordination" and then to claim that coordination matters as Cummings and Kiesler (2003) do. Instead, I propose the concept of *adaptive capacity* to label the “how” behind coordination. Adaptive capacity tells us what work enables coordination.

6. A. Adaptive Capacity: Bending without Breaking

ECC – the material the WAB Project was undertaken to test – outperforms other concretes because it can bend farther without breaking. ECC is engineered to endure tensile strain and even to heal itself from small fissures and cracks. ECC embodies the idea that something that can bend without breaking can be more useful and effective than something that is strong but fragile. As the ECC inventor noted, “a tighter, higher strength material tends to be more brittle. That’s a material secret” (Dr. Wang, 11/08). Concrete is quite strong, but stronger materials are not necessarily tougher. During the same interview, the ECC inventor mentioned, we may “think that stronger materials make stronger structures, but that’s wrong … [It] turns out steel has strength properties that go inverse with toughness” (Dr. Wang, 11/08). My data indicates that like in materials, rigidity does not make a tougher (i.e. more resistant to failure) collaboration; instead, an engineered coupling of the materials (e.g., the people involved, their combination, their properties) and the structure (e.g., the social arrangement and its management) can help ensure that collaborations are successful by allowing the collaboration to adapt – to bend without breaking.

After a presentation early in ECC’s public life, Dr. Wang was approached by an audience member who said something like, “ECC works just like an abalone oyster shell. That’s so interesting.” Dr. Wang was not familiar with abalone shells, but after looking into them, realized that ECC did rely on similar principles on which abalone shells rely – namely that spreading the energy from a blow throughout the shell allows it to absorb the blow without failing. Dr. Wang had not set out to achieve biomimicry, but he had, in part, done so. Adaptive capacity has roots in biology as well. The phrase is often used to describe the ability of an ecosystem to adjust to changes in its environment (Folke et al., 2002). I propose that the concept of adaptive capacity is also useful for understanding how human systems adapt to their environments. When discussing the changes human systems much make, we often use “coordination” language (T. W. Malone & Crowston, 1994; March & Simon, 1993, p. 48) to describe the dependencies that must be managed. Adaptive capacity describes the proficiencies a group develops and leverages in service of coordination. Prior work tells us something about occasions for coordination – e.g., face-to-face meetings, phone calls (Cummings & Kiesler, 2003) – and dependency management strategies – e.g., standardization, direct supervision, and mutual adjustment (March & Simon, 1993). These discussions stop short of explaining how groups gain the ability to manage dependencies or to capitalize on those occasions for coordination. They also emphasize survival and longevity as reasons for making adjustments. We are left with an incomplete understanding of how coordination work gets done and with a perspective that makes little sense for temporary endeavors such as projects.

6. A. 1. Reviewing Results from WAB Project Data

Chapter 4 provided data from the WAB Project’s contract and supplemental documents and from WAB Project meetings. Data from those documents suggest that the team used them to share knowledge about ECC and to clearly describe roles and responsibilities within the project. Regular meetings during which proactivity and communication were stressed helped the project team stay abreast of others’ work, its impacts on their own, and on the project’s schedule. I used those meeting minutes to construct social network representations of the WAB Project team and their relationships. These networks were dense and closed, and this structure suggests that communication should flow easily among the project team members.

Chapter 5 reported data from the content of meeting minutes and interviews. These data suggest that perspective taking, the ability to put oneself in the place of another and to recognize that others may have views different from one’s own, characterized many interactions among WAB Project team members and that this perspective taking afforded positive relationships among project team members. These positive relationships created a space within which the project team could use the social capital developed during their meetings. The positive quality of these relationships is important for understanding how and why they are useful.

Data from interviews also suggests that multimembership and affect played crucial roles in building relationships among team members. Members of the team were able to leverage their multimembership in different communities of practice in order to facilitate their perspective taking. The researchers, especially, were emotionally committed to the success of the project, and this emotional attachment may have helped them make adjustments to accommodate less invested members of the team, such as contractors.

Together, shared documents, a network that enabled communication flow, perspective taking, multimembership, and affect helped the project team develop the capacity to adapt to changes in their environment such as schedule adjustments and new practices required for working with unfamiliar materials. This ability of the team to adjust – a concept I call "adaptive capacity" – is important for understanding how coordination work gets done. I argue that an adaptive capacity perspective that emphasizes adjustment and the properties of teams that enable them to collaborate effectively is more useful than prior literature's calls for rigidity, longevity, and efficiency.

6. A. 2. Relating Adaptive Capacity to Prior Research

Adaptive capacity builds on prior work that explored the relationship between network structure and shared understandings (C. Jones & Lichtenstein, 2008), the effects of perspective taking (Obstfeld, 2001), meetings (Cummings & Kiesler, 2003), and communication (M. Loosemore & Tan, 2000) on coordination in teams.

Jones and her colleagues argue that shared understandings establish a "macroculture" which serves as a toolkit (Swidler, 1986) that actors use to do coordination work (C. Jones et al., 1997). These shared understandings result from structural embeddedness – a measure that refers to how connected one's connections are to each other (Granovetter, 1992).

Cummings and Kiesler (2003) argue that coordination is central to project success and identify four kinds of coordination mechanisms in distributed teams: supervision, direct communication, special events, and travel. Loosemore and Tan (2000) found that the stereotypes and assumptions team members have about one another can negatively impact the team's communication.

Obstfeld (2001), in a study of innovation in automotive engineering, found that "riffing" – a kind of perspective taking that involves orally representing the voice of another – could create credibility and persuasiveness for a speaker.

This earlier literature tells much of the story of how project teams are able to work together, but they fail, individually, to tell the whole story. I do not argue that coordination and shared understandings are not important but rather that they do not explain the "how" of collaborative work. Adaptive capacity contributes to our understanding of how projects can be successful by helping us understand how activities in a project impact its success – it integrates social capital, shared understandings, riffing, and communication in an effort to explain how teams coordinate.

For instance, social network research tells us that shared understandings *may* develop because information and communication should theoretically flow easily in a dense network like the WAB Project's. Social network analysis cannot tell us about the quality of those relationships – fighting and playing look the same in networks. Literature on coordination in teams emphasizes tasks and meetings but fails to explain how relationships among individuals influence negotiations and what happens in meetings that accomplishes coordination. This dissertation contributes to our understanding by exploring the quality of relationships within an social network and by explaining what about meetings and repeated interaction enabled coordination – namely the development of the team's collective abilities to adjust to one another.

My development of *adaptive capacity* relies heavily on the idea of relational engagement. Relational engagement refers to how the actors in a project interact with one another, and adaptive capacity refers to the capabilities of both individuals and groups to adjust their activities to accommodate or capitalize on work done by others. The way in which actors in the project engage with one another influences the development of adaptive capacity; the two concepts are necessarily linked. Positive relational engagement – the kind of engagement that results from recognizing and valuing multiple perspectives in a project – helps ensure that a team will be able to adapt to changes. This emphasis on the relational engagement among team members is a departure from the traditionally outward-facing perspective of earlier literature on adaptive capacity (Staber & Sydow, 2002). Adaptive capacity offers project teams a positive perspective that emphasizes their own properties and agency over their survival and environment.

In the WAB Project, adaptive capacity developed through positive, repeated interactions and boundary objects that were explained and expanded by knowledgeable individuals. The adaptive capacity the WAB Project team developed enabled them to successfully complete a complicated, time-sensitive redesign of part of their construction plans. Doing so required that project members leverage this capacity to adjust to one another's needs, including the bridge's need for a sidewalk.

6. B. What Did Not Affect the WAB Project

Literature suggests that procurement problems plague all construction projects (Cox & Townsend, 1998; Fairclough, 2002). It also identifies competing goals and aspects of the material innovations used as factors that influence success. The WAB Project team did not mention procurement problems, spoke explicitly about aligning their goals, and offered insights about how ECC is positioned for successful diffusion.

Procurement – a rather broad-reaching and ambiguous term – is the most common potential factor cited by construction literature (Bresnen & Marshall, 2000a; Bresnen & Marshall, 2000b; Cox & Townsend, 1998; Fairclough, 2002). "Procurement method" often refers to the contractual arrangement used to structure the project – for instance, is the project a subcontract or alliance. Arguments about the importance of procurement are, at their core, arguments about the role of project structure on the work of a project. This argument appears in other literature as well. For example, organization literature has extensive discussions about the appropriate structure of a collaborative arrangement. While the structure of a project may influence the work that can happen, members of the WAB Project did not recognize procurement or structure as important aspects of their project.

While literature suggests that the goals of academia, government, and industry are at odds in most construction projects (Fairclough, 2002), the WAB Project participants did not talk about their goals as competing. Rather, they described how the goals of the groups involved in the project complemented, or at least did not compete, with one another.

For instance, the director of the MRL described MDOT and MRL's goals this way:

> MDOT is always searching for a technology to solve a headache – expansion joints. Expansion joints are a necessary evil; necessary but very expensive to maintain day in and day out. MRL invented material and wanted to see material in a structure in order to get feedback about its performance beyond the laboratory. (Dr. Wang, 11/08)

MRL was able to demonstrate that ECC may be able to reduce the headache expansion joints cause MDOT. Therefore, MDOT was able to find value in researching ECC in a production-scale demonstration project. Section 1 shows other examples of noncompetitive interactions – the contractors provided advice on strategic relationships that may help the researchers increase the use of their invention.

Using ECC, a material innovation, also may have influenced the WAB Project's success. According to Rogers (1995), the aspects of innovations that most influence their diffusion are relative advantage, compatibility, complexity, trialability, observability, and flexibility. ECC has many advantages over traditional concrete. Its ductility enables it to withstand many natural assaults such as freeze-thaw cycles and earthquakes that destroy traditional concrete. The initial raw material cost of ECC is higher than traditional concrete, but the lifetime costs, which include maintenance, are much lower.

Using Nonaka's (1994) definition of innovation – "process in which the organization creates and defines problems and then actively develops new knowledge to solve them," (p. 14) the WAB Project employs a number of innovations beyond the obvious "new material" innovation – ECC. The relationships established among MDOT, the University, and the associated contractors are also innovative, as are the roles and responsibilities outlined in the WAB Project documents. For instance, University members were responsible for designing the structure; the idea that someone outside the MDOT Design organization would design MDOT structures was new.

This process Rogers (1995) outlines is very similar to MDOT's approach to ECC: they found out about it, talked to the inventors, commissioned a demonstration project, and then tried out the innovation (e.g. the WAB Project). On another level, MDOT is testing out the innovation of letting researchers design structures and allowing researchers and contractors to make changes to the design in the field. An individual person's or firm's relationships and interactions with others are essential parts of the innovation diffusion process. We learn about innovations from our contacts; we partner with people to test out innovations, and eventually, we tell our networks about our experiences.

According to Rogers's theory, innovations that are likely to diffuse provide a significant relative advantage over the status quo, are compatible with current practice, are easy to understand, allow for adaptation and experimentation, and their success can be witnessed. ECC is an innovative material, and the WAB Project team is a new constellation of actors who have not worked together before. Given these "new" aspects, the WAB Project faces the five challenges Rogers (2005) enumerates for all innovations.

Researchers recognize that the recipe for ECC is uncharacteristically precise for a concrete and that the precision can be problematic. ECC also requires slightly different material components – cement, sand, fibers – and therefore requires that mixing plants empty and refill their towers in order to mix a batch of ECC. ECC also requires different calculations in designs. However, none of the participants of the WAB Project voiced concerns over the compatibility or complexity of ECC and its mixing and design processes. They did emphasize cost and asked questions about how best to mix and pour, but they did not express, at least to me, frustration or concern about the material.

6. C. Summary

In this chapter, I developed the concept of “adaptive capacity” which helps us understand what about a team enables it to accomplish coordination work. Chapters 4 and 5 reported results from the WAB Project that indicated the team was able to effectively allocate roles and responsibilities, to develop shared understandings, to build bridging social capital, to engage one another positively, to use their motivations and affect in service of building the bridge. Each of these activities is studied independently by other literatures, but studying them separately limits our ability to understand how coordination is accomplished. For instance, “social capital” refers to the resources available in a social network but does not tell us how those resources come to be or what they enable beyond “purposive action” (Lin, 2001).

The WAB Project members did not mark ECC as problematic, though literature suggested working with new materials would be problematic (I. Nonaka, von Krogh, & Voelpel, 2006; Rogers, 1995). Procurement methods were also notably absent from their comments; research on construction project in particular predicts that procurement will be problematic in nearly all projects (Cox & Townsend, 1998; Fairclough, 2002).

The WAB Project was able to build adaptive capacity through shared artifacts, a reachable social network, positive relational engagement, multimembership, and affect and to leverage that capacity to effectively coordinate their efforts to address issues such as the sidewalk problem. This concept of adaptive capacity is likely to be useful in many studies of projects, not just in the WAB Project. The next chapter summarizes the relationship between this dissertation and other scholarly studies; it also provides some ideas of future research.

Chapter 7

Conclusions and Future Work

In this chapter I review the key findings from my study. I then discuss implications for theory and policy based on these findings. I also provide some ideas for future research.

7. A. Overview of Key Findings

The WAB Project was a temporary assemblage with an uncertain future that used new materials and required participants to repeatedly adapt to one another and to each other's work. Some participants were joining a production-level construction project for the first time. The stories participants and documents tell about the project repeatedly reference the social and adaptive aspects of the project; people repeatedly mentioned that the larger, unexpected challenges the WAB Project faced related to adapting to scenarios that required quick changes such as redesigning the sidewalk - deck interface.

In chapter 2, I reviewed literature related to projects, collaboration, construction, and coordination. Those literatures suggested that innovation production and use, competing interests and goals, procurement, project management, and coordination influenced the success of collaborations. Table 7-1 summarizes my results in relation to those factors. My data suggest that the challenges related to diffusing innovations – especially the production and use of innovative materials – were not problematic for the WAB Project. Boundary objects such as the special provision and their accompanying agent, namely Mark from MRL, helped ECC become compatible and flexible enough to make material suppliers comfortable working with it. The WAB Project also managed competing goals and procurement methods successfully. Contract documents made MDOT's goal primary legally, and MRL and the contractors adjusted appropriately. My data also indicate that issues (e.g. different goals, material supply) did come up, but that proactive, adaptive coordination work meant that procurement, material production and use, and competing interests were not problematic.

My participants stressed the importance of coordination in construction projects generally and in the WAB Project specifically. I focused on coordination

Table 7-1. Summary of Challenges and Results in the WAB Project

Aspects Likely to Influence a Project's Success	Qualitative Results from the WAB Project
Innovation production and use	The changes required to mix and pour ECC were within the capacity of concrete suppliers; official documents provided the necessary contacts for procuring necessary materials.
Competing interests and goals	MDOT's needs, and the contractors' by extension, were primary, and other groups adjusted to the contractor's needs.
Procurement	Not mentioned as problematic in interviews or documents; official documents describe both process and suppliers for mixing ECC.
Social capital	Bridging social capital developed during biweekly meetings and contract documents and established communication between communities with high bonding social capital.
Project Management	Various levels of managers were responsible for planning, organizing, and leading people and materials; proactive, positive engagement enabled a successful project.
Coordination	Biweekly meetings and open phone and email communication lines served as locations of and opportunities for coordination.

Table 7-2. Using data from the WAB Project to understand the relationship between "adaptive capacity" and coordination

Component of Adaptive Capacity	Coordination Mechanism	Example from the WAB Project
Develop shared understandings	Documents	Special provision
		Meeting minutes
	Communication flow	Social network structure
		Conversations in meetings
	Brokering	Multimembership in communities of practice
Negotiate tasks and schedules	Documents	Special provision
		Meeting minutes
	Positive relationships	Repeated interactions characterized by positive relational engagement
	Motivation	Affect in MRL
		Profit for contractors
		Cost savings for MDOT

in an attempt to help us understand how coordination happens, what about a team makes it possible for them to coordinate effectively. I suggested and further developed the concept of “adaptive capacity.” Adaptive capacity provides a way to talk about the set of capabilities a team develops or possesses that enable them to coordinate their work effectively. Table 7-2 gives examples from the WAB Project data that illustrate components of adaptive capacity and how those components help accomplish coordination.

My data suggest that the WAB Project team used documents and repeated interactions to establish shared understandings about the materials and schedule for the project. Members of the WAB Project who, like Mark, were members of multiple communities of practice leveraged their multimembership to broker shared understandings. My data also show that the WAB Project team developed strong social ties through repeated interactions, especially during regular progress meetings. Data from interviews suggests that members of the WAB Project team engaged one another positively, making those strong social ties qualitatively useful as well as measurable. The management of the WAB Project stressed communication and proactive approaches to coordinating tasks. Lastly, different groups in the project had different motivations for their involvement; MRL was able to weather compromise in part because their motivations included strong affect about the material.

In summary, shared understandings, positive social interactions within the collaboration, strong social ties, multimembership, and the adaptive capacity those characteristics afforded the WAB Project team enabled them to successfully coordinate their efforts and to complete the bridge deck.

7. B. Contributions to Theory

I undertook this study to understand something about *how* people are able to work together effectively. Existing models of collaboration and projects emphasize the "what's" of collaboration – e.g., trust, coordination, common ground – but lack good explanations of the "how's." Terms such as "coordination" and "project management" are minimally useful without an understanding of how coordination and project management work and influence a project. This study advances our understanding of coordination by proposing mechanisms that one project used to accomplish coordination and to adjust to unexpected events – namely *adaptive capacity*.

The detailed analysis of minutes from regular progress meetings makes the work done in meetings apparent. My goal was not to suggest that all projects should have regular progress meetings but to understand what work the WAB Project meetings accomplished – to understand how those meetings influenced the project. Similarly, by analyzing the ECC special provision I was not suggesting that rigid contracts govern all work but rather recognizing that documents we take for granted accomplish some of the coordination work projects require.

Research on boundary objects and contracts recognizes the importance of artifacts used by multiple communities, describing how artifacts help translate between viewpoints (S. L. Star & Griesemer, 1989) and how contracts can establish power dynamics (Fairclough, 2002). But, as other researchers point out, documents gain meaning through interaction (LeBaron & Thompson, in preparation) and overextending the use of the term “boundary object” occludes our ability to see artifacts that often disrupt, rather than cross, boundaries (Lee, 2007). My analysis of the ECC special provision illuminates how objects that cross boundaries do more than translate and disrupt – they coordinate. Contractual documents such as the ECC special provision that are designed specifically to translate the practice of one community (e.g., ECC researchers) to another (e.g., concrete suppliers) and that do so with the weight of the law, establish roles and responsibilities among collaborators. Research on collaboration has recognized the importance of clear roles and responsibilities in helping ease tension (Hinds & Mortensen, 2005) and improving coordination (Kraut & Streeter, 1995); this study advances our understanding by describing how the WAB Project achieved clear roles and responsibilities.

Adler and Obstfeld (2007) helped us understand how affect influences the “motivational underpinnings of … collective creative projects” (p. 19). They explained that affect influences motivation and leads people to care about their collective work. Relational engagement, especially of the positive kind, helps us understand how caring about each other, or at least recognizing each other, influences coordination and cooperation in collective projects. Koschmann and LeBaron (2003) recognize that the metaphor of common ground – commonly invoked in studies of collaboration to explain how coordination happens (e.g., Fussell et al., 1998; H. Jones & Hinds, 2002; Klein, Feltovich, Bradshaw, & Woods, 2004) – is confusing rather than helpful in part because common ground cannot be measured nor located. Adaptive capacity instead tells us that coordination is accomplished through positive interactions and abilities to adjust to one another.

Adaptive capacity's components – especially perspective taking, communication, shared objects, affect, and multimembership – tell us what has to be true for people to be able to make the changes necessary to working together. Perspective taking, on its own, does not explain how people negotiate but rather tells something about the kind of relational engagement that makes people more willing to enroll in a negotiation. Dense, connected social networks enabled smooth communication but do not guarantee it. Shared objects, as LeBaron and Thompson (in preparation) point out, are minimally useful without social representation and enaction. Multimembership provides a set of resources on which individuals draw to develop understandings with one another, but multimembership does not tell us how we work with people who do not share our memberships.

Perspective taking, multimembership, and affect provide the social resources and motivation for engaging in negotiations; strong ties within social networks provide opportunities to communicate. Shared objects help move information among interested groups. Together, these resources produce in a team the capacity to adapt to changes within and outside the team. Adaptive capacity describes the resources that make it possible to find flexible and creative solutions to a collaborative team's coordination needs, and the term itself provides a theoretical concept that unifies previously separate notions of perspective, affect, and objects.

7. C. Implications for Policy and Practice

My data suggests that project teams that include people who respect and understand perspectives that differ from their own may be more successful than other project teams. By "more successful" I mean those teams are more likely to accomplish their goals, have positive affect and impressions of their work, and even to work together again. Perspective taking produces social aspects of relational engagement that ease tension and build commitment among project team members, making it easier for project teams to work together smoothly. It may be that positive relational engagement – interactions among team members characterized by perspective taking and social thinking – is more important than project structure or timing. When we talk about projects, especially engineering projects, we often focus on how they should be managed at the project level – when should what get done, who should do it, to whom should someone report. It may make more sense for us to focus on managing interpersonal relationships on the project team, developing trust and concern for one another. The way we relate to our project teammates is likely to have a huge impact on our ability to work together successfully.

Readers with a social interactionist perspective may not find the impacts of positive relational engagement surprising. Readers may even think that treating others with respect and recognizing and valuing others' perspectives and goals is common sense. My experience and data suggest that this sense is not at all common, or at least it does not extend to practice. For instance, when explaining how a contractor would describe her responsibilities, one crew chief replied, "They are just snarky, flippant like we should be bowing to their every request immediately. You know, they always wanted us at their disposal" (Annie, 5/09). I include "relational engagement" in the WAB Project discussion because it was present in the project, and my participants suggested positive relational engagement is not usually present in construction projects. It's likely that the positive relational engagement present in the WAB Project made it easier for the team to address the challenges that arose – positive relational engagement increased the adaptive capacity of the project team.

If positive relational engagement does increase adaptive capacity and adaptive capacity improves a project's chance of success, it would behoove us to design projects to maximize relational engagement and adaptive capacity. Instead of focusing on the organizational structure of a project, we should focus on recruiting team members who exhibit positive relational engagement as well as professional competence. Adaptive capacity gives practitioners a usable construct or goal for which to strive.

7. D. Limitations of This Study

This study reports results from a single case study, and the characteristics of my research methods and of the case itself influenced the results of the study. My data collection and analyses were both conducted after the bridge project had been completed. It is likely that, in hindsight, my participants were predisposed to speak positively about one another given that the project had been successfully completed. Even though I was introduced to the team members by one of their own, I was still an outsider for this group. Because I was an outsider, my participants may have censored their own descriptions of the work and of each other when talking to me. I used documents the group created in order to mitigate the potential effects of their positive spin in interviews, but those documents represent just a few of the voices involved in the team. For instance, the project meeting minutes represent the project manager's voice, his description of the content of the meetings. Had I been able to observe the meetings, or to see notes taken by a member of the team who was not in charge, I may have found different topics to be more important.

Generating theoretical concepts from a single positive case can be dangerous – without other cases to compare to, it is impossible for me to know what about the WAB Project is unique and what is more broadly generalizable. Without specific negative examples – stories from the WAB Project team about when they did not adapt – it is difficult for me to discuss "not adaptive capacity" and the implications for teams that fail to develop adaptive capacity. It is important to remember that the concepts I propose, especially adaptive capacity and positive relational engagement, are grounded in the data from this project and theorized to be useful in analyses of other collaborative projects. Refining and testing these concepts will be the most important aspects of my related future work. These concepts have limits as well. Adaptive capacity is a property of a team. Adaptive capacity assumes a team exists and that the team must make some adjustments during the course of its work. The data from the WAB Project indicate a number of components of adaptive capacity, but I am not able to use that data to talk about whether those components are substitutes or complements for one another.

7. E. Ideas for Future Research

7. E. 1. Refining the concept of adaptive capacity, especially with regard to projects

I proposed “adaptive capacity” as a conceptual tool for helping us understand the resources that enable coordination in collaborative projects. Because my data, and consequently my proposed concept, stem from a single case, I cannot yet know whether the concept applies narrowly to the WAB Project or whether adaptive capacity is more broadly useful. Future work should explore what using the concept adaptive capacity affords when examining other collaborative projects to help us understand what heavy intellectual lifting adaptive capacity can do.

Staber and Sydow (2002) argue for a structuration perspective on adaptive capacity. They, and Hanssen-Bauer and Snow (1996), recommend the development of adaptive capacity as part of a strategic approach to management in organizations. Further research should explore what projects can learn from literature on strategic management. The temporary nature of projects may protect them from some of the pitfalls of an adaptive capacity approach to management; for instance, temporary projects need not focus on reserving resources for some future environmental state. Future work should explore what else projects can learn from existing literature.

The concept of adaptive capacity has implications for practice, especially for strategic management, and future work should provide more guidance on forming and operating projects to maximize their adaptive capacity. When forming projects, we need to consider financial, social, technological, and structural issues. Adaptive capacity provides a term for focusing management decisions around a central theme, and more clear guidance for managers would be welcome. For instance, research that identifies strategies for developing the abilities that make up adaptive capacity would be helpful – how can projects encourage positive relational engagement or the development of strong bridging social capital? Adaptive capacity provides clarity to the murky area of coordination, but even more clarity about the term itself and its implications for practice will be important areas for future work.

7. E. 2. Unpacking "project"

The term "project" is now so widely used that it is difficult to find work that cannot be described as "project work." I often struggled throughout this dissertation to include or not include an adjective to modify the term "project." What would I have gained by referring to the WAB Project to as a collaborative project? An interorganizational project? What distinctions between the different kinds of collaborative arrangements (see **Error! Reference source not found.**) are meaningful? The term "project" alone no longer tells us enough about an arrangement to make the term useful, and a more detailed understanding of kinds of projects and their characteristics would be a welcome addition to the literature. Identifying what we mean by projects will help us develop a more coherent literature on projects.

7. E. 3. Understanding the role of specific individuals in collaborations involving innovations

An alternative explanation for the success of the WAB Project is that it gathered the right people for the job. Mark was the right graduate student to put in charge of the research arm of the project – he cared deeply about the success of the bridge and had experience working in both research labs and construction sites. Tim was the right general contractor – he is interested in exploring new materials and being a part of innovative teams. I avoided engaging Rogers's (1995) "change agent" notion because I have developed a situated, collective perspective on group work, but it would be interesting to re-examine how specific individuals become effective champions of innovations and contribute to the success of innovative projects. The powers of affect and of one person's ability to motivate others should not be ignored or underestimated, and future work could help us better understand their roles.

7. E. 4. What's going on in meetings?

I was surprised by how often my participants marked meetings or repeated interactions as central to their ability to work together effectively. That meetings and interactions are useful is not surprising, rather the strength of my participants' endorsement of them was. I am anxious to study meetings in a variety of collaborations in order to understand what work gets done in meetings and how they impact collaboration generally. For instance, are meetings really about developing the network embeddedness afforded by repeated interaction, as discussed in section 4. C. 1. Meeting Participation? How important is it that team members engage one another positively, as Mark did when acknowledging others' priorities? Are the benefits of meetings best realized face-to-face, or can we approximate them at a distance to support global teams?

Prepared meeting minutes provide only one perspective on the content of the meetings, and they are necessarily brief. I found myself wanting to have been a fly on the wall during the progress meetings, and I look forward to using video as a tool for collecting more rich data on meetings and the interactions that take place within them.

7. F. Summary

In our efforts to understand how collaborative work can be accomplished, we often turn to discussions of coordination – the management of those activities – for help. The concept of coordination is inadequate. Knowing that dependencies must be managed tells us nothing about how to do that managing (see T. W. Malone, 2004). Finding that face-to-face meetings and direct supervision improve coordination tell us nothing about how to do that supervision effectively (see Cummings & Kiesler, 2003). In this dissertation, I examined a collaborative project with many coordination demands. I used data from this project to develop the concept of adaptive capacity – the set of capabilities a team develops that enable them to adjust to internal and external stresses. Through analyzing meeting minutes, interview transcripts, and documents the project team developed, I was able to identify behaviors and approaches the team took that may have enabled them to better respond to changes in their environment. I used the example of the sidewalk problem – a time when the team successfully redesigned the structure they were building in the field – to illustrate the kind of coordination work adaptive capacity enables. From data about the WAB Project, I identified components of adaptive capacity including perspective taking, multimembership, affect, and social capital. Understanding these components and the adaptive capacity they can develop helps us understand what about teams enables them to accomplish coordination work. Without adaptive capacity, we lack an integrated understanding of the ways in which different components interact and how those components address coordination. This dissertation contributes to our understanding of how collaborative teams accomplish coordination by refining the concept of adaptive capacity and integrating earlier literatures on coordination, collaboration, and adaptation. The concept of adaptive capacity – its definition, its development within teams, its relationship to other ways of understanding change in organizations – is ripe for further study.

References

Abbott, A. (1988). *The System of Professions: An Essay on the Division of Labor*. Chicago, IL: University of Chicago Press.

Ackerman, M. S. (1998). Augmenting organizational memory: a field study of answer garden. *ACM Transactions on Information Systems, 16*(3), 203-224.

Adler, P. S., & Kwoon, S. W. (2000). Social capital: the good, the bad, and the ugly. In E. Lesser (Ed.), *Knowledge and social capital: Foundations and applications* (pp. 89-115). Boston: Butterworth-Heinemann.

Adler, P. S., & Obstfeld, D. (2007). The role of affect in creative projects and exploratory search. *Industrial and Corporate Change, 16*(1), 19-50.

Al-Ani, B., & Edwards, H. K. (2008). A Comparative Empirical Study of Communication in Distributed and Collocated Development Team. Bangalore, India. 35-35-44.

Anderson, T. (2004). *Desk Research: Research Themes.* Unpublished manuscript.

Baker, W. E. (1990). Market Networks and Corporate Behavior. *The American Journal of Sociology, 96*(3), 589-625.

Bechky, B. (2006). Gaffers, Gofers, and Grips: Role-Based Coordination in Temporary Organizations. *Organization Science, 17*(1), 3-21.

Bellotti, E. (2008). What are friends for? Elective communities of single people. *Social Networks, 30*(4), 318-329.

Beyer, H., & Holtzblatt, K. (1998). *Contextual Design: Defining Customer-Centered Systems*. San Francisco, CA: Morgan Kaufmann.

Birnholtz, J. P. (2007). When Do Researchers Collaborate? Toward a Model of Collaboration Propensity. *Journal of the American Society for Information Science and Technology, 58*(14), 2226-2239.

Birnholtz, J. P., & Bietz, M. J. (2003). Data at work: supporting sharing in science and engineering. *GROUP '03: Proceedings of the 2003 International ACM SIGGROUP Conference on Supporting Group Work,* Sanibel Island, Florida, USA. 339-348.

Bourdieu, P., & Wacquant, L. J. D. (1992). *An invitation to reflexive sociology*. Chicago: University of Chicago Press.

Bowker, G. C., & Star, S. L. (1997). How things (actor-net) work: Classification, magic, and the ubiquity of standards. *Philosophia, 25*(3-4), 195-220.

Bozeman, B., & Corley, E. A. (2004). Scientists' collaboration strategies: implications for scientific and technical human capital. *Research Policy, 33*(4), 599-616.

Bozeman, B., Dietz, J. S., & Gaughan, M. (2001). Scientific and technical human capital: an alternative model for research evaluation. *International Journal of Technology Management, 22*(7), 716-740.

Breiger, R. L. (1974). The Duality of Persons and Groups. *Social Forces, 53*(2), 181-189.

Bresnen, M., & Marshall, N. (2000a). Building partnerships: case studies of client–contractor collaboration in the UK construction industry. *Construction Management and Economics, 18*(7), 819-832.

Bresnen, M., & Marshall, N. (2000b). Motivation, commitment and the use of incentives in partnerships and alliances. *Construction Management and Economics, 18*(5), 587-598.

Brown, J. S., & Duguid, P. (1991). Organizational Learning and Communities of Practice: Towards a Unified View of Working, Learning, and Innovation. *Organization Science, 2*(1), 40-57.

Brown, J. S., & Duguid, P. (2000/2002). *The Social Life of Information*. Cambridge, MA: Harvard Business School Press.

Brown, J. S., & Duguid, P. (2001). Knowledge and Organization: A Social-practice Perspective. *Organization Science, 12*(2), 198-213.

Bryman, A., Bresnen, M., Beardsworth, A. D., Ford, J., & Keil, E. T. (1987). The concept of the temporary system: the case of the construction project. In N. Di Tomaso, & S. B. Bacharach (Eds.), *Research in the sociology of organizations* (pp. 253-283). Greenwich, CT: JAI Press.

Burt, R. S. (1992). *Structural holes: the social structure of competition*. Cambridge, MA: Harvard University Press.

Burt, R. S. (2001). Bandwidth and echo: trust, information, and gossip in social networks. In J. E. Rauch, & A. Casella (Eds.), *Networks and Markets* (pp. 30–74). New York: Russell Sage Foundation.

Carlile, P. R. (2002). A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. *Organization Science, 13*(4), 442-455.

Carpenter, M. A., & Westphal, J. D. (2001). The Strategic Context of External Network Ties: Examining the Impact of Director Appointments on Board Involvement in Strategic Decision Making. *Academy of Management Journal, 44*(4), 639-660.

Castells, M. (2000). *The rise of the network society* (2nd ed.). Oxford: Blackwell Publishers.

Chakravarthy, B. S. (1982). Adaption: A promising metaphor for strategic management. *The Academy of Management Review, 7*(1), 35-44.

Clark, H. H., & Brennan, S. E. (1991). Grounding in Communication. In L. Resnick, J. Levine & S. D. Teasley (Eds.), *Perspectives on Socially Shared Cognition* (pp. 127-149). Washington, D.C.: American Psychological Association.

Cohen, S. G., & Bailey, D. E. (1997). What Makes Teams Work: Group Effectiveness Research from the Shop Floor to the Executive Suite. *Journal of Management, 23*(3), 239-290.

Collins, H. M. (1982). Tacit Knowledge and Scientific Networks. In B. Barnes, & D. Edge (Eds.), *Science in context: Readings in the Sociology of Science* () MIT Press.

Corcoran, K. O. C., & Mallinckrodt, B. (2000). Adult Attachment, Self-Efficacy, Perspective Taking, and Conflict Resolution. *Journal of Counseling & Development, 78*(4), 473-483.

Corley, E. A., Boardman, P. C., & Bozeman, B. (2006). Design and the management of multi-institutional research collaborations: Theoretical implications from two case studies. *Research Policy, 35*(7), 975-993.

Cox, A., & Townsend, M. (1998). *Strategic Procurement in Construction: Towards Better Practice in the Management of Construction Supply Chains*. London: Telford.

Creswell, J. (2003). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. Thousand Oaks, CA: Sage Publications, Inc.

Crowston, K. (1997). A Coordination Theory Approach to Organizational Process Design. *Organization Science, 8*(2), 157-175.

Cummings, J. N., & Kiesler, S. (2003). *KDI Initiative: Multidisciplinary Scientific Collaborations*. Washington, D.C.: National Science Foundation.

Cummings, J. N., & Kiesler, S. (2005). Collaborative research across disciplinary and organizational boundaries. *Social Studies of Science, 35*(5), 703-722.

Davies, A., & Hobday, M. (2005). *The Business of Projects : Managing Innovation in Complex Products and Systems*. Cambridge: Cambridge University Press.

Dewey, J. (1922/2002). *Human Nature and Conduct: An Introduction to Social Psychology*. Mineola, NY: Dover Publications.

Dourish, P., & Bly, S. (1992). Portholes: supporting awareness in a distributed work group. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* , 541-547.

Dubois, A., & Gadde, L. E. (2002). The construction industry as a loosely coupled system: implications for productivity and innovation. *Construction Management and Economics, 20*(7), 621-631.

Duguid, P. (2005). “The art of knowing”: social and tacit dimensions of knowledge and the limits of the community of practice. *The Information Society, 21*(2), 109-118.

Duncan, W. (1996). *A Guide to the Project Management Body of Knowledge*. Newton Square, PA: Project Management Institute.

Durfee, E. H., Lesser, V. R., & Corkill, D. D. (1990). Cooperation through communication in a distributed problem-solving network. In S. P. Robertson, W. Zachary & J. B. Black (Eds.), *Cognition, Computing, and Cooperation* (pp. 159-186). Bristol, UK: Ablex.

Eccles, R. G. (1981). The Quasifirm in the Construction Industry. *Journal of Economic Behavior and Organization, 2*(4), 335-357.

Fairclough, S. J. (2002). *Rethinking Construction Innovation and Research: A Review of Government R&D Policies and Practices*. London: UK Department of Trade and Industry.

Finholt, T. A. (2002). Collaboratories. In B. Cronin (Ed.), *Annual Review of Information Science and Technology* (pp. 74-107). Washington, D.C.: American Society for Information Science.

Finholt, T. A. (2003). Collaboratories as a new form of scientific organization. *Economics of Innovation and New Technology, 12*, 5-25.

Finholt, T. A., & Olson, G. M. (1997). From laboratories to collaboratories: A new organizational form for scientific collaboration. *Psychological Science, 8*, 28-36.

Fischer, G., Rohde, M., & Wulf, V. (2007). Community-based learning: The core competency of residential, research-based universities. *International Journal of Computer-Supported Collaborative Learning, 2*(1), 9-40.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: building adaptive capacity in a world of transformations. *AMBIO: A Journal of the Human Environment, 31*(5), 437-440.

Fussell, S. R., Kraut, R. E., Lerch, F. J., Scherlis, W. L., McNally, M. M., & Cadiz, J. J. (1998). Coordination, overload and team performance: effects of team communication strategies. *Proceedings of the 1998 ACM Conference on Computer Supported Cooperative Work,* 275-284.

Gann, D. M., & Salter, A. J. (2000). Innovation in project-based, service-enhanced firms: the construction of complex products and systems. *Research Policy, 29*(7-8), 955-972.

Gehlbach, H. (2004). A New Perspective on Perspective Taking: A Multidimensional Approach to Conceptualizing an Aptitude. *Educational Psychology Review, 16*(3), 207-234.

Gittell, R., & Vidal, A. (1998). *Community Organizing: Building Social Capital as a Development Strategy*. Thousand Oaks, CA: Sage Publications, Inc.

Glaser, B. G., & Strauss, A. L. (1999). *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Hawthorne, NY: Aldine de Gruyter.

Granovetter, M. (1973). The Strength of Weak Ties. *American Journal of Sociology, 78*(6), 1360-1380.

Granovetter, M. (1985). Economic action and social structure: the problem of embeddedness. *American Journal of Sociology, 91*(3), 481-510.

Granovetter, M. (1992). Problems of explanation in economic sociology. In N. Nohria, & R. G. Eccles (Eds.), *Networks and Organizations* (pp. 25-56). Boston, MA: Harvard Business School Press.

Hanneman, R. A., & Riddle, M. (2005). *Introduction to social network methods*. Riverside, CA: University of California, Riverside.

Hanssen-Bauer, J., & Snow, C. C. (1996). Responding to Hypercompetition: The Structure and Processes of a Regional Learning Network Organization. *Organization Science, 7*(4), 413-427.

Hinds, P., & Mortensen, M. (2005). Understanding Conflict in Geographically Distributed Teams: The Moderating Effects of Shared Identity, Shared Context, and Spontaneous Communication. *Organization Science, 16*(3), 290-307.

Hollnagel, E., Woods, D. D., & Leveson, N. (2006). *Resilience engineering: Concepts and precepts*. Hampshire: Ashgate Publishing, Ltd.

Johnson, D. W. (1975). Cooperativeness and social perspective taking. *Journal of Personality and Social Psychology, 31*, 241-244.

Jones, H., & Hinds, P. (2002). Extreme work teams: using swat teams as a model for coordinating distributed robots. *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work,* 372-381.

Jones, C. (1996). Careers in Project Networks: The Case of the Film Industry. In M. B. Arthur, & D. M. Rousseau (Eds.), *The Boundaryless Career: A New Employment Principle for a New Organizational Era* (pp. 58-75). New York: Oxford University Press.

Jones, C., Hesterly, W. S., & Borgatti, S. P. (1997). A general theory of network governance: Exchange conditions and social mechanisms. *Academy of Management Review, 22*(4), 911-945.

Jones, C., & Lichtenstein, B. M. B. (2008). Temporary Interorganizational Projects: How Temporal and Social Embeddedness Enhance Coordination and Manage Uncertainty. In S. Cropper, M. Ebers, P. S. Ring & C. Huxham (Eds.), *Handbook of Interorganizational Relations* (pp. 231-255). London: Oxford University Press.

Jones, C., Lichtenstein, B. M. B., Borgatti, S. P., Hesterly, W. S., & Tallman, S. B. (1998). How human and social capital in architectural and component knowledge influence project performance: An empirical test from the film industry. Retrieved September 9, 2009, from http://www2.bc.edu/~jonescq/Film%20Human%20&%20Social%20Capital.pdf

Kadefors, A. (1995). Institutions in building projects: Implications for Flexibility and Change. *Scandinavian Journal of Management, 11*(4), 395-408.

Kalousdian, A. (2006). ECC Replaces Bridge Joints. *Michigan Contractor and Builder.*

Klein, G., Feltovich, P. J., Bradshaw, J. M., & Woods, D. D. (2004). Common ground and coordination in joint activity. In W. B. Rouse, & K. R. Boff (Eds.), *Organizational Simulation* (pp. 139-184). Hoboken, NJ: Wiley & Sons.

Koschmann, T., & LeBaron, C. D. (2003). Reconsidering common ground: examining Clark's contribution theory in the OR. *Proceedings of the Eighth Conference on European Conference on Computer Supported Cooperative Work, ECSCW 2003,* 81-98.

Koskinen, K. U., & Mäkinen, S. (2009). Role of boundary objects in negotiations of project contracts. *International Journal of Project Management, 27*(1), 31-38.

Kraatz, M. S. (1998). Learning by Association? Interorganizational Networks and Adaptation to Environmental Change. *The Academy of Management Journal, 41*(6), 621-643.

Kraut, R. E., & Streeter, L. A. (1995). Coordination in Software Development. *Communications of the ACM, 38*(3), 69-81.

Latour, B. (1988). *Science in Action: How to Follow Scientists and Engineers Through Society*. Cambridge, MA: Harvard University Press.

Latour, B. (1990). Drawing Things Together. In M. Lynch, & S. Woolgar (Eds.), *Representation in Scientific Practice* (pp. 19-68). Cambridge: MIT Press.

Latour, B. (1996). *Aramis, or the Love of Technology*. Cambridge: Harvard University Press.

Lave, J. (1991). Situated Learning in Communities of Practice. In L. Resnick, J. Levine & S. D. Teasley (Eds.), *Perspectives on Socially Shared Cognitioin* (pp. 63-82). Washington, DC: American Psychological Association.

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge, UK: Cambridge University Press.

LeBaron, C. D., & Thompson, M. P. (in preparation). *Boundary objects and agents: A video-based ethnography of the emergence, evolution, and embodiment of ideas across organizational boundaries.* Unpublished manuscript.

Lee, C. P. (2007). Boundary Negotiating Artifacts: Unbinding the Routine of Boundary Objects and Embracing Chaos in Collaborative Work. *Computer Supported Cooperative Work, 16*(3), 307-339.

Lee, C. P., Dourish, P., & Mark, G. (2006). The human infrastructure of cyberinfrastructure. *CSCW '06: Proceedings of the 2006 20th Anniversary*

Conference on Computer Supported Cooperative Work, Banff, Alberta, Canada. 483-492.

Lin, N. (2001). Building a Network Theory of Social Capital. In N. Lin, K. Cook & R. S. Burt (Eds.), *Social Capital: Theory and Research* (pp. 3-29). New York: Aldine de Gruyter.

Loosemore, M. (1999). Responsibility, power, and construction conflict. *Construction Management and Economics, 17*(6), 699-709.

Loosemore, M., & Tan, C. C. (2000). Occupational stereotypes in the construction industry. *Construction Management and Economics, 18*, 559-566.

Lutters, W. G., & Ackerman, M. S. (2002). Achieving safety: a field study of boundary objects in aircraft technical support. *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work,* 266-275.

Malone, T. W. (2004). *The Future of Work: How the new order of business will shape your organization, your management style, and your life*. Cambridge: Harvard Business School Press.

Malone, T. W., & Crowston, K. (1994). The interdisciplinary study of coordination. *ACM Computing Surveys (CSUR), 26*(1), 87-119.

March, J. G., & Simon, H. A. (1993). *Organizations* (2nd ed.). Cambridge, MA: Blackwell.

McClellan, M. (2003). *Collaborative manufacturing: using real-time information to support the supply chain*. Boca Raton, FL: CRC Press.

Mintzberg, H. (1979). An emerging strategy of direct research. *Administrative Science Quarterly, 24*(4), 105-116.

Munns, A. K. (1996). Measuring Mutual Confidence in UK Construction Projects. *Journal of Management in Engineering, 12*(1), 26-33.

Nonaka, I., von Krogh, G., & Voelpel, S. (2006). Organizational Knowledge Creation Theory: Evolutionary Paths and Future Advances. *Organization Studies, 27*(8), 1179-1208.

Nonaka, I. (1994). A Dynamic Theory of Organizational Knowledge Creation. *Organization Science, 5*(1), 14-37.

Obstfeld, D. (2001). Telling more of what we know: Examining the social processes of knowledge creation and innovation. (Ph.D., University of Michigan).

Obstfeld, D. (2009). *Creative Projects: A Less Routine Approach Toward Getting News Things Done.* Unpublished manuscript.

Olson, G. M. (2004). Collaboratories. In W. S. Bainbridge (Ed.), *Encyclopedia of Human-Computer Interaction* (pp. 107-112). Great Barrington, MA: Berkshire Publishing.

Olson, G. M., & Olson, J. S. (2000). Distance Matters. *Human-Computer Interaction, 15*(2 & 3), 139-178.

Olson, G. M., Zimmerman, A., & Bos, N. (Eds.). (2008). *Scientific Collaboration on the Internet*. Cambridge: MIT Press.

Olson, J. S., Teasley, S. D., Covi, L., & Olson, G. M. (2002). The (currently) unique advantages of collocated work. In P. Hinds, & S. Kiesler (Eds.), *Distributed Work* (pp. 113-135). Cambridge, MA: MIT Press.

Orr, J. E. (1986). Narratives at work: Story telling as cooperative diagnostic activity. *Proceedings of the 1986 ACM Conference on Computer-Supported Cooperative Work,* 62-72.

Oxford English Dictionary. (1996). New York: Oxford University Press.

Palen, L., & Grudin, J. (2002). Discretionary adoption of group support software. In B. E. Munkvold (Ed.), *Organizational implementation of collaboration technology* (pp. 159-180). London: Springer Verlag.

Parsons, T. (1964). Evolutionary universals in society. *American Sociological Review, 29*(3), 339-357.

Pennar, K. (1997). The ties that lead to prosperity: The economic value of social bonds is only beginning to be measured. *Business Week,* (December 15), 153-155.

Pennebaker, J. W. (2008). *Debate 2: Obama vs McCain.* Retrieved September 9, 2009, from http://wordwatchers.wordpress.com/2008/10/07/debate-2-obama-vs-mccain/.

Pfeffer, J. (1987). A Resource Dependence Perspective on Intercorporate Relations. In M. S. Mizruchi, & M. Schwartz (Eds.), *Intercorporate Relations: The Structural Analysis of Business* (pp. 25-55). Cambridge: Cambridge University Press.

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.

Powell, W., White, D., Koput, K., & Owen-Smith, J. (2005). Network Dynamics and Field Evolution: The Growth of Interorganizational Collaboration in the Life Sciences. *American Journal of Sociology, 110*(4), 1132-1205.

Putnam, R. (2001). *Bowling Alone : The Collapse and Revival of American Community*. New York: Simon & Schuster.

Raider, H., & Burt, R. S. (1996). Boundaryless Careers and Social Capital. In M. B. Arthur, & D. M. Rousseau (Eds.), *The Boundaryless Career: A New Employment Principle for a New Organizational Era* (pp. 187). New York: Oxford University Press.

Rogers, E. M. (1995). *Diffusion of Innovations* (Fifth Edition ed.). New York, NY: The Free Press.

Schunn, C., Crowley, K., & Okada, T. (2002). What makes collaboration succeed across a distance?: The case of the cognitive science community. In P. Hinds, & S. B. Kiesler (Eds.), *Distributed Work* (pp. 407-432). Cambridge: MIT Press.

Seo, M. G., Barrett, L. F., & Bartunek, J. M. (2004). The role of affective experience in work motivation. *Academy of Management Review, 29*(3), 423-439.

Shammas-Toma, M., Seymour, D., & Clark, L. (1998). Obstacles to implementing total quality management in the UK construction industry. *Construction Management and Economics, 16*(2), 177-192.

Simmel, G. (1950). *The Sociology of Georg Simmel*. New York: The Free Press.

Smit, B., Pilifosova, O., Burton, I., Challenger, B., Huq, S., Klein, R. J. T., & Yohe, G. (2001). Adaptation to Climate Change in the Context of Sustainable Development and Equity. In J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken & K. S. White (Eds.), *Climate Change 2001: Impacts, Adaptation, and Vulnerability* (pp. 877-912). Cambridge: Cambridge University Press.

Sonnenwald, D. H. (2007). Scientific Collaboration: A Synthesis of Challenges and Strategies. In B. Cronin (Ed.), *Annual Review of Information Science and Technology* (pp. 643–682). Medford, NJ: Information Today.

Sonquist, J. A., & Koenig, T. (1975). Interlocking directorates in the top US corporations: a graph theory approach. *Critical Sociology, 5*(3), 196-229.

Staber, U., & Sydow, J. (2002). Organizational adaptive capacity: A structuration perspective. *Journal of Management Inquiry, 11*(4), 408-424.

Stalder, F. (1997). Actor-Network-Theory and Communication Networks: Toward Convergence. (Ph.D., Faculty of Information Studies, University of Toronto).

Star, S. L., & Griesemer, J. R. (1989). Institutional Ecology, `Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science, 19*(3), 387-420.

Star, S. L. (1999). The Ethnography of Infrastructure. *American Behavioral Scientist, 43*(3), 377-391.

Sundstrom, E., de Meuse, K. P., & Futrell, D. (1990). Work teams: Applications and effectiveness. *American Psychologist, 45*(2), 120-133.

Swidler, A. (1986). Culture in action: Symbols and strategies. *American Sociological Review, 51*(2), 273-286.

Teasley, S. D., Schleyer, T., Hemphill, L., & Cook, E. (2008). Case Studies: Three Distributed Biomedical Research Centers. In G. M. Olson, A. Zimmerman & N. Bos (Eds.), *Scientific Collaboration on the Internet* (pp. 233-250). Cambridge: MIT Press.

Teasley, S. D., & Wolinsky, S. (2001). Scientific collaborations at a distance. *Science, 292*(5525), 2254-2255.

Trist, E. (1981). *The Evolution of Socio-Technical Systems: A Conceptual Framework and an Action Research Program*. Toronto: Ontario Ministry of Labour.

Wasserman, S., & Faust, K. (1994). *Social Network Analysis: Methods and Applications*. Cambridge: Cambridge University Press.

Weick, K. E. (1976). Educational organizations as loosely coupled systems. *Administrative Science Quarterly, 21*(1), 1-19.

Wenger, E. (1999). *Communities of Practice: Learning, Meaning, and Identity* Cambridge University Press.

Woolcock, M. (1998). Social capital and economic development: Toward a theoretical synthesis and policy framework. *Theory and Society, 27*(2), 151-208.

Wulf, W. A. (1993). The collaboratory opportunity. *Science, 261*(5123), 854-855.

Yohe, G., & Tol, R. S. J. (2002). Indicators for social and economic coping capacity—moving toward a working definition of adaptive capacity. *Global Environmental Change, 12*(1), 25-40.