ABSTRACT

SMITH, CHARLYNNE TODD. Adoption and Implementation of Participatory GIS Technologies in Natural Resource Management Networks: A Study of the U.S. National Trails System. (Under the direction of Dr. Erin Seekamp and Dr. Yu-Fai Leung).

Geospatial technology is a well-established method to facilitate natural and cultural resource management (NRM) activities. Adopting the technology is usually not in question, but when resources extend beyond jurisdictional boundaries and involve collaborative management partnerships, complexities may arise during implementation. Research to date has suggested implementation models for either governmental or non-governmental agencies, ignoring the inter-organizational composition of many NRM networks. Further, research on the geocollaborative potential of GIS has explored design of specific decision support tools. I extend research on NRM GIS use by 1) examining use by inter-organizational networks of geographically dispersed members, 2) identifying factors that influence capacity and implementation of web-GIS to engage collaboratively, and 3) proposing actions to jointly optimize socio-technical network structures for improved implementation. Using the U.S. National Trail System (NTS), I employed an explanatory, sequential mixed methods research design to understand adoption of GIS technologies, and implementation of web-GIS for participatory engagement.

Phase 1 examined technology use and users for 23 trail networks producing a geospatial technology profile (GTP) of the NTS. Using the GTP, I developed a framework to calculate an implementation capacity index for each network, and then compared network characteristics to the level of user engagement deployed. Results show that higher capacity is not indicative of higher engagement levels. Using multiple case study research, Phase 2 compared four networks that implemented collaborative web-GIS to identify factors influencing capacity and implementation of network GIS tools. Findings suggest that the technology 1) enabled users to implement new methods to address network needs, 2) improved efficiency of network related tasks, and 3) provided innovative opportunities for collaboration across organizational boundaries and between great geographic distances. This research validates the ability of geocollaborative tools to extend spatial decision support to non-geomatic experts, and establishes an assessment process for NRM networks to evaluate implementation capacity, integrate engagement needs, and develop a strategic GIS implementation plan.

Adoption and Implementation of Participatory GIS Technologies in Resource Management Networks: A Study of the U.S. National Trails System

by
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DEDICATION

I dedicate this dissertation to my family. My husband Mike supported me in so many ways through this journey – I love you, and cannot express all of the ways you influence me daily. My parents, and my grandparents, instilled a work ethic in me that would not let me give up, and kept me moving forward through challenges I faced. Thank you Mom for your daily conversations, constant support and encouragement. Thanks to my Dad, wish you were still here to see me graduate (*again* ;-). Thanks to my big brother who always provided encouragement and expressed pride in my accomplishments. I love you all.

I must also express gratitude to my family of friends. You encouraged me, celebrated accomplishments along the way, and kept me going when I, and my family, faced challenges. I am ready to cash in on all of our play dates.

BIOGRAPHY

Charlynne grew up in North Carolina, spending much time during her childhood playing outdoors. She was thrilled to find a career that combined her love of the outdoors, made an impact protecting natural and cultural resources, and provided the opportunity to educate others about the environment. After earning a B.S. in recreation administration from NC State, Charlynne worked as a park ranger, historic interpreter, and an environmental educator. She eventually returned to NC State to earn a Master's of Natural Resources specializing in spatial information science with a minor in landscape architecture. Following her interests in park planning, she learned all things spatial and soon began to interpret GIS as a research associate in the Center for Geospatial Analytics.

Her experiences in the field, teaching in the classroom, and continued professional development informed her path at NC State. Extension and outreach remained important to her, and in 2003, she was inducted into the Academy of Outstanding Faculty Engaged in Extension. While working for the College of Natural Resources, Charlynne became a certified Geographic Information Systems Professional, and a Natural Resources Leadership Institute Fellow. Teaching and learning run parallel with her research activities, each element providing fuel to the others. With over 25 years of experience in park and natural resource management, Charlynne is excited to complete her doctorate. Her research interests include the use of innovative technologies – specifically, application of geographic information science for park and natural resource management, planning, and the stakeholder communication process.

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Through everything I do, and everywhere I go, the Lord is my shepherd and my rock.
God is good, all the time.

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CHAPTER 1: General Introduction

Geospatial technology is a well-established method to facilitate natural and cultural resource management activities. Further, as a spatial decision support system, geographic information systems (GIS) offer capabilities for a network of users to engage collaboratively. The power of GIS extends beyond a simple map and enables people to visualize phenomenon, understand complex scenarios, discover opportunities, or find common ground. Natural resource management commonly incorporates GIS as a tool to assist with these type of tasks. Adopting the technology is usually not in question, but complexities arise in the implementation process to successfully deploy and use the technology. Recommendations to successfully implement GIS have been proposed from research of specific government agencies or non-governmental organizations. However, resource management does not always align within the confines of one organization, as natural and cultural resources tend to extend beyond jurisdictional boundaries and involve collaborative management partnerships.

Over the course of my career, I have worked with non-profit organizations, government agencies and collaborative partnerships as they sought to use innovative geospatial technologies to manage or understand resources under their care. My observations, supplemented by the academic literature, helped formulate this dissertation. Related to my experiences, I noticed that substantial organizational structure differences among different groups, as well as a diversity of missions (e.g., some missions focused on community health and well-being; others on natural and cultural resource management). Each organization recognized the benefit of deploying geographic information systems (GIS) through a variety of applications involving data collection, modeling phenomena, or analyzing the community of people in relationship to the built and natural environment. In response, I implemented spatial databases with associated GIS technology to serve as a capacity-building tool and to deliver analysis results through both hard copy maps and interactive web-mapping applications. It has been exciting to see rapidly changing technology over the course of my career. I have witnessed increased use with these technology changes, and also observed that the available technologies needed by organizations when adopting GIS, does not progress at the same rapid pace of technological advances.

In summary, my observations revealed that organizations experienced mixed results with GIS. The movie saying, "build it and they will come" is not a guarantee that when they arrive the application will be used. This was my experience, even when we built the *exact* product requested. Consequently, I began my pursuit to better understand the dynamics of organizational interaction with technology, and explore obstacles to implementing GIS for resource management (NRM). I define NRM as encompassing both natural and cultural resources. Within NRM, I recognize the human dimensions allied in management processes. The social structure comprises a network of people connected through a common purpose: resource management.

Natural Resource Management Networks and GIS

Resource managers commonly implement GIS for inventory, monitoring and analysis of natural and cultural resources (Alrwais, Horan, Hilton & Bechor, 2015; Arciniegas, Janssen & Omtzigt, 2011; Antunes, Zurita, Baloian & Sapateiro, 2014; Aye, Jaboyedoff, Derron, & van Westen, 2015; Li, Bettinger, Danskin, & Hayashi, 2007). Research on the process to implement innovative technologies such as GIS has been addressed across multiple disciplines with foci on specific types of organizations (Antunes, et al., 2014; Eldrandaly, Naguib & Hassan, 2015; Sieber, 2000). The use of GIS began in governmental agencies with related research focused on implementation and use in governmental operations (Alrwais, et al., 2015). Similarly, use of GIS by non-governmental organizations (NGOs) typically grew from resource management focused activities (Sieber, 2000). These studies exposed GIS implementation limitations related to staff continuity or limited funds for skilled personnel, hardware or software needs. It was common for resource managers to seek GIS solutions for management, communication and collaboration as an approach to conflict resolution (Brown & Donovan, 2013; Wright, Duncan & Lach, 2009).

NRM frequently involves inter-organizational arrangements such as partnerships between governmental agencies, NGO, or citizen groups to monitor watersheds or manage cultural heritage sites (Anderson, Beazley & Boxall, 2009; Elwood, Goodchild & Sui, 2012; Nyerges, Jankowski, Tuthill, & Ramsey, 2006). I define these inter-organizational structures for management as NRM networks. Managers overseeing resources are faced with a multidimensional scale that presents challenges to network members seeking to resolve problems that require interdisciplinary approaches (Bodin, Crona, & Ernstson, 2006; Scarlett & Boyd, 2015). The scale may also shape multi-jurisdictional circumstances that place decision-making across organizational boundaries, and include geographically dispersed network members (McGuire & Silvia, 2010; Prager, 2010; Scarlett & Boyd, 2015). In these scenarios, spatial decision support mechanisms provided through GIS assist network members as they address land management issues, such as protecting cultural artifacts or monitoring public access to ecologically sensitive areas. Application of GIS technologies typically include a set of common tasks (e.g., mapping resources, conducting spatial analysis); however, GIS technology can also function as a communication medium to engage colleagues and share ideas when teams are dispersed (Sarker & Valacich, 2010; Sun & Li, 2016; Wright, Duncan & Lach, 2009).

Web 2.0 was a term introduced due to the change in World Wide Web design that represents the idea of new media as an interactive and collaborative method to engage online (O'Reilly, 2005). Social media, such as Twitter, shares information among networks of people. Beyond a specific NRM network, it is important to understand that communication about the environment in general has taken full advantage of social media outlets to disseminate information as well as gather information. For example, Darwish and Lakhtaria (2011) examined integration of new technology and found that Web 2.0 has been successfully used to supplement communicative practices in today's society. With a worldwide focus, groups are using open source software to enable people to develop communication tools aimed at democratizing information by lowering barriers to engage by sharing stories (Ushahidi, n.d.). Other studies simply examined the use of Web 2.0 technologies (regardless of NRM or GIS) and stated that Information and Communications Technology (ICT) are appropriate tools for knowledge sharing projects.

Focused on GIS, Warf and Sui (2010) coined the term "neogeography" to describe how Web 2.0 technologies are combined with geography that incorporate an individual's use of online geospatial tools to document personal interactions with locations. These place-based descriptions are tied to cultural contexts and in some cases an online community of users. One consequence of neogeography is the change to GIS and its use. Participatory GIS is one example of how neogeography enables extensive and bilateral contact between producers and analysts of geographic data resulting in a constantly changing, even mutating, body of work. Moreover, participatory GIS leads to a paradigm shift where non-technical participants are viewing and interacting with technical or scientific data in the participatory decision-making process (Elwood et al., 2012).

Engagement levels for participatory applications may range from simple display of a map, to use of applications that facilitate scenario comparisons between users. However, several capacity requirements become increasingly complex depending on the intended application of the technology. Eldrandaly et. al (2015) summarized success models for organizations to implement GIS, listing critical success factors I categorize as “hard” technologies or “soft” technologies. Soft technologies are related to the interactions of people, policies or organizational dynamics. On the other hand, hard technologies, are those typically considered in the discussion of technology, such as hardware and software infrastructure (Mayer & Davidson, 2000; Rogers, 2005; Tushman, Anderson & O’Reilly, 1997). Capacity is measured by these characteristics, including expertise to manage the system, hardware and software to host applications, and financial and training resources to support NRM network users, as well as the overall utility of the system for users (Eldrandaly et al., 2015). However, research on NRM network capacity using measures for both hard and soft technology, and then compared to the level of engagement deployed through GIS technology is limited.

GIS web-applications have not been categorized by level of engagement. Considering Web 2.0 capability that permits user interaction with online maps, a user may encounter one-way or two-way communication. In one-way applications, users simply retrieve data (e.g. view a map), or send data (e.g. upload information). Two-way communication presents a higher level of engagement between application users. This participatory level of interaction is expressed by a user's ability to engage the map and share information, and can be measured by tasks (map capabilities).

In a NRM setting, interactive GIS applications serve as a collaborative or participatory mechanism. GIS-based collaboration tools gravitate to the theoretical lens of technology acceptance. Research models that examine acceptance and adoption of technology within information systems are well established. Venkatesh, Morris, Davis and Davis (2003) expanded on Davis' 1983 Technology Acceptance Model (TAM) to develop the Unified Theory of Acceptance and Use of Technology (UTAUT). UTAUT explains user intentions to use information systems and the usage behavior surrounding the technology. Building on that work, Brown, Dennis and Venkatesh (2010) integrated theories from collaboration research with UTAUT to explain the adoption and use of collaboration technology. This second study pursued analysis at the group level of analysis to understand group characteristics for successful adoption of technology for collaborative activities (i.e., discussion and idea generation through technology rather than face-to-face meetings). These models incorporate the roles of individual or group characteristics, task characteristics and situational characteristics.

This study does not frame GIS, specifically web-based mapping applications, as the primary method of communication evaluated with UTAUT. Rather, web-based GIS is an innovative tool to share information. I incorporate UTAUT concepts related to environment for adoption using individual and group characteristics, task characteristics, and situational characteristics.

The group (network), or individual (network member), are both influenced by the design and implementation process. Applying diffusion theory to technology acceptance, the primary factors influencing success are technical compatibility, technical complexity (ease of use), and the relative advantage or perceived need of the technology (Davis, Bagozzi, & Warshaw, 1989; Moore & Benbasat, 1991; Bradford & Florin, 2003). Rogers (2005) presents five characteristics of innovation that enhance the opportunity to be rapidly diffused: simplicity, compatibility, relative advantage, observability, and trialability. Diffusion of innovation theory intersects information technology adoption and acceptance research by examining the situational context and related characteristics of an innovation more likely to be diffused within an organization. Combined characteristics from these theories lead to three primary constructs to evaluate successful implementation: *access*, *support* and *utility*. To expand research related to the environment for adoption, individual and group characteristics, I examine diffusion of GIS technology for multiple inter-organizational NRM networks comprised of geographically dispersed members.

Returning to my experiences with GIS implementation and the requisite knowledge from the literature, the question becomes how do we build and effective SDSS for NRM networks when members may not be technically savvy or have the geomatics expertise to feel comfortable using the technology? I consider network members as domain experts, representing contributors of specialized knowledge (e.g. biologist, social scientist, landscape architect, archeologist, community planner). Enabling access for domain experts to engage network members with GIS use can enhance the decision support process, especially in inter-organizational arrangements of geographically dispersed network members. Conversely, disregarding the capacity of a NRM network to implement participatory web-based mapping tools can lead to inappropriate design of tools that are costly to develop and maintain, or may not be used appropriately in meeting network goals. Therefore, this study addresses this research need by exploring factors that influence capacity to adopt and implement technological innovation for collaborative activities across multiple NRM networks.

Research Goal and Objectives

Focused on the problem of deploying effective SDSS for NRM networks, my research goal is to better understand what factors influence capacity and implementation of participatory GIS technologies. To elucidate those factors, I first explored a network's technology use and users by developing an implementation capacity index for a series of similar networks, then comparing capacity to the level of implementation. Then, I conducted in-depth examination of networks that have deployed web-GIS tools for collaborative activities among network members to identify factors of influence and understand the socio-technical structure of the community of users.

Study Context

In the context of resource management, my focus is on linear corridors and the recreational trails within those passageways. Trails may take many forms and are often classified by the type of use: hiking, biking or kayaking for example. As such, the management of trail resources may vary depending on the designed use, purpose, and location. Location can influence management when a trail corridor crosses jurisdictions. Long distance trails, for example, traverse multiple administrative boundaries and private lands. Purposes range from historic themed tourism in the US (Moore & Barthlow, 1998), to recreational hiking in Scotland (den Breejen, 2007), or cycling routes serving transportation and tourism needs in Europe (Lumsdon, Downward, & Cope, 2004). Resource managers, together with trail users and corridor neighbors, make up the network people influencing management activities.

I examined resource management networks using the US National Trails System (NTS) as the population of study. NTS represents a network of resource managers comprised of inter-organizational groups that must work collaboratively to develop and maintain the national trails system. The National Trails System Act of 1968 established the NTS and recognized the value of volunteers, private and non-profit trail groups working with Federal agencies to manage and maintain trail resources (National Park Service, 2016). Designed to follow a path of partnership development across organizational boundaries the National Trails System Act (2012) policy states:

> The Congress recognizes the valuable contributions that volunteers and private, nonprofit trail groups have made to the development and maintenance of the Nation's trails. In recognition of these contributions, it is further the purpose of this Act to encourage and assist volunteer citizen involvement in the planning, development, maintenance, and management, where appropriate, of trails. (p. 1)

For the purposes of this research, a network is defined as a group of people connected through a common purpose: involvement in management activities for a specific national trail. More specifically, the network consists of members tasked with the objective of building, promoting and maintaining the trail. Network members are representatives of trail partner organizations. They may be professional, full-time employees of the administering or managing agency (e.g., National Park Service, USDA Forest Service), a volunteer with the trail association, a representative of a local government agency, a private landowner, or a contracting agency working with member groups to accomplish trail goals.

The National Scenic and Historic Trails system are, by design, complex partnerships of Federal agencies, state governments, nonprofit trail organizations and volunteers. According to American Trails, this collaborative approach to public land stewardship also involves communities linked by these trails in management and promotion, making the National Trails System a “culture of people-based community conservation” (American Trails, n.d.). Geospatial technology tools through web-based mapping interfaces offer an innovative method for trail partners to engage with one another to meet network management needs.

Dissertation Organization

This dissertation is organized as three-manuscript format, followed by a general conclusion chapter. Chapters 2 – 4 were prepared as three distinct peer-review publications and conform to the manuscript organization, style and format of the target journal. Each manuscript has a separate purpose with specific research objectives, but together they represent a broader foundation for overall research goals (Table 1).

Table 1. Study Questions by Manuscript.

Phase 1 – Adoption of GIS Technologies by Resource Management Networks.
Manuscript 1 – Understanding technology use and users by answering the following questions: ▪ How do individual networks vary across levels of implementation capacity and users engagement? ▪ What network characteristics are indicative of high, medium or low implementation capacity? ▪ How does implementation capacity compare to level of engagement using GIS tools for network tasks?
Phase 2 – Implementation of Web-based Collaborative GIS technologies.
Manuscript 2 – Identifying factors that influence capacity and implementation by answering the following questions: ▪ What factors influence access to web-GIS tools implemented for network tasks? ▪ What user support structures are in place to use the technology, and what do users identify as support needs? ▪ How do different users describe the utility of the web-GIS tools to accomplish individual and network tasks? ▪ What are individual perceptions of success of the tool based on access to the tool, support to use the tool and usefulness of the tool?
Manuscript 3 – Understanding the community of users by answering the following question: ▪ How may social and technical structures of a network be jointly optimized to influence implementation of web-based collaboration GIS tools across the network?

Chapter 2 presents phase one of the research study, an inventory documenting geospatial technology use by the U.S. National Trails System (NTS). In that study, I sought to identify GIS platforms in use, staffing and level of user engagement offered by a series of similar NRM networks. Using the inventory data, I introduced an assessment framework to measure a network's GIS implementation capacity. Comparing capacity to level of engagement based on the technology implemented, I developed a geospatial technology profile for each network. The results present recommendations for evaluative processes to assist networks with developing strategies to balance system implementation based on user ability and map capabilities.

Chapters 3 and 4 report findings from phase two of the study, which included a multiple case study of four NTS networks that have deployed high-level engagement tools (e.g. offering two-way communication) through web-GIS technologies. Chapter three examined factors that influence capacity and implementation of web-GIS as a participatory engagement tool for collaboration and data-sharing across the network. The in-depth look at four individual cases, with cross case comparisons, used measures of access, support and utility to explore four networks representing different capacity and implementation levels. The study fills research gaps by exploring GIS implementation for inter-organizational NRM networks as a collaborative tool.

Chapter 4 explores socio-technical structures (STS) that influence implementation and diffusion of web-GIS tools for participatory engagement. In tandem with the objectives for Chapter 3, I used the multiple case study to explore users' role by applying STS and DOI theories by framing the NRM network as a community of users. This study contributes to the literature by examining socio-technical implications of varying user roles that may limit access to participatory GIS technologies. Results suggest that access to spatial decision support technologies through web-GIS provides domain experts the opportunity to accomplish network tasks using innovative methods to visualize and communicate their work across the network. Outcomes include recommendations to optimize implementation of web-GIS tools for NRM networks.

The final chapter provides general conclusions based on the research findings and summarizes implications for GIS technology implementation value, contribution, and process for NRM networks. This research contributes to three areas of understanding, 1) technology use and users, 2) factors influencing network capacity and technology implementation, and 3) strategies to optimize socio-technical structures to enhance technology implementation.

Study Key Terminology

Trail Network: A group of people connected through involvement in management activities for a specific national trail. Members are tasked with the objective of building, promoting and maintaining the trail. They may be professional, full-time employees of the administering or managing agency (e.g., National Park Service, USDA Forest Service) or a volunteer with the trail association, or representative of a local government agency, a private landowner or contracting agency working with member groups to accomplish trail activities.

Domain experts: Professionals with specialized knowledge, who are trained in a specific domain of study (e.g. biological, social sciences).

Geomatics experts: Professionals trained in geospatial disciplines.

GIS, GIS software: Geographic Information Systems is a set of hardware, software and data. It may be accessed on a desktop computer (or similar tablet, laptop or mobile device) through a stand-alone software program. It may also be accessed through a web-based interface in which no software is installed on the computer.

Data, Spatial Data, Geospatial: Data represents information used by the trail network and/or network organizations. Data may be tabular, (e.g. excel or database format) or may be spatial. Spatial, or geospatial, data is digital and typically represents tabular data with a geographic location. It may be represented in a map on the computer, GPS devices or similar digital format.

Manage data: To manage data is to collect, store, manipulate, archive, analyze, generate, or distribute data for the trail network.

Maps: Maps may be hard-copy or digital versions for handouts, brochures, displays or web access. Note: brochure does not mean that you create the brochure or related trail media, but that you are responsible for providing map data to those who create the brochure or related media.

Web-GIS, web-maps: Web-based maps may be interactive applications in which a user may perform specific tasks using a cursor or buttons to alter the appearance or change the view of the map display. Web-based maps that do not permit interaction may be represented by downloadable documents (i.e. PDF, image formats) from a website. These are typically presented a digital versions of hard-copy maps available through a web page.

Hard Technology: Technologies related to hardware and software infrastructure.

Soft Technology: Technologies related to the interactions of people, policies or organizational dynamics.

List of Acronyms:

GTP: Geospatial Technology Profile

NTS: National Trails System

NHT: National Historic Trail

NST: National Scenic Trail

PGIS: Participatory Geographic Information System

SDSS: Spatial Decision Support System

SoCE: Spectrum of Capacity and Engagement

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CHAPTER 2. Assessing Geospatial Technology Implementation Capacity for Natural Resource Management Networks: A Proposed Framework

Abstract

Recommendations to successfully implement geographic information systems (GIS) for natural resource management (NRM) have been proposed from study of government agencies and non-governmental organizations. We extend research on the use of GIS for NRM by examining inter-organizational network structure of geographically dispersed members. Using the U.S. National Trail System (NTS), we developed an assessment framework to inventory adoption and implementation of geospatial technologies. The inventory informed a geospatial technology profile of 23 individual networks to identify the network's implementation capacity, and then compared capacity to implementation based on level of user engagement using GIS. Results show that higher implementation capacity is not indicative of higher levels of GIS user engagement. We make recommendations for evaluative processes to assist networks with developing strategies to balance system implementation based on user ability and map capabilities using the proposed framework. The results demonstrate the value of geospatial needs assessment, highlighting the benefits of multi-level evaluation based on GIS platforms and use. The proposed framework provides a foundation to refine GIS implementation assessment for NRM networks. Understanding the range of GIS technology use by multiple, geographically dispersed networks can further inform development and deployment strategies to mitigate barriers to successful GIS implementation in inter-organizational scenarios.

Introduction

Resource managers commonly implement geographic information systems (GIS) for inventory, monitoring and analysis of natural and cultural resources (Alrwais, Horan, Hilton & Bechor, 2015; Antunes, Zurita, Baloian & Sapateiro, 2014; Li, Bettinger, Danskin, & Hayashi, 2007; Tsou, 2004). For example, Arciniegas, Janssen & Omtzigt (2011) examined the technology as a stakeholder negotiation support tool for land use allocation, where Aye, Jaboyedoff, Derron, & van Westen (2015) assessed a specific web-GIS tool for natural hazard and risk management analysis. We use the term natural resource management (NRM) to encompass natural and cultural resources, as well as the social interactions that contribute to the management process. The social structure represents a network of people performing NRM tasks. We operationalize the management structure as a NRM network. Within those networks, GIS serves to facilitate spatial decision support processes. The varying scale of natural resource management (NRM) present challenges to network members seeking to resolve problems that require interdisciplinary approaches (Bodin, Crona, & Ernstson, 2006; Scarlett & Boyd, 2015). The scale may also be shaped by multi-jurisdictional circumstances that place decision-making across organizational boundaries, and include geographically dispersed network members (McGuire & Silvia, 2010; Prager, 2010; Scarlett & Boyd, 2015).

In these scenarios, spatial decision support mechanisms through GIS assist network members as they address land management issues, protection of cultural artifacts, or monitoring public access to ecologically sensitive areas. Application of GIS technologies include common tasks (e.g. mapping resources, conducting spatial analysis), but implemented for dispersed teams GIS technology can function as a communication medium to engage colleagues and share ideas (Sarker & Valacich, 2010; Sun & Li, 2016; Wright, Duncan & Lach, 2009).

Disregarding the capacity of a network to implement participatory mapping tools can lead to inappropriate design of systems that are costly to develop and maintain, or may not be used appropriately to meet network goals. The ever-changing aspect of technology presents the need to enhance implementation planning as well as routine evaluation of systems in place. For example, Smith et al. (2015) introduced a geospatial data management system assessment process for Federal agencies that included evaluation of personnel and hardware and software infrastructure to sustain a system. We propose an assessment that examines specific types of technologies in place combined with the types of tasks performed by users. Understanding the range of GIS technology use by multiple, geographically dispersed NRM networks can further inform deployment strategies for successful GIS implementation (Eldrandaly et al., 2015; Göçmen & Ventura, 2010). The assessment will identify a network's implementation capacity, allowing us to compare capacity to implementation based on level of user engagement (application intricacy) using GIS. We frame our assessment using theories of socio-technical systems, diffusion of innovation, and technology acceptance to better understand network characteristics for implementation and identify strategies for successful systems.

Literature Review

Implementation of Geographic Information Systems

Research on implementation of GIS systems spans multiple disciplines. For example, research has examined implementation in diverse settings [e.g., local government (Alrwais, et al., 2015), federal agencies (Smith, Slocumb, Smith & Matney, 2015), and non-governmental organizations (NGOs) (Sieber, 2000)] as well as with the integration of planning scenarios (Göçmen & Ventura, 2010; Olafsson & Skov-Petersen, 2013). In this context, we recognize the multi-disciplinary composition of NRM networks, and that members may be geographically dispersed.

Application of GIS technologies include common tasks (e.g. mapping resources, conducting spatial analysis), but implemented for dispersed teams GIS technology can function as a communication medium to engage colleagues and share ideas (Sarker & Valacich, 2010; Sun & Li, 2016; Wright, Duncan & Lach, 2009). Engagement levels may be developed across a range from simple display of a map to use of applications that facilitate scenario comparisons between users. There are several capacity requirements that become increasingly complex depending on the intended application of the technology.

To specifically examine GIS implementation, Eldrandaly et al. (2015) developed a model to measure GIS implementation success based on previous IS research. Their model provided one level to measure diffusion success, with a second level to measure post-implementation success. Eldrandaly et al. (2015) identified critical success factors for the GIS implementation process that included organizational characteristics, software and hardware selection, educational resources, user skill and experience, and task characteristics. Additionally, Alrwais et al. (2015) proposed a comprehensive model to assess GIS use by local governments stating that the system, tasks, users, lead GIS staff, and the organization are necessary dimensions in studying organizational GIS use. Local government use of GIS is expected, but we recognize that the type of organization may influence successful outcomes. For example, Sieber (2000) identified challenges associated with GIS implementation by NGOs (e.g. upper management commitment, sufficient training) and recommended adopting non-traditional methods to accommodate individual organizational characteristics, such as outsourcing GIS management to volunteers or partnering with universities. Research found when investigating GIS implementation of applications spanning organizational boundaries, constraints related to system management responsibilities, data sharing policies, and user experience emerged and influenced success (Anderson, et al., 2009).

Hard and Soft Technologies

The balance between understanding the technology and the organization introduces an approach to evaluate the process as a socio-technical system (STS) (Doherty, 2014). STS presents characteristics identified as either soft or hard technology. Eldrandaly, Naguib and Hassan (2015) summarized success models for organizations to implement GIS, listing critical success factors we categorize as “hard” technologies or “soft” technologies. Soft technologies are related to the interactions of people, policies or organizational dynamics. Hard technologies, on the other hand, are those typically considered in the discussion of technology, such as hardware and software infrastructure (Mayer & Davidson, 2000; Rogers, 2005; Tushman, Anderson & O'Reilly, 1997). Information system (IS) research explores hard and soft technology factors in reference to implementing a successful system. Peppard and Ward (2004) postulated the concept of IS capability related to hard and soft technology, extending the concept beyond a strategic planning focus to apply resource-based theory to IS management. While their work was conceptually broader than GIS implementation, the framework included design and delivery of the system. Delivery of IS includes capability to maintain the system while continuing to evolve and innovate IS for an organization.

Capacity is measured by hard and soft technology characteristics, including expertise to manage the system, hardware and software to host applications, financial and training resources to support network users and maintain system utility appropriate to users (Eldrandaly et al., 2015). The soft technology, or human factor of system implementation, is as much a part of success as the hard technology components. For example, geomatics experts, professionals trained in geospatial disciplines, are necessary to develop, maintain and manage the systems for an organization, but the utility of the applications may need to accommodate non-expert users (Anderson, Beazley, & Boxall, 2009; MacEachren & Brewer, 2004; Vacca, Fiorino, & Pili, 2017). Due to this complexity, systems can be costly to develop, deploy and support across an organization. Paudyal, McDougall and Apan (2013) suggested that adoption and implementation of strategies could facilitate spatial data sharing to advance NRM communities in efforts to become spatially enabled.

Adoption and Diffusion of Innovation

Prior research has well established that organizational structure, culture, and characteristics can influence the process of technology adoption, acceptance and implementation (Brown, Dennis, & Venkatesh 2010; Kiwanuka, 2015; Obermeyer & Pinto, 2008; Rogers, 2005). Specifically, organizational environments establish the capacity of a network to adopt and implement an innovation as a standard operating procedure (Rogers, 2005). Adoption and dissemination is dependent on factors related to group perceptions (e.g., technical fit with tasks, technical complexity of tasks), as well as individual characteristics (e.g., technical experience, support and resources to use technology) of group members (Sarker & Valacich, 2010; Venkatesh, Viswananath, Morris, Davis & Davis, 2003). The lens of group adoption of technology is needed when examining the diffusion of innovations such as GIS applications for a network of users. The organization may support at the group level, but the ability of individual network members to be successful using technology must also be addressed through implementation strategies (Alrwais, et. al, 2015; Paudyal et. al, 2013; Sarker & Valacich, 2010).

Göçmen & Ventura (2010) found that access to use the technology and confidence to effectively use it once accessed vary among less experienced users in a local government planning context. Access to the technology, coupled with support resources such as training are essential to implementation strategies (Alrwais, et. al, 2015; Eldrandaly, et. al, 2015; Göçmen & Ventura, 2010). The coupled resources of training or instructional materials can provide support to improve confidence among users. At the same time we find that exposure to spatial technology is on the rise through daily access to Web 2.0 and related geo-locational map applications on our phones (Darwish & Lakhtaria, 2011; Elwood, Goodchild & Sui, 2012). Research on these societal trends also provide context to understand how technology is used, and better assess suitability of the environment for adoption and implementation (Kar, Sieber, Haklay & Ghose, 2016; Poore, 2011; Singhal & Dearing, 2006; Wright, et al., 2009). These trends are especially important when seeking to engage novice GIS users who may have confidence to explore the technology even though they have no geomatics training.

Research gaps. GIS implementation has been studied across multiple disciplines, including NRM. Recommendations to successfully implement geographic information systems (GIS) for natural resource management (NRM) have been proposed from study of government agencies and non-governmental organizations. We extend research on the use of GIS for NRM by examining inter-organizational network structure of geographically dispersed members. Recognizing that both hard and soft technologies contribute to adoption and diffusion, we propose an assessment framework to measure GIS technology use and users for NRM networks.

Research Framework

The implementation process includes delivery of the technical system through hard and soft technology measures. Beginning with the potential range of platforms (hard technology), we acknowledge that a network may use multiple platforms, with each offering different tasks and experiencing different frequency of use. Frequency of use serves as an indicator of routinization of GIS operations for individual NRM networks (Eldrandaly et al., 2015; Rogers, 2005). Delivery requires human influence and interaction for operation, or soft technology components. Operation includes skilled staff to design and maintain the technical system, and to provide support for system users. Together these components encompass a network's implementation capacity. We propose that the capacity of an organization to implement GIS is based on hard and soft technology constructs. Indicators for *access, support* and *utility* can provide measures to calculate a network's implementation capacity as an index (ICI) for comparison (Figure 1). Using this implementation capacity framework, in combination with organizational characteristics, a network can appropriately select the level of implementation to meet GIS needs.

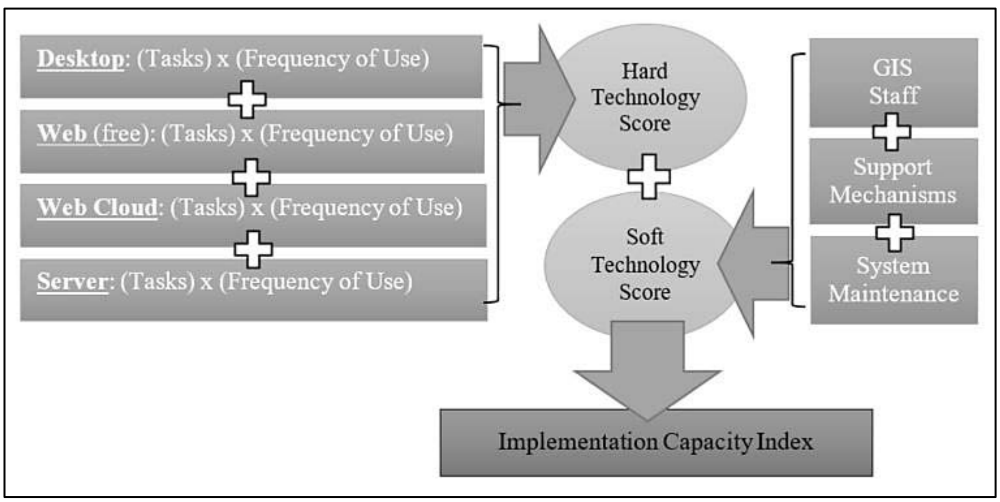

Figure 1. Implementation Capacity Framework

To further explore NRM network GIS implementation capacity, we look to research that extends spatial decision support systems to the collaborative processes of NRM (Antunes, et al., 2013; MacEachren & Brewer, 2004; Sidlar & Rinner, 2009). These researchers conceptualized multiple stakeholder perspectives for geocollaboration based on use of GIS tools for communication, interaction and decision-making. A higher level of engagement represents a higher capacity level, requiring more complex system design and additional user support resources (Alrwais, et. al, 2015). To apply the ICI, we incorporate GIS tool design. Tool design dictates level of interaction, or engagement, that an individual employs with GIS. Collaborative opportunities with distant network members may take different forms based on the level of engagement. Higher engagement, such as tasks permitting two-way communication or data sharing, require higher complexity in application design. Adding engagement to our full assessment of GIS use, we may compare implementation capacity to level of use deployed as an evaluative measure for implementation.

Study Population

The NRM network population of study are U.S. National Trails System (NTS). NTS was established "to promote the preservation of, public access to, travel within, and enjoyment and appreciation of the open-air, outdoor areas and historic resources of the Nation" by the 1968 National Trails Systems Act. Furthermore, the National Trails System Act of 1968 established the NTS, recognizing the value of volunteers, private and non-profit trail groups working with Federal agencies to manage and maintain trail resources (National Park Service, 2016). In this study, the set of 30 NTS network members designated as National Historic Trails (NHTs) and National Scenic Trails (NSTs) were selected, as these trail systems span long distances, multiple political jurisdictions, and public and private lands. The 30 NTS members are comprised of 19 NHTs and 11 NSTs and the federally mandated inter-organizational structure represents a network of groups that must work collaboratively to develop and maintain the national trails system. Each NST and NHT includes an administrating Federal agency and a private, non-profit trail association. The trails, illustrated in Figure 2, are located across the continental United States, in Alaska, and Hawaii.

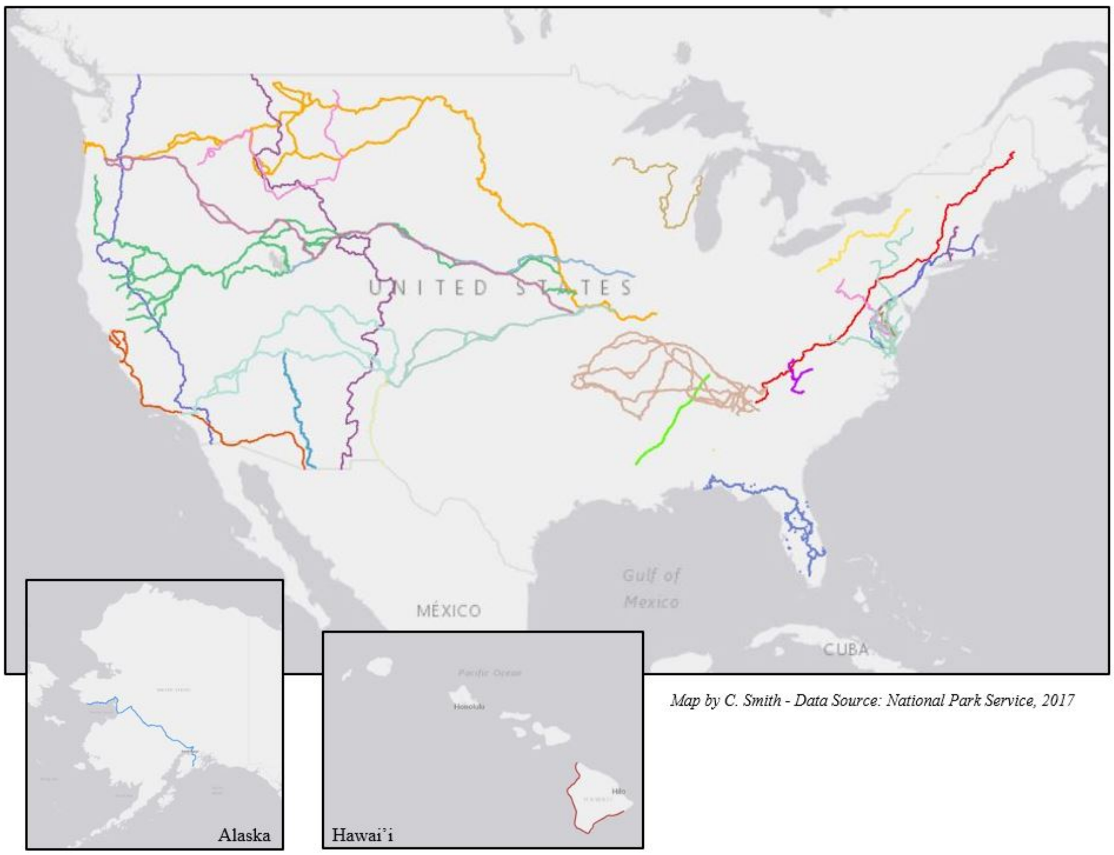

Figure 2. U.S. National Trails System Map

Methods

Using theories of technology adoption and diffusion of innovation, we conducted a geospatial technology inventory survey for a series of NRM networks. The survey instrument was developed using constructs of socio-technical systems (STS) to frame inventory components of GIS in place for the network including: 1) the community of users, or network; 2) hard technology, representing hardware, software and tasks; and 3) soft technology, represented by people and the organizational processes in place. The inventory was administered to assess adoption by developing a network geospatial technology profile based in two areas: implementation capacity and level of engagement.

GIS technology platform, tasks, frequency of use and support data were gathered through survey questions to assess hard and soft technology indicators. These indicators are based on the researcher's experience with GIS and through feedback from GIS colleagues who implement and manage GIS for natural resource managers on a daily basis. The lead researcher for this study has twenty years of experience in the field of geospatial information science and technology as a researcher and educator and holds Geographic Information Systems Professional (GISP) certification. She worked with one NTS network to develop their initial GIS infrastructure, researching data sharing strategies, and designing web mapping applications for public engagement. She is an active participant with the National Trails System GIS Network discussion group. Familiarity with the experiences and needs of the study group, combined with expertise in the technology being studied, informed the research framework and opened communication channels.

Sampling and the Community of Users

Twenty-nine NTS networks were invited to participate in a survey to determine the level of GIS technology used for trail management activities. One NHT network was excluded from the study to eliminate bias, as the researcher actively participates in development of geospatial databases and web-mapping applications for that trail. The NTS Program Leader, with the National Park Service, provided Administrative Agency and Association contact information, and indicated the primary GIS staff member, for each trail network. The Trail Superintendent or Administrator (Agency Lead) and the designated GIS staff member (GIS Designee) served as the initial and primary points of contact for data collection.

Implementation Capacity Measures: Hard and Soft Technology

Network capacity to implement GIS technologies are related to hard and soft technology. Platforms, used as indicators (Table 1), represent software in place as classified by the targeted audience. The base level of GIS technologies may be represented through desktop computer software. In this scenario, each user must have access to a machine with GIS software installed, and access to data. Additionally, the data may not be shared in a method that permits everyone to view the most recent version. A server based system permits an “Enterprise” data structure where all users have access to the same data, and updates are synchronous. GIS Designee responses were evaluated by level of reported skill, and how they categorize their work with GIS. For example, server based systems require additional IT support and have a higher implementation cost associated with the hard technology involved (e.g., equipment, software and associated license fees). Implementation capacity indicators are presented in Table 2 by variables of interest for hard and soft technology measures. Measure values are assigned from low to high to reflect a continuum representing simple to more complex scenarios.

Table 2. Implementation Capacity Indicators

Hard Technology Variable of Interest	Selection Options: Yes / No	Value Assigned
GIS Software Platform(s) in use by the network. (*select all platforms in use*)	▪ Web-based applications (free) ▪ Desktop (no web interaction) ▪ Web-based Cloud (subscription) ▪ Web-based Cloud / Server in-house (customized)	▪ 1 ▪ 2 ▪ 3 ▪ 4
Categories of tasks performed for each platform in use. (*select all tasks that apply*)	**Basic** ▪ Display ▪ Query ▪ Print Maps **Intermediate** ▪ Edit Attribute Data ▪ Download Data ▪ Data Upload (e.g. GPS) **Advanced** ▪ Edit Spatial Data ▪ Generate Reports ▪ Simple Analysis **Specialized** ▪ Use Customized Scripts / Tools ▪ Mark up Maps ▪ Send/Post Comments	▪ 1 ▪ 2 ▪ 3 ▪ 4
Frequency of GIS use for network operations for each platform in use.	▪ Never ▪ Several times a year ▪ Once a month ▪ Weekly ▪ Daily	▪ 0 ▪ 1 ▪ 2 ▪ 3 ▪ 4

Table 2 (continued)

Soft Technology Variable of Interest	**Selection Options**	**Values Assigned**
GIS Designee: Education, Knowledge, Experience, Role & Responsibilities (*Self-reported – select one*)		
Education and training	**Education / Training** ▪ Self-Taught ▪ Workshop ▪ College Coursework ▪ GIS Degree	 ▪ 1 ▪ 2 ▪ 3 ▪ 4
GIS Knowledge & Experience	**Knowledge, Experience** ▪ Novice ▪ Average ▪ Above Average ▪ Expert ▪ Professional	 ▪ 1 ▪ 2 ▪ 3 ▪ 4 5
Role	**Position Title & Role** ▪ GIS Title & Dedicated Position ▪ Other Position (e.g. landscape architect)	 ▪ 3 ▪ 2
Support & System Maintenance		
Support resources to use software and related GIS tools for each platform in use. (*Select all that apply for each platform*)	**Basic Assistance** ▪ Online ▪ Written ▪ Other (e.g. general workshop) **Intermediate Contact** ▪ Email ▪ Phone **Advanced** ▪ Face to Face ▪ Video Demo	▪ 1 ▪ 2 ▪ 3

Tasks indicate the level of user skill required to interact with the technology. GIS offers a wide range of tasks, from simple to complex, and most users' only access a subset of software or system capabilities. Tasks were associated to the platform selected, and to evaluate how users typically use the software. Skill and experience criterion (novice, user, and professional) were modified from the GIS Certification Institute (http://www.gisci.org/) standards for GIS Professional Certification.

Survey protocols followed procedures with initial contact and inquiry to insure consistent data collection from appropriate trail network members. Each trail Agency Lead was contacted by email to introduce the study purpose and scope. A survey link was included to inquire if the Trail used GIS for trail management needs, if spatial data existed for the trail and to confirm the GIS Designee for the trail, including their role and contact information. The GIS Designee was then contacted by email to set up a time to complete the survey by phone. Each participant was asked a set of questions prior to completing the GTP Survey instrument, to confirm their role as GIS Designee for the Trail. These questions included GIS Designee job title, a description of their role using GIS for the Trail and if they maintained data or systems for other trail networks. Since the use of GIS terminology may vary among targeted respondents, the survey questions were asked via phone interview so that the interviewer could clarify questions, using examples of technology and tasks, to insure consistency in answers across the networks. If the Designee managed multiple networks, then the survey was repeated for each trail. When multiple agencies shared administrative responsibility for the trail, the survey was administered to designees from both agencies. All responses were recorded using the web-based survey software Qualtrics. Qualtrics provided data organization throughout the data collection process and permitted data export to Excel for storage, cleaning and analysis. Upon completion of the survey, responses were reviewed with the interviewee to ensure the network was represented appropriately for the type of software platform in use, tasks performed, frequency of use, and support offered for each platform.

Hard Technology Score

Hard technology survey questions documented the types of platforms available to the network, the types of tasks performed on each platform and estimated frequency of use (see Table 1). The survey responses were entered in Qualtrics survey software using a binary (yes/no) option for type of platform, then selection of frequency of use categories. Platforms included desktop software and web-based delivery. Desktop (e.g. ArcMap GIS) was categorized as a non-web interface application. Web-based platforms were categorized as free (e.g. Google Maps, Google Earth), cloud based delivery provided through either a licensed subscription service (e.g. ArcGIS Online), or an in-house server provided application. Ordinal measurement of the frequency of platform use ranged from never (0), several times per year (1), once a month (2), weekly (3), to daily (4). Tasks were categorized by functionality as Basic (e.g. display, query, print), Intermediate (e.g. edit attributes, upload or download data), Advanced (e.g. edit spatial data, generate reports, conduct simple analysis), or specialized (e.g. customized scripts or tools, map mark-up, share data via two-way interaction). See Table 3 for platforms and associated level of tasks typically available for each.

Table 3. GIS Platform and Task Performance

GIS Software Platform Examples	**Basic Tasks**	**Intermediate Tasks**	**Advanced Tasks**	**Specialized Tasks**
Web-based Applications (free)				
Google Maps, Google Earth				
Web-based Cloud (subscription)				
ArcGIS Online				
Web-based Cloud (customized)				
Server Applications (in-house)				
Desktop (no web interaction)				
ArcMap Desktop				

Soft Technology Score

Soft technology measures recorded included three sub-measures: Designee, User Support, and System Maintenance. GIS Designee measures included the title and role of the lead GIS position for each network. Self-reported education, knowledge and experience with GIS technologies were recorded to gauge employee GIS skill from novice to professional.

Higher values within the final soft technology scores represent trail networks with dedicated GIS personnel that offer user support across multiple platforms using a range of mechanisms (e.g. video tutorial, written documentation, phone support), and have more complex systems to maintain. A maximum soft technology score would require all applications in use by the network, with the highest level of support offered to users. It is unlikely for a network to have a value of 100% for either the hard or soft technology measures. To do so, a network would have to offer all possible tasks on every platform, with high level support resources in place for all tools.

Network Characteristics

A trail network's characteristics were gathered from ancillary sources (e.g. annual reports, strategic plans), and website content of the National Trails System, National Park Service, US Forest Service, Bureau of Land Management and affiliated trail organizations. Network characteristics were classified as either a network structure or geographic extent category (Table 4). Structure represents the inter-organizational elements of organizational policies, procedures, and missions that may influence management processes. Geographic extent, in the context of NTS, represents additional complexities for management related to the potential number of network partners (range: 3 to over 50), jurisdictional boundaries traversed, and trail infrastructure (e.g. trailheads, bridges, protected areas).

Table 4. NTS Network Characteristics

Category	Characteristic
Network / Organizational Structure	▪ Trail Type ▪ Lead Administering Federal Agency ▪ Estimated Staffing (Agency / Association) ▪ Number of Affiliated Associations ▪ Trail Age (*Date of Congressional Designation*)
Geographic Extent	▪ Authorized Length ▪ Number of States Traversed ▪ Percent of Trail Complete

Level of Engagement

To further examine how a network uses GIS, we evaluated the level of engagement based on data gathered from the survey. Engagement was determined by the type of technology and user interaction available to network users or the public as reported for the technology profile survey. From the survey, level of engagement was assigned to each trail network using a two-step process (see Figure 3). Trails were first grouped into comparison areas (a) no GIS; (b) desktop GIS only; (c) web-based mapping applications offering user interaction beyond individual computer access. Next, the web-based mapping groups were divided into one of three categories representing interactive functionality offered by the web application (a) simple one way communication from map owner to application user; (b) mid-level communication that allows an application user to add information, but not engage in discussion; (c) two-way communication between the map owner, and the map application user. The levels of engagement were categorized based on tasks reported, application purpose, and network users as described by the GIS Designee during the technology profile survey.

Step 1
GIS Technology
No GIS
Desktop Application Only
Web-based GIS Applications

Step 2		
Engagement Level	**User Interaction**	**Information Flow**
Low	One-Way Communication	User retrieves information
Mid	One-Way Communication	User may also provide information
High	Two-Way Communication	User may share *and* discuss information

Figure 3. Engagement Assignment Two-Step Process: Level of User Interaction

The two types of one-way communication offer tasks such as display, query, printing, simple analysis, or GPS data upload for display. Low-level scenarios represented applications in which data and maps were pushed out to the end-user. Mid-level scenarios included the same capabilities, as well as interfaces that permitted user interaction such as user input data (e.g. address, buffer distances). The highest level of engagement for web-based mapping applications provided a mechanism for two-way communication. Networks reporting the higher end tasks (e.g. creating and saving map notes through the application interface or posting and receiving comments) offer capability for two-way communication and meet high-level engagement criteria.

Analysis

Implementation Capacity

Implementation capacity was calculated based on results of the technology survey using hard technology and soft technology scores. Data were exported from Qualtrics into Excel for analysis. Data were grouped by platform to calculate a hard technology score for each network, then added to the soft technology score to derive an implementation capacity score. The raw score was converted to a ratio to better compare results.

Hard technology analysis. Hard technology scores were generated as a simple index (Miller & Salkind, 2002) for each platform in use based on platform level, plus the task categories available, then multiplied by the frequency of use (see Figure 4). The score for each platform was summed to produce a hard technology score for the trail network.

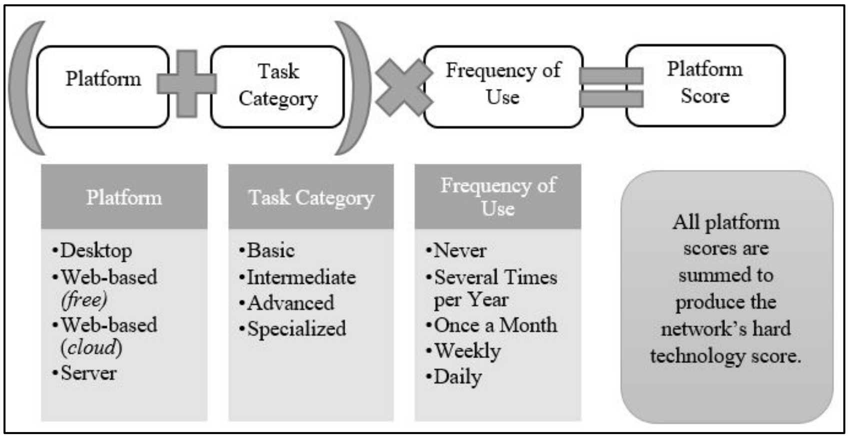

Figure 4. Hard Technology Score Calculation

Soft technology analysis. Soft technology variables of interest were incorporated to generate a score for the GIS Designee, then summed with the values for user support mechanisms and system maintenance required for the platforms in use (Figure 5). Reported values were summed and the title and role of the GIS designee was used as a multiplier to assign the final score. For example, if the designee was in a dedicated GIS role, the score is increased. If their position was split with responsibilities assigned to more than one trail or included additional (non-GIS) responsibilities, the score decreased.

Support mechanisms (see Table 1) range from online resources provided by software developers to personal contact with colleagues familiar with the network data and personnel. The lower value support options are not customized for the specific network personnel or GIS application being used, but are the general "help" documents for the software or application. The highest system support measures included video and face-to-face support (i.e., custom support) for a specific network and/or application.

The system score was computed by multiplying the type of maintenance value by the maintainer value (see Table 1). Multiplication of these two values, rather than addition, separates the desktop-only GIS users from those networks that used web-based GIS applications as well. Using a multiplier also recognizes differences in staff role responsibilities for maintaining the system. Agency-level IT personnel typically have more knowledge and training for maintaining technology than staff or interns with primary work responsibilities in other areas. The final soft technology score sums the designee score with user support and system scores to represent a simple index based on the range of values (Figure 5).

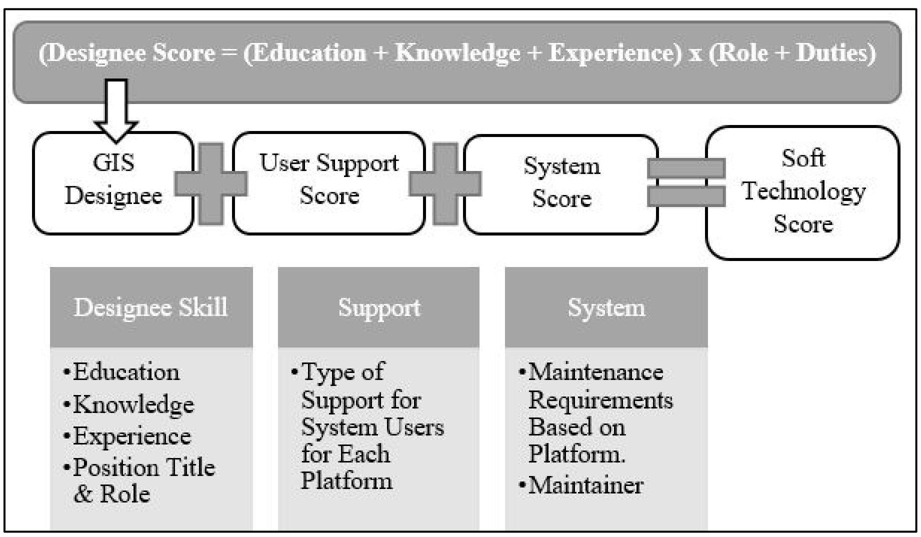

Figure 5. Soft Technology Score Calculation

Implementation capacity index. The ICI represents a composite index measure derived from combining the simple index values of hard technology and soft technology scores using the process outlined in the research framework section (see Figure 1).

Specifically, the sum of the hard technology and soft technology scores was divided by the total possible score to derive an implementation capacity index value for each network. The ICI is not weighted, rather the hard and soft technology rating scale employs levels of technology characteristics to calculate the score (Miller & Salkind, 2002). Final survey results with detailed measures and calculation procedures for each ICI component are provided in Appendix A. Due to the small population for this study, statistical analysis is limited to descriptive statistics (frequency counts and percentages) categorized by level of capacity, level of engagement and trail characteristics.

Results

Twenty-three of the 29 trails (79% response rate) participated in the survey, with 64% of the NSTs and 89% of NHTs GIS Designees responding. Only one invitee opted out of the survey after initial contact, but provided no reason for declining. The other trail designees were contacted at least three additional times to participate in the study. In some situations it was noted that the Agency lead or GIS Designee staff members were in transition (e.g. position vacancy). Non-response bias for the six trails not participating in the survey was checked relative to network characteristics. It was noted that of the six trail non-responding networks, four were NST's. Also of note, the USDA-Forest Service (FS) shares land management with many of the trails, but is lead agency for only six trails (5 NST, 1 NHT). Only two of the six trails led by the FS participated in the survey. To mitigate some of the non-response by FS networks, a lead GIS data manager for the FS trail systems contributed to the study by providing an agency-wide overview of data management roles and responsibilities and web mapping status. The participating FS trails interviewees provided additional insight by describing general responsibilities of the GIS Designees within the FS. These roles appeared broader than those employed by the NPS. The trail characteristics and socio-technical structure of hard and soft technology are further described with a visualization of capacity and engagement based on the GTP for each network.

Trail Characteristics

Trails varied in authorized distance (86 to 9,064 kilometers), number of states intersected (1 to 14), and number of years since Congressional designation (7 to 48 years). The complexity of trail management, and the NTS as a whole, is marked by this range of network characteristics. A summary of trail characteristics gathered for the study are listed in Table 5. The participating trails are listed by name with the year established through Congressional legislation, authorized length and designated Federal Agency administering the trail. The percentage of trail completion is based on the 2013 Annual Report of the National Trails System. The number of states intersected by the trail corridor is listed as an indicator of jurisdictional changes along the trail in combination with trail miles. The last two columns present an estimate of agency and association staffing for each trail derived from ancillary data sources including the original survey contact list provided by the national NTS office, and supplemented by review of trail association websites.

Table 5. Summary Characteristics of Trail Networks Surveyed

Trail Name	Year Designated	Authorized Length (Mi)	Authorized Length (km)	% Complete	States	Administering Agency	Est. Staffing: Agency/Assoc.	No. of Association(s)
Appalachian NST	1968	2,158	3,453	100%	14	NPS	10/50+	2
Pacific Crest NST	1968	2,638	4,221	100%	3	USDA-FS	1/21	1
Iditarod NHT	1978	2,350	3,760	85%	1	BLM	2/1	1
Lewis and Clark NHT	1978	3,700	5,920	100%	11	NPS	19/4	2
Mormon Pioneer NHT	1978	1,300	2,080	100%	5	NPS	20/5	1
Oregon NHT	1978	2,170	3,472	98%	6	NPS	20/5	1
Ice Age NST	1980	1,000	1,600	64%	1	NPS	8/5	1
North Country NST	1980	3,200	5,120	85%	7	NPS	2/13	1
Natchez Trace NST	1983	95	152	100%	3	NPS	3/1	1
Potomac Heritage NST	1983	700	1,120	99%	4	NPS	1	1
Santa Fe NHT	1987	1,203	1,925	2%	5	NPS	20/5	1
Trail of Tears NHT	1987	5,045	8,072	0%	9	NPS	20/5	1
Juan Bautista de Anza NHT	1990	1,200	1,920	21%	2	NPS	3/2	2
California NHT	1992	5,665	9,064	100%	10	NPS	20/5	1
Pony Express NHT	1992	1,966	3,146	100%	8	NPS	20/5	1
Selma to Montgomery NHT	1996	54	86	?	1	NPS	4/0	None Listed
Ala Kahakai NHT	2000	175	280	11%	1	NPS	5/2	2
El Camino Real de Tierra Adentro NHT	2000	404	646	2%	2	NPS/BLM	20/5	1
Old Spanish NHT	2002	2,700	4,320	0%	6	NPS/BLM	20/5	1
El Camino Real de los Tejas NHT	2004	2,580	4,128	0%	2	NPS	20/5	1
Captain John Smith Chesapeake NHT	2006	3,000	4,800	68%	4	NPS	5/2	1
Star-Spangled Banner NHT	2008	290	464	?	3	NPS	1	1
Arizona NST	2009	761	1,218	100%	1	USDA-FS	1/2	1

Key:

NST: National Scenic Trail
NHT: National Historic Trail

NPS: National Park Service
BLM: Bureau of Land Management
USDA-FS: US Forest Service

The two oldest trails are NSTs and have the highest number of association staff in support trail operations at 50 and 21 employees. Of these two, the NPS administered trail has 10 agency employees and the USFS administered trail lists only one agency employee assigned to the trail. A third NST lists the next highest number of association staff, at 13 employees, compared to two NPS agency staff members. The group of nine historic trails has the highest number of agency staff listed, at 20 NPS employees. Those staff members are located in two separate regional offices, work with individual association representatives and provide support across the nine trail networks. One trail without regional support list 19 agency (NPS) staff members and four association staff. The remaining trail networks range in agency staff between one and eight, and association staff members between zero and four.

Four of the 23 trails list two affiliated associations with the trail and one listing no non-profit partner association.

No major differences were noted between NST and NHT networks. Due to the different purposes between these two types of trails, the data type and GIS tasks vary. Geospatial data for NSTs may represent trail tread, maintenance structures, public hiking access and safety vehicle access points recorded by association volunteers. NHT data is primarily representative of documented historical locations that are validated. Similarly, NHT archeological resources represent data of concern when sharing information, which may not be readily accessible data in web-based applications unless restricted to specific, registered users. Both types of trails use spatial analysis tool to evaluate and monitor the visitor experience and both types are invested in the use of GIS to document trail signage, access points, kiosks and auto tour route wayfinding.

These characteristics demonstrate the range of organizational structure that define the community of users within a network. Individual networks may have different management goals, varied network composition and extent, and contrasting goals for engagement. To enhance understanding an inventory of hard and soft technology was gathered.

Hard Technology Summary

GIS software and platforms were categorized into four categories (see Table 5): Desktop, Web-based (Free), Web-based cloud (subscription), Server-based cloud (customized). The latter category represented server-based applications licensed, developed, managed and maintained by the network. ESRI ArcMap for Desktop, web-based free Google

Earth, web-based subscription platform ESRI ArcGIS Online, and server applications were reported in use by respondents.

Table 6. Hard Technology Summary by Platform

Platform	Results Summary
Desktop Only	▪ Two networks (7%) using desktop only, with one of the two using GIS through regional office support.
Web-based (free) ▪ Google Earth	▪ Twenty networks (87%) reported using Google Earth to complete some geospatial tasks for trail management. ▪ Most frequent use of Google Earth was to quickly display a location along the trail corridor, or to convert and share data in a format that other network members (or citizens) could easily view.
Web-based (cloud subscription) ▪ ArcGIS Online (AGOL)	▪ (AGOL) reported as the newly emerging technology most networks (78%) were moving to in place of desktop for network users because it provides ability to share data among the trail network members. ▪ Sixteen networks (70%) reported tasks completed using AGOL, with four reporting four or more routine tasks in the AGOL environment.
Server ▪ Server with customized applications specific to the network (*web or desktop*)	▪ Fourteen networks (61%) reported using a server based system to complete GIS tasks. ▪ Eight networks (35%) reported developing and using customized scripts or applications for either desktop or web-based platforms.
All Platforms **All Platforms *except* Server**	▪ Twelve networks (52%) reported using all four platforms. ▪ Three (13%) networks using all platforms except for server.

Based on hard technology responses, the majority of networks have the capacity to deploy a selection of hard technology options. User interaction was reported to be based on both task and intended audience. For example, sharing data with non-agency partners elicited use of free web-based platforms such as Google Earth to alleviate access issues due to organizational policy. Platform selection was not always determined by user skill. Google

Earth was also indicated as the platform of choice by geomatics experts for efficiency of imagery display as compared to desktop software.

Soft Technology Summary

GIS staff. GIS Designees for the trail networks ranged from no assigned personnel to GIS-specific positions to support trail management efforts. One trail reported minimal use of GIS, where the Agency Lead used regional GIS staff support as needed. Within the full range were personnel assigned duties outside of GIS responsibilities, or for areas outside the scope of the national trail network. One GIS Designee reported that his primary duties required GIS activities for the greater area managed by his park unit, rather than just the national trail under the park unit purview. Therefore, all recorded responses related only to national trail network tasks. Due to shared responsibilities duties, and one trail not formally using GIS, a total of 12 respondents provided input to the GTP. Every effort was made to appropriately account for networks that share a GIS designee. For example, one group of nine (9) NHTs were administered by a single NPS office. The GIS Designee for the regional group of trails responded for the nine trail networks. Two of the nine networks were co-administered with another federal agency; therefore, the trail lead with the second agency was also interviewed to complete the GTP survey and confirm responses. A description of soft technology based on GIS administration is summarized in Table 7.

Table 7. Soft Technology Summary

Designee Characteristics	GTP Response Summary
GIS Designee : *Agency, Association, Contract*	GTP input for the 23 networks were from 12 total respondents due to split responsibilities. ▪ One network has no formal GIS and did not complete the GTP. The Agency Lead for that trail reported use of regional GIS staff support when needed. ▪ One lead GIS designee represented a regional group of nine (9) NHTs (39%). o Two (8%) networks were co-administered with another Federal agency. Additional input was gathered from the second agency GIS Designee. ▪ Two (8%) of the 13 remaining networks also shared a GIS designee. ▪ Three networks (13%) enlist the Association staff for primary GIS responsibilities. ▪ One network contracted out web-based mapping development and system maintenance, while maintaining desktop systems in-house (Agency). ▪ Each of the four networks (17%) that do not use Federal Agency as GIS lead, work closely with agency personnel in data management and, in some situations, software licensing.
GIS Education and Experience: *Self-reported education, knowledge and experience* .	Education ▪ Three networks (23%) employ a designee with a degree in the geomatics field with two (9%) reporting they are self-taught (e.g. *on the job training)*. Knowledge & Experience ▪ One respondent reported knowledge at the novice level, and experience as average. A second respondent reported an average knowledge level, with novice experience level. ▪ Three (23%) with degrees in geomatics field, reported both knowledge and experience at the professional level.

Role and Responsibilities: *Primary duties, shared GIS responsibilities.*	▪ Six of the 12 (50%) GIS Designees surveyed held a GIS-specific position.
	    o Three provided support for one trail: two as Agency staff, one as Association staff.
	    o Two were in a regional support position.
	    o One provided GIS support for two trails.
	▪ The remaining six (50%) Designee position titles and roles included archeologist, trail administrator, operations manager, outdoor recreation planner, and scenic resources coordinator.
	    o The latter two positions provided duties beyond GIS tasks for the trail.

Designees were asked to report levels of skill based on knowledge and experience. Asking for both of these perspectives provided a stronger result for actual skill level as some GIS designees noted a change over time. For example, one designee stated his knowledge level was above average, where previously he would rate himself as an expert; recent advancements that require new programming skill influenced how he reported knowledge. Considering both attributes, his final experience rating was expert level.

Through the role and responsibility of the designee, the soft technology score takes into consideration split duties. Where a network may have a dedicated GIS position, if that person has responsibilities across multiple trails, tasks may not be accomplished by a full-time staff member.

Support mechanisms. Support for network users of geospatial technology were minimal. Most networks (39%) offered software help documents or general application workshops; however, these types of support were not specific to the network platform or tools. One network reported customized help videos to demonstrate use of a specific tool or application. Six of the thirteen designees reported network members have the option for one-on-one support via email, telephone or face-to-face contact with someone in person for support in using GIS technology. Developing support resources across multiple platforms varied, with only one network (4%) providing support across three platforms and two networks (9%) across two platforms. The remaining 87% reported support for only the primary platform in use.

System maintenance. Of the 22 trail networks using GIS, twelve networks maintain their own server systems, with three networks maintaining desktop-only environments. Nine of the networks use agency staff with IT expertise to maintain the systems, and one network contracted server-based system maintenance. Only one trail, which was a network in transition to hiring a full-time GIS staff member, reported non-GIS staff as the system maintainer. All other trail networks reported that the GIS Designee was responsible for maintaining software, licenses and systems.

Implementation Capacity Index

ICI results were categorized as low (0-25%), medium (26-50%) and high (51-75%) implementation capacity. For the NTS, ICI values ranged from zero to 64%, with the zero-capacity network reporting minimal use of GIS. It is of note that the zero-capacity network has the lowest geographic extent in the NTS. The next highest implementation capacity score was 7% by a network using volunteer support for GIS, and in the process of hiring a full-time GIS position.

The results of a dedicated position to support GIS activities equates to higher implementation capacity. The highest ICI value is 64% for a network with a high soft technology score due to support resources in place. The next highest ICI value is 54%, and assigned to the group of nine networks that share a GIS specialist, who is assigned to a regional office with other agency staff supporting all nine networks. However, differences exist between individual trail networks within the region, and were noted in the hard and soft technology measures. The GIS Designee reported that two of the nine trails more frequently use spatial technology (based on activities of the affiliated associations for those networks). Two other networks within that group have joint agency leadership between two federal agencies. Surveying the second agency lead for those specific trails revealed differences in the amount and type of GIS activity for the individual trail network. The differences were reported for specific areas of responsibility along the trail corridor. Due to division of responsibility, some trail networks that shared staff resources reported less GIS activity.

A summary of trail networks categorized by high, medium and low ICI values, based on GTP results for soft technology, hard technology is provided in Table 8. Of the 23 networks surveyed, nine showed high implementation capacity for geospatial technologies. The dispersion of network implementation capacity matched well with soft technology scores; however, hard technology results showed that the majority (53%) of surveyed networks fell in the medium range of scores.

Table 8. ICI Summary for NTS Networks

Capacity Category	**ICI Value Range**	**Number of Trail Networks**
High	51% and above	9
Medium	26 - 50%	8
Low	0 – 25%	6

Low capacity networks are characterized by networks without a dedicated GIS staff member, or use only a few platforms. Medium capacity networks are characterized by networks leveraging geospatial technologies across the network and ones that use multiple platforms; however, these networks tend to place primary use and support to one platform option. High capacity networks are representative of agency led GIS operations that have dedicated GIS staff and support mechanisms in place for the network.

Level of Engagement

To visualize use of geospatial technologies by the networks surveyed, we used platforms and tools reported from the GTP, supplemented with ancillary information, to create a Spectrum of Capacity and Engagement (SoCE). Ancillary data included trail network websites (agency and/or association) that included downloadable map products or web-based mapping applications to guide placement for level of engagement. GTP survey results (Figure 6) show implementation capacity on the vertical scale (high, medium and low) and level of engagement on the horizontal scale. Each point on the spectrum represents a trail network. A high number of networks are grouped as high capacity, mid-level engagement. These networks have the capacity for high-level engagement, but have not implemented tools to accommodate the network by using those capabilities. In comparison, low engagement networks are using basic capabilities of geospatial technologies, primarily on desktop to produce maps to share with network members or the public. Only two networks have implemented high-level engagement tools, and each has medium level ICI value. Each of those networks has lead GIS responsibilities outside the federal administering agency. The trail association leads GIS activities for one network, while the second hired an outside contractor to manage web-based GIS development and maintenance. The association-led network primarily uses web-based cloud solution, resulting in a lower hard technology score due to reduced systems maintenance requirements. Conversely, the network contracting services has a lower soft technology score since GIS personnel are not on staff.

Several networks have the capacity and reported a desire to have high level engagement tools, but are limited based on policy barriers. Server infrastructure policy restricting access by non-agency personnel slowed deployment of two-way, web-based applications. To navigate the barriers, exchange of data by email or file sharing takes place. This process is not optimal as it duplicates data and effort, impacting efficiency. Two networks are sharing data and communicating with network members using GIS technology, but have not fully implemented a web-based system for two-way communication.

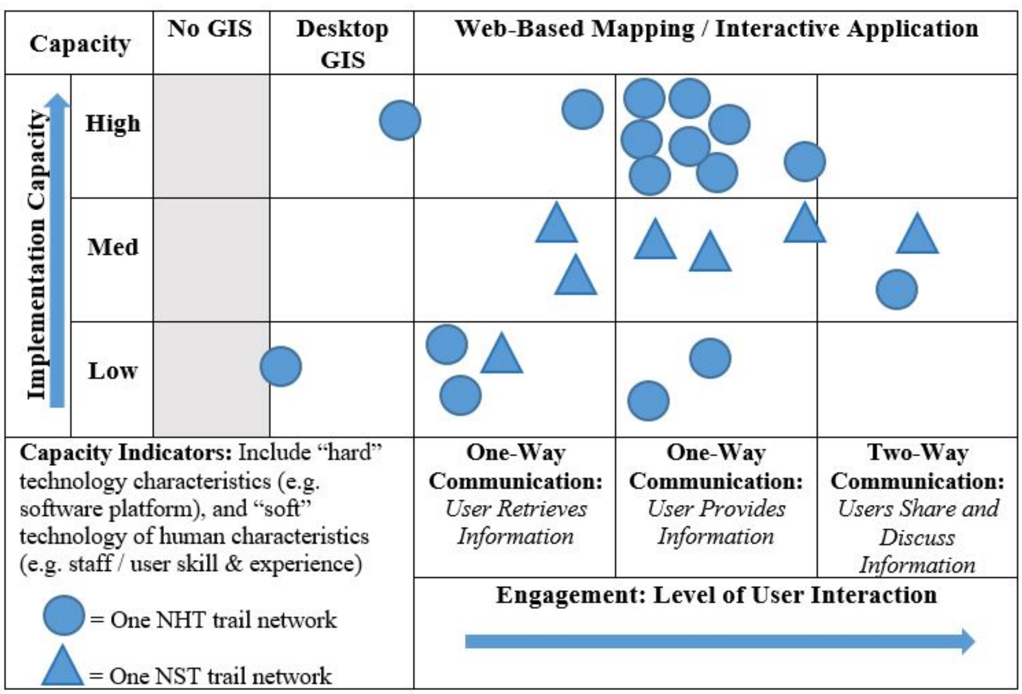

Figure 6. Spectrum of Capacity and Engagement: Geospatial Technology Profile of the U.S. National Trails System

GTP results (Figure 6) are presented on the SoCE. Moving from left to right on the engagement line, the level of user interaction increases. Applications that fall on this end of the spectrum, offering two-way communication with data sharing capabilities for example, require a higher level of capacity to implement. However, it is possible for an application design to represent low level implementation capacity but provide high level of engagement. One example is use of cloud based systems to deliver web-maps offering users the ability for two-way communication by posting comments and getting feedback from other users. Likewise, a network may have access to a high-level platform (e.g. web map server) to deploy a map, but do not have the implementation capacity (staff) to respond to user-posted comments or data uploads. The use of cloud-based systems reduces hard technology resources required to be in place for implementation. The success of implementing a tool across the network, to include representatives from multiple agencies, may vary. Several of the NTS respondents indicated that policy prevented implementation of web-based tools that permitted sharing with non-agency network members. Interestingly, a participatory tool may be adopted with the intention for all network member groups to utilize, but only one or two groups have the ability to actively engage with the tool, establishing an overall low implementation level.

Discussion

In this paper, we researched the adoption and use of the technical system to better understand GIS use by a NRM network community of users. Comparison of implementation capacity to system use revealed that capacity may not align with the level of engagement implemented for the network. Additionally, networks may deploy a range of geospatial capabilities to meet the varied technical skills of the target audience. This study provided a framework for NRM networks to build an inventory using the GTP to document the range of platforms to engage network members. The inventory was designed to enable evaluation of the socio-technical system in place and guide decision processes for delivery of the technical system. Visualization through the SoCE illustrated the range of capacity and use of web-based applications by the NRM study population.

Hard and soft technologies indicate capacity to implement levels of geospatial technology (Eldrandaly, et al., 2015; Kiwanuka, 2015; Obermeyer & Pinto, 2008; Rogers, 2005. As with this research, other studies recognized the multiple stakeholder (soft technology) aspect of assessment, which focused at the organizational level for governments, or NGOs (Alrwais, et al., 2015; Sieber, 2000). Our results support and extend Smith et al. (2015) needs assessment process by applying capacity measures to NRM networks and compares post implementation results to understand if level of engagement matches capabilities. This new level of assessment reflects best practices for GIS implementation scholarship by examining hard and soft technologies to better understand implementation capacity of NRM networks of geographically dispersed users.

Our findings support previous research by demonstrating the range of needs of user networks. Olafsson and Peterson (2013) indicated that multiple stakeholder arrangements for trail planning typically implement more advanced GIS technology in operations. As NRM networks typically focus on collaborative processes with stakeholder groups, GIS offers the opportunity for engagement and geocollaboration in NRM. This study documents the need to provide a range of options based on diverse needs in multi-stakeholder networks.

The type of tasks and level of user skill, as well as the organizational structure, comprise the community of users of a technical system. Research recognizes that implementation is a process that evolves over time and is influenced by a community of users (Kiwanuka, 2015; Rogers, 2005). This implementation study demonstrates that task complexity dictates the infrastructure needs of a system, as well as level of support required for users to successfully use a system. If the goal is to engage users with spatial decision support systems (SDSS), we must understand the capacity of an organization to meet the associated demands. The results of this NTS case study support MacEachren's (2001) recommendations for geocollaboration efforts aimed at distant users. The human factor of soft technology suggested in MacEachren's study reveals the habit of users to move between technologies to accomplish tasks. ICI compares platforms, tasks and engagement, helping to identify characteristics across the set of networks, such as staffing, roles, and network goals (e.g. NST, NHT missions) ICI results show that even though implementation capacity is high, that the level of engagement may remain low. Further research is needed to explore why a network does not implement high engagement tools even though capacity to do so appears evident. Investigation to determine potential barriers to implementation of high engagement tools should examine potential users or uses of specialized GIS technology for the network.

Implications

In reviewing the wealth of research aimed at predicting user satisfaction, system usability, or measuring GIS implementation success, we saw that the majority studies were broadly applied to government agency or NGO systems. We sought to enhance earlier research by investigating a smaller scale of inter-organizational networks of users. This scale permitted us to compare implementation capacity to actual use of the GIS system. Network characteristics indicate a range of platforms balanced with tasks appropriate for the targeted user. Results shared by GIS designees further indicated the selection of a GIS application might change over time and by user skill level. As a result, we show that a continuum of map capabilities, user skills, and task needs are represented in the socio-technical system of the NTS networks. First, solutions may include a range of platforms to meet needs across the network. Second, it is not necessary to maximize engagement to meet needs of the network. Even if a network has high implementation capacity, the needs of the network may require only a smaller level of capacity to address an appropriate solution. Case study research to explore individual networks in depth can ascertain additional capacity indicators and may guide development of a more specific evaluative tool.

Based on NTS network characteristics we provide three recommendations for NRM networks that wish to deploy higher level engagement tools to support those efforts.

1. Recommendation one is for NRM networks to conduct a needs assessment to identify the strengths and weaknesses of hard and soft technologies based on implementation capacity. Extending Smith et al. (2015) from Federal agencies to an assessment

process that examines NRM network partners can clarify partner responsibilities, identify network needs and define user roles in development of implementation strategies.

2. Recommendation two focuses on enhancing soft technology components of the socio-technical system by providing a dedicated position for GIS, and providing user support resources (e.g. routine training). The results of Alrwais et al. (2015) research supported the value of dedicated GIS personnel or a department to improve the overall effectiveness of GIS implementation for a system of users. This position can guide the needed training and support to improve user access to, understanding and use of GIS technology. Soft technology is a higher indicator or success and has greater influence on diffusion and use (Eldrandaly et al. 2015; Obermeyer & Pinto, 2008). Similarly, Olaffsson and Peterson (2013) found that additional user support resources showed a reduction to access barriers.
3. Recommendation three necessitates selection of hard technology options that meet implementation capacity. This recommendation centers on multiple-stakeholder and inter-organizational structures representative of NRM networks. Networks may accomplish this by (a) identifying platforms to accommodate tasks needed by the network users, (b) matching hard technology to GIS staff roles and responsibilities, and (c) extending the availability of tools for SDSS aligned with available user support. Research has shown a deficiency in using the full potential of GIS technologies by practitioners, the typical NRM networks user (Alrwais et al., 2015; Göçmen & Ventura, 2010; Olafsson & Petersen, 2013). Those studies show that

selection of tools appropriate to the targeted users capabilities, combined with educational support will improve use of the system.

NRM networks seeking to adopt and implement GIS technologies should understand the range of potential users (soft technology), and the types of tasks needed to accomplish network goals to identify the platforms (hard technology) best suited to meet needs. Task utility, including complexity of map capabilities and user skill will dictate the type of platform selection. GIS platform and task performance will, in turn, guide the skill and expertise needs of geomatics staff to develop, deploy and maintain a system. Soft technology works in balance with hard technology, and if the capabilities of the mapping application are higher due to the number or complexity of user tasks, then user expertise or the amount of instruction required will be higher as well.

The assessment process developed and employed in this study permits a NRM network to evaluate GIS implementation capacity for the network and identify engagement needs to develop a strategic implementation plan. For example, if high level engagement is desired, then alternatives for hardware and software should be considered with the staffing needs and user capabilities. Balancing the user experience of using technology with management requires evaluation of access and utility compared to evaluation of tasks and required support prior to design, deployment and delivery of the technical system.

Limitations and Future Research

The GTP survey is provided to inventory associated GIS hard and soft technology adopted and implemented by a NRM network. It cannot be used as a predictive assessment, but rather guide evaluative processes. The goal is to understand and explain GIS implementation for a series of similar NRM networks by evaluating the status of geospatial technologies for the NTS. Even though the NRM networks studied are similar, each is a community of users with unique characteristics (e.g. individual user technology skill) that may influence implementation. Where some GIS models predict success based on critical success factors, we sought the flexibility to use those factors as an evaluative measure of the tools being used by NTS networks compared to implementation capacity. Predictive models do not elucidate the comparison be between capacity and use.

Additional study to assess the GTP survey is needed to refine engagement categories for a network. As part of the engagement questions, the survey included level of implementation, specifically density of network users for the tools in place. Several designees did not report high confidence in their responses to this question, with many reporting groups of users in the network (e.g., City Planning Department), rather than a precise number of individuals. Limited confidence in their reporting demonstrates the varied partnerships that are present across networks, emphasizing the need for a flexible measurement tool. Their response is also indicative of whether they are able to track use of web-based tools. Refinement of this measurement can provide recommendations for networks to better track use of web-based tools.

Similarly, data collected to measure hard and soft technology constructs may differ in other NRM network scenarios. Where application to NRM networks of inter-organizational composition will reflect organizational barriers to implementation, the current application was only applied to long distance trail networks with designated GIS personnel. In a network without a staff member employed in the primary GIS role, data to index hard and soft technologies may be challenging to ascertain.

Future research is needed to gather input from network users to better assess the level of implementation, and identify factors that may influence capacity and implementation. Building on research that identifies barriers and use patterns by planning agencies, we can extend the results to consider inter-organizational structured NRM networks. The varied partnerships within NRM networks permit further study to refine the GTP measures of capacity. Examining networks based on levels of engagement through case study approaches can reveal barriers to access and use patterns. For example, identifying how a network adopted and used high-level engagement tools for collaboration among network members can confirm ICI measures.

ICI calculations included both hard and soft technology measures. Future application to NRM networks should examine hard and soft technology factors separately. An in-depth exploration of implementation capacity focused on these two factors can further refine measures, and then index computation. Additionally, a larger sample size may elucidate differences between network structure, technology in use, and number of users. Revealed differences may demonstrate a need to weight measures depending on the application desired (e.g. post implementation time period, number of network members, types of GIS platforms in use). The NTS networks in this study all had a federal agency partner with access to GIS technology. While not all of the networks implemented GIS, the technology was adopted across the NTS. Future research should apply the ICI to inter-organizational NRM networks without the same level of GIS adoption that the NTS exhibited. Building a data set of geospatial technology profiles across a range of NRM networks will allow further analysis to validate the tool, thereby refining measures in an effort to fully understand implementation capacity.

Conclusions

This study provides a foundation to understand characteristics of GIS adoption by NRM networks with geographically dispersed members and establishes the value of needs assessment to determine strategies for successful implementation. NRM uses stakeholder-driven, collaborative processes. GIS provides opportunity to enhance those processes, particularly where GIS is already in place for other management operations. The NTS geospatial technology profile demonstrated that GIS is commonly used across the networks but in different ways (one-way and two-way communications, or data sharing to data generation). The potential to implement GIS for inter-organizational access is possible, but must consider socio-technical relationships with organizational policies that may restrict access. While technology will continue to evolve, tasks and level of user interaction to engage those tasks are more consistent. Categorizing basic, intermediate, advanced and specialized tasks will permit the assessment to evolve with the technology by indicating a current level of use based on platforms. For example, some tasks that are considered advanced at this time, may be termed basic in the future. Classifying individual tasks by complexity category will keep the evaluation relevant. In turn, the platform and types of tasks indicate the soft technology requirements for successful implementation.

Through this study, the critical factors for identifying a network's capacity to implement GIS technologies were identified through triangulating findings from the literature with the results of GTP survey and then comparing parallels to how a network structures the technology for use. Researchers can further test and refine the introduced geospatial technology assessment by applying it to other inter-organizational NRM networks of users. For geomatics experts, those in charge of GIS operations for a network, the assessment framework introduced can guide appropriate system development based on network capacity. Appropriate design will accommodate domain experts, those users with non-geomatic expertise, providing access to spatial decision support tools based on individual user skill and application need. Overall, enhancing decision support through use of spatial information applications can improve network performance of collaborative engagement in natural resource management.

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CHAPTER 3. Factors Influencing Capacity and Implementation of web-based GIS Tools for Collaboration: Case study of the U.S. National Trails System

Abstract

Participatory processes for natural resource management (NRM) networks include the use of web-GIS applications to communicate with members who may not have geomatics expertise but nonetheless benefit from spatial decision support tools. We add to research on NRM use of GIS by applying technology acceptance and diffusion of innovation theories through case study of inter-organizational networks implementing web-GIS for collaborative engagement. We examined and compared *access*, *support*, and *utility* to identify factors influencing capacity and implementation among four long-distance trail networks. Results showed access and support influenced capacity, while utility influenced implementation. Findings suggest the greater the utility, the higher the interest to navigate barriers. The cases showed that use of participatory GIS tools 1) enabled network members to implement new methods to address network needs, 2) improved efficiency of network related tasks, and 3) provided innovative opportunities for collaboration across organizational boundaries and between great geographic distances. This study provides a foundation for researchers to further explore GIS implementation capacity for collaborative engagement. Implications for resource managers include recognizing challenges of technology implementation, while illustrating opportunities to engage and innovate across the network.

Introduction

Natural resource management (NRM) comprises a complex network of stakeholders. This diverse structure is needed to address the technical, scientific, social, and political aspects of natural and cultural resource management (Bodin, Crona, & Ernstson, 2006; Scarlett & Boyd, 2015). Likewise, the diverse needs of resource management require that network members are able to share information, communicate, and engage in decision support processes. Another complexity of NRM networks is that they may include inter-organizational membership and members that are physically dispersed (McGuire & Silvia, 2010; Prager, 2010). When network members are disconnected geographically, organizationally, or operationally, they must deploy innovative methods to communicate to achieve network goals (Sidlar & Rinner, 2000; Sun & Li, 2016). For simplicity purposes, we use the term natural resource management to encompass natural and cultural resources, and include the social structure of people contributing to the management process as a network performing NRM tasks. We operationalize this management structure as a NRM network. Within those networks, geospatial technologies serve to facilitate spatial decision support processes.

Many NRM networks look to innovative tools through geographic information systems (GIS) to help facilitate communication (Brown & Weber, 2011; Paudyal, McDougall & Apan, 2013). The operational use of geospatial technologies in the realm of NRM is well-documented. GIS may offer collaborative opportunities to enhance communication, share data for decision-making, and document natural and cultural resources (Poore, 2011; Warf & Sui, 2010; Wright, Duncan & Lach, 2009). Extending use of GIS as a collaborative asset, we see that participatory GIS (PGIS) applications are a trending technology for collecting and validating data, seeking input from users on perceptions and values of natural and cultural resources, and crowdsourcing information gathering (Arciniegas, Janssen & Omtzigt, 2011; Brown & Weber 2011; Poore, 2011; Warf & Sui, 2010; Wright et al., 2009).

Participatory processes for NRM include use of web-based GIS applications as a means to reach network members that may not have geomatics expertise (e.g. trained in geographic sciences), but can benefit from spatial decision support tools (Brown, 2012; Olafsson & Skov-Petersen, 2014). Recognizing capacity of a network to successfully implement GIS technologies permits appropriate design of tools based on capacity and network needs. Disregarding capacity can lead to inappropriate design of tools that are costly to develop and maintain, or may be ineffective for users. The purpose of this study was to identify and better understand factors that influence capacity and implementation of web-based GIS tools for collaborative activities of NRM networks. Designing collaborative tools to mediate such factors can improve a networks' ability to navigate implementation challenges, experience fuller implementation levels across the network, and ultimately find greater collaborative success.

Background

GIS Adoption and Geo-Collaboration

GIS research crosses many disciplines but the adoption and implementation of technology frequently follows two streams of research: Information systems (IS) models for technology acceptance and use and diffusion of innovation constructs. In the 1990's, research focused on examining the decision of an organization to adopt geospatial technologies

(Eldrandaly, Naguib & Hassan, 2015). In the following two decades, researchers examined methods to measure successful adoption and proposed models for implementation by both government and non-governmental organizations (Alrwais, Horan, Hilton & Bechor, 2015; Sieber, 2000). Networks charged with protecting our natural and cultural resources do not question adoption of GIS, as it has become a standard tool of choice. Rather, network members seek to find ways to make implementation of such innovative technology successful.

GIS progressed from inventory and analysis to be a contributor in spatial decision support (SDSS) processes. SDSS serves to facilitate collaborative efforts, and researchers have documented the important role of spatial data to aid understanding between groups and evaluated geocollaborative environments (MacEachern & Brewer, 2004). Antunes, Zurita, Baloian, and Sapateiro (2014) followed that line of research to further examine integration of collaborative decision support with GIS tools. Collaboration scenarios vary depending on the groups involved, the temporal stage of decision making, and whether needs are strengthened by geospatial or decision support resources. Understanding the environment for adoption and use has extended to real time collaboration (synchronous) activity. Sun and Li (2016) recently reviewed real time collaborative GIS technology and expressed the need for further research at the geomatics level of technology design in synchronous environments. Their review recognized the number of end product usability studies, and presented the need to model applications in an effort to identify best design practices. Across these studies of GIS as a tool to enable collaborative processes, usability for the intended audience emerged as a common requirement, connecting technology adoption with diffusion of innovation.

Technology Acceptance Models and Diffusion of Innovation

This focus on GIS-based collaboration tools gravitates to the theoretical lens of technology acceptance. Research models that examine acceptance and adoption of technology within information systems are well established. Venkatesh, Morris, Davis and Davis (2003) expanded on Davis' 1983 Technology Acceptance Model (TAM) to develop the Unified Theory of Acceptance and Use of Technology (UTAUT). UTAUT explains user intentions to use IS and the usage behavior surrounding the technology. Building on that work, Brown, Dennis and Venkatesh (2010) integrated theories from collaboration research with UTAUT to explain the adoption and use of collaboration technology. Brown et al.'s (2010) study pursued analysis at the group level, in addition to individual level of analysis, to understand group characteristics for successful adoption of technology for collaborative activities (e.g. discussion, idea generation through technology rather than face-to-face meetings). These models aim to predict use based on technology characteristics and perceived usefulness, and incorporate the roles of individual or group characteristics, task characteristics and situational characteristics. PGIS for our study is not a collaborative technology, but a technological tool used for collaborative activities. In this context, technology characteristics of UTAUT do not apply, as the web-based mapping tool is not the primary method of communication. Rather, PGIS is an innovative tool to share information, including data. We incorporate the concepts related to environment for adoption using individual and group characteristics, task characteristics, and situational characteristics.

Rogers (2005) describes five phases of innovation adoption: 1) knowledge of the innovation, 2) persuasion to make a decision on use, 3) decision to adopt or reject, 4) implementation by placing innovation in use, and 5) confirmation to continue use or reject the innovation. Understanding this process, researchers have examined technology adoption and success for both governmental and non-governmental organizations, exposing differences in capacity and outcomes for long-term use of geospatial technologies (e.g., Alrwais, et al., 2015; Göçmen & Ventura, 2010; Sieber, 2000). The temporal nature of technology influences capacity on several levels. First, we recognize that GIS adoption means the technology changes rapidly through software updates, hardware requirements, and support. Second, whether the innovation adoption phase is prior to the decision or post implementation can influence individual user familiarity and network level capacity.

Technology adoption, acceptance, and diffusion focused studies include pre-adoption aspects, suggesting careful identification of stakeholder needs in the design of technology tools (Karikari & Stillwell, 2004; Pinto & Onsrud, 1995; Sieber, 2000; Venkatesh, Thong, & Xu, 2016). GIS focused research examined the post-adoptive, implementation phase to evaluate success using GIS, or measured success based on use and satisfaction (e.g., Eldrandaly et al., 2015). All of these studies recognized the critical aspects of human interaction, the environment for collaborative tasks to take place, and a common task or goal for using the technology for successful diffusion across a network of users. Over time, individual users may accept or reject use, and leave or enter the network. Thus, the dynamic nature of collaborative GIS applications influences network capacity as a whole.

Both group (network) and individual (network member) are influenced by the design and implementation process. Applying diffusion theory to technology acceptance, the primary factors influencing success are technical compatibility, technical complexity (ease of use), and the relative advantage or perceived need of the technology (Davis, Bagozzi, & Warshaw, 1989; Moore & Benbasat, 1991; Bradford & Florin, 2003). Rogers (2005) presents five characteristics of innovation that enhance the opportunity to be rapidly diffused: simplicity, compatibility, relative advantage, observability, and trialability. Diffusion of innovation (DOI) theory intersects information technology adoption and acceptance research by examining the situational context and related characteristics of an innovation more likely to be diffused within an organization. Combined characteristics from these theories lead to three primary constructs to evaluate successful implementation: *access*, *support* and *utility* (Table 9).

Table 9. Research Framework to Evaluate Implementation

Study Construct	**TAM / UTAUT Models** (Venkatesh, Morris, Davis and Davis, 2003)	**DOI Theory** (Rogers, 2005)
Access to use the tool	Situational, individual & group characteristics	Trialability
Support to use the tool	Situational characteristics	Complexity
Utility of the tool	Task characteristics	Compatibility, relative advantage, observability

Most studies on GIS adoption provide recommendations for planning successful technology implementation. However, real-world scenarios do not always incorporate pre-adoption planning or allow for routine evaluation and review of post-adoptive systems in place. For example, a non-profit organization may be provided access to GIS technology via other stakeholders and simply work with the product given to them. In inter-organizational situations like this, it is important to understand how to best use innovative technologies to enhance outcomes for the entire network. Specifically, we seek to understand how a network should introduce use of geospatial technology so that it meets network needs and provides an environment for users to access the tool to perform network tasks. Our assumption is that once users are comfortable with the technology, by using it to perform everyday tasks, they will be better prepared to extend the technology for other collaborative activities. Additionally, we claim that the environment for adoption, including the network relationships, are key to if and how the technology will be used.

In the context of geographically dispersed NRM networks of governmental and non-governmental partners, this paper examines the factors that influence capacity and implementation of web-GIS technologies for collaborative network activities. It evaluates use of collaborative GIS tools in the post-adoptive phase using constructs of technology acceptance and diffusion of innovation theories to identify factors that influence capacity and implementation. Through case study, we present potential barriers to using GIS, how to best support the range of users in a network, and what factors provide a path to navigate challenges to successful implementation.

Methods

Study Population

The NRM network population of study were U.S. National Trails System (NTS) members designated as National Historic Trails (NHTs) and National Scenic Trails (NSTs) according to the National Trails System Act. The National Trails System Act of 1968 established the NTS and recognized the value of volunteers, private and non-profit trail groups working with Federal agencies to manage and maintain trail resources (National Park Service, 2017). NTS represents a network of resource managers comprised of inter-organizational groups that must work collaboratively to develop and maintain the national trails system. Each NST (11 members) and NHT (19 members) has a network of partners including an administrating Federal agency and a private, non-profit trail association.

In a previous study, Smith et al. (2017[1]) measured hard and soft technology constructs of GIS technologies in use by the NTS. In that study, 23 NRM networks were surveyed to evaluate a network's capacity to implement geospatial technologies for network stakeholders and document the type and level of implementation. Specifically, that study created a geospatial technology profile (hereafter, "GTP" survey) that categorized NTS networks by implementation capacity (low, medium, high) and level of user engagement (one-way retrieval of information; one-way provision of information, and two-way sharing and discussion of information). This study utilizes the GTP survey results by strategically selecting four of the NTS networks to gain a more in-depth understanding of the use of GIS for collaboration, specifically the use of web-based mapping tools. The NTS offers the opportunity to investigate multiple NRM networks that have adopted and implemented GIS technologies for collaboration purposes within their trail network.

Multiple Case Study Design

To better understand the complexity of individual and organizational factors that influence NRM networks capacity to use web-based GIS tools for collaborative activities, we

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[1] Chapter 2 of this dissertation.

used a multiple case study design (Yin, 2009) to gain a deeper exploration of network situational contexts within the NTS. We defined a network as a group of people connected through a common purpose: involvement in management activities for an individual national trail such as building, promoting and maintaining the trail. Network members included representatives of trail partner organizations such as full-time employees of the administering or managing agency (e.g., National Park Service, USDA Forest Service), staff member or volunteer with the affiliated trail association, or contracting agency working with member groups to accomplish trail management activities. Again, the NTS is comprised of 30 National Trails; 19 National Historic Trails (NHT) and 11 National Scenic Trails (NST). One NHT was excluded from our case selection pool to eliminate bias, as the lead researcher actively participates in development of geospatial databases and web-mapping applications for that trail.

Criteria to select four representative cases followed a combination of purposeful sampling strategies by case type (Patton, 2002) to identify cases that provided information-rich situations and best illustrated the concepts of implementation and technology acceptance across an inter-organizational NRM network. Case selection from GTP survey results included the following criteria (Figure 8): level of engagement (high), implementation capacity (high or low), and level of implementation (full or low). First, we selected only those cases with high engagement, which exemplifies networks that have adopted and implemented web-based GIS tools for two-way communication among network members, such as data-sharing across the network. Next, we sought to contrast high and low implementation capacity using implementation capacity index (ICI) values from the GTP survey. Lastly we sought to compare level of implementation to contrast the number of reported network users.

The GTP survey included a 79% response rate from NTS. The resulting GTP assessed implementation capacity and engagement characteristics of adopted GIS technologies. The respondents included 63% of the NST networks and 89% of NHT networks. The inventory profile categorized NTS Networks using ICI and the level of engagement deployed using GIS technologies. The GTP results (Figure 7) determined the number of cases available as candidates for case selection. From those candidates, further screening was conducted to select cases best fit for replication design of the study (Yin, 2009).

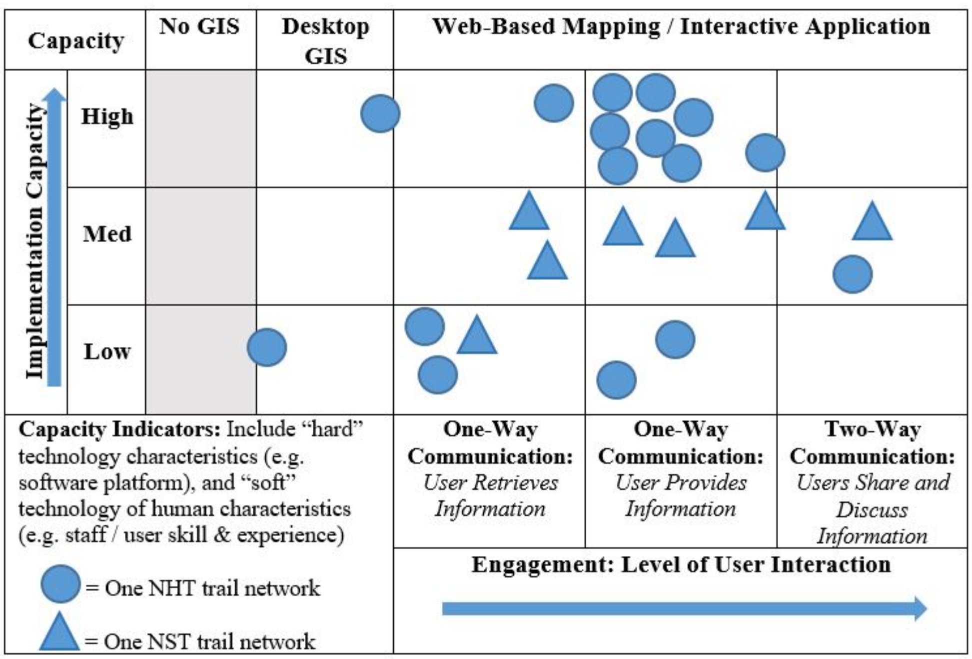

Figure 7. Geospatial Technology Profile of the U.S. National Trails System

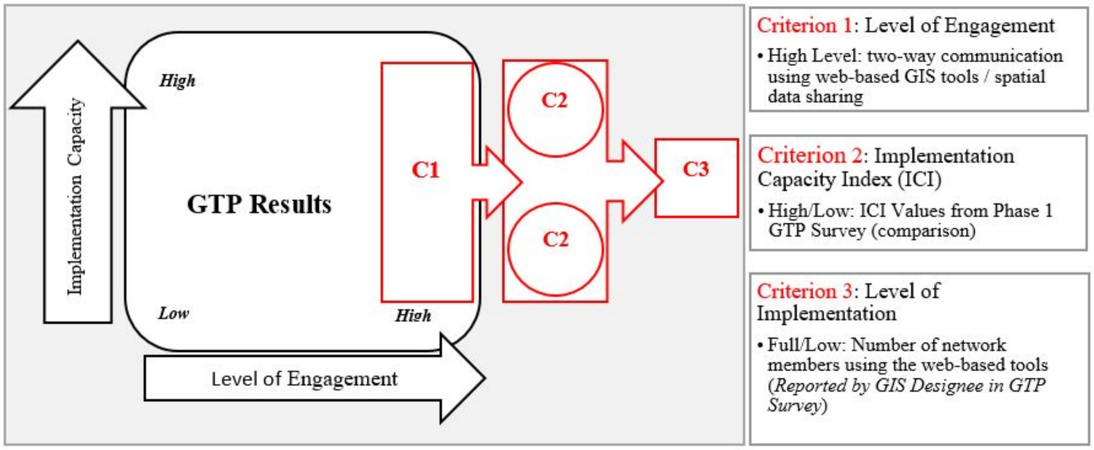

Figure 8. Case Selection Process Using Engagement Level, Implementation Capacity, and Implementation Level

To select the final four cases, we also strategically selected for trail type, as NSTs and NHTs differ in their network characteristics. NSTs manage corridors protected for scenic quality, typically own or lease property, work with partners to protect viewsheds, build and maintain publicly accessible trails within the corridor. NHTs represent a route where history occurred and most often *do not* own or lease property; rather, NHTs work with partners to protect cultural resources (e.g. archeological sites, viewsheds) and promote publicly accessible trails. Thus, the differences between the broader goals and overall management of NSTs and NHTs may lend to different network needs in access, support and utility when using GIS.

Protocols and Instrument

Upon case selection, we first contacted each case's agency NTS lead contact to seek support and participation in the study. Once this support was received, we contacted the GIS designee, as a key informant, to request participation in the study and asked that individual to provide a list of network members introduced to the web-GIS tools developed for their specific trail network. Every effort was made to include user and non-user participants in the case study interviews. Between April and June, 2016, phone interviews were scheduled and conducted for each case until no new insights emerged (i.e. theoretical saturation, see Glaser & Strauss, 2009). We conducted 14 semi-structured interviews, which ranged in duration from 10-30 minutes, with an average length of 20 minutes. The interviews were digitally audio recorded and transcribed verbatim. Detailed notes were taken during the interview and reflective memos were written after each interview to note new and confirming insights revealed.

Guiding questions for access, support and utility (design) of the tool were asked during the interview process, allowing participants to contribute data that reflected their experiences in accessing and using the tool, as well as their perceptions of tool utility and outcomes in meeting individual and network goals. These questions provided focus to capture data on the variables of interest but were broad enough to elicit additional information related to use of GIS technology, network relationships and interactions related to sharing data for collaborative activities of the trail network. Network members were asked about their perceptions of the GIS application goals, and how the tool meets both network and individual needs. The variables of interest for implementation assessment centered on guiding questions to examine technology acceptance and, under the analytical lens of group adoption, to explore organizational situational and environmental factors that may influence individual user adoption of technology (Table 10). Questions examining utility of the tool sought additional information to measure how the tool is being used in relation to intended and actual use (tasks performed).

Table 10. Case Study Guiding Questions and Variables of Interest

Variable of Interest	Conceptual Definition
Access to the Tool:	How easy is it to use the tool when needed? ▪ Opening the web tool in desktop internet browser ▪ Login / User Account requirements ▪ Viewing / Interacting with the tool interface
Support to use the Tool	Do you have help resources if experiencing problems with the tool? ▪ Type of help resources: written documentation, knowledgeable person to ask (in person, by phone, email)
Utility of the Tool (Design)	Perceptions of tasks performed when using the tool: ▪ Description of tasks performed ▪ Perceived benefit to individual and to the trail network Success of the tool in meeting objectives for trail & individual ▪ Perception of tool being used as initially intended? ▪ Perception of outcomes originally envisioned

Data Analysis

Interview transcriptions, notes and memos were imported to QSR NVivo 10, a qualitative analysis software package used to organize data. Analysis occurred concurrently with the interview process. Techniques developed for grounded theory methodology (Charmaz, 2006) were used to logically and consistently analyze data, allowing themes to emerge explaining the implementation results, or behavior, of each network. This process allowed for inductive analysis through examination and analysis of data within each case study and across cases.

Starting with a framework of technology acceptance examining access, support and utility, we identified emerging themes and evaluated factors influencing capacity and implementation of web-based GIS tools designed to accomplish network tasks. More specifically, the answers for each guiding question were consolidated under each interview guide question heading, and the results sorted and categorized into first order concepts using common themes within the three key evaluative concepts of the tool: access, support, and utility. This initial analysis produced second order themes displayed as an outcomes matrix for visual display of the factors of influence. Outcomes were developed using NVivo analysis tools to explore common word frequency results, code themes, and compare with memo notations documented during the interview. These data were further compared by type of respondent (network role) and network capacity for implementation. The matrix provided a method for pattern matching (Yin, 2009) within each case (network). Then, we examined for relationships related to implementation level and compared across all areas of analysis, seeking rival explanations (Yin, 2009) within individual cases and through our cross comparison of networks. Cross case comparison allowed deeper evaluation by comparing level of implementation, implementation capacity and trail type (Figure 9).

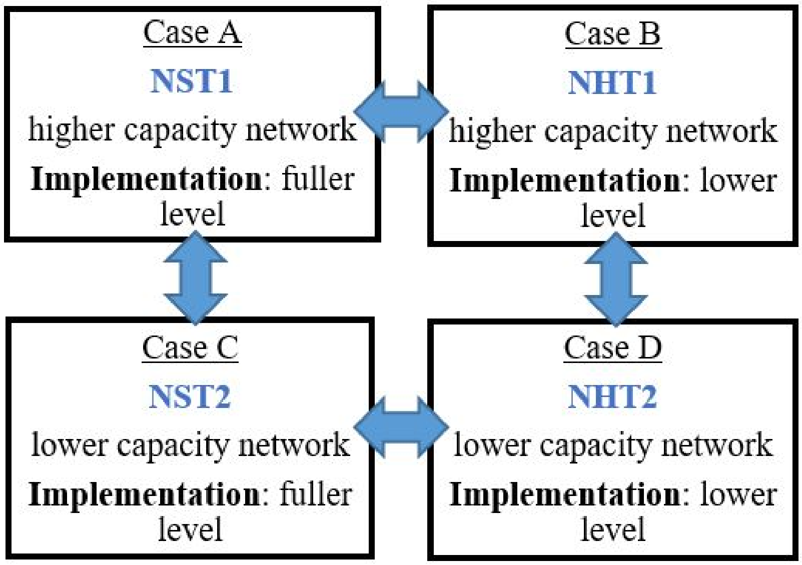

Figure 9. Cross Case Comparisons by Capacity

Data Management and Presentation

We conducted member-checks through feedback with network members and GIS Designee. Specifically, we shared the results with the interviewee to further validate the data collected (i.e., member checking; see Patton, 2002). Each set of responses from an individual were assigned a code to categorize interview responses by: trail network, respondent role (e.g. GIS, staff, volunteer), organization category (agency, volunteer association), and case context (capacity and implementation). Data gathered by phone during the GTP survey process were used to cross check results for each network as a means of internal validity, including the responses from the GIS designee (i.e. an agency staff member with lead responsibilities for Trail network GIS) about the purpose of the GIS application in use within each of our cases.

Case findings are supported by quotes from informants who are assigned a number appended the Case Name (e.g., Case A) and informant role (i.e., A, S, V, and O for agency, association, volunteer, and other network member, respectively). Participants are referred to as network members based on their role with the organization category assigned. Informants are affiliated with the lead agency (e.g. National Park Service or US Forest Service employees), a trail association affiliated with a specific case, or in another network member role such as volunteer.

Results

Case results are shown in Table 3, denoting implementation capacity, level of implementation and a summary of network members interviewed when gathering data. The results of the GTP survey revealed only two networks implementing high level engagement web-based GIS tools (trails NST1, NHT2). Two additional trails, with medium level of engagement, were selected as case studies since the networks were using GIS technology as an engagement method to communicate and share information (data) among network members for trail management activities (trails NST2, NHT1). Trail NST2 was testing use of web-based applications for collaboration between network members. Trail NHT1 was using web-GIS to engage with network members, but had not fully implemented two-way communication processes. Results of the GTP study indicated that organizational constraints limited implementation of web-based, two-way engagement tools for the latter two networks, even though the capacity and desire to produce web tools at that level was present. The final number of interviewees listed in Table 11 include the GIS designee for all four cases, plus the agency lead for Case A.

Table 11. Implementation Assessment Case Data Input

		Case A: NST1	**Case B: NHT1**	**Case C: NST2**	**Case D: NHT2**
Implementation Capacity		High	High	Lower	Lower
Level of Implementation		Full	Lower	Full	Lower
Interviewee Role	**Interviewee Code**				
GIS Designee	A or S	1	1	1	1
Agency Staff	A	1	1	1	1
Association Staff	S	4	1	2	
Volunteer	V		1		1
Contractor*	O				1
Other Network Member	O				1

** Contractor: Developer / Maintainer of GIS Tool for NHT2*

The summary descriptions of each of the four cases are provided in Table 12. The networks have commonalities in that all represent a partnership of stakeholders including a lead Federal agency and a non-profit association. Management differs across the four networks, and is indicated in the summary based on the lead GIS staff: agency, association, or contractor. The time-period since each network adopted collaborative, web-based tools differed across the four networks as well, and is denoted in the post-adoptive time period category. The two NST networks were earlier in the process of establishing collaborative GIS technology tools than the two NHT networks.

Table 12. Case Summary of Trail Network Characteristics & Post-Adoptive Time Period

Case ID:	**Case A: NST1**	**Case B: NHT1**	**Case C: NST2**	**Case D: NHT2**
Category				
National Trail Type	Scenic	Historic	Scenic	Historic
GIS Management Lead	Association	Agency	Agency	Agency with Contractor
Agency Staff	≤ 5	≥ 10	≥ 10	≤ 5
Association Staff	≥ 10	≤ 5	≥ 10	≤ 5
Post-Adoption Time Period	1 – 2 Years	> 3 Years	1 – 2 Years	> 3 Years
GIS Use, Design & Deployment Summary	▪ Association staff leads trail support activities and are primary web-GIS users. ▪ Primary tasks are data entry, validation, communication and information sharing.	▪ GIS technology in place many years by the agency including data sharing with partners (non-web). ▪ Association network members primarily contribute information (data) related to historic locations along the trail route.	▪ Association & agency have geomatics expertise on staff. ▪ Desktop GIS in use for many years to share data and information between the agency & association network members.	▪ Agency is GIS lead, coordinating with Contractor to manage web-GIS tool. ▪ Contractor works closely with the Agency Lead and GIS Designee, and is developer and primary maintainer of the trail network GIS system. ▪ System was designed from the start with a goal to provide access across the organizational barriers present with other trail networks.

Initial interview analysis produced common themes, which are displayed as an outcomes matrix for visual display and pattern matching of the factors of influence in Table 13. *Access*, *support* and *utility* were the three constructs used to build the GTP survey, and frame the case study interview questions. Outcomes are presented by categorical area, with emerging themes from each category illustrated by case. The results are displayed based on the frequency mentioned by interviewees to enhance both case, and cross-case comparisons.

Table 13. Outcomes Matrix by Case and Technology Construct

Factors Influencing Capacity & Implementation		Case A: NST1	Case B: NHT1	Case C: NST2	Case D: NHT2
Access	*Barriers to use*				
Individual	technology / knowledge				
Organizational	policy				
	procedures (role based access)				
	cost				
Support	*Efficient & Effective use*				
Resources in Place	online				
	video tutorial				
	document - *tool specific*				
	colleague - *in person, phone or email*				
Training / Resources Needs	task specific				
	trail (network) specific				
	face to face				
Utility	*Types & Focus of tasks described*				
Operational	inventory				
	reports				
	data validation				
Communication	visualization				
	communication - in general				
Collaboration	collaboration				
	communication - across great distance				
	problem solve				
	research				
	share data				
	planning				

Pattern Key

	no mention
	at least one mention
	several sources mentioned
	concept repeated multiple times by multiple sources

Access

Case results reveal barriers described to *access*, or use, the GIS tool emerged at the individual user level or the organizational level. Individuals described knowledge about how to effectively use the tool as a barrier and others described hard technology limitations, such as computer hardware or software that prevented use of the tool. Some users described barriers to efficient interaction using the tool as desired. Individual barriers described were related to the user's comfort level using GIS, or a specific application feature. One respondent stated, "I don't use it as much as I should, mostly because I don't understand it fully…" (Case A-S2). Another described hard technology access barriers due to changing computer capabilities. "My machine couldn't keep up with the evolving applications that are out there, that are requiring more memory, more graphics…" (Case C-S2). As illustrated by Case C (Table 5), technology barriers such as hardware limitations, can impede display and overall usability of a web application.

Organizational policy difference, a soft technology, presented a barrier to access for Cases A, B and C. Case D respondents did not report the same type of policy barriers. While both agency and association staff are tasked with trail operations and need to use and contribute to the same data, policy hampers the ability to do so. One association GIS staff member described the arrangement as "the data is hosted on a Park Service server out in Denver, and being a Partner, I don't necessarily have any type of access to that server and neither do a lot of folks working for the [association] here" (Case C-S1). This represents emerging theme of a network member's role when describing access limitations. Access barriers were either accessing the tool at all, or described as limited functionality access. For example, when seeing the *Advanced Toolbar* on the interface, one computer savvy user noticed, “there are probably more features to that if you have an account, and are authorized to log in” (Case B-S1). Specifically, the application disables permission to use it without authorized login. He recognized the availability of additional tools, but noted they were only available to users with a specific access role or permissions. An agency staff member described the process with this scenario,

> “Typically the maps are sent to me by our GIS staff and they have the particular layers that they want me to look at…Those layers are already turned on, so I don’t really have to do much with them except occasionally check a couple of boxes” (Case C-A1).

This informant acknowledged the utility in GIS to enhance her workflow in other areas but because her role is to provide one finite piece in the puzzle, she is not given access to or training of the tool in additional ways.

Case D network members described few to no barriers, stating that the website was very easy to access and use. This network’s web GIS system was designed with a goal to provide access across the organizational barriers identified by other trail networks. The system is hosted on a non-agency server, deployed without the same licensing requirements. The basic site is freely open to public access, contribution to the spatial database may be made by a registered user, regardless of affiliation. The ease of use may be related to the post-adoptive time period, greater than three years, or that users reported a sufficient level of support to use the tool.

Case C was the only network reporting cost as a barrier, as reported by an association member. The association is currently using the agency's organizational license to access the web-mapping application. This shared license has slowed access to all members needing to use this technology. The association is working to purchase their own organizational license to reduce this barrier to access, but face a new barrier of cost. Until that happens, the license to use software, or ability to log onto agency servers is restricted to agency personnel.

Support

Case results for support reveal that network users may be able to overcome barriers to access the tool through user support mechanisms. As network members describe limits to efficient use of the tool, they compared support in place to support needs. Support in place ranged from online help resources, to video tutorials to a colleague in the same office or a phone call away. All Cases described online and video resources, most often described as general help documentation provided by the software vendor rather than for the network specific application. Support needs were most often described as tool specific training to enhance an individual's capability interacting with the technology.

Case D described available support resources very positively, with no one listing a need for additional support. All members of that network stated the web application was intuitive to use and included built-in instructional resources embedded in the interface if needed. When questioned about ease of access and support, an agency network member said, "For me it seems pretty intuitive. Every once in a while, if I haven't dove into it recently and I'm trying to figure something out, I might have to go and refresh my memory. But they have it pretty well set up to where you can figure it out and have the instructions" (Case D-A1).

Case A participants explained that they have been using the tool long enough that they see the utility and potential but do not know how to move forward without additional training. These network members recognize limitations in capacity to provide one on one training, but are still eager to learn and enhance their capacity to complete the work. One user reported, "…I think trainings would help me use it more.", and considering the goal to extend use of the tool throughout the network he added "we have that tool and if we're not utilizing it as much as possible, that's kind of not being as good a steward as we are with this tool" (Case A-S2). Users recognized that more efficient workflows were possible.

Some support situations demonstrate user tendency to ask a colleague rather than use written or video tutorials. One agency staff member who work in close proximity to staff members with GIS expertise explained that she simply asks for personal assistance when needed. Although this member viewed this support favorably, she finds that she does not explore the tool on her own, "it's very convenient, but it doesn't allow me to learn anything new." Recognizing this limitation to enhance learning, she continued that, "getting official training would be wonderful" (Case C-A1). She noted that the additional training desired is beyond her currently assigned role using GIS technology.

Association staff interviewed described role-based training needs as well. Two network members interviewed were tech-savvy and exhibited a self-reliant perspective related to their own use of GIS applications. Their observations about training needs were focused on transfer of knowledge in support of technology adoption by trail volunteers characterized by a wide range of technology skills. Volunteers, conducting operation tasks, computer experience was described as a range from "tech savvy, just out of college, looking to give some time back to the trail, to folks that don't even have a computer in their home" (Case C-S2). The ability for the network to provide tools that are designed to be intuitive and, as such, require minimal instruction was viewed as paramount to successful implementation and positive network outcomes.

Networks may address ease of use through design of initial implementation based on the target audience. However, the network cannot overlook the dynamic nature of technology and continuing need for support. The Case B GIS designee described many support mechanisms, including a demonstration video, developed to promote the web tool and show users how to interact with the tool. This was reaffirmed through interviews with network members and the Agency Lead. Few training needs were described as the network members interviewed had been using the tool for some time and had a comfort level with the interface. Several Case B informants described a background that made them self-reliant in using computer technology. For example, when asked about ease in using the tool a user stated "I just figure it out." On further probing, he confirmed his level of comfort with technology saying he taught computer science. At the same time, one long time agency user recognized the need for updated support for new users and for the public,

> "I've been using it since we created it. Our constituency, not so much. There's all levels of computer capabilities out there and I do think…we need some training available to the general public. I think it would be very beneficial for some people" (Case B-A2).

This desire was echoed by the GIS Designee as the software and web system in use has undergone technological updates, making the existing training materials out of date.

Utility

The utility of a tool focuses on tasks performed. First order concepts under utility fell into three emerging themes based on the type and focus of tasks described by the respondents: *network operation* tasks, *communication* tasks, and *collaboration* tasks. Network members across all Cases frequently described tasks related to visualization, data validation and planning. Those tasks emerged as primary utility of the web based tools. An overview of the three sub-categories further demonstrates how network members utilize the technology for network related outcomes (Table 14).

Table 14. Emerging Themes for Utility of web-GIS Tools

First Order Concepts	Emerging Themes	Case Summary
▪ Inventory ▪ Reports ▪ Data validation	Operational	Tasks included inventory, information for reports and data validation of trail resources. ▪ Cases A and C described higher level of inventory and report tasks than Cases B and D. ▪ All cases described high level of use for data validation tasks.
▪ Visualization ▪ General communication & discussion	Communication	Tasks described by respondents as permitting either: ▪ Visualization to communicate ideas, or as a ▪ General method to communicate information about the trail. All cases described high level of using web GIS tools for visualization, with ▪ Cases A and C reporting slightly higher number of tasks for general communication purposes.
▪ Collaboration ▪ Communication across great distance ▪ Problem solve ▪ Research ▪ Share data ▪ Planning	Collaboration	Tasks ranged from problem solving to data sharing to enhancing the capabilities of communication across great distances. ▪ All Cases described specific instances of using the tool for collaboration with stakeholders, with Case D reporting a slightly higher number. ▪ All Cases described Communicating by using the web tool, with Cases A and C reporting it slightly more consistently. ▪ Problem solving tasks described by all cases, with Case B respondents reporting it more often. ▪ All Cases described data sharing and planning tasks, with Cases A and C reporting data sharing more frequent. ▪ Research tasks were described often by Cases B and D, yet were not mentioned by Cases A and C.

Operational tasks. Respondents described utility of the web tool and use of GIS in general, for completion of operational tasks for the network. For Case A, a primary goal for development of a collaborative GIS tool was to validate information of physical trail locations, trail structures (e.g. water bars) and proposed routes across seven states. Prior to implementing this tool, the centralized GIS system hampered the ability to confirm validity of field data, or was missing data altogether. Headquarters staff, typically the GIS Designee, were geomatics experts trained in the use of GIS. Field staff represent domain experts for trail operations and one association member remarked on the utility the web GIS tool offers,

> "Since we've been using the program we've been able to update so many more miles than we would have been just because it took down that barrier between our staff and our chapters and our staff and the headquarters staff." This network has over 30 chapters of "volunteers … actively building trails, moving the trail, you know, making changes" (Case A-S3).

The Case C association member described similar efficiency improvements for procedures to document trail conditions, conduct inventory assessment and report results on a regular basis to the lead agency. As an example, the association's staff described the previous process to record field data in GIS, "We're having the volunteers fill that out on a paper form and that information is then given to someone in an office and they enter it" (Case C-S1). The shift from paper to higher level of engagement enables volunteers with an innovative method for digital data entry. Comparison to previous methods was described frequently as users without geomatics expertise expressed efficiency and accuracy improvements, "...you know there were a few other of us that had desktop ArcGIS, but it was just that if you weren't trained in it, it was such a struggle" (Case A-S1).

Communication. Efficiencies also describe communication tasks for visualization performed by network members. Utility of the tool for the Case B network centered on planning and resource protection, as cultural resources are primary features to document and communicate. Agency personnel tasks include analyzing proposed action that may impact the trail corridor, such as "oil-gas leases in [Wyoming] or road reconstruction in [Nebraska]." Case B participants explained that the ability to visualize locations from a desktop, when it is not efficient to travel great distances, make the tool an invaluable resource. For example, web-based GIS tools offer a spatial decision support system mechanism to investigate "actions that could potentially affect the visitor experience on the trail…" (Case B-A2). Evaluation using visualization techniques in those situations permits the user to use their desktop computer and web browser to "just look up and see where, what the distance is from the proposed action to the trail corridor" (Case B-A2).

Association network members for both NHT cases described data validation and visualization tasks related to researching historic locations and activities within the trail corridor. Communication between agency and external researchers has been amplified with implementation of the web-based tool. One researcher expressed his experience using this application to view areas of the historic corridor to understand context of other researcher's work. "I liked it because I could see the trail portrayed on you know, uh...topographic maps or on satellite photo maps or whatever. So I liked that feature, and then I liked zooming down and looking at where it went in places where I *didn't* do the research" (Case B-V1).

Improved efficiencies for communication combined with broader access to visualization create opportunities for collaboration.

Collaboration. Research emerged as theme with Case D as well. GIS provides a mechanism to confirm research studies, historic evidence and this web-based tool offers a new way to engage in research discussions. The participatory process provided through web GIS is “enabling citizen historians to contribute to and stay abreast of what was the latest information on the trail” (Case D-O2). This researcher described that this innovative method "seems to allow for the competing theories to both hold some space while that conversation is going on.” A trail volunteer, also a historian, excitedly described the fast, global reach of such conversations with other researchers, "I was here at three o’clock in the afternoon and he was in Madrid [Spain] at midnight. And we were talking!” (Case D-V1).

Case D members were using a GIS tool in place for over three years where Case A members were in the first year of using PGIS technology. For Case A, innovative methods to enhance communication across great distances was described in awe of the technology advancements and real time impacts, “I am on the phone with [GIS designee] and we’re both looking at the map at the same time and he’s making changes kind of on the fly and I can see what he is doing. Which is just amazing!” (Case A-S2). The two individuals were in offices described to be hundreds of miles, and a time zone, apart.

Operational, communication and collaborative tasks concepts overlap. All three themes emerged, with collaboration, being understood as the original goal when the tool was designed. Visualization was described as a communicative task, but Case D participants explained that visualization and planning go hand-in-hand with collaboration efforts for the trail network. Trail partners are able to share data, communicate historic events and visualize recreational assets for the trail corridor. One agency network member stated that the power in a tool like this was to be able to collaborate interactively with community partners. He stated, "it was a great opportunity to connect them to [web mapping application] and for us to have a conference call and [virtually] walk through the area that we're talking about" so they can visualize the area (Case D-A1).

Success in using innovative tools that offer utility can influence users to navigate barriers to access. For example, network members described experiencing the utility and seeing ways to expand use with acquisition of new equipment. One network member expounded on a new method to communicate trail resources to the public stating, "We're still in the, 'let me show you on this paper map where it is.' I think in the future we're going to have to get to the point where we have some kind of device where they can visit our table and we can show them on the device" [Case A-S2]. This evidence demonstrates the potential of the tool when communicating with outside constituents. Additional interview data supporting themes (proof quotes) related to *access*, *support* and *utility* can be found in Appendix B.

Cross Case Comparisons

Furthering explanation of themes that emerged from each case, comparison between cases were conducted to look for similarities and differences in capacity to adopt and implement web GIS tools. Cross case comparison examined differences based on high versus low capacity networks and fuller versus lower implementation level.

Implementation differences among high capacity networks: Case A and Case B. Both Cases are higher capacity networks with Case A exhibiting a fuller level of implementation. The lower level implementation network, Case B, described higher support for use of the tool. These responses were validated by the GTP survey, with Case B capacity index very high due to the amount and type support provided to potential users. Case A described a need for additional training focused on routine tasks and geared towards the network needs and goals, as opposed to generic training materials provided. Informants described tasks related to utility for tool use, for example one informant indicated, “I would like to be able to learn how to accurately measure a section of the trail” [Case A-S4]. Case A reported a high number of tasks related to operational activities for the trail, including inventory, planning and data sharing. Case B reported tasks more frequently associated with planning, assessment or research. Fuller implementation appears more evident when frequent operational management tasks are primary GIS needs of the network users, as with Case A.

Implementation differences among lower capacity networks: Case C and Case D. Both Cases are lower capacity networks. Case D network members described few to no barriers to access the tool, yet Case C exhibits a fuller level of implementation. Support themes emerging from interviews related to roles or task-specific help, with Case D respondents describing tools as intuitive. Case C network members described tasks associated to operational activities. Case D users reported a range of tasks including (but not limited to) data validation, collaboration, planning and research. Between lower capacity networks, fuller implementation appears more evident with the network using the tool for routinely occurring tasks.

Capacity differences among full level Implementation networks: Case A and Case C. Barriers are the primary differences between these two cases. Case C interviewees described heavy reliance on the need to communicate and interact with association members in their network. Organizational policy presented barriers to access of the servers and software licensing by non-agency personnel. Non-agency network members have responsibilities in operations and trail management but cannot use the most efficient tools available. “That’s really our biggest hurdle to overcome. A lot of the volunteers are interested in using this new technology, but we haven’t been able to share it with them” [Case C-S2]. The association plays a major role for both of these networks, but the network with GIS management led by the association, Case A, has lowered the access barrier by implementing the system outside the agency server and licensing. One informant lauded access, “it’s a piece of cake” [Case A-S2]. Even with barriers in place for Case C, both networks exhibit fuller implementation. Regardless of capacity, both networks describe high levels of use, with predominant tasks described as utilitarian. Tasks spanned the themes of operations, communication and collaboration.

Capacity differences among lower level Implementation networks: Case B and Case D. Both Cases present lower levels of implementation based on the number of network users reported on the GTP survey. The ICI values for these two networks differed with Case B reporting one of the highest implementation capacity values on the GTP. The GIS Designee for Case B is a dedicated GIS specialist position, compared to a non-GIS role for the Designee with Case D. The other main difference between GIS technology for these two

NHTs is that Case D contracts development of web-based tools and server maintenance for GIS activities to an outside entity.

The question arises as to why the high capacity network, Case B, is only able to implement low level participation in using web-based collaborative GIS tools compared to a network with lower capacity. Both are NHTs, but Case D has GIS activities and tool development led by a contracted source and designed specifically for collaboration and engagement with network partners. The web GIS tool was “meant to be facilitator for that two-way discussion” [Case D-O2].

Differences between Scenic and Historic Trails. Cross case comparison revealed differences between scenic and historic trail use of web-GIS tools among network members. Cases A and C, scenic trails, more often described using the tools for tasks related to daily operations. Tasks associated with inventory and reporting were a routine operation for the network, whether or not they were using GIS. The ability to perform those type tasks with the GIS tools were described as becoming routinized, “…I can actually start getting my field staff to do some editing for themselves” [Case C-S2]. Cases B and D, historic trails, described a high level of data validation tasks, but those were not identified as a daily operation. Differences may be due to the post-adoption time period between the cases. Web-GIS tools for Cases B and D have been in place over three years, allowing time for routinization to occur, but also time for new types of tasks to emerge for users. Case D informants described that validation tasks took place during initial launch of the web tool, and now the predominant use was associated with collaboration. The tool has “been very helpful…not just document, but also start talking about you know uh..even just opening a dialog about the trail” [Case D-A1].

Discussion

This study examined four NRM network cases using web-GIS tools as a participatory process to engage and communicate across the network. We applied theories of technology acceptance, adoption and diffusion of innovation to understand factors that influenced the network’s capacity to use innovative technology, and to understand implementation level across the network. Information technology studies produced models that predict use (Brown, et al., 2010), measure success (Eldrandaly, et al., 2015), and recommend a user-centered design. The social context of technological systems demand broad input, and Poore (2011) indicated that a range of users contribute to the cyberinfrastructure development process of design to increase the chance of success. Prediction focused models do not provide answers to understand why particular users do, or do not, use the technology. Our individual case results showed that factors influencing use were most often described as access barriers and utility.

Our case study descriptions related to utility of the tool indicated how the technology was used to meet network goals. However, results revealed that differences emerged based on trail type (historic vs. scenic), and the time period, post-adoption, for the network. Case A and Case C implemented the web-GIS system described within one year prior to the research study interviews, and Case B and Case D implemented the web GIS system between three and four years prior to the research study interviews. Less research has been conducted in the post-adoption phase to qualitatively assess use by exploring multiple cases across similar organizations. This study revealed that organizational barriers were more challenging due to agency policies that impeded access by network members across organizational boundaries. Similarly, Göçmen and Ventura (2010) surveyed public planning agencies and found organizational issues were the primary barrier to GIS use as a planning tool. Individual barriers could be overcome with support through training, or updates to equipment. Post-adoptive studies examining user satisfaction via surveys have suggested barriers to use and made recommendations for improvements. Olafsson et al. (2014) researched GIS-based support of recreational trail planning by local governments using factor analysis and found similar results.

Study of the post-adoptive time period to assess user perceptions can provide a valuable contribution of inter-organizational scenarios. Applying complementary theories as a means to evaluate use, and user perceptions, our findings enhance understanding of practices to best bring people to the technology voluntarily. Whether a newly introduced innovation is voluntary or mandated for use changes the situational characteristics (Tsai, Compeau, & Meister, 2016). In this case, the NRM networks voluntarily selected PGIS applications for network members by extending technology access beyond use by geomatics experts. In doing so, the results of studying these select networks show that the use of PGIS tools enabled network members to implement new methods to address network needs, improved efficiency of network related tasks, and provided innovative opportunities for collaboration across organizational boundaries and between great geographic distances.

Diffusion of innovation theory complements TAM by providing characteristics of innovation more likely to diffuse rapidly. More recent studies explored the gap between these theories by examining application of the two theories. Kiwanuka (2015) examined overlap between the two, and suggested the process of acceptance as technology progresses is not fully considered. User interaction with technology may change during the implementation process and the timeline should be considered. Amagoh (2016) applied these theories to e-government applications in Nigeria and recognized that determinants for implementation are based on factors related to the situational characteristics, environment setting, as well as the target users (e.g. public, or government staff). The NTS case studies support both research studies. The individual case results and cross case comparisons suggest differences based on GIS oversight, trail type, and post-adoptive time period. Using the lens of these two frameworks, we applied the results of the case study to make recommendations for implementation of web-GIS tools for participatory engagement among the network of managers (Table 15).

Table 15. Characteristics of Innovation Diffusion: Case Study Results and Recommendations to Enhance Implementation

Influence	Technology Construct	DOI Characteristic	Web-GIS for NRM Networks Case Study Results	Recommendations to Enhance Implementation
Capacity	Access	Trialability – *test prior to committing to use*	**Ease of access to test the system by potential network users** ▪ Identified barriers for volunteers to access technology due to organizational policy (user role), or compatible equipment or software.	▪ Run test scenarios for varied user roles. ▪ Evaluate hardware needs to use the tools effectively.
	Support	Simplicity – *ease of use or learning*	**Support structures & design** ▪ Users indicated need for GIS training for non-GIS staff (assigned role or responsibility) ▪ Users explained they learn on their own if necessary.	▪ Improve support resources. ▪ Expand training based on specific roles & responsibilities. ▪ Test with potential users to ensure intuitive design.
Implementation	Utility	Relative advantage – *over current tools*	**Comparison of task productivity** ▪ Users described increased efficiency through live geo-collaborative processes. ▪ Managers indicated task delegation to field staff to improve efficiency.	▪ Identify current tasks compatible with Web-GIS.
	Utility	Compatibility- *consistency with current practices*	**Aligns with individual's tasks & work flows** ▪ Enhances field staff ability to record field work accomplishments. ▪ Real-time collaboration with remote stakeholders.	▪ Solicit non-users to determine impediments for use.
	Utility	Observability – *gains are clear to see*	**Demonstrate advantage, and outcomes that meet individual and network needs** ▪ Comparison of enhancements to procedures in place twenty years ago. ▪ Visualize the database to improve understanding / knowledge of field conditions.	▪ Provide relevant examples of tasks when promoting or demonstrating use. ▪ Have users demonstrate to non-users. ▪ Share process and application among fellow network members, as well as to other networks.

NRM networks may become aware of their capacity by evaluating staff and resources in place to host the system. Trained GIS professionals, user access through licenses and computer hardware, and user support structures are integral to capacity and implementation of the system. Access to use the system is primary, and support to provide training and assistance for those networks members who may be less tech-savvy, or have no GIS training provides the foundation for network capacity. Most important to the level of implementation is utility of the tools provided. Do the tasks conform to everyday activities? If the capacity barriers are reduced, the users will be more likely to engage the tool and explore potential use appropriate to their needs. Establishing specific goals, or tasks, for the user to complete is needed when first implemented. As users develop a comfort level by completing routine tasks, they will seek additional information to expand use of the tool as long as it makes their job more efficient. This case study suggested that users are more likely to navigate access or support barriers if the perceived need, and usability, of the tool is high.

Implications

This study contributes new understandings to the adoption and use of geospatial technologies for NRM networks, specifically the use of web-GIS as a collaborative tool for engagement among network members. The results identified common barriers to implementation. We made recommendations to enhance network capacity, and usability of the technology, based on characteristics of network members and required tasks.

Application of results for GIS implementation suggests that user centered design must extend beyond testing in a controlled setting, and consider the range of user roles and responsibilities. For NRM organizations, the design must consider *access,* as NRM networks are frequently comprised of inter-organizational membership. That type of structure represents greater complexity where organizational boundaries, such as policy, procedures, and individual user roles can restrict an individual's ability to use the tool. In turn, those barriers affect the broader network ability to fully use the technology. For trail networks, this study demonstrated the value of engaging network members in participatory applications to communicate management issues with colleagues. The emerging themes (Table 6) document the potential to extend use of GIS from operational tasks to communicative and collaborative tasks. The inter-organizational network structure is representative of the NRM field, and the current body of literature examines that context most frequently using the lens of public participatory GIS (Jankowski, 2009; Mekonnen & Gorsevski, 2015; Sieber, 2008). While the community based approach is important, the non-public resource management side of the network should be studied. NGO use of GIS, or government use of GIS, provides a homophilous study group and neglects to explore the more common heterogeneity of collaborative management processes. Future research should extend integrated heterogeneity composition of NRM networks as presented in our study with emerging areas of geo-collaboration study to integrate geospatial and collaborative decision support models (Antunes, et al., 2014).

Methodologically, this case study exposed temporal differences during the post-adoption time period. The level of technology use by network members may be an indicator of task utility, or overall task goal. Does the task goal change over time or does the network simply does not have a need to use the tool after initial implementation goals were met? Over time a network may experience subtle changes, from tasks, to goals, to changes in network personnel. Future study of inter-organizational NRM networks should provide longitudinal results to address the temporal aspects of development, evaluation and maintenance of geospatial technologies over time. Evaluation should include long-term use of the web GIS tool, beginning with the time period immediately following implementation, to several years post implementation. Reevaluation of the tasks performed by gathering input from network members may guide modification of tools to meet current needs. GIS, people, data, and the system to interact with the data, is dynamic and requires feedback loops to monitor learning and adapt to changes.

Additionally, this study expands upon other research in participatory methods and use of GIS technologies. Connors et al. (2011) used case study research to examine a specific tool used to collect volunteered geographic information; others studied the suitability of participatory GIS tools for NRM tasks (Brown & Weber, 2013; Jankowski, 2009; Ricker, Johnson & Sieber, 2013). Those studies were typically focused on a single network, where this exploration extends beyond single case studies of PGIS to gain a greater understanding of the complexities involved in setting up such technologies across similar networks. Despite this novel methodology in the context of NRM networks using PGIS tools, the generalizability of the results of this study is limited to our case study population of 19 persons, and cannot be inferred to the lead agency or affiliated associations.

The study represents members of four similar NRM networks, identified as users of network web-GIS tools. The researcher attempted to solicit non-users in the study group. Some respondents used the tool when it was first implemented, but have reduced use over time. Future research should include strategies to gather input from network members introduced to the tool, but chose not to use it. The study population is skewed towards members who self-selected to participate in the study; however, the respondents represent a range of GIS expertise, network roles and responsibilities. In-depth interviews from multiples cases provided information-rich insight (Patton, 2002), which was supplemented by cross case synthesis (Yin, 2009) to expound on the network complexities presented.

Conclusions

Assessing capacity and implementation of web-GIS as a participatory tool for NRM networks, through constructs of *access*, *support* and *utility*, builds on theoretical understandings of technology adoption, acceptance and diffusion of innovation. The use of web-GIS offers an innovative method to communicate among network members, share information to make informed decisions, and enhance routine tasks associated with managing natural and cultural resources. This study provides a context to support NRM networks in successful use of geospatial technology. How should a network introduce the technology so that it meets network needs, and provides an environment for users to access tools to perform network tasks? The environment for adoption of geospatial tools, including the network relationships, are key to how, and if, the technology will be used. Once users are comfortable with the technology, by using it to perform everyday tasks, they will be better prepared to extend the technology for other collaborative activities.

Our study broadly explored adoption of innovative technology as a means to increase understanding and encourage use of GIS to facilitate collaborative activities among NRM networks. Networks may employ the strategies to innovate with web-GIS tools as a means to provide spatial decision support, facilitate discussion, share information with virtual teams and across organizational boundaries. The capacity to implement this type of technology is not without obstacles.

Researchers should continue to explore challenges to implementation by geographically dispersed user groups, and to understand the communication flow that GIS technology can provide. Spatial decision support provides a communication mechanism that enables resource experts spanning multiple disciplines greater utility in task performance. Researching innovative tools opens the door for adoption, and research of influencing factors provides strategies for successful implementation by NRM networks.

Results of our study indicate that NRM networks, such as those overseeing long distance or heritage trails, can benefit from web-GIS applications to not only manage resources but also enable a range of network members the ability to use spatial decision support tools. Use of this technology to communicate with colleagues, stakeholders or the general public can be accomplished successfully with strategies to assess network needs, guide and evaluate implementation processes. Continued research of inter-organizational teams implementing geospatial technologies will lead to strategies that facilitate removal of specialized silos of agency-specific information, manage data-sharing, and grow effective engagement to better accomplish resource management efforts.

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CHAPTER 4. Natural Resource Management Networks Navigating Socio-technical Structures to Engage and Innovate using web-GIS Technologies

Abstract

Web-GIS technologies offer an innovative method for those with non-geomatics expertise to access spatial decision support systems (SDSS) for natural resource management (NRM). Our research offers new insight by examining socio-technical structures (STS) across multiple cases representing inter-organizational NRM networks that have implemented web-GIS tools to engage network members. We compared network member role to elucidate differences between tasks performed by geomatics and non-geomatics members. Specifically, we explored socio-technical implications of varying roles that limit access to participatory GIS (PGIS) technologies. Where PGIS research has typically focused on engaging stakeholders outside of management decision-making, this research examined users within the NRM network by applying STS constructs of hard and soft technology to the network's community of users. Our findings indicated that user role and organizational policy limited access, revealing that network characteristics (e.g., guiding purpose, organizational structure) influenced user ability to navigate barriers. Results further suggest that PGIS tools enable non-geomatics experts, who previously experienced barriers, access to enhanced decision support processes. This research extends PGIS principles to advance access to SDSS by domain experts in the network, providing opportunity to accomplish tasks using innovative methods that visualize work and improve network communication.

Introduction

Natural resource management (NRM) networks have long deployed geographic information systems (GIS) to assist with inventory, decision-making and communication activities related to resource management. For the purposes of this study, we use the term resource management to cover both natural and cultural resources, and consider the social structure of the people contributing to NRM management processes as a network. Geospatial technologies provide a means to communicate among network members and with the public (Jankowski, 2009; Nyerges & Aquirre, 2011; Rinner, Keßler & Andrulis, 2008), serving as a spatial decision support system (SDSS) (Nyerges, Jankowski, Tuthill & Ramsey, 2006). NRM networks include *domain* experts who represent contributors of specialized knowledge (e.g. biologist, social scientist, economist, landscape architect). Shared information across areas of specialized knowledge contributes to decision support for network operations and management. As such, GIS can serve as a data delivery mechanism to share information. Implementing GIS requires geomatics experts to develop and maintain tools, processes and systems that are used by the range of domain experts (Smith, Slocumb, Smith and Matney, 2015). Differentiating between domain and geomatic levels of expertise, we define *geomatic* experts as professionals trained in the science of data collection, analysis, interpretation and delivery of geographic data.

Organizational structure, culture, and characteristics can influence the process of technology adoption, acceptance and implementation. Sieber (2000) identified challenges, such as trained staff, or funding to support the technology associated with GIS implementation by grass roots organizations. Similar barriers to accessing GIS technology exist with inter-organizational networks (Rogers, 2005). Inter-organizational structure, representative of a range of networks, introduces implementation challenges that constrains sustainable use of the technologies, such as data sharing policies, user expertise, and system management (Anderson, Beazley & Boxall, 2009; Paudyal, McDougall & Armando, 2013). Additionally, GIS implementation studies have demonstrated that access by domain experts to these SDSS tools vary—particularly at the local government scale—and that for those who have access to SDSS tools many do not have GIS expertise or confidence to use the technology effectively (Göçmen & Ventura, 2010; Olafasson & Skov-Petersen, 2014).

As technology progresses to everyday activities, the ability to drive GIS to a broader audience and improve access to domain experts offers a pathway. For example, the ubiquity of smart phones, including location-based applications, brings greater geospatial awareness to the masses (Warf & Sui, 2010). In this context, web-GIS offers an innovative method for SDSS access to enhance decision-making processes. Research has shown these tools are highly effective for NRM applications. Dragicevic (2004) discussed the potential of web-based GIS more broadly, noting the direction of GIS use and related research: spatial data access and dissemination, spatial data exploration and visualization, and spatial data analysis and modeling. Over ten years later, the technology and its use are still evolving, and research continues to explore new methods of GIS delivery. Complexities of NRM networks, due to inter-organizational structure and associated policies, combined with rapidly changing technology, can hamper the process to adopt and implement these technologies (Rogers, 2005). The balance between understanding the technology and the organizational structure introduces an approach to evaluate the process as a socio-technical system (STS) (Doherty, 2014).

The goal of this study is to identify methods to optimize STS of NRM networks to engage domain experts with access to SDSS tools using web-GIS. The research objective was to examine use of innovative web-GIS technology by NRM networks to explore STS optimization to enhance technology access across the network. We build on GIS implementation research from a participatory GIS (PGIS) perspective, using the theoretical lenses of socio-technical systems, technology acceptance and diffusion of innovation.

Literature Review

Trends in civic engagement, planning, and collaborative decision-making activities call for participatory processes that engage participants to contribute specialized information (Beierle, 2002; Lawrence & Stewart, 2011; Mandarano, Meenar & Steins, 2011). Societal preferences and the use of web-based technologies have pushed participatory planning efforts to adopt once proprietary GIS tools as a resource available to a greater number of stakeholders (Brown & Weber, 2012; Paudyal et al., 2013; Poore, 2011; Warf & Sui, 2010). Embracing such trends, NRM networks use GIS technologies with participatory approaches. PGIS is frequently associated with public participatory processes designed to engage publics in decision-making, gather input, or build capacity (Brown, 2012; Poore, 2011; Sieber, 2006). Characteristics of PGIS incorporate the idea of empowerment through visual, user-friendly applications that are adaptable and promote interactive participation (Rambaldi, Kyem, McCall, & Weiner, 2006). From a societal context, participatory methods focus on enabling groups typically excluded from decision-making processes (Brown & Donovan, 2013; Jankowski, 2009).

For this research, we viewed PGIS as a method to engage non-geomatics experts, since they are typically excluded from effective use of SDSS (Alrwais, Horan, Hilton & Bechor, 2015; Jankowski, 2009). Using the NRM network perspective, PGIS contributors come from within the network rather than the public or network outsiders. Members serve in a role contributing domain expertise to enhance management strategies. For these networks, technologies are typically managed by a geomatics expert. The question that remains is how to gain broader access to spatial decision support tools by those who may benefit from innovative technology but do not always have the expertise or comfort level to use it?

Technological innovation permits the ability to bridge gaps where face-to-face meetings are unavailable, thereby allowing collaboration among geographically dispersed network members. The interaction between a community of users, such as NRM network members, and the technology systems adopted to facilitate management tasks, such as GIS, represents socio-technical systems (STS). Socio-technical theory attempts to explain the interdependence of people and the technology they use. Social behavior of an organization influences how a technology is used, and in turn, the technology influences behavior of the social system (Doherty, 2014; Eason, 1982; Klein, 2014). In this study, we examined implementation of a technological system across four similar NRM networks by applying STS constructs as an evaluative lens. STS includes *hard technology*, *soft technology*, and the *community of users*. Soft technology factors of *access* and *support* to use the technology indicate barriers a user may experience. Hard technology factors are indicative of *utility* a tool provides. How an organization navigates structures in place when adopting a new technology can influence the success of implementation (Rogers, 2005).

We propose that using a socio-technical approach to evaluate web-GIS use by a network of users, can better guide development and implementation of systems. The inter-organizational context of NRM contributes to network characteristics and influence of the community of users to the broader system (Figure 10). The interconnected elements of the community, hard, and soft technology, represent the interdependent structure required to understand how the each influences the other. (Doherty, 2014; Klein, 2014).

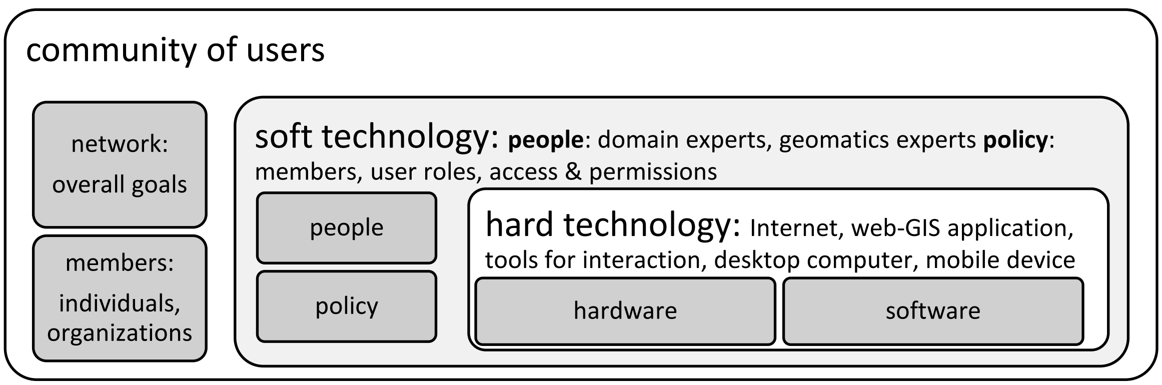

Figure 10. Socio-technical Elements of web-GIS Technology Implementation

Studies on GIS technology implementation incorporate the social aspect of the process to suggest design strategies for successful geocollaboration (Antunes, Zurita, Baloian, & Sapateiro, 2014; MacEachren, 2001; MacEachren & Brewer, 2004). This study does not evaluate the design process of technical systems, but rather examines system use during the post-adoptive time period as a way to explore the structures influencing implementation and diffusion of web-GIS tools for participatory engagement. Rogers (2005) describes five phases of innovation adoption: 1) knowledge of the innovation, 2) persuasion to make a decision on use, 3) decision to adopt or reject, 4) implementation by placing the innovation in use, and 5) confirmation to continue use or reject the innovation. Understanding this process, researchers have examined technology adoption and success using user satisfaction and implementation studies (Eldrandaly, Naguib & Hassan, 2015; Göçmen & Ventura, 2010). Within Phase 4 of Rogers' process, he describes stages of implementation over time: redefining, clarifying, routinization, and discontinued. These do not necessarily all take place, but the estimation of the stage can indicate the use by an individual or group with the innovation (Rogers, 2005). For example, evaluation may include determining if the innovation has been redefined from its original intent when initially adopted, has been discontinued, or is a routinized part of daily operations (Rogers, 2005; Singhal & Dearing, 2006).

The study of GIS as a tool for collaborative decision-making and spatial decision support has provided a broad range of evaluative outcomes related to the socio-technical structures in place within either government agencies or non-governmental organization applications with external stakeholders (Alrwais et al., 2015; Göcmen & Ventura, 2010; Karikari et al., 2005; Paudyal et al., 2013; Sieber, 2006). For example, Paudyal et al. (2013) examined GIS strategies across NRM communities in Australia, with the results indicating constraints that influence data sharing between government agencies and NRM communities. Karikari, Stillwell and Carver (2005) researched implementation of GIS technology in a developing country, Ghana, to understand appropriate applications of GIS for governmental land sector needs, with the political, social and institutional contexts playing key roles in recommending implementation strategies.

In this paper, we seek to extend previous research by providing in-depth study focused on the inter-organizational structure present in NRM. Specifically, we explore socio-technical implications of varying user roles that may limit access to PGIS technologies. The research we present provides new insight by examining socio-technical structures across multiple cases representing inter-organizational NRM networks including both government and NGO members. Additionally, we compare the role of network members by domain expertise classification to elucidate differences between tasks performed by geomatics and non-geomatics members. Rather than focus on outside stakeholders, we compare the role of users with specific reference to geomatics experts and domain experts to assess the potential of web-GIS as a PGIS method to engage non-geomatics experts in processes that support use of spatial decision support systems.

Methods

This research employed a sequential mixed-methods, explanatory research design (Creswell, 2014) to identify socio-technical structures influencing implementation and diffusion of innovative geospatial technologies. We used techniques derived from grounded theory methodology (Charmaz, 2006) to logically and consistently analyze data, allowing for substantive theory to emerge explaining the implementation results (i.e., behavior) of each network. In phase 1, Smith (2017[2]) administered a GIS technology adoption survey of the US

[2] Chapter 2 of this dissertation

National Trails System (NTS) to produce a geospatial technology profile of 23 trail networks. Phase 2 employed a multiple-case, case study approach to identify the factors that affect capacity to implement participatory web-mapping tools for collaboration among trail partners. A network was defined as a group of people connected through a common purpose: involvement in management activities (e.g. build, promote, maintain) for an individual national trail. Network members included non-governmental organization (NGO) staff, volunteers, contractors and full-time employees of the administering agency (e.g. National Park Service, USDA National Forest Service).

This study, as part of Phase 2, used purposefully selected trail networks that have implemented web-based GIS collaboration tools, and examined socio-technical factors influencing the use of web GIS tools by members of NRM networks. Specifically, our grounded theory approach enabled us to identify emerging themes and evaluate factors related to *access*, *support*, and *utility* of web GIS tools implemented by the network. The grounded theory process also allowed for inductive analysis techniques by examining and analyzing data from specific examples of each case study as well as conducting cross case comparisons. Criteria to select four representative cases followed a combination of purposeful sampling strategies by case type (McMillian & Schumacher, 1997) to gather information through in-depth interviews (Patton, 2002), and provided information-rich intelligence across networks about GIS technology access and use. This research approach was followed with cross case synthesis (Yin, 2009) to examine network complexities.

The lead researcher for this study brings twenty years of geospatial information science and technology experience as a researcher and educator, and holds Geographic

Information Systems Professional (GISP) certification. Her work with one NTS network to develop their initial GIS infrastructure, design a public facing web mapping application, and research data sharing strategies for the network led to active participation with the National Trails System GIS Network discussion group. Her expertise in the field and familiarity with experiences and needs of the study group informed case study guiding questions, conceptual definitions of study criterion, as well as opened communication channels to conduct the study.

Sampling

The NTS inventory profile (Smith, 2017[3]) classified 23 of 29 trails based on technology implementation capacity and level of engagement deployed using web GIS. The results determined the number of cases available as candidates for case selection in this study. From those candidates, further screening allowed selection of cases best fit for replication design of the study (Yin, 2009). Criteria to select four representative cases followed a combination of purposeful sampling strategies by case type (Patton, 2002) to identify cases that (a) provided information rich situations and (b) best illustrated the concepts of access to and use of web-GIS by inter-organizational NRM network members. We selected four cases using the criteria which included: 1) use of high-level engagement web-GIS; 2) trail type (NST or NHT); 3) management lead for GIS operations; and 4) the post-adoptive time period that the tool has been in use (Table 16).

[3] Chapter 2 of this dissertation

Table 16. Case Study Selection Criterion and Rationale

Criterion	Classification Description	Rationale
1. High level engagement web GIS	Implementation of tools that permit participatory use and two-way communication	Indicative of Participatory GIS
2. Trail type	National Scenic (NST) or National Historic (NHT) trail network	Network type presents differences in network tasks and member roles.
3. GIS operations lead	Agency or non-agency partner	Organization type presents differences in policy, organizational structure.
4. Post-Adoptive Time Period	Early: 1 – 2 Years since implementation Later: 3+ Years since implementation	Stage of implementation estimation: redefining, clarifying, routinization, discontinued (Rogers, 2005).

Case selection based on network characteristics allows comparison using socio-technical structures of hard technology, soft technology and the community of users. NST networks were compared to NHT networks, and with one another. The trail types have varying needs associated with access, support and utility of GIS tools as characterized by network similarities and differences. Specifically, NSTs manage corridors of public lands protected for scenic quality, work with partners to protect viewsheds, and build and maintain publically accessible trails within the corridor, while NHTs represent a route where history occurred and not necessarily land ownership. As such, land ownership or lease is infrequent by lead federal agencies within NHT networks; rather NHT networks collaborate with outside partners to protect cultural resources such as archeological sites and viewsheds and publically accessible segments of trails are may be owned by a local government within the trail corridor.

Data Generation

The variables of interest for implementation assessment of web GIS tools centered on guiding questions (Table 17) to examine socio-technical systems structure. Questions about access and support permitted exploration of soft technology influences (e.g., organizational, situational, and environmental factors or barriers) that may influence an individual's adoption of technology. Questions examining utility of the tool solicited description of tasks performed, and sought additional information to measure hard technology influences on level of adoption.

Table 17. Case Study Guiding Questions and Variables of Interest

	Variable of Interest	**Conceptual Definition**
Soft Technology	Access to the Tool:	How easy is it to use the tool when needed? ▪ Opening the web tool in desktop internet browser ▪ Login / User Account requirements ▪ Viewing / Interacting with the tool interface
Soft Technology	Support to use the Tool	Do you have help resources if experiencing problems with the tool? ▪ Type of help resources: written documentation, knowledgeable person to ask (in person, by phone, email)

Table 17 (continued)

Hard Technology	Utility of the Tool (Design)	Perceptions of tasks performed when using the tool: ▪ Description of tasks performed ▪ Perceived benefit to individual and to the trail network Success of the tool in meeting objectives for trail & individual ▪ Perception of tool being used as initially intended? ▪ Perception of outcomes originally envisioned

The GIS designee, as a key informant, was contacted to request participation in the case study. As lead for network GIS operations, the GIS designee previously provided data in response to a geospatial technology profile survey (Smith, 2017[4]), including responses about web-GIS tools, support resources, and network member participation (e.g. number of potential users and actual users). The GIS designees were asked to provide a list of network members introduced to the web-GIS tools in use by their trail network. Every effort was made to include user and non-user participants in the case study interviews. Between April and June, 2016, semi-structured phone interviews were scheduled by email and phone contact, then were conducted for each case until no new knowledge emerged (data saturation; see Glaser & Strauss, 2009). Interviews, averaging 20 minutes in length, were audio recorded and transcribed verbatim. Detailed notes were taken during the interview and entered directly into Qualtrics survey software using text fields aligned with the interview guide. Additional notes were taken at the end of each interview to capture emerging and confirming themes.

[4] Chapter 2 of this dissertation

Both sets of notes served as additional forms of data. We also included data gathered during the geospatial technology profile survey (Chapter 2) to cross check results for each network as a means of internal validity (i.e., data triangulation, Creswell, 2014).

Interview transcriptions were imported to QSR NVivo 10, a qualitative analysis software package used to organize data. Analysis occurred concurrently with the interview process. After each interview, the digital audio recordings were transcribed verbatim, and reviewed with the notes taken during and immediately after each interview. The results were shared with the interviewee to further validate the data collected as a form of member checking (Patton, 2002). Each set of informant responses were assigned a code to categorize interview responses by: trail network, participant role category, and case context (trail type and GIS lead). Participant position and roles were categorized into one of four types, based on position duties and expertise: Planning (PL), Research (RE), Operations (OP) or Geomatics (GS). Case findings are supported by quotes from informants who are assigned a number appended the Case Name (e.g. Case A) and informant role (e.g. Case A-OP1). Readers are cautioned not to infer generalizability to the lead Agency or affiliated Associations, as only 19 persons participated in the study interviews.

Analysis

Using NVivo, the answers were consolidated by interview guiding question heading. The results were sorted and categorized into first order concepts using the three key evaluative concepts of the tool: *access*, *support*, and *utility*. For each case, a theoretical review of findings evaluated tasks performed based on individual user role and responsibilities. This initial analysis produced second order themes displayed as an outcomes matrix for visual display of user roles, skills, and methods to accomplish network tasks. Outcomes were developed using NVivo analysis tools to explore common word frequency results and coding themes, and then compared with memos drafted that outlined each case context. These data were further compared based on opportunities to engage network members or innovate network tasks. The matrix provided a method for pattern matching within each case (Yin, 2009), which was first examined for relationships related to roles, use, and barriers encountered within cases and then compared across cases. Rival explanations (Yin, 2009) were sought throughout review of interview findings and document analysis (e.g. trail annual reports) within individual cases and through cross comparison of networks. Cross case comparison (Figure 11) allowed deeper evaluation by comparing trail type, GIS operations lead, and time period of post-adoptive use.

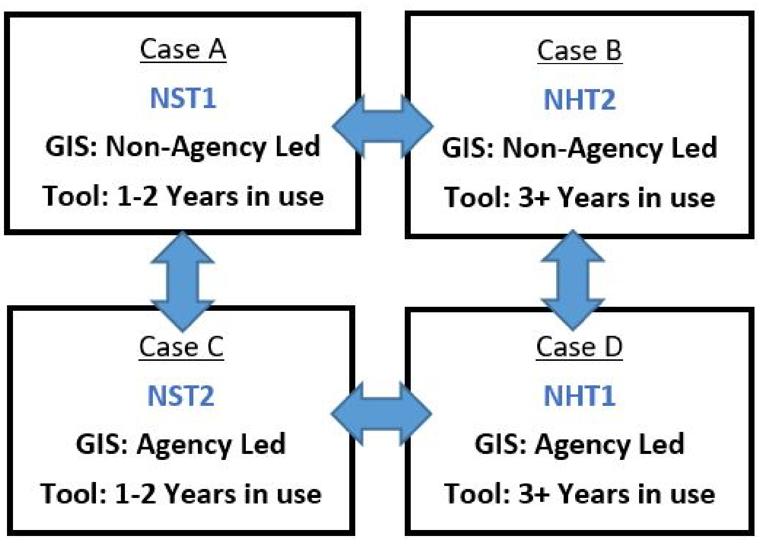

Figure 11. Cross Case Comparisons by GIS Lead

The results were consolidated to elicit themes, which we present as a composite across all cases to illustrate the overall results. The composite provides a way to present the emerging themes from this study, describing how network members represent different levels of knowledge and comfort using GIS technologies, contribute expertise to meet network goals, and face a range of challenges and opportunities based on network characteristics. Composite textual descriptions are a technique to present the "essence" of a phenomenon in which a research provides a summary that "focuses on the common experiences of the participants" (Creswell, 2013, p. 82).

Results and Discussion

Case descriptions are provided in Table 18, denoting trail type, GIS operations lead for the network (GIS designee), years since adoption of the web GIS tool, and roles of case informants for each network. The final number of interviewees (19) listed in Table 18 include 14 network members, the GIS designee for all four cases, plus an agency representative for Case A.

Table 18. Web GIS Access and Use Case Data Input

	Case A: NST1	**Case B: NHT2**	**Case C: NST2**	**Case D: NHT1**
Trail Type	Scenic	Historic	Scenic	Historic
GIS Lead	Non-Agency	Non-Agency	Agency	Agency
Interviewee Position				
GIS Designee	1	1	1	1
Agency Staff	1	1	1	1
Association Staff	4		2	1
Volunteer		1		1
Contractor*		1		
Other Network Member		1		

** Contractor: Developer / Maintainer of GIS Tool for Case B*

Across the four networks selected, commonalities and differences among the networks included the type of trail, GIS operations management lead, and post-adoptive time period the web-GIS tool has been in use. Each participant described their role, associated responsibilities, and how they engaged using the web-GIS tool to accomplish network tasks. A summary of network member roles and responsibilities are listed in Table 19. Roles were assigned one of four classifications to aggregate the responses by domain expertise and to protect anonymity.

Table 19. Network member role, domain expertise, responsibilities and tasks accomplished with web-GIS

Role	**Domain Expertise Classification**	**Network Tasks**	**Web-GIS Use**
GIS Specialist	Geomatics	Coordinate GIS Activities for the network.	Develop, maintain, and update data and web GIS tools for network members.
Field Manager	Operations	Coordinate volunteers, build trails, generate reports.	Plan based on locational data, document activities.
Facilities & Operations	Operations	Maintain infrastructure, budget, reporting with other software systems (e.g. Facility Management Software System).	Calculate results; prepare maps for integration with other software systems used to formulate budgets, produce reports.
Volunteer	Operations	Build or maintain trail infrastructure, validate locations via ground-truth protocols.	Document fieldwork.
Planner	Planning	Determine trail routes, meet and collaborate with communities.	Evaluate trail routes, share results with community stakeholders.

Table 19 (continued)

Development / Marketing	Planning	Communicate to the public.	Communicate with interactive visualizations (e.g thematic maps, scale changes, alternating background imagery). Embed map in website(s) for public consumption.
Researcher	Research	Validate locations, explore historic records in preparation of research documents.	Compare temporal map data, propose new (location-based) theory about historic events.

A summary of trail network characteristics and interviewee roles by case (Table 20) include GTP level of implementation, full time staffing levels, post-adoption time period, and if the agency or association has dedicated full time geomatics staff. Interviewee role classifications are listed by case with the number of network members interviewed for each domain area.

Table 20. Case Summary: Network Characteristics and Interviewee Roles

	Case A	**Case B**	**Case C**	**Case D**
Trail Type	NST	NHT	NST	NHT
GIS Lead	Non-Agency	Non-Agency	Agency	Agency
Characteristic				
Post Adoption Time Period > 3 Years		x		x
Fuller Implementation Level (GTP Survey)	x		x	
Agency Staff > 5			x	x
Association Staff > 5	x		x	
Dedicated Geomatics Trained Network Staff	x	*	x	x
Interviewee Roles Represented *(count)*				
Planner	1	2	0	1
Trail / Field Operations	4	0	3	1
Researcher	0	2	0	1
Geomatics	1	1*	1	1

* *Case B Geomatics expertise represented by an outside contracted agency.*

The two networks with fuller implementation level are NST networks, and have a larger association staff. Cross-case comparisons, presented later, elucidate differences between network tasks and the use of web-GIS between the network types. Other task differences may be explained by the interviewee roles represented by the study group. From the case results, NST networks included more staff in operations roles, and only the NHT networks included researcher roles.

The following composite scenario represents the varied roles of NRM network members, challenges and opportunities when using web-GIS tools for their network. Comparison and contrast of tasks, barriers and network influence, defined by the user role within the network, exposes how web-GIS tools provide an innovative method to engage domain experts for these NRM networks.

> Imagine you are a part of a natural resource management network that supports a public trail that stretches two thousand miles through eight states. Your role as a non-profit association member in the network, is to manage volunteers as they build or maintain trail infrastructure. In fact, you are considered the NTS expert for engaging and organizing volunteer work crews. You must coordinate activities to make the most efficient use of volunteer resources to accomplish network goals. You have a list of tasks from the trail's managing agency that you partner with to manage the valued public resource. Maintenance is paramount to provide a quality user experience that includes a safe hiking route that protects both the hiker and the natural resources within the trail corridor. You coordinate efforts to keep the trail in optimal condition with assistance from 35 Trail Clubs.
>
> You use Google maps to approximate locations of trailheads and related trail resources to communicate needs. One of your trail volunteers has learned to use a terrain navigator software they purchased with personal funds, to be able to visualize the gradients of the trail surface the work crew will use to carry shovels, construction materials in by hand. You have requested a map of the area from the lead GIS staff for the trail network. You will use that paper map to mark locations where work has been completed, make notes in the margins about volunteer hours spent and indicate future work needs.

> A colleague, working on a section of trail several hundred miles away, has a method to use a tablet with an electronic PDF copy of the map to make her notes. She can share that electronic version with an agency operations specialist to enter the data into the facility management system. That information feeds into a process for documenting budget expenses for the current year and funding requests for approaching new fiscal year.
> You understand the value of GIS technologies and know those systems could streamline the tasks you perform and reduce the amount of paperwork that duplicates efforts to record network tasks. However, your training is minimal and you do not feel confident learning how to use such a tool on your own. Your GIS colleague with the trail association has created an interface for data entry, but the ability to mobilize the technology for field work is limited due to cost. The managing agency has the capacity to use mobile variations, but as a non-federal trail staff member, you do not have permission to access those online maps. If you could take your expertise to the next level through a system like other trail networks have implemented, it could revolutionize the work you do for the trail.

The composite represents the collection of stories told by participants, and illustrates innovation in action by describing processes in place since implementation of web-GIS tools, or recognition of potential the technology offers for accomplishing network tasks. To investigate each case, emerging themes began with the study framework using *access*, *support* and *utility* constructs from the guiding questions. Based on role of the network member, themes became clear around the idea of comparison. Comparison of user roles, comparison of user skills, and comparison of previous methods were common threads based on interviewee descriptions. When making these comparisons, interviewees revealed associated barriers, challenges and opportunities to engage and/or innovate. The coding process, theme development and outcomes are listed in Table 21 with supporting quotes categorized by the network participant’s role.

Table 21. Emerging Themes Supporting Opportunities to Engage and Innovate

First Order Concepts	Emerging Themes	Supporting Quotes by Network Role	Case / Cross-Case Opportunities to Engage, Innovate
Access	**Comparing User Role** ▪ Connecting to GIS data and systems ▪ Desktop GIS: not available, or inexperienced user	**Geomatics** "…current configuration…is that the data is hosted on a Park Service server out in Denver. And being a Partner, I don't necessarily have any type of access to that server and neither do a lot of folks working for the [Association] here" [Case C-GS1]. **Operations** "volunteers are interested in using this new technology, but we haven't been able to share it with them" [Case C-OP1]. "there are probably more features to that if you have an account, and are authorized to log in, than I have" [Case D-OP2]. **Planning** "you know there were a few other of us that had desktop ArcGIS, but it was just that if you weren't trained in it, it was such a struggle" [Case A-PL1]. "That was actually the first opportunity I had to work with the community group. For them to get a chance to actually use the tool and upload photos and notations and correct alignments and things like that" [Case B-PL1]. **Research** "enabling citizen historians to contribute to and stay abreast of what was the latest information on the trail" [Case B-RE2].	**Barriers Experienced** ▪ **Policies in place** - Alternatives for access ▪ **Hardware / Software Limitations** - Access to compatible resources, devices

Table 21 (continued)

Support	**Comparing User Skill** ▪ Current training resources ▪ Expressed needs	**Geomatics** "getting my field staff to do some editing for themselves" [Case C-GS1]. **Operations** "I don't use it as much as I should, mostly because I don't understand it fully and I think trainings would help me use it more" [Case A-OP1]. "…principally use ArcGIS for modeling and that kind of thing. The… online GIS …we use daily, more for public interaction. I personally don't do hard core GIS. I have [staff] who [are GIS Specialists], our geographer...you know they work inside GIS" Case D-OP1]. **Planning** "logging in to ArcGIS desktop was just overwhelming for those of us that weren't schooled in it" [Case A-PL1]. "we're still in the, "let me show you on this paper map where it is". I think in the future we're going to have to get to the point where we have some kind of device where they can visit our table and we can show them on the device" [Case A-PL1]. **Research** "I make it a point that whatever tool that I use...I train myself and learn it to where I am capable of achieving the best results with the tool" [Case B-RE1]. "…the way it is right now it's easy to access. The one that the park service has needs more of an explanation on what colors mean. You know, trails are portrayed in different colors. I figured that out having the experienced the research, but the average user will come that and they won't know what those colors mean" [Case D-RE1].	**Overcoming Obstacles with Support Mechanisms** ▪ **Support resources and needs** - I could do more if… - Now I can do this easily. ▪ **Recognizing potential** - Yes, I can use this technology.

Table 21 (continued)

Utility	**Comparing Task Methods** ▪ Routine network tasks ▪ New opportunities	**Geomatics** "..having it stored in one place. Before it was just a few shapefiles on the server in an NPS office somewhere. Other people didn't have access to viewing it" [Case B-GS1]. "Usually we would send out yearly or quarterly updates of our data. If we had new protected lands that we put in, or facilities or if something changed. We'd send out an email with an attachment and all the desktop files, you know, the shapefiles or some other spatial format, similar to kml files and put that out there" [Case C-GS1]. **Operations** "he is sitting at the halfway point and he can't really understand the local geography everywhere. If you have the ability to work real time together with people, it's almost like you can be there. Which is just amazing" [Case A-OP1]. "Our people that don't really understand forms, but can understand maps, can put a point down and say they did a certain amount of work... on a map and send that to us" [Case C-OP2]. "I'm indirectly collaborating with several researchers now. …making the trail research more accessible" [Case D-OP2].	**Embracing Technology** ▪ **Accomplishing tasks efficiently** - This used to take hours, lots of paper. - This used to depend on geomatics experts. ▪ **Innovation** - We never had this opportunity before.

Table 21 (continued)

Utility		**Planning** “Since we’ve been using the program we’ve been able to update so many more miles than we would have been just because it took down that barrier between our staff and our chapters and our staff and the headquarters staff” [Case A-PL1]. “[Our trail] doesn’t tend to be, in my experience, one of those trails that has a lot of name recognition usually. ...when you start talking about it the first question people have is, ‘well where is it and what are you talking about?’ So it opens a whole conversation about the historic corridor…So, this [tool] provides a visual for all of that. This provides a way for people to connect the dots” [Case B-PL1]. **Research** “to me one of the things you have a concern about when you are at a University is that the projects you work on don’t fully percolate out into the domain where actual public users would be benefiting from that information. So to me it was a great thing to see that the [web-GIS tool] was in place and the project that we were doing would feed right into that…as opposed to be a stand-alone thing and a report that goes on a shelf” [Case B-RE2].	

The emerging themes of comparison demonstrate the impact of web-GIS tools to current network operations. Some users described differences between past and present methods, while other descriptions revealed the potential of the web-GIS tool to further enhance capabilities to accomplish work tasks or meet network goals. Limitations to using the tool are categorized as barriers. Users described potential of innovative methods once barriers to access or support are successfully navigated. Some participants even noted they may not be aware of the potential.

> We're incredibly happy with the things we have been able to accomplish with it. But there is that strong feeling that it can do a lot more that we're not doing just because we don't know it can do certain things [*laughter*]. And you know that is where the training comes into play, trying to figure out what are we missing. [Case A-PL1]

In the following sections, we present the process innovation in action, compared across four similar Cases from a socio-technical perspective to demonstrate the value of participatory web-GIS to NRM networks. We discuss the outcomes using the framework of *hard technology, soft technology,* and the *community of users.*

Hard Technology and Innovation: "What Was" to "What Is"

Network tasks are facilitated through hard technology options, where hard technology represents hardware and software. Current methods to conduct work may include desktop GIS, web-GIS, mobile GIS, paper or digital forms and even other software packages that are used to accomplish network tasks. Research of local government networks implementing GIS recognized that understanding the environment (systems and users) of the organization (Alrwais et al., 2015) is a necessary component of evaluation and design. Whether examining broad system goals, or focused on specific needs to integrate field data collection using mobile devices (Tsou, 2013), the related hardware needs must be considered. NTS Case study participants expressed comparisons of methods to complete routine tasks, identified new opportunities realized, and felt enabled to use GIS (see Table 1, Utility section). Overall, the excitement of innovation when comparing to previous methods had users considering greater potential. One operations staff member described the "*what was*" to "*what is*" paradigm in this way:

> You know, 20 years ago people didn't even have good enough paper maps to be able to look at that. Now you can almost see real time, which is just amazing! I think with the migration of everything to smart phones, to be able to have that powerful data in your hands while you are out there...is phenomenal. It's just a different era, and it's pretty exciting! [Case A-OP1]

At the same time, the powerful data he described, combined with access to applications demand powerful hardware. The NTS study illustrated that equipment was needed to overcome access barriers. Operations staff reported that "My machine couldn't keep up with the evolving applications that are out there, that are requiring more memory, more graphics" [Case C-OP1], and GIS staff acknowledged other hard technology limitations for field staff, "some of our folks that don't have a mobile device that can support the App" [Case C-GS1]. Hard technology needs are as dynamic as GIS. MacEachren and Brewer (2004) described the need for systems to support geocollaborative activities, and Sun and Li (2016) present research on real time collaborative infrastructure needs. The changing environment invites change in specific technology, and research will continue to address changes to hard technology to meet the needs of the user.

Soft Technology Barriers: Recognizing "What Could Be"

Hard technology brings the innovation to the user and can present hardware or software barriers. Eason (1982) presented a paper on the process of introducing information technology, where key concepts included planning for the organizational ramifications of implementation. Since that time, research shows that the greatest barriers are presented in the soft technology arena (Eldrandaly, et al., 2015; Nedović-Budić & Godschalk, 1996; Pinto & Onsrud, 1995). Soft technology barriers may represent people (support mechanisms) or policy (access constraints) and for these cases were reportedly overcome, or still limiting use. This may include an individual's skill level or comfort using GIS technologies, or may be limitations placed on an individual through organizational policy.

Case study participants described a range of barriers to use the web-GIS tool based on their role within the network affected by policy, or on individual skill. In the scenario, a mix of technologies to facilitate the mapping needs of an individual's work are described that may offer greater efficiencies to accomplish work tasks (see Table 1, Access and Support section). The option selected may indicate presence of, or success in navigating, soft technology barriers. Policy may limit level of access for an individual, as described for Case D, "there are probably more features to that if you have an account, and are authorized to log in, than I have" [Case D-OP2]. Organizational policy can have a broader impact as described by Case C participants, "Volunteers, who are really a partner to the park, working with the [Trail, need to] have access to that application, but right now they don't. …It's our biggest hurdle to overcome" [Case C-OP1]. In addition, users recognize "what could be" with additional training (see Table 6, Support Section). An operations staff member noted that "I don't use it as much as I should, mostly because I don't understand it fully and I think trainings would help me use it more" [Case A-OP1]. Supporting similar research results (Anderson et al., 2009; Göçmen and Ventura, 2010), these type of access barriers—in particular, when the individual sees the value in using the technology—highlight the innovative potential of web-GIS as a tool to enhance collaboration within a network.

NRM Networks and the Reach of a Community "Working Together"

The composite scenario illustrated how these NRM networks cross both organizational and jurisdictional boundaries, often across great geographic distance, to accomplish tasks. Each network is a community of users focused on a common goal. The broader community of users is represented by the all trail networks within the NTS. NTS networks communicate and share information, ideas and processes to enhance the work they do. For example, one operations staff member described the NTS as a "community where we are working together, on different trails but we learn from each other and we get together and share stories and share tools" [Case A-OP1]. In doing so, the participants compared methods to accomplish tasks before and after implementation of the web-GIS tool, and described barriers faced, navigated or abandoned.

In situations where collaboration has proved successful, research has shown these relationships were comprised of network ties among stakeholders that helped facilitate the process. For example, Prager (2010) examined multi-stakeholder partnerships and collaboration in NRM and the challenge of bridging interagency or government levels.

Technology adoption research incorporates both individual and group characteristics and Brown, Dennis and Venkatesh's (2010) evaluation of collaborative technology indicated greater success when users were familiar with each other. The community of users represented by a singular trail network positively influences success factors due to a guiding purpose for the network, even though separate organizations comprise the network. Where inter-organizational structure may present barriers to access technology across organizational boundaries, the ability of users to navigate such barriers may be positively influenced by the common network goals. This study's cross case comparisons revealed trail type (associated tasks), post-adoptive time period (implementation phase), and lead GIS organization (organizational policy) may prompt NRM members to navigate barriers whether they be access or support.

Trail Type & Associated Tasks

The *utility* based questions focused on network tasks and elicited positive responses from all participants within four cases. Many participants noted comparison to previous methods to accomplish similar tasks in meeting network goals more efficiently. Others compared utility as an innovative method of accomplishing tasks. Contrast between NST and NHT trail types emerged in cross case comparisons. Specifically, NST trails (Cases A and C) more often referred to daily operational tasks when describing utility of the tool. A NST association staff member described the routinized network activity that the association must perform and report to NPS, "So we're counting all the steps and waterbars, and other trail structures like that. We're having the volunteers fill that out on a paper form …to enter it into this map" [Case C- GS1]. He further explained how the volunteers will soon be able to make their own edits directly into the map when the access barrier is removed. NHT participants described periodic tasks rather than routine operations.

Post-Adoptive Time Period

In the vein of task differences based on trail type, other differences fell along the lines of post-adoptive time period. The two NHT web-GIS tools have been in place longer than the two NST network tools. As described above, the NST networks (Cases A and C) indicated daily operational tasks as the primary use for the tools. Alternatively, an operations staff member with a NHT explained that he used to web tool periodically, such as receiving a call from the public about a potential trail impact.

> You know, I'll get a call from someone with a concern, …we'll have a proposed action that potentially will impact the trail, whether it's oil-gas leases in [State A] or road reconstruction in [State B]. Whatever, folks want to take action that could potentially affect the visitor experience on the trail. I frequently just look up and see where, what the distance is from the proposed action to the trail corridor. [CaseD-OP1]

Another consideration is that tasks change over time. A NHT planner with Case B explained how the tool was used when it was first implemented, "when it was developed I think it was developed with a mind towards inventory. Just document what's there, what we have on the ground" Also, he then described a transition in use, "I think where it's starting to be developed and where I think some of the real power can be in working with communities is as a planning tool" [Case B-PL1].

Organizational Policy

Inter-organizational networks introduce barriers based on access policies. This may emerge for individuals based on role, or influence a broader group of users based on agency affiliation. For example, an association member described challenges for data access using this scenario, "…current configuration…is that the data is hosted on a Park Service server out in Denver. And being a partner, I don't necessarily have any type of access to that server and neither do a lot of folks working for the [Association] here" [Case C-GS1].

Cross case comparison revealed differences between Case A and Case C, where the association led network (Case A), described minimal organizational barriers to access the tool. Between these two cases, barriers differed depending on the employer of the lead GIS staff member. Case C participants represented both agency and association network members. Each of these groups described barriers to access the tool due to role. "Volunteers, who are really a partner to the park, working with the [Trail, need to] have access to that application, but right now they don't" [Case C-OP1]. In contrast, the association led network (Case A), described minimal organizational barriers to access the tool since their system was established outside the agency infrastructure, and available to association network members. Case A and Case C networks include a high number of association staff engaged with network operations that utilize geospatial technology. Case B and Case D, the NHT networks, do not maintain a similar relationship between agency and association members. The shared responsibility for network operations appears to bring the community of users closer together, leveraging the ability to navigate barriers.

Implications

Hard and soft technology considers the human and the technological aspects of a system. When applied to a network of people and system operations, this study demonstrates the need to investigate the community associated with the system. Assessing needs leads the design of GIS infrastructure, which serve as a precursor to web-GIS and PGIS tool design (Smith et al., 2015). Individuals represent an organization with goals focused on network level tasks. We applied a socio-technical approach to the select cases from the US National Trails System and integrated supporting literature to make recommendations for implementing web-GIS tools for participatory engagement within NRM networks (Table 22). Selection of hardware and software, and design of tasks require understanding of the users, specifically their role in the organization. A network user's role dictates access based on policy, and tasks based on network responsibilities. The organization influences the ability to engage across organizational boundaries, most often due to policy. Integrating the community across boundaries serves as a positive influence to successful implementation. More specifically, the community of users hold the system together through the network's mission, policy, leadership, and support to meet network goals.

Table 22. Recommendations to Implement Web-GIS Tools

Recommendations	**Literature & Case Study Support**
Hard Technology – *hardware and software* ▪ Evaluate needs for access: desktop, mobile, fieldwork, internet connection. ▪ Test utility of user tasks. ▪ Assess benefit – intended and unintended outcomes.	**Literature**: ▪ Alrwais, Horan, Hilton & Bechor (2015) ▪ Tsou (2004) **Case Study**: ▪ Case C: Fieldwork, Mobile device needs ▪ Case B: Research benefit by researcher & historian

Table 22 (continued)

Soft Technology – *people and policy* ▪ Evaluate design based on user roles, user skill, organizational policy. ▪ Develop range of support options. ▪ Document organizational access to develop, implement and support complex technology. How to best leverage available resources.	**Literature**: ▪ Karikari, Stillwell & Carver (2005) ▪ Nedovic-Budic & Godschalk (1996) ▪ Olafasson & Skov-Petersen (2014) ▪ Sieber (2006) **Case Study**: ▪ Case A: skill, support ▪ Case C: access to tool ▪ Case D: integrating support options (e.g. video tutorial)
Community of Users – *network of individual, organizational members* ▪ Define network goals for the tool, member collaboration, data / information sharing. ▪ Evaluate over time to address changing needs.	**Literature**: ▪ Eldrandy, Naguib & Hassan (2015) ▪ MacEachren & Brewer, 2004 ▪ Paudyal, McDougall & Apan (2013) **Case Study**: ▪ Case A, C: sharing information ▪ Case B: goals for tool, collaboration ▪ Case D: change instructional documentation

NRM networks will continue to use GIS technologies to manage assets. Yet, the ways in which they approach use of spatial information can influence the network as a whole. Applying STS theory, we were able to explore the benefit of a community of users as part of the structure. By focusing on network level tasks and benefits, user roles, user skill and network tasks, NRM networks may improve design for implementation. This multiple case study of the US National Trails System shows that use of participatory web-GIS tools among the network can enable non-geomatics experts more efficient access to resources that enhance decision support processes.

Limitations and Future Research Needs

Generalizability of the results to NRM networks is limited, as our study was limited to four networks and 19 participants, all of whom represent members identified as users of network web-GIS tools. Additionally, our population were network members who self-selected to participate in the study; however, the participants represent a range of network roles, responsibilities, and GIS expertise. As such the in-depth interviews of four similar NRM networks provided information-rich insight (Patton, 2002) from multiples cases, which was supplemented by cross case synthesis (Yin, 2009) to expound on the community of users. Thus, our results highlight some commonalities among NTS networks, as well as differences based on type of trail, suggesting some level of transferability within the NTS system. Long distance trails, and corridor parks managed through inter-organizational arrangements may exhibit similar results.

As some participants indicated they used the tool when it was first implemented but have since reduced use, future research should include strategies to gather input from network members that stopped using the tool after a period of time, as well as those introduced to the tool, but did not to use it. Additionally, future research should strive to include non-users in the sample to better understand barriers among network members who either do not have access or have since stopped using their network's web-GIS collaborative tools. Spatial information tools such as PGIS offer a new system to measure information flow. Characteristics of the network environment, such as information flow among members, current use patterns of technology, support and resources from organizational levels, provide insight into the network's capacity to successfully implement innovative solutions. Research on stakeholder management in NRM has provided much information about building social capital, participatory decision-making, how teams work together, and whether the activity was deemed successful or unsuccessful (Bodin & Crona, 2009; Bodin, Crona & Ernston, 2006; Hirschi, 2010; Prell, Hubacek, Quinn & Reed, 2008). Furthering the study of NRM team decision-making processes in the context of spatial decision support tools can inform how a network deploys technology using efficient and effective strategies in protection of natural resources.

Similarly, the study of communication patterns between PGIS users and non-users may be enriched using social network analysis (SNA) methods. This approach can develop from diffusion of innovation concepts to reveal opportunities to increase participant engagement using SDSS. SNA requires a larger sample size to build on results presented in this study, but the community of users connected through inter-organizational NRM networks offer prime systems to expand knowledge of web-GIS as a collaborative communication mechanism.

Conclusions

Participatory GIS should bridge the gap between GIS experts and domain experts to enable non-GIS professionals the opportunity to engage spatial decision support systems in performance of network tasks. Studies have shown GIS use by most agencies remain at a base level of use, such as inventory, monitoring, and visual presentation. For example, the types of tasks used by planners have not evolved to higher end use such as analytical modeling scenarios (Olafasson & Skov-Petersen, 2014; Alrwais et al. 2015). At the same time, the barrier to expand beyond the basic GIS tasks is comfort by users to adopt the technology and use it to supplement decision support. Web-GIS offers new opportunities for access, such as fieldwork through mobile devices (Tsou, 2004). This study confirmed a similar level of use through new opportunities (e.g. field data collection) by NRM network members. Web-GIS platforms do not easily offer a deeper level capabilities, nor should they for the targeted domain experts of a typical NRM network. However, access to even simple GIS tasks can open the door to new opportunities in a participatory process. PGIS is meant to bring people to the table; yet in doing so, we must consider not only traditional view of PGIS for the general public to engage, but also engage domain experts in charge of resource protection, decision-making, and communication with the public.

Inter-organizational NRM networks add complexity to the process of collaboration. As a collaborative communication tool, geospatial technology further complicates interaction among network members and is influenced by design of the GIS tools (Eldrandaly et al., 2015; Jankowski, 2009). The cases presented in our study exemplify these two complexities. For some situations organizational policy of one member group served as an access barrier to other member groups. In other situations, organizational roles were reflected in technology design that limited available capabilities to individual users. However, the results also demonstrated that navigating barriers is possible, especially when the technology offers utility that serves the entire network. In these cases, access to spatial decision support technologies through web-GIS provides domain experts the opportunity to accomplish network tasks using innovative methods to visualize and communicate their work across the network. Researchers should extend study of GIS technology access based on inter-organizational composition of NRM networks, to understand how social structures between member roles may influence navigation of barriers.

Practitioners may apply the results of this research to expand use of SDSS through collaboration among the “community of users.” The role of the geomatics expert remains that of using geospatial technologies to conduct complex analyses and visualizations. Specifically, geomatic staff serve as the leader for data development, data sharing, and design of web-GIS tools in concert with domain experts. The community as a whole facilitates communication across the network to meet network goals. Web-GIS provides an approach to extend use of geospatial technology to network members previously without access, thereby offering spatial decision support opportunities for natural resource management. When deploying web-GIS technologies for collaboration, the ability to optimize socio-technical structures permit network members to engage and innovate.

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CHAPTER 5. General Conclusion

The goal of this dissertation was to investigate capacity and implementation of geospatial technologies for natural resource management (NRM) networks. Geospatial technology is a well-established mechanism to facilitate natural and cultural resource management activities (Sarker & Valacich, 2010; Sun & Li, 2016; Wright, Duncan & Lach, 2009). Further, as a spatial decision support system (SDSS), geographic information systems (GIS) offer capabilities for a network of users to engage collaboratively. Adopting the technology is usually not in question, but complexities arise in the implementation process to successfully deploy and use the technology (Paudyal, McDougall & Apan, 2013). Capacity incorporates both soft and hard technologies to support and use the system. Soft technologies are related to the interactions of people, policies or organizational dynamics. Hard technologies, on the other hand, are those typically considered in the discussion of technology, such as hardware and software infrastructure (Mayer & Davidson, 2000; Rogers, 2005; Tushman, Anderson & O'Reilly, 1997). Capacity is measured by these characteristics, including expertise to manage the system, hardware and software to host applications, financial and training resources to support NRM network users as well as the overall utility of the system for users (Eldrandaly, Naguib, & Hassan, 2015). It is this socio-technical nature of deploying a GIS system that necessitates a network have technological capacity for successful outcomes. Disregarding the capacity of a NRM network to implement participatory web-based mapping tools can lead to inappropriate design of systems that are costly to develop and maintain, or may not be used appropriately in meeting network goals.

Research presented in this dissertation examined inter-organizational networks comprised of geographically dispersed members. This network structure echoes the collaborative nature of NRM with partnerships that may be prevalent when managing complex resources. Understanding technology implementation by networks requires an assemblage of building blocks laying the foundation for the socio-technical structures involved. This research analyzes three components, 1) adopted technology and network users, 2) use of implemented technology, and 3) strategies to optimize socio-technical structures.

The population of study, the U.S. National Trails System (NTS), was established by the 1968 National Trails Systems Act, which recognized the value of volunteers, private and non-profit trail groups working with federal agencies to manage and maintain trail resources (National Park Service, 2016). In this study, the set of 30 NTS network members designated as National Historic Trails (NHTs) and National Scenic Trails (NSTs) were selected, as these trail systems span long distances, multiple political jurisdictions, and public and private lands. The 30 NTS members are comprised of 19 NHTs and 11 NSTs and the federally mandated inter-organizational structure represents a network of groups that must work collaboratively to develop and maintain the national trails system. Each NST and NHT includes an administrating federal agency and a private, non-profit trail association.

Synthesis of findings

Viewed in concert, the results of each study contributed to understanding diffusion of innovation for resource management, social structures of NRM networks engaging through technology adoption, and the effect of web-GIS to extend collaborative interaction. Additionally, the findings contribute to the current literature by exploring NRM network use of geospatial technologies through a multi-level examination of implementation and diffusion processes across a series of similar networks. The first level provided a method to assess implementation capacity and compared the level of engagement using GIS technology. In-depth exploration through case studies presented a greater depth of understanding by identifying factors that influence capacity and implementation while elucidating strategies to navigate those challenges. The results showed that higher implementation capacity is not indicative of higher levels of GIS engagement for users. Informed by theories of technology acceptance, diffusion of innovation, and socio-technical systems, I made recommendations for evaluative processes to assist networks with developing strategies to balance system implementation based on user ability and map capabilities. The results demonstrated the value of geospatial needs assessment, documented the need for strategies to enhance soft technology structures, and provided categorization of GIS utility to identify appropriate tasks and platforms to serve a network's needs.

At the initial level of investigation, Chapter 2 explored network capacity to implement GIS technologies for the network based on hard and soft technologies. Results produced a spectrum of capacity and engagement (SoCE) to visualize the range of network's capacity to implement GIS compared with actual implementation based on level of engagement. A snapshot of GIS use by similar NRM networks showed that capacity for high level of implementation was in place for most networks; however, few networks implemented systems that resulted in a high-level of user engagement. GIS can serve as a pathway for innovative collaboration and communication methods for these geographically dispersed networks. High-level engagement that offer two-way communication to share data, communicate ideas, and collaboratively address resource management needs provides a valuable asset in dispersed management scenarios, such as the National Trails System.

Chapter 3 explored factors that influence the capacity and implementation of high-level engagement using web-GIS tools implemented by NRM networks through examination of 1) network member access to use the technology, 2) availability of support resources, and 3) utility of the tool to accomplish individual and network tasks. Findings revealed that access and support factors influenced capacity, where utility influenced implementation. This study contributed to research of GIS implementation by specifically examining high-level engagement for communication among NRM network members. The inter-organizational structures within these NRM networks present challenges to share data, technological resources, and even personnel across organizational boundaries. Organizational policy proved the greatest barrier to technology access; however, networks were more likely motivated to navigate barriers if tool utility was high. When resource managers have awareness that policy barriers impede access to, and therefore diffusion of technology, the recommendations from this study afford strategies to assess, evaluate and then mitigate impediments.

As demonstrated in the Chapter 3 study, the inter-organizational composition of NRM networks posed barriers to access. The in-depth case study revealed factors influencing implementation, but also exposed differences in technology access and use based on an individual network member's role in the organization. The findings indicated that participatory GIS, through web-based interfaces, enabled domain expert's access to SDSS, and enhanced ability to engage in collaborative network activities. Chapter 4 uncovered strategies to guide decision processes for delivery of technical systems through optimization of socio-technical structure of the network community of users. Recommendations centered on the community of users through strategies in three primary areas: hardware and software, people and policy, and the network of individuals with different organizational membership. Recommendations were supported by both case study results and interdisciplinary research from geographic information science, computer information systems, environment and natural resource policy, and organizational administration research. The study adds to socio-technical systems literature by approaching the community of users from a participatory GIS perspective to demonstrate enhanced access to SDSS by non-geomatics experts.

Implications

This research fosters NRM network integration of collaborative, web-based geospatial technologies by recommending guidance for GIS technology adoption, implementation and diffusion. Moreover, collaborative management scenarios benefit from decision support systems for resource managers. Yet, providing a base level of spatial decision support for domain experts is a challenge for inter-organizational arrangements. Understanding how to develop and design technology to meet the needs of NRM networks can enhance the successful use of collaborative, spatial decision support activities. Longitudinal studies, including use of social network analysis, can further this line of research by investigating the influence of GIS to build density within a network. This research could address the question: how does use of web-GIS increase collaborative activities along a network?

As GIS technology continues to evolve and greater access to using GIS is available to those not trained in geomatics, strategies for efficient and effective deployment of the technology is vital in provision of SDSS for NRM. The combined results of this study extends research documenting the value of needs assessment practices, and reveals factors influencing capacity of technology implementation for geographically dispersed NRM networks. Overall, this study provided,

1. A framework for NRM networks to build an inventory using the geospatial technology profile (GTP) to document the range of platforms to engage network members.

2. Visualization through the SoCE illustrated the range of capacity and use of web-based applications by the NRM study population.

3. A foundation to understand characteristics of GIS adoption by NRM networks with geographically dispersed members and establishes the value of needs assessment to determine strategies for successful implementation.

4. Protocols to enable evaluation of the socio-technical system in place and thereby guide decision processes for delivery of the technical system.

Insights and future directions

GIS offers a valuable asset to NRM networks as a collaborative tool. The complexity of NRM network structure, specifically inter-organizational arrangements of geographically dispersed members, brings challenges to GIS implementation while offering new opportunities for engagement and collaboration. Challenges are present across the literature, including data sharing, organizational policy, and user ability to use the technology. Such implementation challenges were confirmed through my research, and then studied further to explore the influencing factors. Organizational policy proves a strong barrier to access; however, in phase 2 of this study, I found that utility of the technology influenced users to navigate barriers to access. In addition, users who recognized the utility, requested support resources to enhance those abilities.

While the majority of NTS networks have adopted GIS, not all implemented use of the technology across the network. I suggest that the high level of adoption for NTS is most likely due to fact that each network includes a federal government agency partner. These partners have access to GIS technology; still the non-agency partners faced organizational policy barriers to use the technology. Future research should apply the ICI to inter-organizational NRM networks that may not exhibit as high of a level of GIS adoption as the NTS. Building a data set of geospatial technology profiles across varied patterns of NRM network structure will allow further analysis to validate the tool, thereby refining measures to improve understanding implementation capacity.

The very nature of linear networks, such as long distance trails or corridor parks, presents inter-organizational management arrangements. These are unique recreational and natural landscape spaces permitting special insight into the social structure for management scenarios. Marić, Zaninović, & Šćitaroci (2013) presented research exposing challenges associated with jurisdictional boundaries for managed public spaces. Framing landscape as a connection, their research surveyed linear parkways, waterfronts and urban spaces internationally to demonstrate the ability of developing connections beyond governmental boundaries to that of cultural or natural landscapes. It is vital that we understand both the human connection to landscapes and administrative barriers to efficient management as we address resource protection at a global level. This study sought to explore the role of geospatial technologies used by geographically dispersed resource managers as a collaborative decision support tool to oversee resource protection needs.

Opportunities exist to broaden the reach of geospatial technology. The evolution of Web 2.0 capabilities is rapidly changing the landscape of technology adoption. Even away from work, people use their phones for geo-spatial enablement. Many do not even think about their phone as a map enabled device, but they want directions from the conference center to a coffee shop, or to remember where they parked their car. This societal shift to geolocation, is an opportunity to engage non-geomatics experts into the arena of SDSS. GIS has been used in NRM for decades, but analysis or everyday use has been limited to a select few. If we take the principles of participatory GIS and apply that to NRM network members, we should seek to engage those without geomatics training with the technology. As with PGIS, we recognize network members as domain experts. Regardless of expertise, why should network members be at the table without appropriate resources? My Phase 2 case study revealed that use of GIS enabled such members to engage while bridging long distance gaps to collaborate with fellow network members.

Looking forward we should continue to develop tools to enable network members access to GIS technology. This research demonstrated the challenges, and how they were navigated to find opportunity. On one side of the GIS implementation equation, we have map developers with geomatics expertise; the other side are the map users. Map users have the opportunity to engage as data contributors, analysts, decision-makers, or advocates. Balancing the equation, a network must identify goals and objectives for GIS, then lay out strategies to meet needs in the realm of both hard and soft technologies. Capacity includes having geomatics staff to manage GIS operations, maintain systems, lead analysis methods, and develop applications for network users. For users to take full advantage of the systems, the geomatics expert must be aware of their individual capacity to use the system.

Research continues to document barriers to technology acceptance and present evidence that many organizations with GIS only use a precursory few functions. Support through training is key to engage users, and it must be sustainable and developed in a manner that the system may be sustained with change in personnel. Domain experts, even with training resources and access to the technology, will not take the place of the need for geomatics professionals to manage the system. Some tasks will (and should) remain with that level of expertise (e.g. viewshed analysis, invasive species growth modeling). The purpose of this research was to demonstrate the level of engagement that may be appropriate to further NRM network capacity to benefit from geospatial technologies. Web-GIS is one tool that can lead the way, and our findings revealed benefits of web-GIS as a collaborative tool for the community of users. The technology 1) enabled users to implement new methods to address network needs, 2) improved efficiency of network related tasks, and 3) provided innovative opportunities for collaboration across organizational boundaries and between great geographic distances. Further, I explored socio-technical structures to examine participatory

GIS technology within the context of resource management decision-making group members. The technology extended network collaborative capabilities by enabling users, specifically non-geomatics experts, access to resources that enhanced decision support processes.

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APPENDICES

APPENDIX A: Supplement to Chapter 2

Implementation Capacity Index Calculations

Implementation Capacity Measures: Hard and Soft Technology

Network capacity to implement GIS technologies are related to hard and soft technology. Platforms, used as indicators (Table A.1), represent software in place as classified by the targeted audience.

Table A.1. Implementation Capacity Indicators

Hard Technology Variable of Interest	Selection Options: Yes / No	Value Assigned
GIS Software Platform(s) in use by the network. (*select all platforms in use*)	▪ Web-based applications (free) ▪ Desktop (no web interaction) ▪ Web-based Cloud (subscription) ▪ Web-based Cloud / Server in-house (customized)	▪ 1 ▪ 2 ▪ 3 ▪ 4
Categories of tasks performed for each platform in use. (*select all tasks that apply*)	**Basic** ▪ Display ▪ Query ▪ Print Maps **Intermediate** ▪ Edit Attribute Data ▪ Download Data ▪ Data Upload (e.g. GPS) **Advanced** ▪ Edit Spatial Data ▪ Generate Reports ▪ Simple Analysis **Specialized** ▪ Use Customized Scripts / Tools ▪ Mark up Maps ▪ Send/Post Comments	▪ 1 ▪ 2 ▪ 3 ▪ 4
Frequency of GIS use for network operations for each platform in use.	▪ Never ▪ Several times a year ▪ Once a month ▪ Weekly ▪ Daily	▪ 0 ▪ 1 ▪ 2 ▪ 3 ▪ 4

Table A.1. (continued)

Soft Technology Variable of Interest	**Selection Options**	**Values Assigned**
GIS Designee: Education, Knowledge, Experience, Role & Responsibilities (*Self-reported – select one*)		
Education and training	**Education / Training** ▪ Self-Taught ▪ Workshop ▪ College Coursework ▪ GIS Degree	 ▪ 1 ▪ 2 ▪ 3 ▪ 4
GIS Knowledge & Experience	**Knowledge, Experience** ▪ Novice ▪ Average ▪ Above Average ▪ Expert ▪ Professional	 ▪ 1 ▪ 2 ▪ 3 ▪ 4 ▪ 5
Role	**Position Title & Role** ▪ GIS Title & Dedicated Position ▪ Other Position (e.g. landscape architect)	 ▪ 3 ▪ 2
Support & System Maintenance		
Support resources to use software and related GIS tools for each platform in use. (*Select all that apply for each platform*)	**Basic Assistance** ▪ Online ▪ Written ▪ Other (e.g. general workshop) **Intermediate Contact** ▪ Email ▪ Phone **Advanced** ▪ Face to Face ▪ Video Demo	▪ 1 ▪ 2 ▪ 3
System Operation & Maintenance Requirements to maintain the software or web application for network users. (*Highest level in use*)	Type of system in use: ▪ Desktop (*not web-based*) ▪ Online Accounts (*cloud type*) ▪ Custom Programming / Server (*server manager)*	▪ 1 ▪ 2 ▪ 3
System Maintainer (Personnel) (*Select one*)	▪ Staff / Intern ▪ Self (GIS Designee) ▪ Agency or Contracted IT	▪ 1 ▪ 2 ▪ 3

Hard technology analysis. Hard technology scores were generated for each platform in use based on platform level, plus the task category available, then multiplied by by the frequency of use (see Figure A.1). The score for each platform was summed to produce a hard technology score for the trail network.

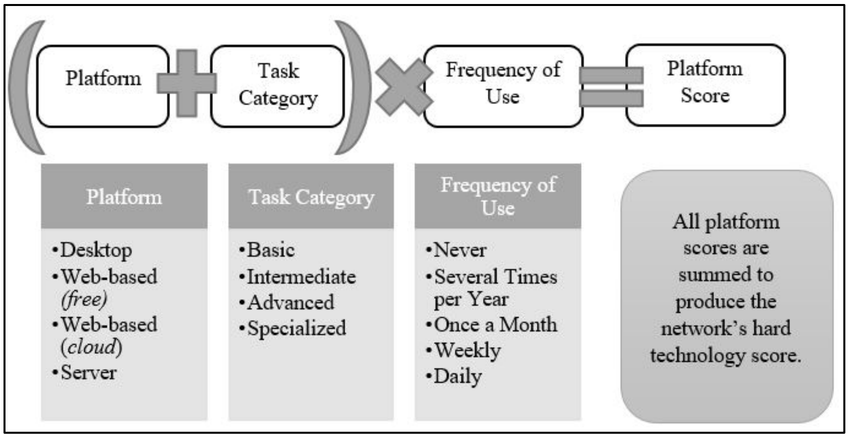

Figure A.1. Hard Technology Score Calculation

Soft technology analysis. Soft technology variables of interest were incorporated to generate a score for the GIS Designee, then summed with the values for user support mechanisms and system maintenance required for the platforms in use (Figure A.3). Reported values were summed and the title and role of the GIS designee was used as a multiplier to assign the final score. For example, if the designee was in a dedicated GIS role, the score is increased. If their position was split with responsibilities assigned to more than one trail or included additional (non-GIS) responsibilities, the score decreased.

Support mechanisms (see Table A.1) range from online resources provided by software developers, to personal contact with colleagues familiar with the network data and personnel. The lower value support options are not customized for the specific network personnel or GIS application being used, but are the general “help” documents for the software or application. The highest system support measures included video and face-to-face support (i.e., custom support) for a specific network and/or application.

The System score was computed by multiplying the type of maintenance value by the maintainer value (see Table A.1). Multiplication of these two values, rather than addition, separates the desktop-only GIS users from those networks that used web-based GIS applications as well. Using a multiplier also recognized differences in staff role responsibilities for maintaining the system. Agency-level IT personnel typically have more knowledge and training for maintaining technology than staff or interns with primary work responsibilities in other areas. The final soft technology score sums the designee score with user support and system scores (Figure A.2).

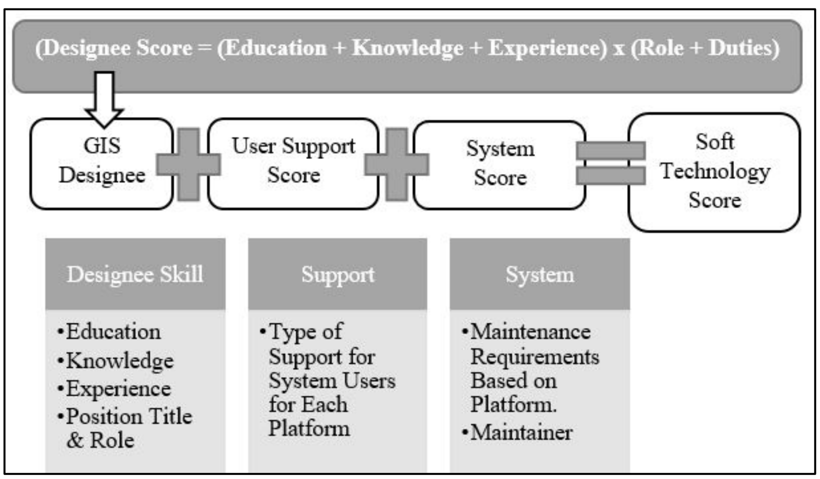

Figure A.2. Soft Technology Score Calculation

Implementation capacity index. The implementation capacity index (ICI) represents a composite index calculated using the process outlined in the research framework section (see Figure A.3). Specifically, the sum of the hard technology and soft technology scores was divided by the total possible score to derive an ICI value for each network. Final survey results are listed in Table A.2.

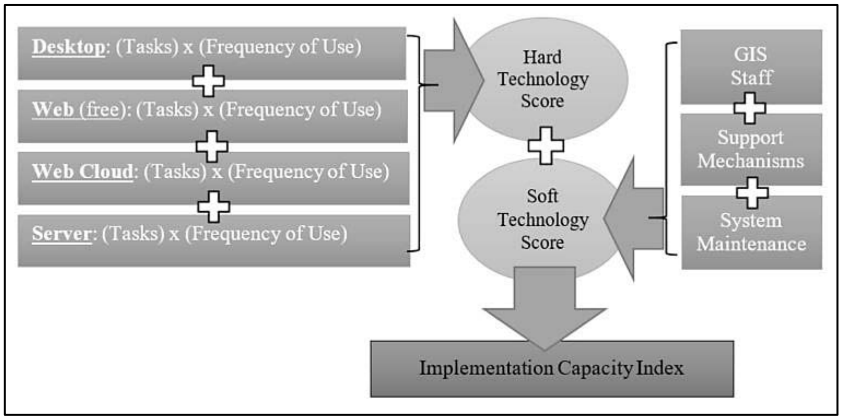

Figure A.3. Implementation Capacity Index Calculation

Table A.2. GTP Survey Results

Trail Name	Soft Tech	Hard Tech	ICI Value	ICI Ratio	Capacity Rating
Ala Kahakai NHT	25	21	46	22.66%	LOW
Appalachian NST	34	50	84	41.38%	MED
California NHT	35	75	110	54.19%	HIGH
Captain John Smith Chesapeake NHT	17	22	39	19.21%	LOW
El Camino Real de Tierra Adentro NHT	19	75	94	46.31%	MED
El Camino Real de los Tejas NHT	35	75	110	54.19%	HIGH
Ice Age NST	38	31	69	33.99%	MED
Iditarod NHT	29	21	50	24.63%	LOW
Juan Bautista de Anza NHT	30	62	92	45.32%	MED
Lewis and Clark NHT	71	59	130	64.04%	HIGH
Mormon Pioneer NHT	35	75	110	54.19%	HIGH
Natchez Trace NST	22	38	60	29.56%	MED
North Country NST	54	38	92	45.32%	MED
Old Spanish NHT	35	75	110	54.19%	HIGH
Oregon NHT	35	75	110	54.19%	HIGH
Pacific Crest NST	11	4	15	7.39%	LOW
Pony Express NHT	35	75	110	54.19%	HIGH
Potomac Heritage NST	20	50	70	34.48%	MED
Santa Fe NHT	35	75	110	54.19%	HIGH
Selma to Montgomery NHT	0	0	0	0.00%	LOW
Star-Spangled Banner NHT	17	22	39	19.21%	LOW
Trail of Tears NHT	35	75	110	54.19%	HIGH
Arizona NST	23	43	66	32.51%	MED

APPENDIX B: Supplement to Chapter 3

Table B.1. Proof Quotes for *access*, *support* and *utility*

Thematic Area	Supporting Data: Quotes
Access	▪ "That's really our biggest hurdle to overcome. A lot of the volunteers are interested in using this new technology, but we haven't been able to share it with them" [Case C-S2]. ▪ "some of the agencies do not want users to have detailed information because they are concerned about damage to the cultural resources" [Case B-V1]. ▪ "some of our folks that don't have a mobile device, that can support the App" [Case C-S1]. ▪ "it's a piece of cake!" [Case A-S2].
Support	▪ "I would like to be able to learn how to accurately measure a section of the trail" [Case A-S4]. ▪ "I just figure it out" [Case B-V1]. ▪ "GIS person is overstretched and can't really spend the time with us regional folks" [Case A-S3]. ▪ "figure out a way to make the NPS give non-GIS people GIS training" [Case C-A1].

Table B.1 (continued)

Utility	**Data Validation** ▪ "…I can actually start getting my field staff to do some editing for themselves" [Case C-S2]. ▪ "do some kind of logical testing about some of the data points and say, this isn't right" [Case D-02]. ▪ "twenty years ago people didn't even have good enough paper maps to be able to look at that. Now you can almost see real time" [Case A –S2]. ▪ "I'll snap a photo and I'll upload it in [the web GIS] so that it's part of the documentation of resources. A lot of that was put in the ground 20-25 years ago and never tracked" [Case D-A1]. **Communication** ▪ "get a better of what's on the trail. what it might be near, things my database won't tell me" [Case C-A1]. ▪ "If it's in...well there are places I need to get to, to photograph, on the river for example, I find out, oh, this is BLM land, I can actually get there without trespassing. It's a great way to find access" [Case B-S1]. ▪ "whose land we're on, or whose land we're not on" [Case C-A1]. ▪ "Looking at kind of the natural resources along the trail. Looking at timber sales. Looking at relocations. You know, trying to find a better route through an area with wetlands, or avoiding a clearcut area" [Case A-S2]. ▪ "Our people that don't really understand forms, but can understand maps, can put a point down and say they did a certain amount of work... on a map and send that to us" [Case C-A1]. ▪ "no longer do people have to rely on buying our paper maps" [Case A-S1]. **Collaboration** ▪ "[network partner] can see the changes live on the other end" [Case D-O1]. ▪ The web GIS tool was "meant to be facilitator for that two way discussion" [Case D-O2]. ▪ "… you have the ability to work real time together with people, it's almost like you can be there. Which is just amazing" [Case A-S2]. "I just zoom in to what I want, and then click share, current map, extent, and copy that link when I have questions from people [about] a specific location" [Case A-S1]. ▪ The tool has "been very helpful for them in being able to work with communities and not just document, but also start talking about you know uh..even just opening a dialog about the trail" [Case D-A1]. ▪ "I'm indirectly collaborating with several researchers now. I can see what they are thinking. Which is really helpful" [Case B-S1].