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Managing the Unmanageable: How IS Research Can Contribute to the Scholarship of Cyber Projects

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Abstract

Cyber projects are large-scale efforts to implement computer, information, and communication technologies in scientific communities. These projects seek to build scientific cyberinfrastructure that will promote new scientific collaborations and transform science in novel and unimagined ways. Their scope and complexity, the number and diversity of stakeholders, and their transformational goals make cyber projects extremely challenging to understand and manage. Consequently, scholars from multiple disciplines, including computer science, information science, sociology, and information systems, have begun to study cyber projects and their impacts. As IS scholars, our goal is to contribute to this growing body of inter-disciplinary knowledge by considering three areas of IS research that are particularly germane to this class of project, given their characteristics: development approaches, conflict, and success factors. After describing cyber projects, we explore how IS research findings in these three areas are relevant for cyber projects, and suggest promising avenues of future research. We conclude by discussing the importance and unique challenges of cyber projects and propose that, given our expertise and knowledge of project management, IS researchers are particularly well suited to contribute to the inter-disciplinary study of these projects.

Keywords: *Cyberinfrastructure, Cyber Projects, Information Systems Research.*

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1. Introduction

What will science look like in the future? Imagine plant biologists building simulations and complex computational models to better understand evolutionary relationships among species rather than growing plants in a lab. Imagine oceanographers analyzing data that is streamed in from sensors placed in oceans around the globe to capture the changing distribution of marine species rather than wading through water to collect samples. Imagine climatologists using complex visualization technologies to predict and understand climate change rather than observing actual changes in plants and the physical environment that may take years to unfold. These scenarios describe nothing short of a transformation in the way science is conducted (Atkins et al., 2003).

Agencies such as the National Science Foundation (NSF) in the US, the U.K. Research Council, and the European Science Foundation (ESF) are encouraging this transformation of science by funding massive projects to build digital infrastructures that support scientific collaboration and discovery. Digital infrastructures include “basic information technologies and organizational structures, along with the related services and facilities necessary for an enterprise or industry to function” (Tilson, Lyytinen, & Sørenson, 2010, p. 748). Traditionally, infrastructure has been viewed as relatively stable, and something that could be studied and managed independent of its use (Atkins, 2005). However, as information technologies become increasingly pervasive and embedded into interactions and transactions, infrastructure becomes more than simply a group of technologies and structures, or basic services. Indeed Tilson et al. (2010) argue that contemporary digital infrastructure can be understood as a relational and socio-technical system in the sense that users interact with the infrastructure as its design and technologies evolve and adapt over time in response to changing user needs and technological capabilities.

In the realm of science, such digital infrastructures are called “cyberinfrastructure”. Scientific cyberinfrastructure refers to integrated information technologies (i.e., hardware, software, digital sensors, middleware, networks, and data components) that support scientific research activities (Berman, 2008; Bietz, Baumer, & Lee, 2010; Edwards, Bowker, Jackson, & Williams, 2009; Edwards, Jackson, Bowker, & Knobel, 2007; Lee, Dourish, & Mark, 2006a; Olson, Zimmerman, & Bos, 2008). A specific objective of scientific cyberinfrastructure is to promote the development of new scientific collaborations on a large scale through the use of technologies that support collaborative work among geographically dispersed researchers utilizing complex and sophisticated computational models and technologies (Bos et al., 2007; De La Flor et al., 2010; Ribes & Lee, 2010). Cyberinfrastructure technologies are embedded in the work practices and work-related relationships of the scientists using them; to further interdisciplinary and inter-institutional collaboration, the technologies are designed to span academic fields and institutions (Lee et al., 2006a; Finholt & Birnholz, 2006).

A cyberinfrastructure project (or “cyber project”) refers to the information technology (IT) development activities that design, build, integrate, test, and implement a scientific cyberinfrastructure. Such projects can involve thousands of participants from multiple universities, colleges, government agencies, and businesses that have interests and stakes in cyberinfrastructure-enabled research. Cyber projects have numerous stakeholders with varying goals and requirements, require massive budgets, and often take years to develop (Finholt & Birnholz, 2006).

There is a growing body of scholarly work investigating cyberinfrastructure, cyber projects, and their impacts. This scholarship around the cyber phenomenon is carried out by researchers from diverse disciplines, including computer science, sociology, information science, and IS. Our goal is to contribute to this interdisciplinary body of knowledge by considering how existing IS research can be brought to bear in this context and by identifying additional avenues of research for IS scholars. Cyber projects often experience problems that are similar to more traditional information systems development (ISD) projects, which include late or missed deliverables, overrun budgets, political maneuvering, conflict, misaligned goals, and lack of leadership. IS researchers are very familiar with these issues because they have conducted a considerable amount of research on them (e.g., DeLone & McLean, 2003; Kraut

& Streeter, 1995; Henderson & Lee, 1992; Mähring, Keil, Mathiassen, & Pries-Heje, 2008; Markus & Bjorn-Andersen, 1987; Robey, Farrow, & Franz, 1989; Tiwana, Keil, & Fichman, 2006).

In Section 2, we examine two cyber projects, NEES and GENI, which provide the context for the remainder of the paper. In Section 3, we consider three phenomena that are particularly challenging to this class of projects: development approaches, conflict, and success factors. We close in Section 4 with observations about how the IS research community can contribute to scholarship in these areas.

2. Cyber Projects: Two Examples

This section describes in detail two cyber projects in the US: NEES (the Network for Earthquake Engineering Simulation) and GENI (the Global Environment for Network Innovations)[1]. Table 1 describes key aspects of the NEES Cyber Project, and Table 2 describes key aspects of the GENI Cyber Project.

Table 1. The NEES Cyber Project

Description	The George E. Brown Jr. Network for Earthquake Engineering Simulation (or NEES) was created to better understand earthquakes, their causes, and effects (see www.nees.org).
Goal	To promote collaborative research, shared understanding, and shared equipment (including engineering equipment sites, computational resources, and digital libraries) among the earthquake engineering community.
Stakeholders	A diverse set of academics and professionals with different expertise, backgrounds, institutional affiliations, needs and requirements, including earthquake engineers, computer scientists, information technology and project management specialists from industry, and government sponsors.
Project Objectives	Develop a cyberinfrastructure component—a large-scale network designed to connect researchers and experimental equipment sites comprised of advanced earthquake testing capabilities. Integrate information technology and systems to provide a distributed collection of laboratory facilities and repositories, which engineers could use to perform model-based experimental simulations of earthquakes.
Phases	Three major phases: pre-construction, construction, and operation. Pre-construction began in 1999 and lasted until 2001. During this phase the funding for NEES was approved by the U.S. Congress, the NEES development community was organized, requests for proposals for NEES construction activities were issued and proposals were funded, and detailed plans for NEES construction were completed and approved. In late 2001, construction commenced and was completed in 2004. During construction, equipment site projects were funded, with 15 universities constructing or upgrading earthquake engineering laboratory facilities. A systems integration effort was undertaken to develop the information technology infrastructure needed to support NEES, such as the data repositories, telepresence tools, and networking. NEES operation started in 2004.
Teams	Two different teams of computer scientists worked on the systems integration effort. Team 1 was the primary team for the system integration tasks, while Team 2 was the secondary team for system integration. The two teams that were involved in the construction phases of the NEES cyberinfrastructure espoused different architectural designs (grid system vs. user-centered peer-to-peer system). The two teams had different software development approaches, with Team 1 using a less structured, more iterative approach, and Team 2 favoring a waterfall-based software development process. At the time that the NEES cyberinfrastructure was built, the two architectural designs and development options were considered incompatible. Initially, the infrastructure was developed by Team 1 using the grid system architecture, and Team 2 was charged with usability testing. Despite a promising start to the project, the development approach used by Team 1 did not have significant engagement of users from the earthquake engineering community. This approach ultimately proved unpopular, and the construction of the NEES cyberinfrastructure was transitioned to Team 2.

[1] Examples of cyber projects in other countries include the Earth Simulator project in Japan, the Discovery Net project in the UK, and the eScience Infrastructure for Huge Interferometric Datasets project in the Netherlands.

Table 1. The NEES Cyber Project (cont.)	
Project Governance	A Board (called "NEESinc") was organized to engender support from the engineering community for NEES and to provide governance for NEES. The cyber project organization is a top-down, multi-layered governance structure in which NSF (the project sponsor) directed the NEES Board of Directors (a group of senior academics in the earthquake engineering community) which governed NEESInc (a professional project director and staff) that managed a variety of NEESInc committees. One of the NEESInc committees included a director who managed NEESIT (the IT development organization). At the end of the construction phase in 2004, a different institution from those involved in construction was engaged and made responsible for the operation of NEES (now called "NEEShub").
Current Status	The NEES cyberinfrastructure, connected via Internet2, currently provides interactive simulation tools, a simulation tool development area, a curated central data repository, animated presentations, user support, telepresence, mechanisms for uploading and sharing resources, and usage patterns. Over 1,000 research experiments have been conducted using the NEES cyberinfrastructure since its implementation in 2004.

Table 2. The GENI Cyber Project	
Description	GENI, or the Global Environment for Network Innovations, is a cyber project funded by NSF to develop a virtual laboratory for at-scale networking experimentation (see www.geni.net).
Goal	Initially envisioned as a cyber project to develop the next generation of the Internet to "meet society's future requirements and expectations that the Internet will need to be better: more secure, more accessible, more predictable and more reliable".
Stakeholders	Initially, the project was provided initial guidance from the Network Science and Engineering Council (NetSE), a group of prominent networking researchers. In addition to networking researchers, stakeholders include NSF, BBN, members of organizations in the public sector and private sector, and international participants.
Project Objectives	Today, the overall objectives of GENI focus on creating a cyberinfrastructure providing a virtual laboratory that would enable practitioners and academics to run experiments and tests to create innovations for the enhancement of the Internet and to explore future internets at scale.
Phases	Uses a spiral development approach. The GENI Project Office or GPO has instituted year-long development spirals wherein investigators submit proposals for specific development activities that are either accepted and receive funding, or are rejected. It is expected that during the spiral year that the proposed task will be developed, coded and implemented as proposed. As each spiral has unfolded, the overall objective of the spirals has become less focused on the development of underlying technologies and more focused on efforts to bridge previous technologies, experiment within the test bed, and encourage collaboration among established technologies. Development spirals represent the increasing maturation of the cyber project and the natural progression of a massive system from a development stage towards implementation. In early spirals development activities were undertaken to build the specific cyberinfrastructure technologies. During later spirals, GENI-wide clusters were created along with meso-level projects that bridge the clusters, and experiments that perform a variety of tests within and across the various clusters.
Teams	Development activities were organized by the GPO into five major "clusters" (or technical platforms), which represent groups working on different networking technologies such as optical, wireless, and traditional router and switch. Each technical cluster consists of researchers that develop different pieces of GENI.
Project Governance	The NSF initially created an internal group to manage this project and to oversee the funding of researchers to fulfill these objectives. However, with the passage of time, this group determined that additional expertise, particularly in large-scale project management, would increase the likelihood of success for GENI. Thus, a private consulting company, BBN Technologies (BBN), was selected to provide project management oversight in conjunction with NSF. BBN created a dedicated team to oversee GENI, called the GENI Project Office (GPO).
Current Status	At the present time, GENI is commencing with Spiral 5, and two additional spirals are anticipated as GENI moves to Operation.

Figure 1 illustrates NEES as of 2004 when NEES was in development, not the NEES cyberinfrastructure today when it is in operation, and Figure 2 illustrates the organizational structure of the GENI cyber project in its first year.

3. Cyber Project Challenges and IS Research

From a broad perspective, much is at stake with the cyberinfrastructure initiative: not only is significant funding devoted to cyber projects, but, perhaps more importantly, society's ability to understand complex global issues and solve pressing "grand challenges". If cyberinfrastructure is truly a catalyst for transforming the nature of science, it is imperative for researchers to develop a better understanding of how to structure and manage cyber projects.

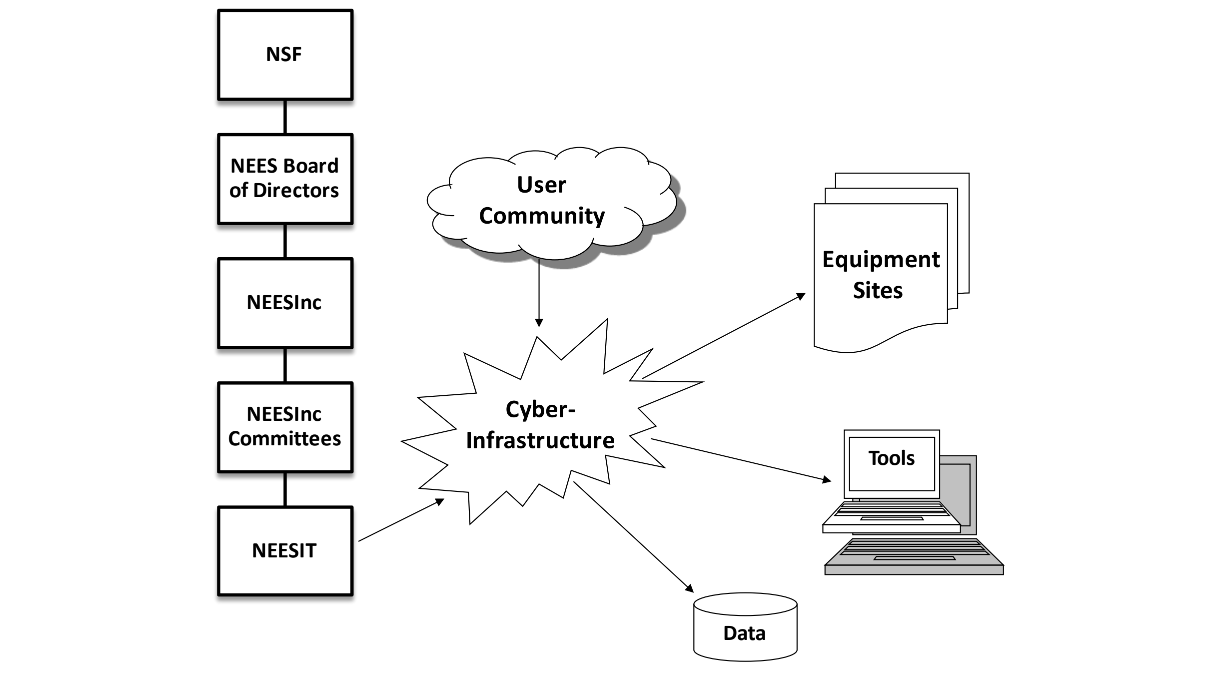

Figure 1. A Diagram of the NEES Cyber Project in 2004

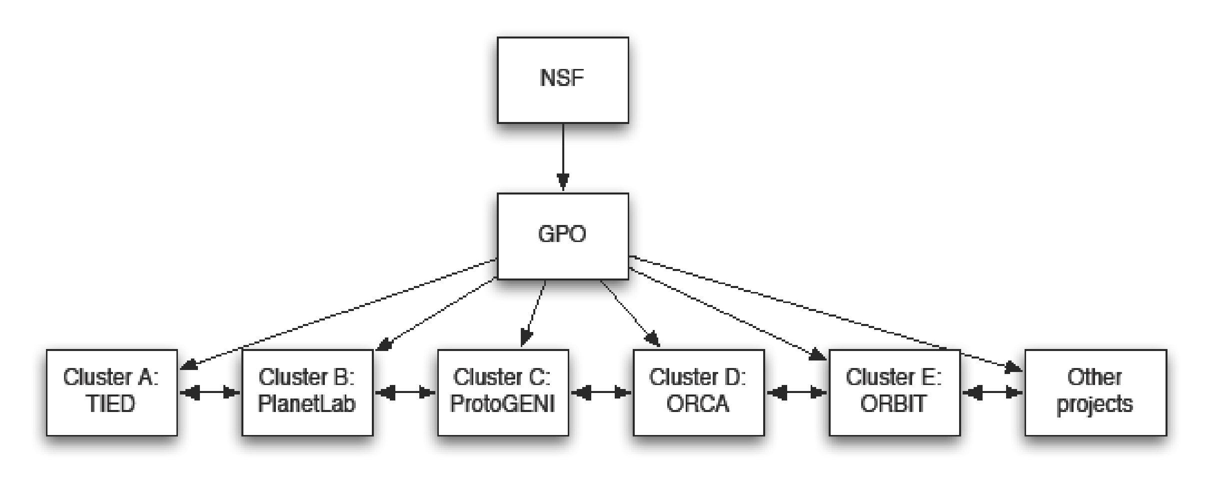

Figure 2. A Diagram of the GENI Cyber Project in 2008

Scholars from multiple disciplines have studied cyberinfrastructure and the various aspects of cyber projects. For example, researchers in computer science and information schools have examined the concept of infrastructure and distinguished traditional physical infrastructure from cyber- or e-infrastructure (e.g., Edwards et al., 2009; Berman, 2008). In the field of computer-supported cooperative work (CSCW), researchers have examined cyberinfrastructure from a sociotechnical perspective to reveal how heterogeneous stakeholder communities form (e.g., Karasti, Baker, & Millerand, 2010) and how members collaborate, build relationships, and conduct their work (e.g., Ribes & Lee, 2010) and how cyberinfrastructure communities resolve technical issues such as standards formation (e.g., Faniel & Jacobsen, 2010). CSCW researchers have also identified the communication and collaboration challenges and opportunities facing cyberinfrastructure projects (or e-science projects as they are called in Europe) (e.g., Spencer, Zimmerman, & Abramson, 2011).

While researchers from many disciplines are conducting research of the cyberinfrastructure phenomenon, it is our contention that IS researchers can contribute to the growing scholarship of cyber projects. We identify three areas where we believe IS researchers are particularly well positioned to contribute, given our expertise and capability in research on ISD projects: development approaches, project stakeholder conflict, and assessing project success. Prior IS research has demonstrated that selecting a development approach that fits the characteristics of the project is important (Avison & Fitzgerald, 2003; Fitzgerald & Russo, 2003; MacCormack, Kemerer, Cusumano, & Crandall, 2003; Shenhar, 2001). Moreover, with the number and diversity of stakeholders associated with cyber projects, it is inevitable that there will be differences in priorities and goals, which often leads to conflict (e.g., Barki & Hartwick, 1994; Espinosa, Delone, & Lee, 2006; Robey et al., 1989). Finally, prior research suggests that understanding success factors of projects that are large, complex, and uncertain is challenging (Kraut & Streeter, 1995; Harter, Krishnan, & Slaughter, 2000; Delone & McLean, 2003); this is particularly true in the context of cyber projects, where the ultimate goal is transformational. In Section 3.1, we first describe and compare cyber projects to other project types. In Sections 3.2, 3.3, and 3.4, we explore development approaches, conflict, and success as they relate to cyber projects. We explain the challenges associated with these areas for cyber projects in some detail, and examine how extant IS research contributes to an understanding of these areas. We conclude the discussion of each area with ideas about promising avenues of future research on cyber projects.

3.1. Comparing Cyber Projects to Other Project Types

Although cyberinfrastructure has the potential to transform science in new and unimagined ways, the development of cyberinfrastructure poses significant challenges. Such projects are extremely complex and large in scope: they typically cost millions of dollars and require years, even decades, to complete. The projects are also innovative, risky, and novel, and they develope and use technologies that are themselves emergent. Before considering the question of which development approach is appropriate for cyber projects, it is instructive to consider the characteristics of cyber projects themselves, and how these characteristics compare with other types of projects. Table 3 summarizes the characteristics of cyber projects, open source software (OSS) projects, research and development (R&D) projects, information systems development (ISD) projects, and mega-infrastructure projects (projects that include the construction of large physical infrastructure such as a tunnel under the English Channel).

Table 3. Comparison of Different Project Types

	Scientific collaborations (cyber projects)	Open source software (OSS) projects	Research & development (R&D) projects	Information systems development (ISD) projects	Mega-infrastructure projects
Goal	Transformational Science	Quality	Innovation	Efficiency	Provide foundation for ongoing use
Size	Very large	Varies by project	Varies by project	Varies by project, from small development projects to extremely large ERP projects	Very large, but with regularity in activities
Requirements volatility	Very high - requirements emerge and evolve	High but incremental after kernel developed	Varies by project	Varies by project	Varies by project
Innovation process	Uncertain and dynamic	Uncertain in incubation process, then iterative once a kernel exists	Varies by project and project stage	Structured but may allow for iteration	Structured with repeatable processes but may allow for iteration
Budget & schedule constraints	Budget and schedule constraints are imposed and must be met	Minimal	Varies by project	Budget and schedule constraints are imposed and must be met	Budget and schedule constraints are imposed and must be met
Quality constraint	High but not mission critical	High but not mission critical	Varies by project	Varies by project	Usually very high, can be mission critical
Stakeholders	Numerous, high diversity, geographically distributed, from various institutions; users and developers are different communities	Numerous, primarily developers, geographically distributed	Core stakeholders internal to one organization, often co-located; users and developers are different	Core stakeholders internal to one organization, developers and users are different	Numerous, high diversity, geographically distributed, from various institutions; users and developers often from different organizations; many contractors
Control	Formal organizational and peer-based behavioral control	Peer-based behavioral control	Formal organizational and supplementary informal control	Formal organizational and supplementary informal control	Primarily formal organizational control
Funding	Complex, external agencies	Not relevant at project level	Usually from organization	Usually from organization	Complex, can be a mix of internal and external organizations and agencies

As Table 3 shows, both ISD and cyber projects face real budget, schedule, and quality constraints that must be met. ISD projects are usually funded in a straightforward manner, typically by an internal business unit. In contrast, cyber projects have complex funding arrangements in which project resources can come from a variety of public and private agencies, with each source requiring potentially different types of management, reporting, and oversight, and offering different types of incentives to project participants.

Cyber projects also share some similarities with OSS and R&D projects, which are innovative in nature, with a considerable amount of uncertainty about specific requirements and project outcomes. However, OSS projects tend to evolve in a more predictable, albeit organic, manner once an initial kernel exists. Many of the best OSS communities have a specific "incubation" process to start new projects, and the key design, development, and implementation decisions originate from the founders of the projects (Von Krogh, Spaeth, & Lakhani, 2003). For R&D projects, the innovation process is often constrained by laws and regulations (such as in the pharmaceutical industry). The innovation process in cyber projects is more unbounded than in OSS and R&D projects: typically, there are few regulatory constraints and the way in which the project unfolds is less predictable. Indeed, cyber projects are intended to be transformational in both process and outcome.

Finally, as Table 3 shows, infrastructure projects—whether cyber or physical—are massive projects that involve a large number of geographically dispersed stakeholders with specialized expertise. Both types of projects are often composed of many sub-projects, which increases the complexity of their management. However, while both cyber and physical infrastructure projects are bound by budget and schedule constraints, physical infrastructure projects must create a product with a mission-critical level of quality as the product provides a physical foundation for ongoing use. In contrast, cyber projects aim to transform science in new and unimagined ways, and to explore and develop new technologies. Because cyber projects involve emerging information technologies, there is almost an expectation that quality will be compromised in the sense that technology breakdowns occur as "bugs" to be discovered and addressed.

As evident from the prior discussion, cyber projects share some characteristics with ISD, OSS, R&D, and physical infrastructure projects, but also differ in important ways. Cyber projects are large and complex, with many moving parts that require precise planning and coordination, but are also emergent and unpredictable in terms of fluctuating requirements and unknown (or indeed unknowable) outcomes. Therefore, the development of cyber projects requires both discipline and flexibility. An important question is how development approaches can effectively embrace both discipline and flexibility on a large scale.

3.2. Development Approaches for Cyber Projects

IS researchers have examined, documented, and helped shape a variety of IS development approaches, such as waterfall methods (e.g., Avison & Fitzgerald, 2003). In very large projects, disciplined processes and methods are required to track and report on budget, schedule, and quality performance, and to coordinate and manage the large numbers of stakeholders. The conventional waterfall approach—planning, analysis, design, coding, testing, implementation, and maintenance (George, 1999)—is well suited for this type of discipline. However, cyber projects must also remain open to the possibility of new technologies emerging during the development process and evolving visions of the ultimate deliverables, and therefore also require flexible and dynamic approaches that allow for shifts in goals, emergent requirements ,and accommodating change on a large scale. The waterfall approach is often seen as too cumbersome and time-consuming to be effective when flexibility, speed, and agility are paramount (Lyytinen & Rose, 2006; Slaughter, Levine, Ramesh, Baskerville, & Pries-Heje, 2006). Nevertheless, to take advantage of the discipline embodied in the waterfall approach, the NEES project adopted this approach, and, perhaps predictably, experienced both the benefits and the downfalls associated with it.

Agile methodologies, a set of practices intended to minimize unnecessary bureaucracy and maximize adaptability and responsiveness, have emerged as a flexible way to develop information systems (Ågerfalk, Fitzgerald, & Slaughter, 2009). Agile methods have been used effectively for certain types of ISD projects. For example, in their case study at Intel Shannon, Fitzgerald, Hartnett, and Conboy (2006) found that the use of agile practices resulted in reductions in code defect density by a factor of 7, and that projects of 6-month and 1-year duration were delivered ahead of schedule. However, these methods may be ill suited to very large scale projects that span years, face specific budget and schedule constraints, and require the coordination of a large number and wide variety of geographically dispersed participants in various organizations (Lee, Delone, & Espinosa, 2006b; Nerur, Mahapatra, & Mangalaraj, 2005). It is not clear how one could implement the key techniques of agile methodologies (such as pair programming) in the cyber context because the stakeholders are not co-located and have differing levels of engagement in the project. To coordinate even a weekly meeting among all of the relevant stakeholders may be challenging.

Another development option is the spiral approach. In the GENI project, for example, flexibility is introduced by organizing the development of the cyberinfrastructure into year-long spirals. Spiral development—an approach from software engineering (Boehm, 1988)— is a way to incorporate more flexibility into the management of very large projects by dividing a large project into smaller phases or spirals that last from 6 months to 2 years. Each spiral has its own goal, requirements and design, and a prototype of the system is generated during the spiral. The performance of the prototype is evaluated at the end of the spiral, changes may be made to shift course, and the next spiral starts with its own goal and requirements. A spiral approach may be especially useful for projects that are large and need flexibility to embrace new opportunities and reduce the risk of failure (Boehm, 1988; Kumar, 2002). However, as the GENI project is experiencing, the spiral approach may add significant complexity to project management. With each spiral some development teams may continue with their work from the prior spiral, some teams may drop out of the project, and other new teams may join. Therefore, the difficulty of coordination, control, and system integration increases dramatically because there are many moving parts in different stages of development, and, eventually, given sufficient spirals, the project may be very difficult to manage at a detailed level.

In addition, development approaches not often used in ISD projects may be especially relevant for performance in cyber projects. A typical ISD project is structured as a “sequential” search process (Weitzman, 1979), usually with multiple stages. That is, one basic technology platform is used, and the development progresses over time in stages as the developers leverage the platform to develop an application. This approach is appropriate when the budget available is limited or highly constrained, significant technical advances are not sought, it is possible to clearly define the goals for the project, the goals are relatively stable, and it is possible to reduce uncertainty and converge on a solution by obtaining information at different points in the project.

In contrast, cyber projects have the objective of transformational impact. Thus, it is not clear at the outset of a cyber project what is the best technical approach because there are often multiple approaches possible, and the best technical approach may emerge at any time during the project. A sequential search approach as used in typical ISD projects may not offer significant potential to reduce technical uncertainty and explore new opportunities. Cyber projects, therefore, may more usefully be structured using “parallel” search processes similar to those used in the pharmaceutical industry. A parallel search process evaluates multiple technical approaches all having the same overall objective. A parallel search process segmented into multiple stages offers the opportunity to drop a technical approach, continue a promising approach or add a new approach in each stage of the process. Parallel search strategies are particularly appropriate for projects when there is value in considering alternative designs, the technical advances sought are large, additional information can be gained from prototyping, and when the cost of prototypes is small relative to total system cost (Nelson, 1961). For example, as Section 2 notes, the GENI project includes sub-projects organized into clusters corresponding to different networking technologies: traditional router and switch, optical, and wireless. These clusters have the same overall objective (transformational science) and the projects are run in parallel in each spiral. Performance is evaluated at the end of a spiral to determine which technical approaches should continue, which should be discontinued, and which should be added.

In sum, it is clear that IS research can offer insights into the development of cyber projects. From its inception, the field of IS has focused on the development and implementation of technology-based solutions in organizations. Numerous studies have examined approaches such as waterfall, agile, and spiral methods, which has shed considerable light on the strengths and weaknesses of each (Iivari, Hirschheim, & Klein, 1998). As a field, we have developed some understanding of which processes are best suited for which projects, given their characteristics (Austin & Devon, 2009; Slaughter et al., 2006). We have also witnessed considerable evolution of systems and methods (Agerfalk et al., 2009). As the types of systems have changed over time, from in-house single purpose systems to inter-organizational systems to web-based systems to mobile applications, so too have development approaches. Cyber projects represent another evolution of projects that are similar to, but different from, other types of projects (see Table 3). From a development perspective, the defining characteristic for cyber projects is the need for both discipline and flexibility in the development approach adopted. Existing approaches tend to be strong in either discipline or flexibility, but not both. The challenge for IS researchers is to build on our knowledge of different types of development approaches to design a process that can be effective for cyber projects.

3.3. Conflict in Cyber Projects

Cyber projects have a large number of stakeholders, including domain scientists, researchers, industry experts, and funding agents. However, because stakeholder interests may differ, it is likely that conflicts may surface. For example, researchers interested in knowledge creation may not see eye-to-eye with industry experts who are interested in technology commercialization. Not only might there be conflict across stakeholder groups, but it is conceivable that conflicts within groups will occur as well. In the GENI project, for example, the researchers associated with any one particular cluster are competing with researchers associated with other clusters for scarce funding dollars and the ultimate design of the GENI infrastructure.

It is well known that development projects are prone to conflict. IS researchers have demonstrated that conflict can arise from ineffective communication behaviors (Bostrom, 1989; Salaway, 1987), poorly understood or ill-structured project requirements (Kirsch & Haney, 2006; Robey & Farrow, 1982), differences in priorities, goals, and agendas of project stakeholders (Robey & Markus, 1984; Robey et al., 1989), and power differences (Markus & Bjorn-Andersen, 1987; Markus, 1981). Projects that are complex in scale and scope, risky, and that involve a diverse set of stakeholders who are geographically distributed are even more prone to conflict and more difficult to manage (Carmel, 1999; Espinosa et al., 2006; Espinosa, Slaughter, Kraut, & Herbsleb, 2007; Hinds & Bailey, 2003). Given their size, uncertainty, diversity, and geographic spread, cyber projects, by their very nature, present a context in which conflict is likely to develop and fester.

One of the distinguishing characteristics of cyber projects is the large number and diversity of stakeholders involved. A number of studies in the IS and management literature suggest that diversity contributes to conflict (Barclay, 1991; Jarvenpaa & Leidner, 1999; Thatcher, Jehn, & Zanutto, 2003). Given the diverse group of individuals and institutions associated with cyber projects, and the feasibility of conflict occurring, a deeper understanding of the role of diversity in prompting conflict is a promising avenue to pursue in the cyber context.

Researchers have identified two types of diversity: demographic—stable and easily discernable characteristics such as age, gender, and race; and informational—stable but nonvisible characteristics such as educational level, work experience, and level of expertise (Cronin & Weingart, 2007). Findings from empirical studies of diversity are inconclusive in that diversity is sometimes found to be beneficial to group outcomes such as performance, tenure, and satisfaction; sometimes found to have no effect; and sometimes found to have negative effects (Thatcher et al., 2003). Further, research on diversity has traditionally examined the effect of a single factor such as gender, age, or education level. A richer way to examine diversity may be provided by the faultlines literature. Faultlines are hypothetical dividing lines that divide a group into subgroups based on one or more attributes (Lau & Murnighan, 1998). Rather than focusing on the effects of individual differences in one dimension, faultlines force researchers to consider how groups of individuals are aligned across multiple dimensions.

In a context such as cyber projects in which many diverse stakeholders are involved, this theoretical lens presents an opportunity to better understand how coalitions might form as groups divide into subgroups, and how conflict can be triggered across subgroups. For example, faultlines provide a potential explanation for why conflict might erupt between a group of scientists from academia and project managers from industry: the focus is not on whether there are gender differences between the scientists and managers, but whether cliques have formed between groups of similar background, expertise, and worldview. There is some evidence that faultlines are related to conflict, although the relationship may be complex. Specifically, Thatcher et al. (2003) found a non-linear relationship between faultlines and conflict: groups of individuals aligned on multiple attributes or dimensions, or groups with little alignment, exhibited high levels of relationship and process conflict; groups with a moderate level of alignment exhibited low levels of conflict.

The presence of a faultline does not necessarily mean that conflict will occur. Recent research suggests that faultlines erupt into conflict when a high-profile or controversial triggering event occurs (Slaughter et al., 2007). Consider NEES (Kirsch, Slaughter, Diamant, Ma, & Harney, 2009): as the cyber project unfolded, two teams from different universities were involved in developing part of the cyberinfrastructure. The teams knew that only one team would be selected to produce the final, integrated version of the infrastructure. The teams were not only competing for the final funding award, but were also competing technologically: they were developing infrastructure based on different technical models. Thus, a faultline existed between the two teams, based on location and on technical perspective. Eventually, funding for integrating the efforts of both teams was awarded to Team 1 with the expectation that Team 2 would cooperate with Team 1. However, Team 1 failed to get buy-in from Team 2 and, in fact, was also unsuccessful in involving the users (the earthquake engineers) themselves in the integration effort. This high-profile event – the funding award – triggered the eruption of a faultline that existed between Teams 1 and 2, which led to open conflict. As Kirsch et al. (2009, p. 13) observe:

> *The developers on Team 2 who were initially excluded from the system integration effort, from funding, and from having decision-making authority over the technology, adopted divisive or counterproductive measures to gain influence and have their views heard, and in doing so further reinforced the faultlines that had been created by those who had excluded them from the development efforts in the first place.*

In sum, the context of cyber projects seems ripe for conflict. The strong tradition in IS of studying conflict in development projects provides many insights into the causes of conflict and its impact that seem applicable to cyber projects. Opportunities for advancing this line of research may lie in a richer conceptualization of conflict, such as that offered by the faultlines perspective. With this theoretical lens, researchers can examine why specific events trigger conflict in large, complex projects such as cyber projects. Moreover, the faultlines perspective suggests a temporal dimension to conflict in which changing stakeholders, priorities, and project goals will likely influence the formation and eruption of faultlines over time. This line of research promises to yield interesting insights for the management of cyber projects.

3.4. Cyber Project Success

Conceptualizing success, and understanding the factors that contribute to success, can be particularly challenging in the context of cyber projects that must achieve both transformational science and typical project schedule, budget, and quality goals. Thus, to determine whether a cyber project is successful, it is necessary to first define the dimensions by which “transformational science” will be assessed and to determine how the dimensions will be measured. For example, consider GENI. As Section 2 notes, the goal of the GENI project is to create a cyberinfrastructure that provides a “virtual laboratory” for computer networking researchers to explore future internets at scale. GENI affords networking researchers the opportunity to “conduct transformative research at the frontiers of network science and engineering; and inspire and accelerate the potential for groundbreaking innovations of significant socio-economic impact” (see www.geni.net). The goals of GENI are ambitious. GENI is also intended to develop and support a networking research community and facilitate education and outreach. Given these objectives, the success of a cyber project such as GENI may need to be conceptualized and measured broadly and assessed in the long term and near term.

Considerable focus has been placed on understanding success in the IS literature, in large part because of the high failure rate of ISD projects. It is not uncommon for ISD projects to be over budget, to run over schedule, and to not deliver the required functionality (Keil, 1995; Barki, Rivard, & Talbot, 2001). Some projects are abandoned without developing any useful parts of a system. A classic example of a failed ISD project is the Denver baggage handling system (Montealegre & Keil, 2000). The goal of the project was to develop an airport-wide, computerized baggage handling system for the Denver International Airport. The project experienced numerous issues and went significantly over budget and behind schedule; it also delayed the opening of the airport. Ultimately, the project was abandoned, and a manual baggage handling system had to be deployed. When the Denver airport finally opened in 1995, it was 16 months behind schedule and almost $2 billion over budget. Another class of ISD projects that are particularly prone to failure include enterprise resource planning (ERP) systems which are global in scope, extremely large and expensive, and require years to implement, often with extreme difficulty and high failure rates (e.g., Soh, Kien, & Tay-Yap, 2000; Collins & Kirsch, 1999). IS researchers have studied these high-value, large-scope projects and have identified lessons learned in how such projects can be managed successfully.

ISD project success is often defined in terms of performance on schedule, budget, system quality, user satisfaction, business value, and other dimensions (Delone & McLean, 1992, 2003). The IS literature further defines the general types of factors that are associated with project success, including people, process, management, and environment characteristics. For example, dimensions of the project environment (such as uncertainty or complexity), attributes of the development team (such as experience, knowledge and skills), aspects of development practices (such as use of computer-aided software engineering tools, methodologies, and maturity of software development processes), and various management practices (such as formal and informal control and coordination mechanisms) have been linked to project performance (e.g., Nidumolu, 1995; Espinosa et al., 2007; Harter et al., 2000; Kraut & Streeter, 1995; Henderson & Lee, 1992).

In sum, the rich tradition in IS of exploring project success has yielded an understanding of the factors leading to schedule, budget, and quality performance. Factors such as project size, complexity, and structure will impact cyber projects, just as they impact other more traditional ISD projects. The cyber context, though, presents an opportunity for IS researchers to extend existing knowledge and develop an even deeper understanding of project success. With a goal of transformational science, these extremely large projects, characterized by diversity of stakeholders, high uncertainty of the innovation process, and volatility of requirements, present a rich context for identifying additional factors of success.

4. Discussion and Conclusion

This paper highlights an important new class of technology-based projects called “cyber projects”. Cyber projects develop scientific infrastructure with the goal of spurring scientific innovations that transform society. Given their massive size, scope, and high costs, their numerous and diverse set of stakeholders who are geographically distributed, their disparate and emergent requirements and objectives, and their goals that are ultimately transformational in nature, managing cyber projects can be extremely challenging.

Although numerous researchers from a variety of disciplines have begun to study cyberinfrastructure initiatives, we argue that IS researchers are particularly well positioned to contribute to the study of cyber projects. IS researchers have conducted significant research on the management of ISD projects that have similarities to aspects of cyber projects and are familiar with many of the socio-technical issues that arise in technology-based projects. Project management is a core knowledge area in the IS discipline (Baskerville & Myers, 2002). Therefore, there is potentially much to be gained by bringing existing IS research to bear in this context.

In particular, we focus on three areas that are both germane to ISD project management and that are especially challenging for cyber projects: the choice of development approaches, conflict, and understanding the factors that contribute to project success. We focus on areas that we argue are critical to all projects, but can be especially problematic for cyber projects given their characteristics. In each of these three areas, there is a rich history of IS research and thus substantial insight from the IS community that can be leveraged in the cyber context and can serve as the basis for future research. In addition to these three, there are undoubtedly other areas of IS expertise that could be brought to bear in the study of cyber projects. For example, IS research on open source software development (e.g., Stewart & Gosain, 2006; Roberts, Hann, & Slaughter, 2006) could inform questions about motivations for contributing to cyber projects and issues of scalability and community self-organization; IS research on implementation and acceptance (e.g., Rivard & Lapointe, 2012; Lim, Sia, & Leow, 2011) could provide insights as cyber projects move into operation and institutionalization phases; and research streams in IS on socio-technical issues (e.g., Stahl, 2007; Mumford, 2006) address the construction of complex social and technical infrastructures and may be relevant to cyber projects.

Cyber projects are an important new type of project and can open up new areas for IS research. For IS researchers interested in studying the tension between discipline and flexibility, the challenges of conflict management, and identifying the measures of project success, cyber projects would seem to pose an ideal "laboratory" to test existing IS theories and develop new IS theories on project management. Cyber projects are having a profound impact on a number of disciplines. These projects are forcing a dialogue and examination of the way in which research is currently conducted and how it should be conducted in the future. To achieve their visions, scientific disciplines must successfully develop and implement sophisticated cyberinfrastructure, and scientists must adopt and use this technology. IS researchers have been studying the development, implementation, adoption, and use of information technology and systems for years, and are in a position to impact the trajectory of cyber projects, and, in so doing, to push the boundaries of IS research. Studying cyber projects offers IS researchers an opportunity to contribute the insights and expertise we have gained from our research on ISD projects. At the same time, cyber projects represent "extremes" along many dimensions and thus present IS researchers with an opportunity to not only test the boundaries of our knowledge but also to discover new ways of managing projects that may transform our thinking about ISD projects. Thus, we call on IS researchers to engage in the study of these fascinating projects.

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