Expanding the Spatial Data Infrastructure Knowledge Base

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ABSTRACT

Research on spatial data infrastructures (SDIs) is not well grounded in theory, and SDI practice often does not adequately take into account previous experiences. The purpose of this paper is to raise awareness about knowledge areas available to academics and professionals involved in studying or developing SDIs. Along with technical tools, both groups need to engage the theoretical and conceptual apparatus in their efforts to understand and address technological and organizational processes and requirements of SDIs. After briefly addressing the existing SDI literature and identifying research gaps, the paper reviews the main disciplinary areas that would contribute to institutionalization of SDIs and to ensuring their broad utility: (1) information infrastructure, (2) interorganizational collaboration-cooperation-coordination (3C), (3) intergovernmental relations, (4) action network theory, and (5) use-utility-usability (3U) of information systems. We assess their value and limitations in supporting SDI research and development. The following elements are identified as potentially contributing to the SDI conceptual framework: the mutually supporting role of SDIs, geographic information systems (GIS), and information and communication technologies (ICT) and infrastructures; the notion of an installed base and capacity building activities responsive to the local conditions and needs; consideration of political, social, economic, cultural, and institutional context; incorporation of 3C principles and opportunities; attention to intergovernmental relations and the emergence of E-governance; understanding of the networked environment of data users, producers, and managers; employing user-centered approaches; and evaluating SDI accessibility and utility. The proposed framework is comprehensive, although it excludes important but often less challenging technical topics in order to focus on organizational and user perspectives.

INTRODUCTION

A functional spatial data infrastructure (SDI) is an important asset in societal decision and policy making (Feeney 2003), effective governance (Groot 2001), citizen participation processes (McCall 2003), and private sector opportunities (Mennecke 1997). Driven by those expectations, national SDIs have grown worldwide during the last decade (Crompvoets et al. 2004; Masser 2005a; Onsrud 1998). The benefits, however, have been slow to materialize. For example, Butler et al. (2005) assert that the United States national spatial data infrastructure (NSDI) has been only partially successful after 15 years of struggle. Masser (2005a) categorizes a number of European SDIs as partially operational or nonoperational. Similarly, Crompvoets et al. (2004), in their worldwide survey of national spatial data clearinghouses, observe a declining trend of clearinghouse use. In line with these observations, Masser (2005a) cautions that "some formidable challenges lie ahead and the task of sustaining the momentum that has been built up in creating SDIs in recent years will not be easy" (p. 273).

The above cautions require close attention, particularly given the considerable amount of resources that SDIs require (i.e., on the scale of billions of dollars) (Onsrud et al. 2004; Rhind 2000). One way to secure the return on these investments is to better conceptualize and understand SDI developments and ascertain their effects. However, the SDI knowledge base is quite limited (Georgiadou et al. 2005). Georgiadou and Blakemore's (unpublished) examination of articles in seven major geographic science journals yields a disappointing finding that only 5 percent of SDI-related articles are theoretically grounded and critical. They report that most of the works are focused on either technology or applications; the conceptual domain and social and organizational ramifications have been addressed the least. While a successful SDI balances the technology and application domains, it can hardly do so without a sound theoretical foundation. Without such a knowledge base, SDI development efforts are excessively driven by either technology or application and are unlikely to become fully operational and serve the expected purposes. The conceptual knowledge and framework are crucial for informing the technological and institutional choices in a variety of circumstances and for capitalizing on the SDI promise to aid problem solving and decision making in different application realms.

In this paper, we attempt to expand the SDI theoretical base by reviewing the literature on five potentially useful knowledge areas. We first briefly identify the existing SDI research and its gaps. We then point to sources in the areas of (1) information infrastructure (II), (2) interorganizational collaboration-cooperation-coordination (3C), (3) intergovernmental relations (IGR), (4) actor network theory (ANT), and (5) use-utility-usability (3U) of information systems. We summarize the value and limitations of the reviewed knowledge areas and propose a tentative but pragmatic conceptual framework encompassing some of the key concepts. Those five fields are not comprehensively treated, and a more extensive literature review would present them more accurately and fully. Our objective is to provide information that would raise awareness of the potential that those areas bring to advancing SDI research and practice and furthering the transformation of the current worldwide SDI initiatives into functional infrastructures.

SDI RESEARCH

Masser (2005a) maintains that an SDI:

> . . . supports ready access to geographic information. This is achieved through the coordinated actions of nations and organizations that promote awareness and implementation of complementary policies, common standards and effective mechanism for the development and availability of interoperable digital geographic data and technologies to support decision making at all scales for multiple purposes. These actions encompass the policies, organizational remits, data, technologies, standards, delivery mechanisms, and financial and human resources necessary to ensure that those working at the (national) and regional scale are not impeded in meeting their objectives (p. 16).

This definition emphasizes the following three areas that underpin all SDIs:

1. Policy and organization (organizational, institutional, management, financial, political, and cultural issues)
2. Interoperability and sharing (backbone of SDIs)
3. Discovery, access, and use of spatial data (main purpose of SDIs)

Limited but important and encouraging seed research has been conducted in all three areas.

Policy and organization. After a decade of SDI initiation worldwide, research has begun to focus on various aspects of "second generation SDI" (Rajabifard et al. 2003). Georgiadou et al. (2005) underscore the shift from data-centric research to the notion of infrastructure; Masser (2005b) and Rajabifard et al. (2003) promote a shift from a product to a process model; Coleman et al. (2000) and Craig (2005) address human resources and leadership; Bernard and Craglia (2005) emphasize important but scarce research on the socioeconomic impact; Georgiadou and Blakemore (unpublished) sound a warning about the Western-centric and technical nature of most of the ongoing research and call for a globally relevant research program centered on the human component.

The most frequent organizational approach to SDIs is hierarchical (Rajbifard et al. 2003), with a network model as an alternative. In his evaluation of first-generation SDIs, Masser (1999) provides a generic model of national SDIs or SDI-like centers and, like most other authors, describes the growth and organization of some of the major SDI-related organizations (e.g., EUROGI, PCGIAP, Global Map; Victoria's Property Information Project) as a source of learning (Jacoby et al. 2002; Lachman et al. 2002; Masser et al. 2003). It is clear, however, that existing organizational and institutional arrangements often impede SDI advancement, and new organizational and institutional mechanisms are needed (Kok and Loenen 2005; Masser 2005b).

Interoperability and sharing. Despite the enhanced data transfer capabilities allowed by advances in information and communication technologies (ICT) and the World Wide Web in particular, sharing of spatial information is still impeded by substantial noninteroperability. This noninteroperability can be broadly classified into two categories: technical and nontechnical. According to Bishr (1998), technical interoperability has six levels: (1) network protocols, (2) hardware and operating systems, (3) spatial data files, (4) database management systems (DBMS), (5) data models, and (6) semantics. He argues that the first four items have been reasonably resolved, and research in federated database systems is expected to contribute to resolving the fifth one. The sixth one—semantics of geographic information—is addressed by a number of researchers (Bishr 1998; Fonseca et al. 2000; Harvey et al. 1999; Klien et al. 2006; Kuhn 2003; Nogueras-Iso et al. 2005; Pundt and Bishr 2002; Visser et al. 2002) and has recently benefited from a discussion of spatial ontologies (Mark et al. 2000).

In data sharing, however, nontechnical interoperability (or soft interoperability as termed by Nedović-Budić and Pinto 2001) is more challenging than the technical issues. The impediments to sharing have been identified, although the solutions to overcome them are not easily deployed (Azad and Wiggins 1995; Craig 1995; Montalvo 2003; Nedović-Budić and Pinto 1999a, 1999b; Nedović-Budić et al. 2004; Pinto and Onsrud 1995). For example, Craig (2005) argues that key individuals can make a difference in a sharing scenario; Harvey (2003) underscores trust as the most important mutual feature of the sharing entities; Nedović-Budić et al. (2004) comprehensively discuss the process and determinants of interorganizational sharing. While all these solutions are quite pragmatic and relevant to SDI policy, they are yet to be fully applied in practice.

Spatial data discovery, access, and use. Discovery of and access to spatial data are necessary initial steps in SDI use, and true SDI utility is demonstrated with a wide variety of users (Masser 2005a; Williamson 2003). The discovery of spatial data is facilitated through metadata catalogues (Craglia and Masser 2002; Craig 2005; Smith et al. 2004) and relies on metadata standards (Kim 1999). Recently, some of the metadata systems deploying a multiplicity of national and technical standards have been gradually adopting the international ISO 19115 standard, and translations have been created between different metadata standards (Nogueras-Iso et al. 2004). There are also a few preliminary assessments of the usability of the metadata standards (Fraser and Gluck 1999; Walsh et al. 2002). Several studies discuss other aspects of geoportals as gateways to SDI: Bernard et al. (2005), Maguire and Longley (2005), and Tait (2005) focus on the capabilities of second-generation geoportals to access spatial data and services; Askew et al. (2005) and Beaumont et al. (2005) describe the UK experience in building on the government's ICT investments and the difficulties in developing geoportal-related partnerships due to different levels of technological experience, goals, and expectations among the partners.

Access to spatial information is usually measured as portal hits. For example, the Geography Network receives (an encouraging) 300,000 hits by an estimated 50,000 users per day (Tait 2005). The use of spatial information seems to fall a bit behind, with some preliminary indications that contemporary SDIs do not fulfill their purpose and expectations. Crompvoets et al. (2004) report that user-unfriendly interfaces and the discipline-specific nature of metadata and clearinghouses are among the primary reasons for the declining trend in clearinghouse use. Nedović-Budić et al. (2004), in their evaluation of the use of SDIs for local planning in Victoria, Australia, and Illinois, United States, also conclude that SDIs do not effectively serve local needs. These studies reinforce the findings from a large-scale survey conducted in the United States by Tulloch and Fuld (2001) who find that using framework data in an SDI environment is challenging both technically and institutionally—technically because these data are in various formats and of different accuracies and institutionally because the data producers are not fully prepared to share data.

SDI RESEARCH GAPS

Without claiming to be exhaustive and specific, we identify the following gaps in the current SDI literature and invite the research community to direct their future work to these general areas and many potential topics within them.

Definition and conceptualization. The many definitions of SDI (Rajabifard et al. 2003) differ in emphasis and purpose, and no clear consensus on the concept of SDI and its constituting elements and principles exists. While a multiplicity of definitions and meanings is not unusual for any phenomenon, it tends to frustrate research and development. Similarly, literature does not help much in differentiating between GIS and SDI and specifying their unique roles and relationships. For example, Bishop et al. (2000) believe that a GIS cannot be built without an SDI, whereas Georgiadou et al. (2005) argue that an SDI requires a strong GIS base. Inconsistent definitions and concept operationalizations result in ambiguous research findings and prevent comparison of studies conducted independently on the same subject (Budić 1994). In essence, they stand in the way of building a coherent body of SDI knowledge.

Models. Although the hierarchical model corresponds closely to current efforts at creating SDIs at different administrative levels, more complex horizontal and vertical interactions require further exploration and more elaborate representation. An alternative model (or models) is needed to outline SDI presence and use across all levels and organizational configurations and to accommodate all relevant participants. Public access, in particular, is a crucial component of the connectivity claimed by SDIs. While the general public is anticipated to eventually be the largest SDI user group (Dangermond 1995; McKee 2000), very few sources discuss the issue of public access and explicitly include it in SDI modeling and building attempts.

Standards. Other than the sporadic migration to ISO standards by some national SDIs, little is known about which standards are used in SDIs worldwide. Moellering (2005) started to fill this gap by reviewing metadata technical requirements and developments around the globe, including many international and national examples. Still, robust empirical work on metadata systems is lacking, for example, in terms of their matching the users' mental models, their value in assessing the fitness-for-use of the underlying data, and the complementary use of social networks in data discovery. Moreover, research on substantive standards and compliance to them in a variety of data domains is important for advancing the possibilities for transfer, sharing, and use of spatial information.

Monitoring and evaluation. Ongoing SDI research is more focused on access to spatial data than on the use and utility of the infrastructure. With utility in mind, looking at the process of SDI establishment comprehensively from conception to operation will help create a more relevant and useful infrastructure. Beyond counting portal hits, there is no clear evidence about who the users are, what they are using the information for, and how well they are served by the geoportals (Askew et al. 2005). In general, continuous monitoring and evaluation should contribute to establishing effective and valuable SDIs. Georgiadou et al. (2006)

suggest a variety of methodologically rigorous evaluation approaches suited to progressively complex foci on data, services, and E-governance. The formation of a new Spatial Data Interest Community on Monitoring and Reporting (SDIC MORE 2005) in conjunction with the implementation of the Infrastructure for Spatial Information in Europe (INSPIRE) testifies to the importance of tracking the establishment, contents, and use of SDIs. The group, however, is only beginning to identify indicators and monitoring mechanisms and procedures.

Balancing the technical and the social. We need to better understand the interaction between the technical and the nontechnical, but research efforts have been mostly limited to one or the other. In reality, the two realms interact and influence each other to give rise to a whole new set of factors, which are calibrated through a mutual adjustment between the two (Nedović-Budić 1997). Timely involvement of prospective users in the development of SDIs will contribute to enhanced usability and overall success. The diverse backgrounds and often limited skills of nonspecialists require approaches different from the ones taken for specialist users. The traditional information system development methodology of technology-centered design may work for small systems but is inadequate and too risky for SDIs. In addition, capacity building has to be included as an inherent part of SDI development (Enemark and Williamson 2004; Georgiadou and Groot 2002; Masser 2004; Williamson et al. 2003).

Politics and policy. SDIs are also susceptible to geopolitical, economic, and sociocultural issues and all the associated opportunities and threats of cyber spaces and interactions (Pickels 2004). This is particularly obvious for national SDIs, which often exhibit centralizing tendencies that run counter to federated and devolutionary system concepts. The SDI community cannot afford to overlook the relationship between the state and geographic information and thereby become a nonplayer in addressing this crucial dimension of SDI policy.

Multi- and interdisciplinary approach. SDIs draw on knowledge from many disciplines, including but not limited to sociology, cognitive science, political science, organizational studies, economics, and computer and information science (Masser 2005b). Current research, however, tends to be inward oriented, failing to reach out to other disciplines and their theories, concepts, and frameworks.

In sum, the current SDI knowledge base is not sufficient to inform development of sustainable SDIs. Therefore, in agreement with Georgiadou et al. (2005) and Masser (2005b), we direct the attention of the SDI academic and professional community toward alternative sources. The following section provides a brief overview of five key knowledge areas that can strengthen the SDI theoretical and conceptual foundation.

FIVE KNOWLEDGE AREAS

Information infrastructure. Most literature considers information infrastructure (II) in a rather narrow sense within a specified domain, for example, biology (Sepic and Kase 2002), urban planning (Langendorf 2001), academia (Begusic et al. 2003; Cramond 1999; Sepic and Kase 2002), or media (Anderson et al. 1994). Some view the Internet as II, while others equate the digitalization of libraries with II. However, the II envisioned by the former U.S. Vice President Al Gore, the U.S. Information Infrastructure Task Force (1993), and the European Union task force (Bangemann Group 1994) has much broader expectations and ramification for all sectors of society. A number of researchers also move from the domain-specific to the broad societal front and attempt to develop the general II conceptual base (Hanseth and Monteiro 1998, 2004; Monteiro 1998; Monteiro and Hanseth 1995; Star and Ruhleder 1996) (table 1). They suggest that all IIs build on their technological and social installed base and maintain that IIs are open and support any number of users and their diverse needs. These authors view information infrastructures as not only gradually expanding but also transforming, as work practices are continuously inscribed in them.

Star and Ruhleder (1996) argue that IIs cannot be independently built and maintained, but rather, they emerge through practice and get connected to other activities and structures. They criticize the highway metaphor of II as technology biased. Similarly to Borgman (2000), they view IIs as much more than the physical substrate and consider broader social relations integral to IIs. Hanseth and Monteiro (2004) suggest that some of the II characteristics may be present in certain information systems (IS), especially in interorganizational systems (IOS) or distributed information systems (DIS), and therefore, some commonalities and overlapping characteristics exist between IS and II. They state that IIs are initiated when (1) new and independent actors become involved in the development of an IOS or DIS, so that development is not controlled by one actor anymore, or

Star and Ruhleder (1996)	
Embeddedness	Infrastructure is "sunk" into (inside of) other structures, social arrangements, and technologies
Transparency	Infrastructure is transparent in use, in the sense that it does not have to be reinvented each time or assembled for each task but invisibly supports those tasks
Reach or scope	This may be either spatial or temporal—infrastructure has reach beyond a single event or one-site practice
Learned as part of membership	The taken-for-grantedness of artifacts and organizational arrangements is a *sine qua non* of membership in a community of practice. Strangers and outsiders encounter an infrastructure as a target object to be learned about. As they become members, new participants acquire a naturalized familiarity with its objects.
Links with conventions of practice	Infrastructure both shapes and is shaped by the conventions of a community of practice
Embodiment of standards	Modified by scope and often by conflicting conventions, infrastructure takes on transparency by plugging into other infrastructures and tools in a standardized fashion
Installed base	Infrastructure does not grow *de novo;* it wrestles with the "inertia of the installed base" and inherits strengths and limitations from that base
Becomes visible upon breakdown	The normally invisible quality of a working infrastructure becomes visible when the infrastructure breaks down
Hanseth and Monteiro (2004)	
Enabling	Infrastructures have a supporting or enabling function
Shared	An infrastructure is shared by a large community (collection of users and user groups)
Open	Infrastructures are open and support heterogeneous environments
Sociotechnical network	Information infrastructures are more than "pure" technology; rather, they are sociotechnical networks
Ecology of networks	Infrastructures are connected and interrelated, constituting ecologies of networks
Installed base	Infrastructures evolve by extending and improving the installed base

Table 1. Characteristics of information infrastructures.

Compiled from Star and Ruhleder 1996; Hanseth and Monteiro 2004.

(2) one of the design objectives for IOS or DIS is growth and transformation into an II (or a part of an II) in the future.

Interorganizational collaboration-cooperation-coordination. The IS literature reinforces the argument that organizational complexities increase further in interorganizational contexts and therefore require different information system development, management, and use practices (Doherty and King 2001; Lambert and Peppard 1993; Mahring et al. 2004; Suomi 1994; Williams 1997). The elements of interorganizational collaboration-cooperation-coordination (3C) are often necessary for IOS or DIS implementation and successful operation. Cooperation covers the middle ground between collaboration and coordination, with the former being least intensive and most autonomous and the latter being most intensive and least autonomous (McCann 1983).

The essential elements in studying interorganizational exchange include organizational exchange theory (Cook 1977), determinants of interorganizational relationships (including necessity, asymmetry, reciprocity, efficiency, stability, and legitimacy; Oliver 1990), and organizational interdependence (Thompson 1967). Levine and White (1969) define exchange as “any voluntary activity between two organizations which has consequences, actual or anticipated, for the realization of their respective goals or objectives” (p. 120). Exchange is usually sought with the minimum loss of organizational autonomy and power and depends on the availability of alternative resources. Thompson (1967) identifies three types of organizational interdependences: pooled, sequential, and reciprocal (in the order of increasing complexity). Kumar and van Dissel (1996) provide a typology of interorganizational systems based on type of interdependence (table 2). Meredith (1995) postulates that already existing organizational interdependence will reduce resistance to interorganizational sharing. This is particularly true for cooperative interdependence (Tjosvold 1988). However, increased

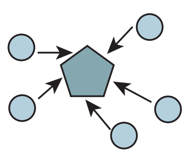
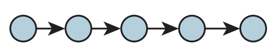
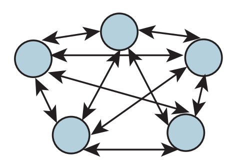
Dimension	Characteristic for the following type of interdependence		
	Pooled	Sequential	Reciprocal
Configuration			
Coordination mechanisms	Standards and rules	Standards, rules, schedules, and plans	Standards, rules, schedules, plans, and mutual adjustment
Technologies	Mediating	Long-linked	Intensive
Structurability	High	Medium	Low
Potential for conflict	Low	Medium	High
Type of IOS	Pooled information resource IOS	Value/supply-chain IOS	Networked IOS
Implementation technologies and applications	Shared databases, networks, applications, electronic markets	EDI applications, voice mail, facsimile	CAD/CASE data interchange, central repositories, desktop sharing, videoconferencing

Table 2. Organizational interdependence.

interdependence and need for cooperation can in some networked organizations lead to conflicts over authority, jurisdiction, and distribution of power (Ekbia and Kling 2005; Kumar and van Dissel 1996). The interdependence and greater mutual resources also tend to increase the number of decision points and thus constrain joint actions and diminish the probability of successful implementation (Aiken and Hage 1968; Pressman and Wildavsky 1984).

Finally, underlying the discussion of the value and importance of 3C to interorganizational IS and database activity is the need to identify the motivations that would impel organizational units to get actively involved in multiparty relationships and projects. A number of factors contribute to the perceived need to seek out interorganizational geographic information relationships, whether they are voluntary or mandated (Cummings 1980). Gray (1989) refers to achievement of a shared vision and conflict resolution as the two main motivators of collaborative organizational design.

According to O'Toole and Montjoy (1984), coordination can be based on (1) authority (i.e., obligation), (2) common interest, or (3) exchange inducements based on expected or received returns.

Intergovernmental relations. As much as interorganizational systems and databases are manifestations of interorganizational relationships (Kumar and van Dissel 1996), in the public sector they also reflect models of government and intergovernmental relations (IGR). According to Cameron (2001), IGR vary along three dimensions: degree of institutionalization, extent of decision making, and level of transparency. IGR also relate directly to political and administrative decentralization (Koike and Wright 1998). For a federal context like the United States, Australia, and potentially the European Union, Agranoff (2001) proposes the pattern of intergovernmental interaction known as cooperative federalism, consisting of the following elements: federalist theory, administrative techniques, dual government structure, and context-specific cooperation. Nice and Frederickson (1995) advance a few alternative models of federalism: competitive (nation-centered, state-centered, and dual federalism), interdependent (cooperative, creative, and new federalism), and functional ("picket fence" and "bamboo fence" federalism). O'Toole (1985) differentiates between federalist models with overlapping authority, coordinative authority, and inclusive authority.

Politics are inherent in government at all levels—local, national, and international. The evolution of government toward the practice of governance[1] that is increasingly accepted worldwide more explicitly incorporates intergovernmental relations among a broader set of stakeholders and interest groups involved in decision-making processes. The increasingly participative but also politicized environment is not uncommon to collaborative alliances formed around interorganizational information systems (Kumar and van Dissel 1996). In addition to changes in institutions and the political and economic context, the intensified use of information and communication technologies (ICTs) also influences the models of governance and democratic processes (Falch 2006). For example, Radin and Romzek's (1996) comparison of Weberian and virtual bureaucracies (table 3) demonstrates how ICTs facilitate transformations from government to governance. Furthermore, Fountain's (2001) analytical framework (figure 1) relates organizational forms and institutional arrangements to the process of technology

Weberian bureaucracy	Virtual bureaucracy
Functional differentiation, precise division of labor, clear jurisdictional boundaries	Information structured using information technology rather than people; organizational structure based on information systems rather than people
Hierarchy of offices and individuals	Electronic and informal communication; teams carry out the work and make decisions
Files, written documents, staff to maintain and transmit files	Digitized files in flexible form, maintained and transmitted electronically using sensors, bar codes, transponders, handheld computers; chips record, store, analyze, and transmit data; systems staff maintain hardware, software, and telecommunications
Employees are neutral, impersonal, attached to a particular office	Employees are cross-functional, empowered; jobs limited not only by expertise but also by the extent and sophistication of computer mediation
Office system of general rules, standard operating procedures, performance programs	Rules embedded in applications and information systems; an invisible, virtual structure
Slow processing time due to batch processing, delays, lags, multiple handoffs	Rapid or real-time processing
Long cycles of feedback and adjustment	Constant monitoring and updating of feedback; more rapid or real-time adjustment possible

Table 3. Weberian and virtual bureaucracies

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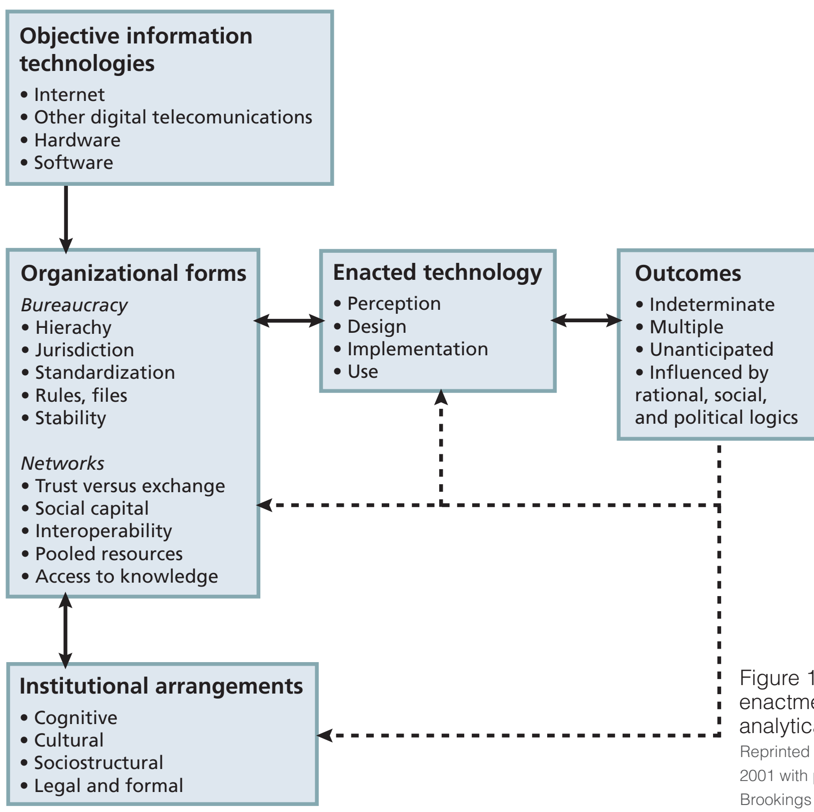

Figure 1. Technology enactment: an analytical framework.

Reprinted from Fountain 2001 with permission of Brookings Institution Press.

enactment. The author suggests that different cognitive, cultural, sociostructural, and legal forms are required for hierarchical and network organizations.

Actor network theory. Actor network theory (ANT) is often used instead of conventional social theory (e.g., Giddens 1979; structuralist theory) to examine and explain the interaction between information technology and society (Hanseth et al. 2004; Monteiro and Hanseth 1995). ANT applies semiotics in explaining social phenomena and their attributes and forms as resulting from relations with other entities; in addition, all entities have to satisfy the performativity aspect of ANT, in other words, to be performed in, by, and through those relations (Law and Hassard 1999). The focus is on undoing the artificial boundaries between social and technical systems and related processes. For example, Faraj et al. (2004) employ ANT in their study of the complex interdependences that characterize the evolution of Web browsers and demonstrate that technological and human agents are inseparable in constructing new sociotechnical artifacts.

According to Callon (1986) and Mahring et al. (2004), creation of an actor network, which is also called translation, consists of four major stages: problematization, interessement (recruitment), enrollment, and mobilization (table 4). The translation process does not have to pass through all four phases and may fail at any stage. In addition to translation, there is the process of inscription of ideas in given technologies; as those technologies diffuse within specific contexts, they are assigned relevance and help achieve sociotechnical stability (Latour 1987). Another ANT phenomenon is irreversibility, which is the degree to which a network can be brought back to a state where alternative possibilities exist. Hanseth and Monteiro (1998) find that irreversibility is due to the inscription of interests into technological artifacts, whereby those individual and organizational interests customize the system and become increasingly difficult to change. In the context of changing but sometimes irreversible networks, the authors propose three actor network configurations (elements of decomposition): disconnected networks, gateways, and polyvalent networks.

Use, utility, and usability of information systems (3U). Although the terms "usability" and "usefulness" (referred to in this work as "utility") are often

Problematization	An actor initiating the process (also called focal actor) defines the identities and interests of other actors that are consistent with the interest of the focal actor. In this initial stage of building the actor network, some actors position themselves as indispensable for solving the problems defined. They define the problem and solution and also the identities and roles for other actors in the network.
Interessement (recruitment)	Convincing other actors that the interests defined by focal actors are in line with their own interest. Depending upon situation, this phase also involves creating incentives for actors so that the obstacles to bringing these actors into the network are overcome. A successful recruitment confirms the validity of problematization, locks new actors into the network, and corners the entities that are not yet co-opted.
Enrollment	The roles of the actors in the newly created network are defined. The focal actor strives to convince other actors to fully embrace the underlying ideas of the growing network and become an active part of the mission. Multilateral negotiation takes place.
Mobilization	Focal actor makes sure that all actors are acting in accordance with the underlying spirit of the network mission. The focal actor seeks continued support from all the enrolled actors in order to keep the network stable. The actors are mobilized to further stabilize and institutionalize the network.

Table 4. Actor network theory: stages of translation.

Adapted from Callon 1986 and Mahring et al. 2004.

employed interchangeably in the context of ICT systems, they are not equivalent. Blomberg et al. (1994) suggest that "usability refers to the general intelligibility of systems, particularly at the interface; usefulness means that a system's functionality actually makes sense and adds value in relation to a particular work setting" (p. 190). The concept of effective use subsumes both usability and usefulness. Effective use of ICTs, according to Gurstein (2003), is the capacity and opportunity to successfully integrate these technologies to achieve the users' self-defined or collaboratively defined goals, and it requires carriage facilities (i.e., appropriate communication infrastructure), input/output devices, tools and supports, content services, service access/provision, social facilitation (e.g., network, leadership, training), and governance. In the IS realm, DeLone and McLean (1992) suggest the amount and duration of use (e.g., number of functions performed, reports generated, charges, frequency of access) and nature and level of use as objective measures.

Although the post–World War II growth of scientific literature marked the beginning of a more systematic study of information systems, the focus of research efforts did not shift from technology to information users and their behavior until the 1980s (Wilson 1994, 2000). Consequently, the design of information systems and services started to shift from system-centered to user-centered approaches and sociotechnical designs (Eason 1988). User study is now a well-established area of information science (Bates 2005; Dervin and Nilan 1986; Dervin 1989; Foster 2004; Lamb and Kling 2003; Leckie et al. 1996; Orlikowski and Gash 1994; Savolainen 1995; Stewart and Williams 2005; Taylor 1991). Among the questions it poses are the following: How do people seek information? How is information put to use? How do information needs and activities change over time? The user-centered studies operate at two main levels of analysis: individual level (Attfield and Dowell 2003; Brashers et al. 2000; Chatman 1996; Cobbledick 1996; Ellis 1993; Savolainen 1995) and organizational level (Lamb and Kling 2003; Leckie et al. 1996; Orlikowski and Gash 1994; Taylor 1991).

In addition to individual-level studies that consider users in a more passive fashion (i.e., as relevant but not substantially influential and powerful participants), there is a prominent trend of viewing users as innovators, "sense-makers," and "domesticators" of information technologies and systems (Bruce and Hogan 1998; Dervin 1989; Griffith 1999; Stewart and Williams 2005; Williams 1997). The central tenet of domestication and its associated concept of idealization-realization of technology (Bruce 1993) is that technology gets appropriated and its meaning is constructed by situated use. By implication, designers cannot design the system; they can only invoke the design process. It is through the users' continued appropriation that an information system and services become useful.

CONCLUSIONS

This paper was motivated by the increasingly recognized failure of SDI research and practice to both utilize the existing theoretical and empirical knowledge base and develop its own conceptual framework. The majority of contributions to gray and refereed literature tend to be anecdotal, unsystematic, and isolated from the broader scientific discourse. This situation limits the development of functional and relevant SDIs worldwide. The importance of expanding the knowledge base is even more obvious when considering the magnitude and multiplicity of challenges the SDI efforts face, including politics, finance, technical capacity, human resources, and utility. In this paper we offer a substantial overview of existing SDI research, point to research gaps, and review five areas as potential major resources for strengthening the SDI conceptual base: information infrastructure, interorganizational collaboration-cooperation-coordination, intergovernmental relations, action network theory, and use-utility-usability of information systems (table 5). Figure 2 shows a tentative but pragmatic conceptual framework for SDI development.

Conceptual framework derived from the expanded SDI knowledge base. The notions of information infrastructure and of the installed base, in particular, are useful in taking a deeper look at SDIs. The concept of the installed base implies that the existing technical systems (e.g., hardware, software, and data) and organizational structures (e.g., human resources and skills, management practices, and legal arrangements) may play facilitating or constraining roles. Infrastructure openness implies that SDIs should accommodate a growing number of heterogeneous actors and artifacts. Georgiadou et al. (2005) incorporate some of these concepts in analyzing the Indian NSDI. The usefulness of the concepts, however, needs to

Knowledge area	Key premises	Value for SDI	Limitations
II	Open, transparent, standardized, and widely accessible network based on Internet and other ICT, serving a broad set of users and communities	Special type of infrastructure and the notion of the installed base	Factors, strategies, and processes for developing IIs are not elaborated or tested
3C	Interorganizational systems require 3C; they relate to interorganizational interdependences, involve complex mechanisms, and carry potential for conflict	Information sharing and exchange are fundamental to SDIs; successful 3C is necessary for SDIs to become functional and relevant	Focus on private corporations and profit maximization; difficulty in identifying viable motivators in the public sector
IGR	Models of governments and societal decision making range on a continuum from centralized to decentralized (including federalist), with different types of authority and administrative approaches	Governments at all levels are the majority stakeholders of SDIs; SDIs build upon and adjust to (as well as affect) intergovernmental settings and relationships; SDIs are an element of the envisioned virtual bureaucracy	Nongovernmental actors—private sector, academia, nonprofit organizations, and population at large (citizen associations and interest groups)— are not addressed
ANT	All phenomena take their form and attributes in relation to other entities and are "performed" in, by, and through them; membership grows through a process of translation (problematization, interessement, enrollment, and mobilization)	SDIs are often modeled as hierarchies, but they are more likely to evolve as networks and Internet-based access points to acquiring data and services; the translation process is one way of understanding and cultivating SDIs	Flexibility and uncertainty do not easily translate into implementable models; more a method for explaining and interpreting reality than for acting on it to stimulate new developments
3U	Extending traditional IS focus with sociotechnical design, user involvement and action, and evaluation	Useful in bottom-up approaches; recognizing the major role of many potential SDI users and their creativity	Developed for single systems and organizations; needs rigorous evaluation methods to apply to the evolution of SDI from data and service to E-governance

Table 5. Key premises, value, and limitations of the five knowledge areas.

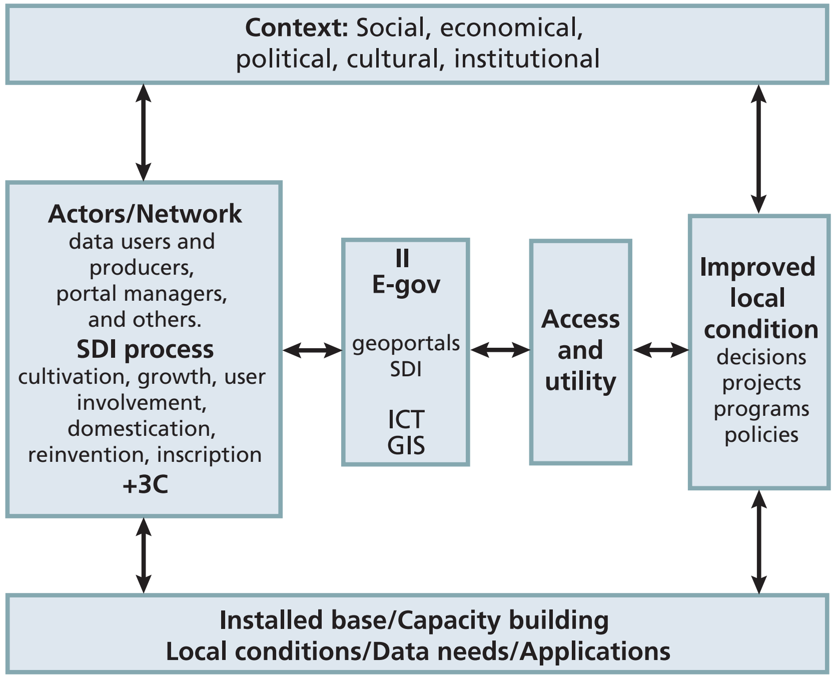

Figure 2. Proposed framework for SDI development.

be explored further. Creating SDIs with all the envisioned characteristics of a full-blown and operational infrastructure is not easy. Moreover, information infrastructures are neither created from a void nor completely designed. Rather, the process of "building" is replaced by "cultivation" of the sociotechnical installed base to gradually incorporate diverse actors in a networked environment. The cultivation approach has sufficient flexibility to accommodate local circumstances and practices. It also turns attention to capacity building needs at all levels, including the so-called "interagency collaborative capacity (ICC)" (Bardach 1998), individual agency GIS capacity (Mackay et al. 2002), and citizen/user capacity (Tettey 2002).

The ideas discussed in the studies on interorganizational relationships and 3C are useful and easily applied. The majority of studies on interorganizational IS are situated in the context of large corporations and employ productivity and maximization of profit as success criteria (Doherty and King 2001; Johnston and Gregor 2000; Munkvold 1999; Suomi 1992, 1994; Williams 1997). Interorganizational exchange and consensus are essential factors in SDI development. The 3C concept is employed in GIS research (Azad and Wiggins 1995; Craig 2005; Harvey 2001; Nedović-Budić and Pinto 1999b; Nedović-Budić et al. 2004) but remains incompletely exploited and leaves the question of how to successfully initiate and maintain SDI coalitions among diverse stakeholders incompletely answered. Also, in the context of the public sector, which prevails among SDI participants, understanding intergovernmental relations and the impact on and of E-governance would also be indispensable to establishing effective SDIs.

Actor network theory offers a rich perspective on how a network of aligned interests, as well as nested smaller networks, can be created with diverse human actors and heterogeneous technical systems. ANT provides a useful theoretical toolset to investigate the coalitions required for SDIs to become functional and effective within the context of overall societal progress. Though few researchers apply actor network theory to study GIS activities (Harvey 2001; Martin 2000; Walsham and Sahay 1999), they use it within a limited organizational context and do not employ it in studying the creation of SDI networks. But more generally, we find that ANT has more facility in research than in practice. It is more helpful for observing and interpreting sociotechnical networks than for developing viable relations among targeted actors and ensuring specific outcomes of such relations.

Between usability and utility, the latter is certainly more relevant for studying large-scale infrastructures such as SDIs. The user perspective, in general, has gained widespread popularity. Gurstein's (2003) framework of effective use of information resources is applicable to SDIs. It reveals that there are other important organizational and social structures that can enable or limit SDIs. The lens of effective use thus allows us to see SDIs beyond the current paradigm of provision of and access to geospatial information. In the words of Stewart and Williams (2005, p. 2):

> Design outcomes/supplier offerings are inevitably unfinished in relation to complex, heterogeneous and evolving user requirements. Further innovation takes place as artifacts are implemented and used. To be used and useful, ICT artifacts must be 'domesticated' and become embedded in broader systems of culture and information practices. In this process artifacts are often reinvented and further elaborated.

Despite the convincing criticism of the traditional user-centered and sociotechnical approaches and their limited applicability to single systems and organizations, the proponents of more radical views have not operationalized their ideas or offered practical solutions that can be implemented in actual development projects. In huge systems like SDIs, identifying who the potential users are and how to represent them in the process of an evolving SDI remains difficult. The complexities of SDIs require further studies of use and users and continuous monitoring and evaluation. The challenges, however, should not undermine the essential importance of strong representation and active participation of users as "domesticators," "sensemakers," and "innovators" who ultimately evaluate the utility of SDIs.

The literature discussed in this paper suggests the following conceptual base: cultivation approach to SDI; focus on SDI users, access, and derived utility; capacity building in the installed base; understanding of the networking relationships and attributes of data users, producers, and managers; incorporation of 3C principles and opportunities; attention to intergovernmental relations and the emerging trends in E-governance; capitalizing on mutually interdependent and supporting roles of GIS, ICT, and II; and evaluation of SDIs in terms of their ultimate goal of improving local conditions by enabling various communities and stakeholders to get involved in decision-making processes and affect implementation of local projects, policies, and programs. Last but not least, all SDI activities and participants are situated within specific societal, cultural, and institutional contexts.

All these elements constitute the core of the proposed conceptual framework. However, the framework is only preliminary and intended to serve as a starting point for integration of the multi- and interdisciplinary knowledge base in studying and developing SDIs worldwide.

The five knowledge areas discussed in this paper are by no means sufficient or exhaustive sources for informing SDI research and practice. In fact, none of them individually offers a comprehensive knowledge base required to develop and sustain SDI networks. Knowledge areas of policy implementation, federated databases and systems development, capacity building, and public administration and finance are worth considering as well. In addition, the literature on technical concepts and models, which are also important but often less challenging, is not addressed in this paper. The five selected areas are used to illustrate the wealth of concepts and theories available and accessible to academics and professionals interested in SDIs. The expanded knowledge base provides better information for both studying and developing SDIs. By incorporating existing theoretical and empirical knowledge from other relevant fields, the SDI community will not only avoid reinventing the wheel but also be more effective in establishing SDIs and furthering scientific discourse with new insights, ideas, concepts, theories, and applications. Most importantly, the long-awaited societal benefits are more likely to emerge with SDIs that are guided by intelligence from the past as a basis for creativity and innovations for the future.

ENDNOTE

1. According to Stewart (2003), ". . .'[g]overnment' can be defined as the activity of the formal governmental system, conducted under clear procedural rules, involving statutory relationships between politicians, professionals and the public, taking place within specific territorial and administrative boundaries. It involves the exercise of powers and duties by formally elected or appointed bodies, and using public resources in a financially accountable way. 'Governance' is a much looser process often transcending geographical or administrative boundaries, conducted across public, private and voluntary/community sectors through networks and partnerships often ambiguous in their memberships, activities, relationships and accountabilities. It is a process of multistakeholder involvement, of multiple interest resolution, of compromise rather than confrontation, of negotiation rather than administrative fiat" (p. 76). In governance, transaction costs are minimized, trust maximized, and collaborative advantage extracted.

REFERENCES

Agranoff, Robert. 2001. Managing within the matrix: Do collaborative intergovernmental relations exist? *Publius* 31 (2): 31–56.

Aiken, Michael, and Jerald Hage. 1968. Organizational interdependence and intra-organizational structure. *American Sociological Review* 33 (6): 912–30.

Anderson, Rachael K., Alice Haddix, Jeannette C. McCray, and Timothy P. Wunz. 1994. Developing a health information infrastructure for Arizona. *Bulletin of the Medical Library Association* 84 (2): 396–400.

Askew, David, Sharon Evans, Ruth Matthews, and Phillipa Swanton. 2005. MAGIC: A geoportal for the English countryside. *Computers, Environment and Urban Systems* 29 (1): 71–85.

Attfield, Simon, and John Dowell. 2003. Information seeking and use by newspaper journalists. *Journal of Documentation* 59 (2): 187–204.

Azad, Bijan, and Lyna L. Wiggins. 1995. Dynamics of inter-organizational geographic data sharing: A conceptual framework for research. In *Sharing geographic information,* eds. Harlan J. Onsrud and Gerard Rushton, 22–43. New Brunswick, NJ: Center for Urban Policy Research.

Bangemann Group. 1994. *Europe and the Global Information Society.* Recommendations of the high-level group on the information highway to the Corfu European Council.

Bardach, Eugene. 1998. *Getting agencies to work together: The practice and theory of managerial craftsmanship.* Washington, DC: Brookings Institution Press.

Bates, Marcia J. 2005. An introduction to metatheories, theories, and models. In *Theories of information behavior, ASIST Monograph Series,* eds. Karen E. Fisher, Sanda Erdelez, and Lynne E. F. McKechnie, 1–24. Medford, NJ: Information Today.

Beaumont, Peter, Paul A. Longley, and David J. Maguire. 2005. Geographic information portals: A UK perspective. *Computers, Environment and Urban Systems* 29 (1): 49–69.

Begusic, Dinko, Nikola Rozic, and Hrvoje Dujmic. 2003. Development of the communication/information infrastructure at the academic institution. *Computer Communications* 26 (5): 472–76.

Bernard, Lars, and Max Craglia. 2005. SDI: From Spatial Data Infrastructure to Service Driven Infrastructure. *Position paper presented at research workshop on cross-learning between SDI and II.* International Institute for Geo-Information Science and Earth Observation (ITC). March 31–April 1. Enschede, Netherlands.

Bernard, Lars, Ioannis Kanellopoulos, Alessandro Annoni, and Paul Smits. 2005. The European geoportal: One step towards the establishment of a European Spatial Data Infrastructure. *Computers, Environment and Urban Systems* 29 (1): 15–31.

Bishop, Ian D., Francisco J. Escobar, Sadasivam Karuppannan, Ian P. Williamson, and Paul M. Yates. 2000. Spatial Data Infrastructures for cities in developing countries. *Cities* 17 (2): 85–96.

Bishr, Yaser. 1998. Overcoming the semantic and other barriers to GIS interoperability. *International Journal of Geographical Information Science* 12 (4): 299–314.

Blomberg, Jeanette, Lucy Suchman, and Randall H. Trigg. 1994. Reflections on a work-oriented design project. *Paper presented at the Participatory Design Conference (PDC'94).* October. Chapel Hill, North Carolina.

Borgman, Christine L. 2000. The premise and the promise of a Global Information Infrastructure. *Peer-Reviewed Journal of the Internet* 5 (8). http://www.firstmonday.org/issues/issue5_8/borgman/index.html (accessed January 15, 2006).

Brashers, Dale E., Judith L. Neidig, Stephen M. Haas, Linda K. Dobbs, Linda W. Cardillo, and Jane A. Russell. 2000. Communication in the management of uncertainty: The case of persons living with HIV or AIDS. *Communication Monographs* 67:63–84.

Bruce, Bertram C. 1993. Innovation and social change. In *Network-based classrooms: Promises and realities,* eds. Bertram C. Bruce, Joy K. Peyton, and Trent W. Batson, 9–32. Cambridge University Press, NY.

Bruce, Bertram C., and Maureen P. Hogan. 1998. The disappearance of technology: Toward an ecological model of literacy. In *Handbook of literacy and technology: Transformations in a post-typographic world,* eds. D. Reinking, M. McKenna, L. Labbo, and R. Kieffer, 269–81. Hillsdale, NJ: Erlbaum.

Budić, Zorica D. 1994. Implementation and management effectiveness in adoption of GIS technology in local governments. *Computers, Environment and Urban Systems* 18 (5): 295–304.

Butler, Al, Alan Voss, Dennis Goreham, and John Moeller. 2005. The national geospatial coordinating council: A dramatic new approach to build the NSDI. *GeoWorld,* October: 38–41.

Callon, Michel. 1986. Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St. Brieuc Bay. In *Power, Action and Belief: A new sociology of knowledge?* ed. John Law, 196–233. London: Routledge & Kegan Paul.

Cameron, David. 2001. *The structures of intergovernmental relations.* Oxford: Blackwell Publishers.

Chatman, Elfreda A. 1996. Impoverished life world of outsiders. *Journal of the American Society for Information Science and Technology* 47 (3): 193–206.

Cobbledick, Susie. 1996. The information-seeking behavior of artists: Exploratory interviews. *Library Quarterly* 66 (4): 343–72.

Coleman, David, Richard Groot, and John McLaughlin. 2000. Human Resources issues in the emerging GDI environment. In *Geospatial data infrastructure: Concepts, cases and good practice,* 1st ed., eds. Richard Groot and John McLaughlin, 233–44. New York: Oxford University Press.

Cook, Karen S. 1977. Exchange and power in networks of inter-organizational relations. *Sociological Quarterly* 18:62–82.

Craglia, Massimo, and Ian Masser. 2002. Geographic information and the enlargement of the European Union: Four national case studies. *Journal of the Urban and Regional Information System Association* 14 (2): 43–52.

Craig, William J. 1995. Why we can't share data: Institutional inertia. In *Sharing geographic information,* eds. Harlan J. Onsrud and Gerard Rushton, 107–18. New Brunswick, NJ: Center for Urban Policy Research.

Craig, William J. 2005. White knights of Spatial Data Infrastructure: The role and motivation of key individuals. *Journal of the Urban and Regional Information System Association* 16 (2): 5–13.

Cramond, Stephen. 1999. Efforts to formalize international collaboration in scholarly information infrastructure. *Library Hi Tech* 17 (3): 272–82.

Crompvoets, Joep, Arnold Bregt, Abbas Rajabifard, and Ian Williamson. 2004. Assessing the worldwide developments of national spatial data clearinghouses. *International Journal of Geographical Information Science* 18 (7): 665–89.

Cummings, Thomas G. 1980. Inter-organization theory and organizational development. In *Systems theory for organization development,* ed. Thomas G. Cummings. New York: John Wiley & Sons.

Dangermond, Jack. 1995. Public data access. In *Sharing geographic information,* eds. Harlan J. Onsrud and Gerard Rushton, 331–39. New Brunswick, NJ: Center for Urban Policy Research.

Dawes, Sharon S. 1996. Interagency information sharing: Expected benefits, manageable risks. *Journal of Policy Analysis and Management* 15 (3): 377–94.

DeLone, William H., and Ephraim R. McLean. 1992. Information systems success: The quest for the dependent variable. *Information Systems Research* 3 (1): 6–95.

Dervin, Brenda. 1989. Users as research inventions: How research categories perpetuate inequities. *Journal of Communication* 39 (Summer): 216–32.

Dervin, Brenda, and Michael Nilan. 1986. Information needs and uses. *Annual Review of Information Science and Technology (ARIST)* 21: 3–33.

Doherty, Neil, and Malcolm King. 2001. An investigation of the factors affecting the successful treatment of organizational issues in systems development projects. *European Journal of Information Systems* 10 (3): 147–60.

Eason, Ken. 1988. *Information technology and organizational change.* Taylor & Francis, London.

Ekbia, Hamid R., and Rob Kling. 2005. Network organizations: Symmetric cooperation or multivalent negotiation? *Information Society* 21 (3): 155–68.

Ellis, David. 1993. Modeling the information-seeking patterns of academic researchers: A grounded theory approach. *Library Quarterly* 63 (4): 469–86.

Enemark, Stig, and Ian Williamson. 2004. Capacity building in land administration: A conceptual approach. *Survey Review* 39 (294): 639–50.

Falch, Morten. 2006. ICT and the future conditions for democratic governance. *Telematics and Informatics* 23 (2): 134–56.

Faraj, Samer, Dowan Kwon, and Stephanie Watts. 2004. Contested artifact: Technology sensemaking, actor networks and the shaping of the web browser. *Information Technology & People* 17 (2): 186–209.

Feeney, Mary-Ellen F. 2003. SDIs and decision support. In *Developing Spatial Data Infrastructures: From concept to reality,* eds. Ian Williamson, Abbas Rajabifard, and Mary-Ellen F. Feeney, 195–210. Boca Raton: CRC Press.

Fonseca, Fred T., Max J. Egenhofer, Clodoveu A. Davis, Jr., and Karla A. V. Borges. 2000. Ontologies and knowledge sharing in urban GIS. *Computers, Environment and Urban Systems* 24:251–71.

Foster, Allen. 2004. A nonlinear model of information-seeking behavior. *Journal of the American Society for Information Science and Technology* 55 (3): 228–37.

Fountain, Jane E. 2001. *Building the virtual state: Information technology and institutional change.* Washington, DC: Brookings Institution Press.

Fraser, Bruce, and Myke Gluck. 1999. Usability of geospatial metadata or space-time matters. *American Society for Information Science* 25:24–28.

Georgiadou, Yola, and Michael Blakemore. A journey through GIS discourses. (Unpublished.)

Georgiadou, Yola, Orlando Rodríguez-Pabón, and Kate T. Lance. 2006. SDI and E-Governance: A quest for appropriate evaluation approaches. *Journal of Urban and Regional Information Systems* 18 (2): 43–55.

Georgiadou, Yola, Satish K. Puri, and Sandeep Sahay. 2005. Towards a potential research agenda to guide the implementation of Spatial Data Infrastructures: A case study from India. *International Journal of Geographical Information Science* 19 (10): 1113–30.

Georgiadou, Yola, and Richard Groot. 2002. Policy development and capacity building for geo-information provision. A global goods perspective. In *GIS@development: The monthly magazine on geographic information science* 6 (7): 33–40.

Giddens, Anthony. 1979. *Central Problems in Social Theory: Action, Structure and Contradiction in Social Analysis*. Berkeley, CA: University of California Press.

Gray, Barbara. 1989. *Collaborating: Finding common ground for multiparty problems*. San Francisco: Jossey-Bass Publishers.

Griffith, Terri L. 1999. Technology features as triggers for sensemaking. *Academy of Management Review* 24 (3): 472–488.

Groot, Richard. 2001. Reform of government and the future performance of national surveys. *Computers, Environment and Urban Systems* 25 (4–5): 367–87.

Gurstein, Michael. 2003. Effective use: A community informatics strategy beyond the digital divide. *First Monday* 8 (12).

Hanseth, Ole, Margun Aanestad, and Marc Berg. 2004. Actor-network theory and information system. What's so Special? *Information Technology & People* 17 (2): 116–23.

Hanseth, Ole, and Eric Monteiro. 1998. Changing irreversible networks. *Paper presented at the 6th European Conference on Information Systems,* Aix-en-Provence, 4–6 (June).

Hanseth, Ole, and Eric Monteiro. 2004. *Understanding Information Infrastructure*. (Forthcoming book).

Harvey, Francis. 2001. Constructing GIS: Actor networks of collaboration. *Journal of the Urban and Regional Information System Association* 13 (1): 29–37.

Harvey, Francis. 2003. Developing geographic information infrastructures for local government: The role of trust. *Canadian Geographer* 47 (1): 28–36.

Harvey, Francis, Werner Kuhn, Hardy Pundt, Yaser Bishr, and Catharina Riedemann. 1999. Semantic interoperability: A central issue for sharing geographic information. *The Annals of Regional Science* 33 (2): 213–32.

Gore, Al (former U.S. vice president) and Information Infrastructure Task Force. 1993. *The National Information Infrastructure: Agenda for Action*. Washington, DC.

Jacoby, Steve, Jessica Smith, Lisa Ting, and Ian Williamson. 2002. Developing a common spatial data infrastructure between state and local government: An Australian case study. *International Journal of Geographical Information Science* 16 (4): 305–22.

Johnston, Robert, and Shirley Gregor. 2000. A theory of industry-level activity for understanding the adoption of interorganizational systems. *European Journal of Information Systems* 9 (4): 243–51.

Koike, Osamu, and Deil S. Wright. 1998. Five phases of IGR in Japan: Policy shifts and governance reform. *International Review of Administrative Sciences* 64:203–18.

Kim, Tschangho J. 1999. Metadata for geo-spatial data sharing: A comparative analysis. *The Annals of Regional Science* 33 (2): 171–81.

Klien, E., M. Lutz, and W. Kuhn. 2006. Ontology-based discovery of geographic information services: An application in disaster management. *Computers, Environment and Urban Systems* 30:102–23.

Kok, Bas, and Bastiaan V. Loenen. 2005. How to assess the success of National Spatial Data Infrastructures? *Computers, Environment and Urban Systems* 29 (6): 699–717.

Kuhn, Werner. 2003. Semantic reference systems. *International Journal of Geographical Information Science* 17 (5): 405–9.

Kumar, Sundeep, and Han G. van Dissel. 1996. Sustainable collaboration: Managing conflict and cooperation in interorganizational systems. *MIS Quarterly* 20:279–300.

Lachman, Beth E., Anny Wong, Debra Knopman, and Kim Gavin. 2002. *Lessons for the Global Spatial Data Infrastructure: International Case Study Analysis*. Santa Monica: Rand Co.

Langendorf, Richard. 2001. Computer-aided visualization: Possibilities for urban design, planning and management. In *Planning Support Systems: Integrating GIS and Visualization Tools,* eds. Richard Brail and Richard Klosterman, 309–59. Redlands, CA: ESRI Press.

Lamb, Roberta, and Rob Kling. 2003. Reconceptualizing users as social actors in information systems research. *MIS Quarterly* 27 (2): 197–235.

Lambert, Rob, and Joe Peppard. 1993. Information technology and new organizational forms: Destination but no road map? *Journal of Strategic Information Systems* 2 (3): 180–205.

Latour, B. 1987. *Science in Action: How to Follow Scientists and Engineers through Society.* Cambridge, MA: Harvard University Press.

Law, John, and John Hassard. 1999. *Actor network theory and after.* Oxford: Blackwell Publishers.

Leckie, Gloria J., Karen E. Pettigrew, and Christian Sylvain. 1996. Modeling the information-seeking of professionals: A general model derived from research on engineers, health care professionals and lawyers. *Library Quarterly* 66 (2): 162–93.

Levine, Sol, and Paul E. White. 1969. Exchange as a conceptual framework for the study of interorganizational relationships. In *A Sociological Reader on Complex Organizations,* ed. Amitai Etzioni. 2nd ed. New York: Holt, Rinehart and Winston.

Mackay, Ronald, Douglas Horton, Luis Dupleich, and Anders Andersen. 2002. Evaluating organizational capacity development. *The Canadian Journal of Program Evaluation* 17 (2): 121–50.

Maguire, David J., and Paul A. Longley. 2005. The emergence of geoportals and their role in Spatial Data Infrastructures. *Computers, Environment and Urban Systems* 29 (1): 3–14.

Mahring, Magnus, Jonny Holmstrom, Mark Keil, and Ramiro Montealgre. 2004. Trojan actor-network and swift translation: Bringing actor-network theory to IT project escalation studies. *Information Technology & People* 17 (2): 210–38.

Mark, David, Max Egenhofer, Stephen Hirtle, and Barry Smith. 2000. Ontological foundations for Geographic Information Science. University Consortium for Geographic Information Science (UCGIS). 2000 Research White Papers. http://www.ucgis.org/priorities/research/research_white/2000%20Papers/emerging/ontology_new.pdf (accessed June 25, 2006).

Martin, Eugene W. 2000. Actor-networks and implementation: Examples from conservation GIS in Ecuador. *International Journal of Geographical Information Science* 14 (8): 715–38.

Masser, Ian. 1999. All shapes and sizes: The first generation of National Spatial Data Infrastructures. *International Journal of Geographical Information Science* 13 (1): 67–84.

Masser, Ian. 2004. Capacity Building for Spatial Data Infrastructure Development. *Keynote presentation at 7th International Seminar on GIS for developing countries (GISDECO)*. May 10–12. Johor, Malaysia.

Masser, Ian. 2005a. *GIS Worlds: Creating Spatial Data Infrastructures,* 1st ed. Redlands, CA: ESRI Press.

Masser, Ian. 2005b. Some Priorities for SDI Related Research. *Paper presented at the Global Spatial Data Infrastructure* 8. Cairo, Egypt. April 16–21.

Masser, Ian, Santiago Borrero, and Peter Holland. 2003. Regional SDIs. In *Developing Spatial Data Infrastructures: From concept to reality,* 1st ed., eds. Ian Williamson, Abbas Rajabifard, and Mary-Ellen F. Feeney, 59–77. Boca Raton: CRC Press.

McCall, Michael K. 2003. Seeking good governance in participatory-GIS: A review of processes and governance dimensions in applying GIS to participatory spatial planning. *Habitat International* 27 (4): 549–73.

McCann, Joseph E. 1983. Design guidelines for social problem-solving interventions. *Journal of Applied Behavioral Science* 19 (2): 177–92.

McKee, Lance. 2000. Who wants GDI? In *Geospatial Data Infrastructure: Concepts, cases and good practice,* 1st ed., eds. Richard Groot and John McLaughlin, 13–24. Oxford University Press, New York.

Mennecke, Brian E. 1997. Understanding the role of geographic information technologies in business: Applications and research directions. *Journal of Geographic Information and Decision Analysis* 1 (1): 44–68.

Meredith, Paul H. 1995. Distributed GIS: If its time is now, why is it resisted? In *Sharing geographic information,* eds. Harlan J. Onsrud and Gerard Rushton, 7–21. New Brunswick, NJ: Center for Urban Policy Research.

Moellering, Harold. 2005. *World spatial metadata standards.* Oxford: Elsevier Science.

Montalvo, Uta Wehn de. 2003. In Search of rigorous models for policy-oriented research: A behavioral approach to spatial data sharing. *The Journal of Urban and Regional Information Systems* 15:19–28.

Monteiro, Eric. 1998. Scaling information infrastructure: The case of next-generation IP in the Internet. *The Information Society* 14:229–45.

Monteiro, Eric, and Ole Hanseth. 1995. Social shaping of information infrastructure: On being specific about the technology. In *Information Technology and Changes in Organizational Work,* eds. Wanda J. Orlikowski, Goeff Walsham, Matthew R. Jones, and Janice I. DeGross, 325–43. Norwell, MA: Kluwer Academic Publishers.

Munkvold, Bjorn E. 1999. Challenges of IT implementation for supporting collaboration in distributed organizations. *European Journal of Information Systems* 8 (4): 260–72.

Nedović-Budić, Zorica, Mary-Ellen F. Feeney, Abbas Rajabifard, and Ian Williamson. 2004. Are SDIs serving the needs of local planning? Case study of Victoria, Australia and Illinois, USA. *Computers, Environment and Urban Systems* 28 (4): 329–51.

Nedović-Budić, Zorica, and Jeffrey K. Pinto. 1999a. Interorganizational GIS: Issues and prospects. *The Annals of Regional Science* 33 (2): 183–95.

Nedović-Budić, Zorica, and Jeffrey K. Pinto. 1999b. Understanding interorganizational GIS activities: A conceptual framework. *Journal of the Urban and Regional Information System Association* 11 (1): 53–64.

Nedović-Budić, Zorica. 1997. GIS technology and organizational context: Interaction and adaptation. In *Geographic Information Research: Bridging the Atlantic,* eds. Massimo Craglia and Helen Couclelis, 165–84. London: Taylor & Francis.

Nedović-Budić, Zorica, and Jeffrey K. Pinto. 2001. Organizational (Soft) GIS interoperability: Lessons from the U.S. *International Journal of Applied Earth Observation and Geoinformation* 3 (3): 290–98.

Nedović-Budić, Zorica, Jeffrey K. Pinto, and Lisa Warnecke. 2004. GIS database development and exchange: Interaction mechanisms and motivations. *Journal of the Urban and Regional Information System Association* 16 (1): 15–29.

Nice, David D., and Patricia Frederickson. 1995. *The politics of intergovernmental relations,* 2nd ed. Chicago: Nelson-Hall.

Nogueras-Iso, J., F. J. Zarazaga-Soria, R. Bejar, P. J. Alvarez, and P. R. Muro-Medrano. 2005. OGC Catalog Services: A key element for the development of Spatial Data Infrastructures. *Computers & Geosciences* 31 (2): 199–209.

Nogueras-Iso, J., F. J. Zarazaga-Soria, J. Lacasta, R. Bejar, and P. R. Muro-Medrano. 2004. Metadata standard interoperability: Application in the geographic information domain. *Computers, Environment and Urban Systems* 28 (6): 611–34.

Oliver, Christine. 1990. Determinants of inter-organizational relationships: Integration and future direction. *Academy of Management Review* 15 (2): 241–65.

Onsrud, Harlan J., Barbara Poore, Robert Rugg, Richard Taupier, and Lyna Wiggins. 2004. The future of the Spatial Information Infrastructure. In *A Research Agenda for Geographic Information Science,* eds. Robert B. McMaster and E. Lynn Usery, 225–55. Boca Raton: CRC Press.

Onsrud, Harlan J. 1998. Compiled Responses by Questions for Selected Questions: Survey of National Spatial Data Infrastructures. http://www.spatial.maine.edu/~onsrud/gsdi/Selected.html (accessed December 3, 2005).

Orlikowski, Wanda J., and Debra C. Gash. 1994. Technological frames: Making sense of information technology in organizations. *ACM Transactions in Information Systems* 12 (2): 174–207.

O'Toole, Laurence J., Jr., ed. 1985. *American intergovernmental relations: Foundations, perspectives, and issues.* Washington, DC: CQ Press.

O'Toole, Laurence J., Jr., and Robert S. Montjoy. 1984. Interorganizational policy implementation: A theoretical perspective. *Public Administration Review* 84 (6): 491–503.

Pickles, John. 2004. *A History of spaces: Cartographic reason, mapping and the geo-coded world.* London: Routledge.

Pinto, Jeffrey K., and Harlan J. Onsrud. 1995. Sharing geographic information across organizational boundaries: A research framework. In *Sharing geographic information,* eds. Harlan J. Onsrud and Gerard Rushton, 44–64. New Brunswick, NJ: Center for Urban Policy Research.

Pressman, J., and A. Wildavsky. 1984. *Implementation,* 3rd ed. Berkeley, CA: University of California Press.

Pundt, Hardy, and Yaser Bishr. 2002. Domain ontologies for data sharing: An example from environmental monitoring using _eld GIS. *Computers & Geosciences* 28:95–102.

Radin, Beryl A., and Barbara S. Romzek. 1996. Accountability expectations in an intergovernmental arena: The national rural development partnership. *Publius* 26 (2): 59–82.

Rajabifard, Abbas. 2003. SDI diffusion: A Regional case study with relevance to other levels. In *Developing Spatial Data Infrastructures: From concept to reality,* 1st ed., eds. Ian Williamson, Abbas Rajabifard, and Mary-Ellen F. Feeney, 78–94: Boca Raton: CRC Press.

Robey, D., and C. A. Sales. 1994. Designing Organizations. *Journal of Management Information Systems* 10 (4): 183–211.

Rajabifard, Abbas, Mary-Ellen F. Feeney, and Ian Williamson. 2003. Spatial Data Infrastructures: Concept, nature and SDI hierarchy. In *Developing Spatial Data Infrastructures: From concept to reality,* 1st ed., eds. Ian Williamson, Abbas Rajabifard, and Mary-Ellen F. Feeney, 17–40. Boca Raton: CRC Press.

Rajabifard, Abbas, Mary-Ellen F. Feeney, Ian Williamson, and Ian Masser. 2003. National SDI initiatives. In *Developing Spatial Data Infrastructures: From concept to reality,* 1st ed., eds. Ian Williamson, Abbas Rajabifard, and Mary-Ellen F. Feeney, 95–109. Boca Raton: CRC Press.

Rhind, David. 2000. Funding an NGDI. In *Geospatial data infrastructure: Concepts, cases and good practice,* 1st ed., eds. Richard Groot and John McLaughlin, 39–56. New York: Oxford University Press.

Savolainen, Reijo. 1995. Everyday life information seeking: Approaching information seeking in the context of "way of life." *Library and Information Science Research* 17 (3): 259–94.

Spatial Data Interest Community on Monitoring and Reporting (SDIC MORE). 2005. Spatial Applications Division of Leuven (SADL), Katholieke Universiteit Leuven and Laboratorio di Sistemi Informativi Territoriali ed Ambientali (LABSITA), University of Rome La Sapienza. http://www.sdic-more.org (accessed April 11, 2006).

Sepic, Ron, and Kate Kase. 2002. The national biological information infrastructure as an e-government tool. *Government Information Quarterly* 19 (4): 407–24.

Smith, Jessica, William Mackaness, Allison Kealy, and Ian Williamson. 2004. Spatial Data Infrastructure requirements for mobile location based journey planning. *Transactions in GIS* 8 (1): 23–44.

Star, Susan L., and Karen Ruhleder. 1996. Steps toward an ecology of infrastructure: Design and access for large information spaces. *Journal of Information Systems Research* 7 (1): 111–34.

Stewart, Murray. 2003. Towards collaborative capacity. In *Urban transformation and urban governance: Shaping the competitive city of the future,* ed. Boddy Martin, 76–89. Bristol, UK: The Policy Press.

Stewart, James, and Robin Williams. 2005. The wrong trousers? Beyond the design fallacy: Social learning and the user. In *User involvement in innovation processes: Strategies and limitations from a socio-technical perspective,* ed. Harald Rohracher, 9–35. Munich: Profil-Verlag.

Suomi, Reima. 1992. On the concept of inter-organizational information systems. *Journal of Strategic Information Systems* 1 (2): 93–100.

Suomi, Reima. 1994. What to take into account when building an inter-organizational information system. *Information Processing & Management* 30 (1): 151–59.

Taylor, Robert S. 1991. Information use environments. *Progress in Communication Sciences* 10:217–55.

Tait, Michael G. 2005. Implementing geoportals: Applications of distributed GIS. *Computers, Environment and Urban Systems* 29 (1): 33–47.

Tettey, Wisdom J. 2002. ICT, local government capacity building, and civic engagement: An evaluation of the sample initiative in Ghana. *Perspectives on Global Development and Technology* 1 (2): 165–92.

Thompson, James D. 1967. *Organizations in action.* New York: McGraw-Hill.

Tjosvold, Dean. 1988. Cooperative and competitive dynamics within and between organizational units. *Human Relations* 41 (6): 425–36.

Tulloch, David, and Jennifer Fuld. 2001. Exploring county-level production of framework data: Analysis of the national framework data survey. *The Journal of Urban and Regional Information Systems* 13 (2): 11–21.

Visser, U., H. Stuckenschmidt, G. Schuster, and T. Vogele. 2002. Ontologies for geographic information processing. *Computers & Geosciences* 28:103–17.

Walsh, Kuuipo A., Cherri M. Pancake, Dawn J. Wright, Sally Haerer, and F. J. Hanus. 2002. “Humane” interfaces to improve the usability of data clearinghouses. Paper presented at the GIScience 2002 conference.

Walsham, Geoff, and Sandeep Sahay. 1999. GIS for district-level administration in India: Problems and opportunities. *MIS Quarterly* 23 (1): 39–66.

Williams, R. 1997. The social shaping of information and communications technologies. In *The Social Shaping of information superhighways: European and American roads to the information society,* eds. H. Kubicek, W. H. Dutton, and R. Williams, 299–338. New York: St. Martin’s Press.

Williams, Trevor. 1997. Interorganisational information systems: Issues affecting interorganisational cooperation. *Journal of Strategic Information Systems* 6 (3): 231–50.

Williamson, Ian. 2003. SDIs: Setting the scene. In *Developing Spatial Data Infrastructures: From concept to reality,* 1st ed., eds. Ian Williamson, Abbas Rajabifard, and Mary-Ellen F. Feeney, 3–16. Boca Raton: CRC Press.

Williamson, Ian P., Abbas Rajabifard, and Enemark Stig. 2003. Capacity building for SDIs. *Proceedings of 16th United Nations Regional Cartographic Conference for Asia Pacific*. July 14–18. Okinawa, Japan.

Wilson, Thomas D. 1994. Information needs and uses: Fifty years of progress. In *Fifty years of information progress,* ed. B. C. Vickery, 15–51. *A Journal of Documentation Review.*

Wilson, Thomas D. 2000. Human information behavior. *Informing Science* 3 (2): 49–55.