GSDI-9 Conference Proceedings, 6-10 November 2006, Santiago, Chile
Research and Theory in Advancing Spatial Data Infrastructure Concepts (preprint)

Towards an Extended SDI Knowledge Base and Conceptual Framework

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Abstract

Research on spatial data infrastructures (SDIs) is not well grounded in theory and SDI practice is often negligent of 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 pointing to the existing SDI literature and identifying the research gaps, the bulk of the paper is devoted to reviewing the main premises in the areas that would contribute to institutionalization of SDIs and to ensuring their broad utility. Those areas include: 1) information infrastructure, 2) interorganizational collaboration – cooperation – coordination (3C), 3) intergovernmental relations, 4) actor network theory (ANT), and 5) use – utility – usability (3U) of information systems. We indicate their value and limitations in supporting SDI research and development. The following elements are isolated as potentially contributing to the SDI conceptual framework: the mutually supporting role of SDIs, geographic information systems (GIS), information and communication technologies (ICT) and infrastructures; the notion of 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 networked environment of data users, producers, and managers; and employing user-centered approaches and evaluating their access and utility derived from SDIs. The proposed framework is comprehensive, although it excludes important but often less challenging technical topics in order to turn attention to organizational and user perspectives.

Introduction

A functional spatial data infrastructure (SDI) is an important asset in the 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 only been partially successful after fifteen years of struggle. Masser (2005a) qualifies a number of European countries' SDIs as partially operational or non-operational. Similarly, Crompvotes 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; Onsrud et al., 2004; Rhind, 2000). One way to secure the return on these investments is to better conceptualize and understand the SDI developments and ascertain their effects. However, the SDI knowledge base is quite limited (Georgiadou et al., 2005). Georgiadou and Blakemore's (under review) examination of articles in seven major geographic science journals yields a disappointing 5% of SDI-related articles that are theoretically grounded and critical. They discover that most of the works are focused either on technology or applications; conceptual domain and social and organizational ramifications have been treated the least. While a successful SDI balances the technology and application domains, it can hardly do so without a sound theoretical domain. Without such 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 frameworks 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 the five potentially useful knowledge areas. We first briefly identify the existing SDI research and its gaps. We then point to the sources in the areas of 1) information infrastructure, 2) interorganizational collaboration - cooperation – coordination (3C), 3) intergovernmental relations, 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 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 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:

- Policy and organization -- the creation and maintenance of SDIs involves organizational, institutional, management, financial, political as well as cultural issues;
- Interoperability and sharing -- as the backbone of SDIs;
- Discovery, access and use of spatial data -- as the main purpose of SDIs.

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

Policy and Organization. After a decade-long experience with initiating SDIs 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 the human resources and leadership; Bernard and Craglia (2005) emphasize important but scarce research on the socio-economic impact; Georgiadou and Blakemore (under review) alert about the western-centric and technical nature of most of the ongoing research and call for a globally relevant research centered on the human agency.

The most frequently engaged organizational approach to SDI is hierarchical (Rajbifard et al., 2003), with a network model as an alternative. In his evaluation of the first generation SDIs, Masser (1999) provides a generic model of the national SDI or SDI-like centers, but, like most other authors, resorts to describing the growth and organization of some of the major SDI-related organizations (e.g., EUROGI, PCGIAP, Global Map; Victoria's Property Information Project - PIP) 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 the SDIs from advancing, and call for new organizational and institutional mechanisms to be devised (Kok and Loenen, 2005; Masser, 2005b).

Interoperability and Sharing. Despite the enhanced data transfer capabilities allowed by the advances in information and communication technologies (ICT) and World Wide Web (WWW) in particular, sharing of spatial information is still impeded by substantial non-interoperability. This non-interoperability can be broadly classified into two categories: technical and non-technical. 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 solved, and research in federated database systems is expected to contribute to solving the fifth one. The sixth one – semantics of geographic information – is studied 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 recently complemented by introduction and elaboration of spatial ontologies (Mark et al., 2000).

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

Discovery, Access and Use of Spatial Data. Although discovery and access to spatial data are the necessary initial steps in SDI use, the true demonstration of SDI utility is 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 the multiplicity of national and technical standards are gradually migrating to the international ISO 19115 standard and crosswalks are 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 the second generation geoportals to access spatial data and services; Askew et al. (2005) and Beaumont et al. (2005) share the UK's experience in building on the government's ICT investments and assert the difficulties in developing geoportal-related partnerships due to varying levels of technological experience, goals and expectations among the partners.

The access to spatial information is usually measured as counts of portal hits, such as in Geography Network that receives (the encouraging) 300,000 hits by estimated 50,000 users per day (Tait, 2005). The use of this information comes next, with some preliminary indications that contemporary SDIs do not fulfill their purpose and expectations. Crompvoets et al. (2004) report that user-unfriendly interface and discipline-specific nature of metadata and clearinghouses are among the primary reasons for the declining trend in clearinghouse use. Nedovi_-Budi_ et al. (2004), in their evaluation of the use of SDIs in the context of local planning in Victoria, Australia and Illinois, USA, also conclude that SDIs do not effectively serve the local needs. These studies reinforce the findings from a large scale survey conducted in the U.S. 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 Gap

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.* There are many definitions of SDI (Rajabifard et al., 2003) varying in their emphasis and purpose. There is no clear notion and consensus on SDI and its constituting elements and principles. While the multiplicity of definitions and meanings is not unusual for any phenomenon, it tends to frustrate the development activities and research efforts in particular. 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 GIS can not be built without SDI, whereas Georgiadou et al. (2005) argue that SDI requires strong GIS installed base. Extensive experience from the diffusion of innovation research suggests that inconsistent definitions and concept operationalizations result in ambiguous research findings and prevent comparison of studies conducted independently on the same subject (Budic, 1994). In essence, they aggravate the building of a coherent body of SDI knowledge.

- *Models*. Although the hierarchical model corresponds closely to the current efforts in 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 SDIs' 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 be eventually the largest SDI user group (Dangermond, 1995; McKee, 2000), very few sources discuss the issues of public access and explicitly include it in SDI modeling and building attempts.

- *Standards*. Other than the positive but sporadic migration to ISO standard by some national SDIs, little is known about which standards are used in SDIs worldwide. A recent book edited by Moellering (2005) is starting 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, e.g., in terms of their matching to the users' mental models, their value in assessing the fitness-for-use of the underlying data, and the complementary use of the 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*. The ongoing SDI research is more focused on access to spatial data than on use and utility of the infrastructure. Looking at the process of SDI establishment with utility in mind and comprehensively as a whole — from conception to operation — will help create a more relevant and useful infrastructure. Beyond counting the 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 securing effective and valuable SDIs. Georgiadou et al. (under review) suggest a variety of methodologically rigorous evaluation approaches suited to progressively complex focus 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 technical and social.* While it is the factors emerging from the interaction between technical and non-technical that we need to understand better, research efforts have been mostly limited to one or the other. In reality, they interact and influence each other to give rise to a whole new set of factors. Those factors are calibrated through a mutual adjustment between the technological and social systems (Nedovi_-Budi_ 1997). Timely involvement of prospective users in the development of SDIs will contribute to their enhanced usability and overall success. The diverse background and often limited skills of non-specialists, 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 inherent part of the SDI development activities (Enemark and Williamson, 2004; Georgiadou and Groot, 2002; Masser, 2004; Williamson et al., 2003).

- *Politics and policy.* The formation of SDIs at all levels is also susceptible to geopolitical, economic, and socio-cultural issues and all the associated opportunities and threats of cyber spaces and interactions (Pickels, 2004). This is particularly obvious at the national SDIs, which often exhibit centralizing tendencies that run counter to most federalizing and devolutionary concepts. SDI community cannot afford to overlook the inter-linkages of the state regime and geographic information and become a non-player in addressing this crucial dimension of SDI policy.

- *Multi/inter-disciplinary approach*. SDIs draw on the knowledge from many disciplines, including, but not limited to sociology, cognitive science, political science, organizational studies, economics, computer and information science (Masser, 2005b). The ongoing research, however, tends to be inward-oriented, missing to reach out toward other disciplines, their theories, concepts, and frameworks.

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

Overview of Five Knowledge Areas

Information infrastructure (II). Most of II literature considers information infrastructure in a rather narrow sense within a specified domain, e.g., 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 the libraries to II. While both may contribute to II as its components, the II envisioned by the former U.S. Vice-president Al Gore and the Information Infrastructure Task Force (1993) in the U.S. and its European Union counterpart (Bangemann Group, 1994) have much broader expectations and ramification to 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, Forthcoming; 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 gradually expanding, but also transforming as work practices are continuously inscribed in them.

Star and Ruhleder (1996), p. 113	
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 support 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 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 working infrastructure becomes visible when it breaks."
Hanseth and Monteiro (Forthcoming), pp. 41-49	
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."
Socio-technical network	"IIs are more than "pure" technology; rather, they are socio-technical networks."
Ecology of networks	"Infrastructures are connected and interrelated, constituting ecologies of networks."
Installed base	"Infrastructures develop through extending and improving the installed base."

Table 1. Characteristics of Information Infrastructures

While proposing the II characteristics, 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 biased with technical views. Similar to Borgman (2000), they view IIs as much more than the physical substrate and thus consider broader social relations in constituting IIs. Hanseth and Monteiro (Forthcoming) suggest that some of the II characteristics may be present in certain information systems (IS), especially in interorganizational systems (IOS) or distributed information system (DIS) and, therefore, some commonalities and overlapping characteristics exist between IS and II. They consider that IIs are initiated when:

- new and independent actors become involved in the development of an IOS or DIS, so that the development is not controlled by one actor any more;
- one of the design objectives for IOS or DIS is to grow and become an II (or part of II) in future.

Interorganizational collaboration - cooperation – coordination (3C). 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 interorganizatonal 3C are often necessary for IOS or DIS to be implemented and succeed. Cooperation covers the middle ground between collaboration and coordination – as the least and most intensive and, conversely, the most and least autonomous, respectively (McCann 1983).

The building blocks for 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 interdependencies with increasing complexity: pooled; sequential, and reciprocal interdependency. Kumar and van Dissel (1996) provide a typology of interorganizational systems and their characteristics based on the type of interdependence that they encompass. They propose that the most complex reciprocal relationships have low structurability and require networked interoganizational systems, intense technological support and mutual adjustment among the involved parties. Meredith (1995) postulates that already existing organizational interdependence will reduce the resistance to interorganizational sharing. This is particularly true for cooperative interdependence (Tjosvold 1988). However, increased 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 multi-party 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) advances the 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:

- authority, i.e., derived from the sense of duty;
- common interest of organizations that value the same goals; or
- exchange inducements when returns are expected or received.

Intergovernmental relations (IGR). As much as interorganizational systems and databases are manifestations of interorganizational relationships (Kumar and van Dissel 1996), in the public sector they also reflect the models of government and intergovernmental relations. 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). Within the federalist context that is applicable to some of the major SDI clients like the U.S., Australia and potentially 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 the 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). Finally, O'Toole (1985) differentiates between federalist models with overlapping authority, coordinative authority, and inclusive authority.

Finally, politics are inherent to government and governing at all levels – local to national and international. The evolution of government toward the practice of governance[1] that is increasingly accepted worldwide, more explicitly incorporates the 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

[1] According to Stewart (2003), "…the '[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 multi-stakeholder 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.

interorganizational information systems (Kumar and van Dissel, 1996). In addition to changes in the institutional nature 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 the Weberian and virtual bureaucracy demonstrates how the ICTs facilitate the transformations from government to governance. Furthermore, Fountain's (2001) analytical framework (Figure 1) relates the organizational forms and institutional arrangements to the process of technology enactment. The author suggests that different cognitive, cultural, sociostructural and legal forms are required for hierarchical and network organizations.

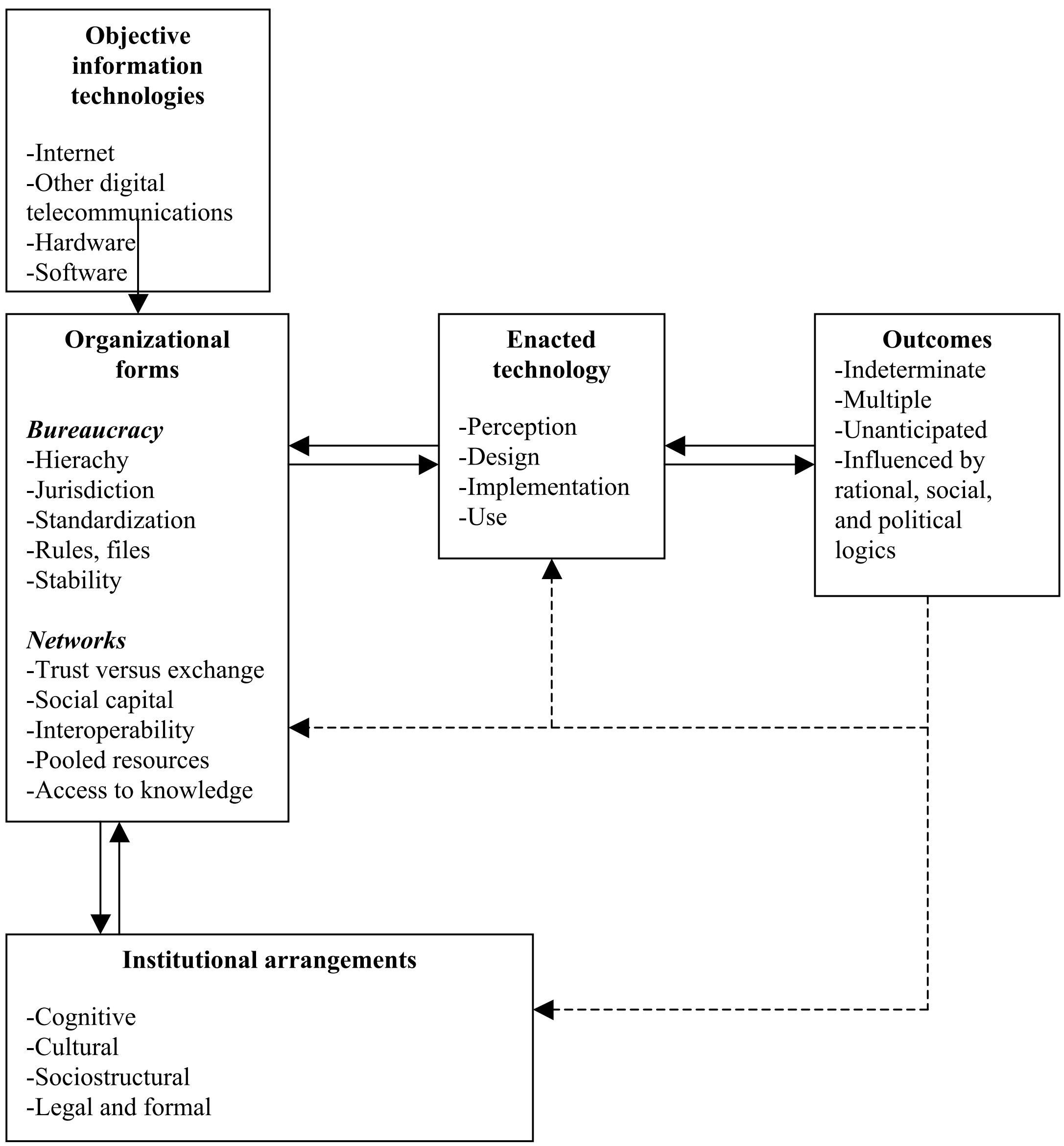


Figure 1. Technology Enactment: An Analytical Framework (after Fountain, 2001, p. 91)

Actor network theory (ANT). Actor network theory is often applied in lieu of the 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, their attributes, and forms as resulting from relations with other entities; in addition, all entities have to satisfy *performativity* aspect of ANT, i.e., to be performed in, by, and through those relations (Law and Hassard, 1999). The focus is on undoing the artificial boundaries between the social and technical systems and the related processes. For example, Faraj et al. (2004) employ ANT approach 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 socio-technical 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, enrollment, and mobilization (Table 2). The translation process does not have to pass thorough all four phases and also 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 socio-technical stability (Latour, 1987). Another ANT phenomenon is irreversibility, referring to 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 interests become increasingly difficult to change. In the context of changing but sometimes irreversible networks, the authors propose three actor-network configurations (also elements of decomposition): disconnected networks, gateways and polyvalent networks.

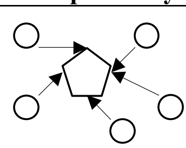
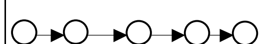
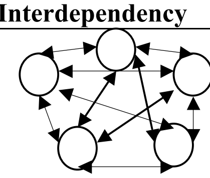
Type of interdependence	**Pooled Interdependency**	**Sequential Interdependency**	**Reciprocal Interdependency**
Configuration			
Coordination Mechanisms	Standards & Rules	Standards, Rules, Schedules & Plans	Standards, Rules, Schedules, Plans & Mutual Adjustment
Technologies	Mediating	Long-Linked	Intensive
Structurability	High	Medium	Low
Potential for Conflict	Low	Medium	High
Type of IOS	Pooled Information Resource IOS	Value/Supply-Chain IOS	Networked IOS
Examples of Implementation Technologies and Applications	Shared databases Networks Applications Electronic markets	EDI Applications Voice Mail Facsimile	CAD/CASE Data Interchange Central Repositories Desk-top Sharing Video-conferencing

Table 2. Organizational interdependence, structure, and potential for conflict (Kumar and Dissel 1996; adapted from Robey & Sales, 1994, fig. 5-3, p. 121; p. 287)

Use, utility and usability of information systems (3U). Although the terms 'usability' and 'usefulness' (referred in this work as utility) are often 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 the ICTs, according to Gurstein (2003), is the capacity and opportunity to successfully integrate these technologies to achieve the users' self- or collaboratively-defined goals. The author argues that effective use of ICT 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 of information system use.

Although the post-WWII growth of scientific literature marked the beginning of a more systematic study of information systems, it is not until 1980s that the research efforts shift from focusing on technology to information users and their behavior (Wilson 1994; 2000). Consequently, the design of information systems and services started to shift from the system-centered to user-centered approaches and socio-technical designs (Eason, 1988). Currently, user study is 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 others, it poses the following questions: 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 or unit 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, "sensemakers," 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 the domestication and its associated concept of idealization-realization of technology (Bruce, 1993) is that technology gets appropriated and its meaning is constructed by the situated use. By implication, the designers can not design the system; they can only invoke the design process. It is through the users' continued appropriation that an information system and services becomes useful.

Conclusion

This paper is motivated by the increasingly recognized lapse of SDI research and practice to both utilize 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 reference to the existing SDI research, point to research gaps, and review five areas as the potential major resource for strengthening the SDI conceptual base. These are: information infrastructure, interorganizational collaboration – cooperation – coordination, intergovernmental relations, actor network theory, and use – utility – usability of information systems. Following is a summary of their key premises and value to enhancing SDI research and practice (Table 3), as well as a tentative but pragmatic conceptual framework to serve as a starting point for further study and deployment of SDIs (Figure 2).

Elements of Weberian bureaucracy	**Elements of a 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, hand-held 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. Comparison of Weberian and Virtual Bureaucracies (after Radin and Romzek, 1996, p. 61)

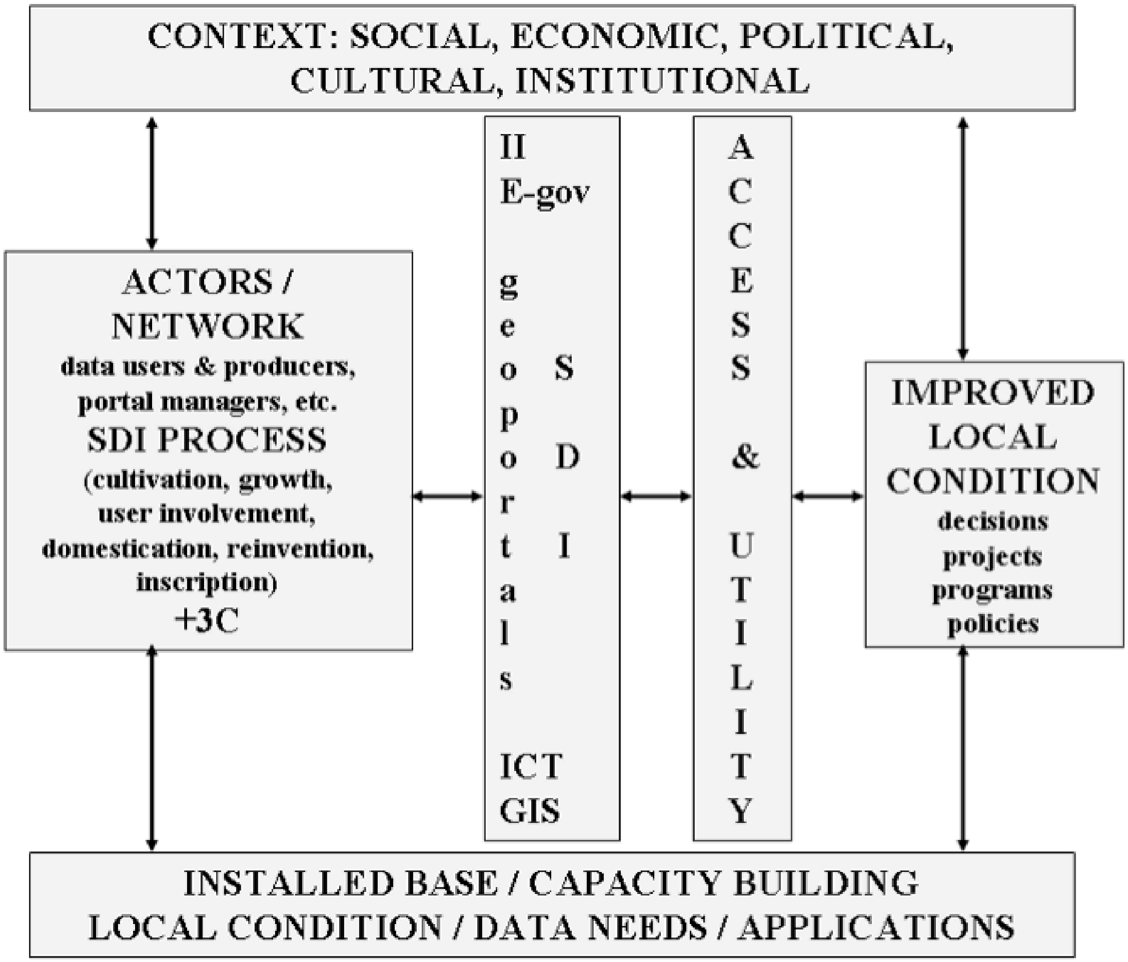


Figure 2 Conceptual Framework Derived from the Expanded SDI Knowledge Base

The notion of information infrastructure and of installed base, in particular, proves to be useful in taking a deeper look at SDIs. The concept of installed base implies that the existing technical (e.g., hardware, software, and data) and organizational (e.g., human resources and skills, management practices, and legal arrangements) setups may play facilitating or constraining role. The 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 Indian NSDI; their usefulness, however, needs to be explored further. Apparently, achieving SDIs with all the envisioned characteristics of a full-blown and operational infrastructure is not easy. Moreover, the information infrastructures are neither created from void nor completely designed. Rather, the process of "building" is replaced by "cultivation" of social and technical installed base to gradually incorporate diverse actors in a networked environment. The cultivation approach gives sufficient flexibility to accommodate local circumstances and practices. It also turns attention to the 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. Majority of studies on interorganizational IS are situated in the context of large corporations and employ productivity and maximization of their business 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 process. The 3C concepts are employed in GIS research (Azad and Wiggins, 1995; Craig, 2005; Harvey, 2001; Nedovic-Budic and Pinto, 1999b; Nedovi_-Budi_ et al., 2004). However, they are not fully exploited and leave the question of how to successfully initiate and maintain SDI coalitions among diverse stakeholders incompletely answered. Also, in the context of public sector which prevails among SDI participants, understanding the intergovernmental relations and the impact on and of E-governance, would also contribute a fruitful standpoint for enabling effective SDIs at all levels.

Actor network theory (ANT) offers a rich approach to understanding how a network of aligned interests can be created with heterogeneous human and technical actors and their relationships, as well as nested smaller networks. ANT provides a resourceful 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 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 the socio-technical networks than for devising solutions or models for developing viable relations among targeted actors and ensuring specific outcomes of such relations.

Between the concepts of usability and utility, the latter certainly offers a more relevant standpoint for studying large scale infrastructures such as SDIs are. The user perspective, in general, has reached its time. 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 underlie SDIs -- enable or limit them. The lens of effective use, thus, allows us to see SDIs beyond the current paradigm of provision and access of geospatial information. In Stewart and Williams' (2005) words:

> *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* (p. 2).

However, despite their convincing criticism of the traditional user-centered and socio-technical approaches and their limited applicability to single systems and organizations, the proponents of more radical views have not operationalized their ideas and offered practical solutions that can be implemented in the 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 to address. In addition to scaling up, the complexities exhibited by SDIs ask for additional efforts in studying SDI use and users and require continuous monitoring and evaluation activities. These challenges, however, should not undermine the essential importance of strong representation and active participation of users as “domesticators”, “sesemakers”, “innovators” who are to ultimately ascertain the utility of SDIs.

The literature sources presented in this paper suggest the following conceptual base: cultivation approach to SDI; focus on SDI users, their 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 evaluating SDIs against 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 the least, all SDI activities and participants are situated within specific societal, cultural and institutional context. 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 multi-and inter-disciplinary knowledge base in studying and developing SDIs worldwide.

The five knowledge areas included in this paper are by no means sufficient or exhaustive sources to inform SDI research and practice. In fact, none of them individually offers a comprehensive knowledge base required to develop and sustain SDI networks. For example, policy implementation, federated databases and systems development, capacity building, and public administration and finance are the candidate areas that are not addressed in this paper, but 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 that are available and accessible to academics and professionals interested in SDIs to draw upon. 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 will be more effective in establishing SDIs and furthering the scientific discourse with new insights, ideas, concepts, theories, and their successful applications. Most importantly, the long awaited societal benefits are more likely to emerge with SDIs that are guided by intelligence of the past as a basis for creativity and innovations for the future.

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 Tomothy 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 Wiggins, L. 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 New Jersey: 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): 472-476.
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, 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 on 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, 269-281: Hillsdale, NJ: Erlbaum.

Budi_, 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 Briuec Bay. In P*ower, 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.* UNESCO – Blackwell Publishers.

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

Cobbledick, Susie. 1996. The information-seeking behavior of artists: Exploratory interviews. *Library Quarterly* 66(4): 343-372.

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,* First ed., eds. Richard Groot and John McLaughlin, 233-244. 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, 107-118. 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): 272-282.

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): 665-689.

Cummings, Thomas G. 1980. Inter-organization theory and organizational development.

In *Systems theory for organization development.* ed. Thomas G. Cummings. New York: John Wiley and Sons.
Dangermond, Jack. 1995. Public data access. In *Sharing geographic information*, eds. Harlan J. Onsrud and Gerard Rushton, 331-339. 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): 216-232.
Dervin, Brenda and Michael Nilan. 1986. Information needs and uses. *Annual Review of Information Science & 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): 147-160.
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): 155-168.
Ellis, David. 1993. Modeling the information-seeking patterns of academic researchers: A grounded theory approach. *Library Quarterly* 63(4): 469-486.
Enemark, Stig and Ian Williamson. 2004. Capacity building in land administration – A conceptual approach. *Survey Review* 39 (294): 639-650.
Falch, Morten. 2006. ICT and the future conditions for democratic governance. *Telematics and Informatics* 23(2):134-156.
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: 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: 251-271.
Foster, Allen. 2004. A nonlinear model of information-seeking behavior. *Journal of the American Society for Information Science & Technology* 55(3): 228-237.
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. (Under review). A journey through GIS discourses. *The Journal of Urban and Regional Information Systems*.
Georgiadou, Yola, Orlando Rodríguez-Pabón, and Kate T. Lance. (Under review). SDI and E-Governance: A Quest for appropriate evaluation approaches. *Journal of Urban and Regional Information Systems*.

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): 1113-1130.

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 (2002) 7: pp 33-40.

Giddens, Anthony. 1979. *Central Problems in Social Theory: Action, Structure and Contradiction in Social Analysis*. Berkeley, CA: University of Californina 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): 367-387.

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): 116-123.

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. Forthcoming. *Understanding Information Infrastructure*: http://www.ifi.uio.no/~oleha/Publications/bok.html., Accessed March 2006.

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): 213-232.

Gore, Al (US 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): 305-322.

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): 243-251.

Koike, Osamu and Deil S. Wright. 1998. Five phases of IGR in Japan: Policy shifts and governance reform. *International Review of Administrative Sciences* 64: 203-218.

Kim, Tschangho J. 1999. Metadata for geo-spatial data sharing: A comparative analysis. *The Annals of Regional Science* 33(2): 171-181.

Klien, E., Lutz, M., and Werner Kuhn. 2006. Ontology-based discovery of geographic information services—An application in disaster management. *Computers, Environment and Urban Systems* 30: 102-123.

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): 405-409.

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*: RAND.

Langendorf, Richard. 2001. Computer-aided visualization: Possibilities for urban design, planning and management. In *Planning Support Systems: Integrating GIS and Visualization Tools*, eds. Brail, Richard, and Richard Klosterman, 309-359. 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): 162-193.

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*. 2nd ed., ed. Amitai Etzioni. New York: Holt, Rinehart & Winston.

Mackay, Ronald, Douglas Horton, Luis Dupleich, and Anders Andersen. 2002. Evaluating organizational capacity development. *The Canadian Journal of Program Evaluation* 17(2): 121-150.

Maguire, David J., & 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): 210-238.

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. URL: 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): 715-738.
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* (First 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. Regionl SDIs. In *Developing Spatial Data Infrastructures: From concept to reality,* First ed., eds. Ian Williamson, Abbas Rajabifard and Mary-Ellen F. Feeney, 59-77: 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): 549-573.
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*, First 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 S*haring 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: 229-245.
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, 325-343. Kluwer Academic Publishers.
Munkvold, Bjorn E. 1999. Challenges of IT implementation for supporting collaboration in distributed organizations. *European Journal of Information Systems* 8(4): 260-272.
Nedovi_-Budi_, 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): 329-351.
Nedovi_-Budi_, Zorica, and Jeffrey K. Pinto. 1999a. Interorganizational GIS: Issues and prospects. *The Annals of Regional Science* 33(2): 183-195.
Nedovi_-Budi_, 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.
Nedovi_-Budi_, Zorica. 1997. GIS technology and organizational context: Interaction and adaptation. In *Geographic Information Research: Bridging the Atlantic,* eds. Massimo Craglia and Helen Couclelis, 165-184. London: Taylor & Francis
Nedovi_-Budi_, 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): 290-298.
Nedovi_-Budi_, 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): 611-634.
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, 225-255. 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 on 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., editor. 1985. *American Intergovernmental Relations: foundations, perspectives, and issues.* Washington, D.C.: 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 field 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*, First ed., eds. Ian Williamson, Abbas Rajabifard and Mary-Ellen F. Feeney, 78-94: CRC Press.

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*, First ed., eds. Ian Williamson, Abbas Rajabifard and Mary-Ellen F. Feeney, 17-40: 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*, First ed., eds. Ian Williamson, Abbas Rajabifard and Mary-Ellen F. Feeney, 95-109: CRC Press.

Rhind, David. 2000. Funding an NGDI. In *Geospatial data infrastructure: Concepts, cases and good practice,* First 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 & Information Science Research* 17(3): 259-294.

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 on April 11, 2006)

Sepic, Ron, and Kate Kase. 2002. The National biological information infrastructure as an e-government tool. *Government Information Quarterly* 19(4): 407-424.

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): 111-134.

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*, eds. 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): 151-159.

Taylor, Robert S. 1991. Information use environments. *Progress in Communication Sciences* 10: 217-255.

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): 165-192.

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: 103-117.

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.*

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): 231-250.

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

Williamson, Ian P., Rajabifard, Abbas 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.