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Reserch Article

Towards a potential research agenda to guide the implementation of Spatial Data Infrastructures—A case study from India

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Recently, Spatial Data Infrastructures (SDIs) has been a rapidly expanding field and broadly assumed to underpin the development of information society and the knowledge economy. In this paper, we argue that the anticipated benefits of SDIs have largely not yet been generally realized in practice due to a lack of a robust theoretical framework as well as insufficient empirical research to guide the implementation efforts. We posit that learnings from the allied discipline of Information Infrastructures, which has matured during the 1990s in response to the proliferation of distributed, complex, and heterogeneous networked systems, can provide a useful theoretical lens to inform the emerging domain of SDIs. We focus on three key concepts identified in the domain of information infrastructure theory, viz. the *installed base*, *reflexive standardization*, and *cultivation approach to design*, to develop a theoretical framework, which is then applied to analyse the ongoing initiative to establish National Spatial Data Infrastructure (NSDI) in India. This analysis helps us to provide the basis to articulate a potential research agenda—for both theory and practice—which, we believe, offers the promise to better conceptualize and implement SDIs, particularly in developing country settings like India.

Keywords: Spatial data infrastructure; Information infrastructures; National SDI; India; Developing countries

1. Introduction

A Spatial Data Infrastructure (SDI) is a special case of Information Infrastructure, specifically geared towards geographic information. SDI subsumes technology, systems, standards, networks, people, policies, organizational aspects, geo-referenced data, and delivery mechanisms to end users (Williamson 2004). Many countries, also in the developing world, are now at various stages of attempts to design, develop, implement, and use SDIs (Crompvoets and Bregt 2003, Rajabifard *et al*. 2003). These initiatives vary in scope and encompass different levels of geographic coverage from local, to state, to regional, and extending to national and supranational levels. Historically, the motivation for SDI development arose primarily from economic considerations—the need to optimally *access* and share capital-intensive geospatial data (Groot and McLaughlin 2000). The contemporary

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SDI discourse also recognizes the need for a strategic infrastructure to underpin the information society and social *progress*, particularly in national or supranational settings, such as the development of National Spatial Data Infrastructures (NSDIs) and the European SDI (Craglia and Johnston 2004). The combination of the criteria of 'access' and 'progress' contributes to a degree of confusion around the nature and purpose of SDI (Wytzisk and Sliwinski 2004, Williamson 2004). While the SDI metaphor of access takes a technical focus, progress invokes the image of a utopian future where SDIs become the prerequisite to address perennial problems of food security, water supply, environmental regulations, law enforcement, and national security (Ezigbalike 2003).

For reasons both technical and institutional, the implementation of SDIs is inherently complex, and the projected benefits remain largely unrealized (Craglia and Johnston 2004), despite active political support and visibility, and promises of new technologies (Masser 1999). Given the complexity of an SDI and the long-term nature of its impacts, it is difficult to evaluate its costs and projected economic impacts, and empirically corroborate the claims of its proponents (Craglia and Johnston 2004). Technically, SDIs are complex because they underlie as well as draw upon various technologies including remote sensing, spatial modelling, database technology, computer networking, and Geographical Information Systems (GIS), while catering to the demands of diverse application domains. Institutionally, tensions arise from various sources, including the need for consensus on standards, for example between the federal and local agencies (Harvey 2003), and over the inclusion of users in the consultative processes to finalize the key components of the SDI (Longhorn 2004). These problems are further magnified in the context of developing countries not only for reasons of financial resources (de Man 2004) but also due to a relative lack of spatial information, trained manpower, capacity of public institutions, as well as security concerns (Fox 1991).

The current research and practice of SDIs reflect an excessive data focus implying a preoccupation with aspects of data standards, interoperability, metadata, etc., which marginalizes the influence of the socio-political–historical–institutional conditions within which the design and use of the end products takes place. The influence of these conditions on the uptake of Information Systems (IS) generally (Walsham 1993) and GIS specifically (Sahay and Walsham 1996, Reeve and Petch 1999) has been emphatically established both theoretically and empirically. Sahay and Walsham (1996), in their analysis of GIS implementation in India, have argued that research in the 'geo domain', rather than reinventing the 'research wheel', should draw upon implications from IS research, and adapt it to analyse GIS implementation taking into consideration the particular characteristics of the technology and institutional conditions.

It is argued in this paper that a similar reasoning can be applied to the understanding of the implementation dynamics around SDIs. The theory of 'information infrastructures' (Hanseth and Monteiro 2004) provides potentially a richer basis to develop a deeper theoretical understanding and for deriving sound and practical implications for planning and implementing SDIs (Georgiadou 2003).

The rest of this paper is organized as follows. In section 2, drawing from the theory of information infrastructures, we present the theoretical underpinnings of our research. In section 3, a case study and analysis of the current NSDI development in India are presented. Using the theoretical lens articulated in section 2, we suggest the basis of a potential research agenda to guide SDI implementation research in the context of developing countries, with a focus on India.

2. A theoretical framework to analyse the implementation dynamics of SDI

This section seeks to develop a theoretical framework to analyse the implementation dynamics of SDIs. Key concepts from the theory of information infrastructure are examined below, which can help inform SDI research and practice.

2.1 *Relevant theoretical concepts from information infrastructures*

The theory of information infrastructures has its roots in the sociology of technology research tradition (e.g. Callon and Law 1986, Latour 1987), and has been extensively applied in IS research to analyse not independent but networked systems whose development is not controlled by any one actor (Hanseth and Monteiro 2004). The information infrastructure perspective emphasizes that the social and technical are not separable and are instead constituted and constitutive of one another. For example, Latour (1999) argues that airplanes do not fly, airlines do, thus implying that the artefact of the aeroplane does not fly on its own but requires a complex and heterogeneous socio-technical network comprising pilots, navigators, runway staff, air-traffic-control towers, radars, runways, and flight schedules. Drawing upon this socio-technical perspective, information infrastructures are described as heterogeneous networks subsuming varied technologies, networks, and standards to support a diversity of application areas over time and space (Hanseth 2000). Hanseth and Monteiro (2004) draw upon the example of the Internet to describe the characteristics of information infrastructures as being *shared*, *open*, and *enabling*. Information infrastructures are thus built not to support one application for a pre-defined set of users but to provide an enabling environment in which a variety of applications and user communities can flourish, and the infrastructure can evolve over time to support changing and often unanticipated needs.

SDIs, too, represent these characteristics described for information infrastructures (Groot and McLaughlin 2000). They are *shared*, as they seek to make available expensive, geo-referenced spatial data digitally to a variety of users for diverse application needs (for example, biodiversity, utilities, and health) based on an integrated approach. SDIs are *open*, as no pre-defined boundaries limiting the user groups are made, and typically various government departments, citizens, and private sector are expected to draw upon them. SDIs are inherently *enabling* as they are not pre-configured to a particular application and can potentially be used by different entities to design their own applications. However, to analyse the implementation dynamics surrounding SDIs, it is important to go beyond Hanseth and Monteiro's ontological characterization of *what an information infrastructure is* (enabling, shared and open) to also examine in an epistemological sense the socio-technical processes and embedded practices by which the *information infrastructure is constructed* and comes to be open, shared, and enabling. Three sets of concepts identified in information infrastructure research provide the potential to develop such an analysis: installed base and lock-in effects, self-reinforcing mechanism of standardization processes, and cultivation strategies of information infrastructure design.

2.1.1 Installed base and lock-in effects. Star and Ruhleder (1996) emphasize that an infrastructure is never built from scratch: 'It wrestles with the "inertia of the installed base"' and inherits strengths and limitations from that base (ibid., p. 113). Given the inherently interconnected nature of information infrastructures, the whole network cannot change instantly, and design strategies need to link the old and the new in an interoperable way. In this way, the old—the installed base—significantly influences how the new can be designed and how existing information infrastructures can be scaled up. Monteiro (1998), in his analysis of the scaling of the Internet, describes the installed base to be constituted of hosts, routers, users' experience and practices, backbones, and specifications. As this installed base becomes better aligned, it increasingly takes on an irreversible nature, thereby creating a lock-in effect. Efforts to design change (for example, adoption of IPv6 in the case of Internet) necessarily then need to consider the dilemma between stability and change.

2.1.2 Self-reinforcing mechanism of standardization processes. Standardization refers to a process of simplification and abstraction with the aim to define and communicate significant aspects of the processes, artefacts, and structures across time and space. The aim is to enable some form of universalization and mass production (Sahay 2003). Standards represent agreed-upon rules for the production of (textual or material) objects required because they span multiple, spatially distributed communities of practice (Bowker and Star 1999). Although standards help to provide a sense of stability, as their temporal and spatial scope increases, they take on an increasingly inertial nature, making it difficult and expensive to change. A key driver for the uptake of standards is described as that of 'network externalities' implying that as the value of a technology increases, more users will adopt it, which further contributes to enhance the popularity of the product (Ciborra and Hanseth 1998). Hanseth and Braa (2001) critique the utopian quest to develop universal standards as 'searching for treasure at the end of the rainbow' because standardization raises the need for further and sometimes conflicting standards as more users and technologies are incorporated into the network. Arguments are made to incorporate a process of reflexive standardization implying that efforts to realize standards, homogeneity, and order might in actual practice produce opposite effects, viz. instability, fragmentation, and chaos (Ciborra *et al.* 2000, Hanseth *et al.* 2004).

2.1.3 Cultivation approach to information infrastructure design. This approach has been emphasized by various proponents of the information infrastructure perspective (e.g. Rolland and Monteiro 2002, Hanseth and Aanestad 2003, Hanseth and Monteiro 2004) as a rich analytical tool to approach the design of information infrastructures. The cultivation methods represent a more conservative approach to design than 'construction', which tends to privilege the power of human agency in 'selecting, putting together, and arranging a number of objects to form a system' (Dahlbom and Janlert 1996, p. 6). Instead, cultivation emphasizes the *power of the material*: 'the tomatoes themselves must grow, just as the wound itself must heal … ' (ibid., p. 6), implying that the 'development organization' or 'product' being developed should be considered as a unified socio-technical network without privileging one over the other. The power of the material which the cultivation approach emphasizes derives from the *installed base* and the resulting *lock-in* effects (Hanseth and Monteiro 2004). This lock-in effect represents a dilemma in evolving an information infrastructure as it creates inertia and with it a conservative influence. This dilemma cautions against adopting radical (construction kind of) approaches to change and instead favours an incremental (cultivation kind of) strategy that involves modifications to small parts at a time while keeping them simultaneously aligned with the rest of the network. A cultivation approach emphasizes the 'improvizational' processes of change, and the potential of what people do in situated action (Suchman 1987), and does not just focus on planned and rational approaches (Ciborra *et al.* 2000). Design is seen not as a well-defined process with pre-configured start and end states but as an ongoing process of ecological change, characterized by 'unanticipated effects' (Walsham 1993) and 'drift' (Ciborra *et al.* 2000), reflecting our inability to fully anticipate future events.

2.2 *A theoretical framework to analyse implementation of SDIs*

In table 1, key learning from information infrastructure for the SDI domain is summarized, which is then drawn upon to analyse the Indian case.

3. The Indian NSDI initiative: Case study and analysis

To understand the perspectives of stakeholders involved in the planning, implementation, and eventual end use of the proposed NSDI, fieldwork was taken up in 2004. The research approach adopted for the collection and analysis of empirical data was based upon the interpretive school because our objective was to develop a rich contextualized understanding of the phenomenon. The focus was on understanding the nature of the social world at the level of subjective experience (Burrell and Morgan 1979), how people assign meaning to them (Devine 1995), and the processes through which intersubjectivity is constructed.

The methodology adopted was to conduct semi-structured interviews with the stakeholders involved, viz. scientists of the Department of Science and Technology (DST) and the Indian Space Research Organization (ISRO) engaged in the NSDI, industry representatives, and potential end users of technology. The interpretive orientation of the research inspired us to examine alternative viewpoints around how stakeholders felt the development and potential use of the NSDI technology was shaping up, and the benefits they felt might accrue from its adoption. A wide range of secondary data was also obtained from government documents and media reports detailing planning and implementation of the NSDI. In addition, participation in workshops, conferences, and review meetings helped enrich the authors' understanding of the dynamics surrounding the NSDI.

The notes taken during interviews were transcribed, and then summaries of these discussions were prepared. Thereafter, understanding of the case developed on the basis of this material which was iteratively studied and reflected upon by the authors both independently as well as in mutual consultation. The description below starts by outlining some of the grand visions underpinning the NSDI and then analyses it in relation to the three theoretical concepts drawn from the information infrastructure domain.

3.1 *Grand visions*

Planning for establishing an NSDI in India commenced in November 2000 with the establishment of a task force to prepare a viable strategy and action plan (DST 2001). The task force was composed of geographers, scientists, GIS experts, and

Table 1. Implications of learning from information infrastructure theory for the SDI domain.

Theoretical concepts	Key learning from information infrastructure theory
Installed base and lock-in effects	History cannot be ignored, such as the existence of paper maps.
	Understanding how existing and embedded technologies influence the new, for example how the existing focus on remote sensing may influence the kind of data that is stored (e.g. of vegetation cover).
	While information infrastructures need to evolve, they are constrained by the inertia of the installed base, such as the lack of map culture, institutional mechanisms and standards to enable sharing.
	The installed base is both technical (e.g. scales of existing maps) and institutional (the ownership of maps within the defence department for example) in nature.
Reflexive standardization	Universal standards are a utopian quest, as SDI is a rapidly changing domain, with respect to new technologies and changes in institutional actors and practices.
	Standards beget the need for new standards, as more users will continue to join (network externalities), which will place new demands on the SDI.
	The use of gateways to develop interfaces between different parts of the network (say different user groups, e.g. forestry and roads), while preserving local autonomy.
	Developing 'hierarchy of standards' to provide flexibility for local levels (for example, the health department) to have their standards while ensuring the core standards (defined by the planning department for example) are maintained.
	Standardization is restricted not only to technical artefacts but also to management practices, for example related to the incentives for data sharing.
	Developing and using standards involve a political negotiation of different stakeholders including scientists, user groups, vendors and policy makers.
	Standards should evolve bottom up and create 'local universalities', implying that standards should suit local needs first and foremost, but these should also conform to more global frameworks.
Cultivation approach to design	Design should be in small steps and incremental, for example, the focus could be on particular sectors (like forestry) and developing their applications within a wider SDI defined framework.
	SDIs can never be designed from scratch, and it is important to build upon existing inventories of spatial databases that exist.
	Grand and top-down designs, such as those defined by central ministries or apex scientific institutions, are liable to failure.
	Small parts of networks (particular user groups) should be changed while keeping consideration of the dynamics of the whole network.
	SDIs should be flexible to absorb unanticipated effects, such as through new global standards being introduced or new user departments joining or leaving the network.

administrators, mainly drawn from survey, mapping, remote sensing, and the Indian space organizations (ibid., p. Tf.1). The discussion document prepared by this team constituted the basis for further action. The key elements identified for development of NSDI were: standards (to allow interoperability; standards for networks, gateways, protocols, software, etc.), evolving metadata, nodes (GIS-based spatial database servers), search and access protocols, electronic clearing house, creating user interfaces, and initiating an NSDI outreach and awareness programme. The

NSDI vision as articulated in January 2001 by the NSDI task force document is provided below:

> National Infrastructure for the availability of and access to organized spatial data. Use of infrastructure at community, local, state, regional and national levels for sustained economic growth.

The influence of the 'information superhighway' metaphor as popularized in the West (Sawhney 1996) is reflected in the following statement of the Secretary of the Ministry of Science and Technology:

> There is a widespread consensus, internationally, that spatial datasets need to be integrated to create what is called a geo-spatial data infrastructure. Such infrastructures have been likened to information highways, linking a variety of databases and providing for the flow of information from local to national levels and eventually to the global community. (DST 2001, foreword by Secretary, DST)

In his foreword to this task force report, the Chairman of the Indian Space Research Organization (ISRO) emphasized the importance of access and sharing:

> Encapsulating these [existing base of] maps and images into a National Spatial Data Infrastructure (NSDI) is the need of the hour and the emphasis has to be on information transparency and sharing with the recognition that spatial information is a national resource and citizens, society, private enterprises and a government have a right to access it, appropriately (DST 2001, foreword by Chairman, ISRO).

At an international conference, the NSDI was described as 'a virtual network of standardized spatial databases of varieties of spatial information that enables easy access and major support to decision-support and sustainable economic growth' (Rao *et al.* 2004).

The above quotes can be interpreted to emphasize the metaphors of both *space* (access and connectivity—information superhighway) and *time* simultaneously. Given its early days, the SDI initiative can be seen to be largely 'technology determinist' in approach (Winner 1989) and interlinked with market arguments. These characteristics are reflected in the following statement of the Secretary, Department of Science and Technology:

> In the emerging market-place, geographic or geo-spatial information occupies a pre-eminent position. In fact, the use of high quality, reliable, geo-spatial information is crucial for every sphere of socio-economic activity—disaster management, forestry, urban planning, land management, agriculture, infrastructure development, business demographics etc. (DST 2001, foreword by Secretary, DST)

The views of industry leaders were, however, in sharp contrast to the rosy picture envisioned by the government scientists. The CEO of a major geo-consultancy firm visualized NSDI in the following words:

> The Indian NSDI planners are attempting to create an institution that would control everyone else's data—re-emphasizing our culture of attempting to control resources in pursuit of exercising power over others. Those (institutions and people controlling them) not used to sharing are now being asked to share. The culture of recognizing

> ownership of data is absent and there is no past experience to guide the sharing mechanisms.

The business head of a prominent telecom company which uses spatial information extensively to strategize its business vision said:

> The Indian spatial industry leaders met with Minister of Science and Technology on February 7 2005 to put forward their points of view in context of the NSDI. The industry had asked for a 'level playing field' if it were to participate meaningfully in this venture. It was also impressed on the Minister that NSDI should have a decentralized and flexible structure, and it should also be established outside the pale of the government.

He went on to say that 'NSDI is being planned to function as a government agency. If this thinking is indeed implemented, the entire initiative would fall flat. There is no way the stated vision and goals of NSDI can be realized under a government umbrella'. Given the diversity of views as the backdrop, the NSDI initiative is analysed further.

3.2 *Existing installed base (technical and institutional)*

A variety of institutional actors serve as custodians of different kinds of maps. At one level, the installed base can be seen to be constituted by the maps that exist in different institutions, the practices that govern their storage, update, distribution, access, etc., and the technologies and standards that are used for supporting these practices. The Chairman of the ISRO acknowledged the existence of this 'installed base':

> The nation has, over the past years, produced a rich 'base' of map information through systematic surveys, geological surveys, cadastral surveys, various natural resources inventory programs, and the use of remote sensing images. (ibid., foreword by Chairman, ISRO)

While the above statement points to the positive potential of the installed base—the availability of maps—what is not emphasized is how simultaneously the institutional aspects of the same installed base create a lock-in effect to constrain the processes of change. Institutions like the Survey of India and Departments of Space and Defence are the powerful custodians of spatial data in the country. These institutions have historically acted in a compartmentalized manner with limited sharing of data or applications, and cited security concerns to limit the access to maps not only to citizens and private sector, but even also to other government agencies (Sahay and Walsham 1996). So, while the existing installed base indeed technically has the potential to contribute to the development of the NSDI, it needs considerable hard work, especially with respect to redefining institutional practices to make it effective in practice. This point is highlighted through an example of three ongoing initiatives around spatial data in the natural resources sector. Table 2 summarizes the three initiatives with respect to their owner organizations, the intended end use of the spatial datasets, and the extent of their coverage.

The three initiatives summarized in table 2 represent overlapping objectives (drawing upon spatial data for natural resources management) but have developed separate databases by different agencies, often for the same district. The spatial

Table 2. Existing installed base.[a]

Existing database	Owning department/ year commenced	Spatial and non-spatial data available	Intended end-use	Extent of coverage
NNRMS National Resource Information System (NRIS) developed under this programme.	ISRO/ 1983	20 map layers on a 1:50 000 scale (e.g. landuse/cover, soil types, drainage, elevation contours, location of wells, settlements, rods, village boundaries, etc.) and eight socio-economic tables (e.g. demographic data (villagewise), education/medical facilities, etc.) prepared for an entire district. Input sources: existing topographic and thematic maps, census maps, and remotely sensed data.	Support GIS-based studies for land/water management (micro-watershed level). Watershed prioritization at state/district level based on severity of land degradation and other related factors (for allocation of funds). 'Expert' systems developed to recommend interventions in the project areas.	30 districts in the country
NRDMS	DST/ 1982	Number of map layers and socio-economic tables not standardized, usually incorporating a subset of the NNRMS database. Prepared independently by DST, using similar input sources mentioned above.	Land/water management in selected parts of the districts. Pilot studies to develop GIS-based methodologies for adoption on larger scale. Mainly an R&D focus.	45 districts in the country
IMSD	DoS/ 1995	Similar spatial coverage, with socio-economic data from secondary sources. Sources of data also akin to those mentioned above.	Improving land productivity and augmenting water availability in arid, semi-arid regions. Interventions and action plans required to achieve these objectives prepared for each micro-watershed using GIS modelling and 'expert' systems (figure 1).	175 districts (about 24% of the land area of the country proposed to be covered).

[a]Sources: Dasgupta *et al*. (2000) and NRSA (2002).

inputs are also drawn from similar sources, though during different time periods. Technical issues surrounding standards, the accuracy of data, thematic coverage, and diversity of non-spatial data sources used constitute a lock-in effect which impedes easy sharing and integration of data that contribute to the NSDI. The disparate functioning of these programmes was explained away by one scientist in the following words: 'While NRDMS focuses on data management issues, the emphasis of NNRMS is on resources management'. Institutional issues arising from data ownership and scientific rivalry also contribute to this lock-in.

The above example is not an isolated instance. In many developing countries, there exists a strong installed base of disparate and outdated spatial datasets (Fox 1991), work practices that do not include a strong culture of using maps (Walsham and Sahay 1999), and security concerns implying control over spatial data by the defence establishment (Fox 1991) and further limited by the dominance of the remote sensing community (Puri 2003). Addressing these lock-in effects is no trivial matter and requires SDI datasets to be linked to the implementation of Strategic Information Systems, which represents a nationwide, information-based social capability—including not only the technology but also the organization, incentives, procedures, and people—that has strategic value for the national development agenda (Georgiadou 2003). A strategic approach will help establish a vision and associated implementation mechanisms that can transcend departmental affiliations and agendas (Talero 2000).

3.3 *Approaches to standardization: Technical focus and top down*

The NSDI strategy proposes to equip each participating institution with one 'NSDI node' (DST 2001, p. 4.7) by installing database servers having all the geospatial data holdings relevant to each of the institutions. For example, the vegetation cover maps of the country (on 1:50 000 and 1:250 000 scales) would be maintained on the Forest Survey of India's server, while the Survey of India node would serve as the repository of the topographic data. All these servers will be interconnected, to a 'master' NSDI server over an Intranet. The 'master' server, which also serves as the metadata server, will function as a gateway to the Internet, and also as the electronic clearing house allowing data access from other nodes based on access protocols.

Metadata version 3.0 and data-exchange standard version 1.1 were developed indigenously, and these have since been adopted. The participating agencies (responsible for generation of spatial data) have been asked to systematize their data holdings and to develop metadata for these as per the approved standards.

The implementation strategy is proposed as creating an Intranet of GIS servers to set up a 'national repository of a digital "warehouse"' (DST 2001, p. 3.1), which the users, in due course, would be able to draw upon through an electronic clearing-house mechanism. The access protocols to be designed by scientists would determine who is allowed what access. A technology demonstration model has been evolved to the satisfaction of scientists and engineers of the Indian Space Research Organization and the Department of Science and Technology (NSDI III Workshop 2003). The standardization process is described in the following words: 'only through common conventions, and technical agreements, standards, metadata definitions, networks and access protocols will it be *easily possible* for the NSDI to come into existence' (Rao *et al.* 2004, emphasis added).

The standardization methodology in the NSDI represents a top-down approach, e.g. for creating metadata standard without an adequate perspective on their relevance and acceptance in local contexts. Harvey (2003) reminds us how complex standards (such as those of metadata) specified by federal agencies in the US are difficult to implement in local settings, leading to resistance and workarounds, which may lead to the bypassing of standards (Barrett *et al.* 2001). While standards are essential, they can also stifle growth and creativity. Williamson (2004) cites the example of building a large-scale cadastral map of Australia for the 1996 census, which was developed without standards, but was adopted as a de facto standard upon its completion. This analysis implies that if the process had focused on developing a standard first, the map would have never been built.

3.4 *Approach to design: Top-down, datacentric approach*

The envisaged role of the NSDI, its broad policy and operational framework, is to be given a formal high-level status through an enabling legislative mechanism to be brought before the Parliament, leading to the establishment of a National Spatial Data Commission (Matthan 2003). While such political visibility is indeed important, care should be taken that the SDI does not become a tool of controlling and manipulating civil society in the hands of a monolithic state (Pande 2004). In the hands of technology producers, SDI serves as a mere 'creator and generator of demand for their products and services' (ibid.).

The Indian NSDI shows little evidence of systematic interaction between its developers (the scientific institutions) and potential end users (for example, district administration) to understand their information needs. The design approach, as Groot (2003) suggests, can be termed datacentric, representing a 'design from nowhere' arising from a specialization of technology where anonymous designers

> with a license afforded by their professional training, problematize the world in such a way as to make themselves indispensable to it and then discuss their obligation to intervene, in order to deliver technological solutions to equally decontextualized and consequently unlocatable 'users'. (Suchman 2002, p. 95)

The NSDI design represents a construction approach characterized by top-down and centrally driven initiatives that seeks to create an 'overarching framework over existing agency-efforts at spatial information generation and format conversion' (DST 2001, p. 4.1). The agency of the material, the existing installed base, is not considered in the design approach, raising the need to complement the bottom-up and top-down approaches (Groot and McLaughlin 2000). The top-down approach is required to specify a strategic goal and vision, prioritize plans, arrange core funding, contribute to the definition of fundamental datasets, build a clearing house, develop metadata standards, and resolve information policy issues. The bottom-up approach aim to promote various local initiatives and build application-specific and enterprise-wide geospatial databases. This should be seen as an evolutionary approach to enable accessing, combining, and using data though user-centric methodologies such as prototyping, and cultivation of standards.

Figure 1 reflects the techno-centric nature of the methodology, adopted under Integrated Mission for Sustainable Development (IMSD) for addressing land degradation and water scarcity, as 'scientific silos'. The action plans for intervention in project areas are generated on the basis of scientifically recognized parameters, the spatial inputs are obtained mainly from modelling of remotely sensed data, and the non-spatial data are derived chiefly from secondary sources. This approach typically represents scientists seeking to reify technology, and with it establish the 'power and success of technical reality construction' (Dahlbom 1992, p. 125).

Table 3 below summarizes the characteristics of the NSDI with respect to the three theoretical concepts from the information infrastructure domain discussed earlier, viz. (1) installed base and lock-in effect, (2) reflexive standardization, and (3)

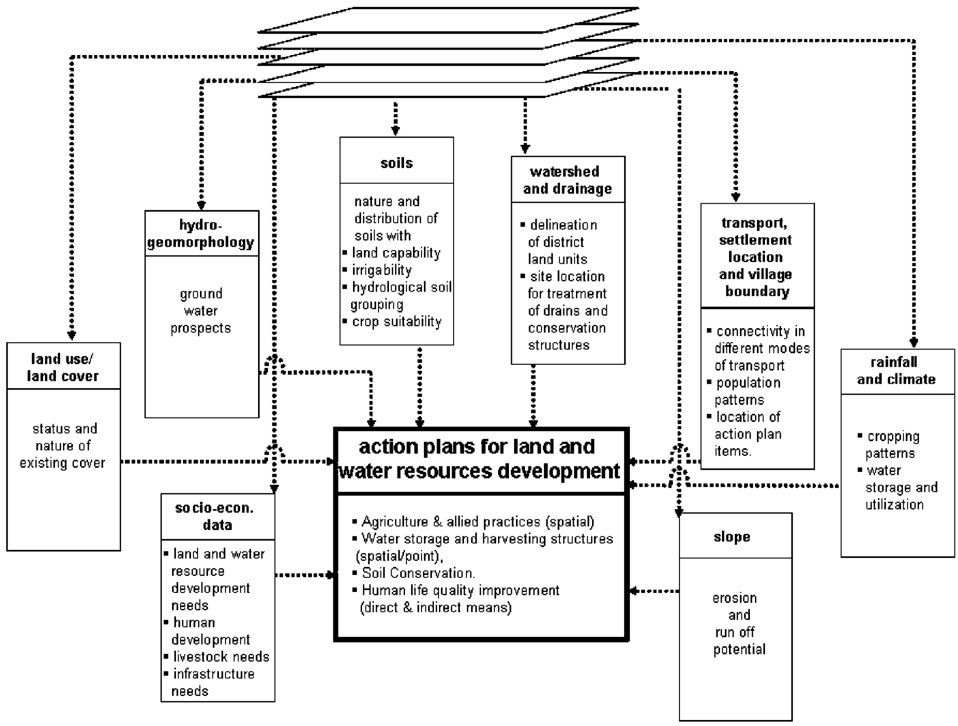

Figure 1. Preparing land and water resource development plans (source: NRSA 2002, p. 62).

Table 3. Key features of the Indian NSDI.

Learning from the domain of information infrastructure	As applied to the Indian NSDI
Installed base and lock-in effect	Installed base recognized, but no clear strategy exists of how it would form the basis of the NSDI. Lock-in created by diversity of maps, other spatial sources, and institutional issues not addressed.
Reflexive standardization	Standardization process mired in scientific thinking. Developing a 'hierarchy' of standards reflexively and as a negotiated process not in evidence.
Cultivation approach to design	Top-down, 'constructionist' approach evident at present, data-centric focus, end users not involved in determining their perceived needs, inculcation of bottom-up approaches also not considered; visions of 'grand' design.

cultivation approach to design. This analytical summary provides a theoretical lens to visualize the contours of a potential research agenda for the NSDI.

4. Conclusion: Towards a potential research agenda for SDI implementation

The theoretical framework developed in section 2 and the case study and its analysis presented in section 3 help to develop the basis for identifying elements of a potential research agenda that can support the theoretical analysis of SDI implementation which will also contribute to improved practice (Molenaar and

Georgiadou 2003). While this discussion is based on a case analysis of India, we believe it has broader implications also for other developing countries. We identify four elements to comprise the basis for this agenda: (1) increasing focus on the *dynamics* of implementing SDIs; (2) examining the nature and also *process* of implementing standards; (3) expanding the *scope* of the design process; and (4) raising the *quality* and extent of empirical investigation. These points are briefly discussed.

4.1 *Dynamics of implementation*

Conceptualized as an information infrastructure, the complexities of SDIs, in both technical and institutional terms, are emphasized. The current focus primarily on data and its associated technicalities provides an inadequate lens to analyse the dynamics surrounding SDIs and its practical implications. First, there is the need to understand the nature of socio-technical *networks* that constitute SDIs, including data, databases, ICTs, standards, people, institutional histories and practices, and applications. This requires opening up the *black-box* of SDI and analysing its interconnections with different constituents of the network. Second, this network needs to be analysed within a *historical context* that emphasizes both the challenges and opportunities posed by the lock-in effects of the existing installed base. Third, moving beyond just making grand visions of what SDIs are, or should do, in theoretical terms, there is a need to focus on the process of implementing them. Information infrastructure implementation is a socio-technical process which takes a long time to bring about and institutionalize. In SDIs, where the complexity is magnified in comparison with traditional information systems/information infrastructures, the need is for sustained and long-term research.

4.2 *Process of standardization*

The current efforts around SDI standardization reflect a top-down and 'one size fits all' kind of approach. Research in information infrastructure has helped to establish the utopian nature of the quest for universal standards, and the political negotiations that are inherent in the manner in which standards are designed, implemented, and revised. Standardization necessarily needs to be a reflexive process, constantly needing monitoring, revisions, and new standards. Within the SDI domain, first, it is fundamental to understand the different *stakeholders* (vendors, user groups, scientific institutions, and infrastructure providers), their interests, and how these are influenced by the standardization process. Second, it is important to understand how different standards relate to each other, and the mechanisms through which a certain institutional level or group of stakeholders is provided with a degree of autonomy and flexibility to define the stakeholders' standards while conforming to standards of the higher levels. There is thus a need to identify a *hierarchy of standards* for different contexts. Third, given the political nature of the standardization process, it becomes important to negotiate, and provide appropriate *incentives* to the stakeholder to engage in the process of standard setting and use.

4.3 *Scope of the design process*

The design process underlying contemporary SDI initiatives can be described as being technically defined and driven primarily through top-down mechanisms. The scope of the design effort needs to be expanded, in terms of who participates and also the focus of the effort. A cultivation approach to design, as argued for information infrastructure researchers, needs to start by first identifying the nature of the *existing* installed base in both technical (e.g. existing maps and their scales) and institutional (e.g. who owns them and their distribution policies) terms. This understanding will help to respect the principle that SDIs cannot be designed from scratch and needs to build upon what exists. Second, there is a need to examine what *components* of the network can be designed or changed while not disturbing the rest of the SDI. Third, this incremental or bootstrapping approach requires the identification of 'gateways' which connects different parts of the SDI, allowing changes to be made in one part while not disturbing the rest. Fourth, the importance of encouraging *participatory* approaches in the design process cannot be emphasized enough.

4.4 *Rigorous empirical research*

As Wilson (2000) points out, the evolution of technological systems is necessarily supported by rigorous empirical research conducted using multidisciplinary perspectives. Ongoing conversation taking place between 'tales from the field' (Van Maanen 1989), and theoretical concepts help to develop both our conceptual understandings and approaches to practice. Given the nature of the SDI phenomenon, research teams should be constituted in *inter-disciplinary* terms (sociologists, anthropologists, geo-scientists, information-system researchers, and economists) and supported to conduct *longitudinal* research (rather than one-time studies) that can follow the unfolding of the process dynamics around SDIs over time. Also, as IS research has emphasized, implementation analysis is best guided by an *interpretive* philosophy where the different social meanings constructed by various stakeholder groups are emphasized, as contrasted to a positivist approach where assumptions are made about objectivity of data and the generation of statistical generalizations (Walsham 1993, Klein and Myers 1999).

In summary, the key elements towards developing a research agenda for supporting SDI implementation in developing countries are summarized in table 4. In this table, we identify specific research questions around each of the four items of the potential research agenda discussed above.

In conclusion, this paper takes a first step towards the development of a potential research agenda that can guide theoretical and practical efforts around the implementation of SDIs in developing countries. We hope this paper will provide a catalyst to debates on appropriate theoretical perspectives and lead to the creation of multi-disciplinary analytical lenses and improved strategies for practical implementation. Through an ongoing dialogue between theoretical developments and empirical experiences, the research questions posed above can be further refined and contextualized for adoption in particular settings.

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Table 4. Key elements of a research agenda around SDIs.

Domain	Emerging questions
Dynamics of implementation	What is the nature of the socio-technical networks that constitutes SDIs? What is the nature of the SDI black-box? What is the nature of the existing installed base, and what are the lock-in influences they create? What challenges and opportunities arise as a result? How does the implementation process unfold over time?
Process of standardization	Who are the different stakeholders that should be involved in the standardization process? How do the different standards relate to each other, and what is the nature of the hierarchy of standards? What kind of incentive mechanisms need to be established so as to enrol the varying interests of different stakeholders?
Scope of the design process	Who are the stakeholders that should be involved in the design process so as to gain an appropriate representation? What is the nature of the existing installed base, and how can be built upon the useful content that already exists? What kind of gateways can be established to link and at the same time provide autonomy to different parts of the network? What mechanisms and structures can be established to encourage participatory approaches to design?
Rigorous empirical studies	How can inter-disciplinary teams be established to conduct research? What kind of longitudinal designs are appropriate to study SDI implementation? How have integrated physical infrastructures evolved in this nation? How can an interpretive research philosophy be operationalized in practical terms to conduct empirical research?

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