The Dynamic Nature of Spatial Data Infrastructures:  
A Method of Descriptive Classification 

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ABSTRACT

Spatial Data Infrastructure (SDI) is understood and described differently by stakeholders from different disciplines and different administrative/political levels. However, current SDI definitions are individually insufficient to describe the dynamic and multi-dimensional nature of SDI. Despite the international interest and activities toward SDI development, SDI remains very much an innovation even among practitioners. There are still doubts regarding the nature and identities of SDI, particularly in connection with how it evolves over time to meet user needs. As a starting point a means to describe SDI’s multi-dimensional capacity as an inter- and intra-jurisdictional spatial information framework is required. The aim of this paper is to better understand and describe the nature of SDI and its components. A method to classify the perceived roles of SDI is identified. The method is extrapolated from a technique to describe different perspectives of Geographical Information System (GIS) diffusion, based on identified parallels between GIS and SDIs. The methodology may facilitate description and understanding of the SDI technological and user environment, by promoting insight into the dynamic roles of SDI.
1. Introduction

Spatial Data Infrastructure (SDI) is an initiative intended to create an environment in which all stakeholders can co-operate with each other and interact with technology, to better achieve their objectives at different political/administrative levels. SDIs have become very important in determining the way in which spatial data are used throughout an organisation, a nation, different regions and the world. In principle, they allow the sharing of data, which is extremely useful, as it enables users to save resources, time and effort when trying to acquire new data-sets by avoiding duplication of expenses associated with generation and maintenance of data and their integration with other data-sets. By reducing duplication and facilitating integration and development of new and innovative business applications, SDIs can produce significant human and resource savings and returns.

Once formed, an SDI has often been assumed to remain a static entity. This has limited the understanding of the nature of SDIs, optimisation of their potential and the capacity for their evolution. Current perceptions and descriptions of SDI fail to convey SDI’s dynamicism and complexity. Better means to describe SDI’s multi-dimensional capacity as an inter- and intra-jurisdictional spatial information framework are required.

The aim of this paper is to better understand and describe the nature of SDIs’ currently variable identification. Researchers and various national government agencies have attempted to capture the nature of SDI in definitions produced in various contexts. This paper briefly reviews these and other definitions and argues that while they provide a useful base for the understanding of SDI, individually on their own they are inadequate for SDI development in the future.
1. Understanding the Nature of SDIs

While there is increasing interest being given to SDI and recognition that SDI promotes economic development and environmental management, the concept and justification of the infrastructure are still unclear. SDI remains very much an innovation even among practitioners and there are still doubts regarding the nature and identities of SDI [Barr 1998, Rajabifard, et al. 2000]. This is emphasised by the generally limited understanding of the innovative concept of SDI even among key players in the spatial information industry [Barr 1998, 1999, Coleman and McLaughlin 1998] all of whom are trying to understand the roles they play, past, present and future. At present, many are feeling their way as they try to position themselves in response to the continual advent of SDI.

SDI is understood differently by stakeholders from different disciplines. It is commonly recognised that an SDI can include core components of policy, fundamental datasets, technical standards, access networks and people, and adopt different design and implementation processes. In this regard, researchers and various national government agencies have attempted to capture the nature of SDI in definitions produced in various contexts (Table 1). Whilst these existing definitions provide a useful base for the understanding of different aspects of SDI, or SDI at a snapshot in time, the variety of descriptions have resulted in a fragmentation of the identities and nature of SDI, derived for the varied purposes of promotion, funding and support. Lack of a more holistic representation and understanding of SDI has limited the ability to describe its evolution in response to the technical and user environment.

Existing definitions have been slow to incorporate the concept of an integrated, multi-leveled SDI. Recent research indicates that SDI is multi-leveled in nature, formed from a hierarchy of inter-connected SDIs at corporate, local, state/provincial, national, regional (multi-national) and
<table>
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<tr>
<th>Source (reference)</th>
<th>Definition of SDI</th>
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<tr>
<td>Australia New Zealand Land Information Council [ANZLIC 1996]</td>
<td>A national spatial data infrastructure comprises four core components - institutional framework, technical standards, fundamental datasets, and clearing house networks</td>
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<tr>
<td>Canadian Geospatial Data Infrastructure (CGDI) [CGDI 2000]</td>
<td>The Canadian Geospatial Data Infrastructure (CGDI) is the technology, standards, access systems and protocols necessary to harmonize all of Canada’s geospatial data bases, and make them available on the internet</td>
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<td>Dutch Council for Real Estate Information (Ravi) [Masser 1998, p.48]</td>
<td>The National Geographic Information Infrastructure is a collection of policy, data sets, standards, technology (hardware, software and electronic communications) and knowledge providing a user with the geographic information needed to carry out a task</td>
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<td>European Commission [European Commission 1995]</td>
<td>The European Geographic Information Infrastructure (EGII) is the European policy framework creating the necessary conditions for achieving the objectives set out below. It thus encompasses all policies, regulations, incentives and structures set up by the EU Institutions and the Member States in this pursuit</td>
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<td>Executive Order of US President [Executive Order of the White House 1994]</td>
<td>National Spatial Data Infrastructure (NSDI) means the technology, policies, standards, and human resources necessary to acquire, process, store, distribute, and improve utilization of geospatial data</td>
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<td>Global Spatial Data Infrastructure Conference 1997 [GSDI 1999]</td>
<td>Global Spatial Data Infrastructure (GSDI) should generally encompass the policies, organizational remits, data, technologies, standards, delivery mechanisms, and financial and human resources necessary to ensure that those working at the global and regional scale are not impeded in meeting their objectives</td>
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<td>McLaughlin and Nichols [1992]</td>
<td>The components of a spatial data infrastructure should include sources of spatial data, databases and metadata, data networks, technology (dealing with data collection, management and representation), institutional arrangements, policies and standards and end-users</td>
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<td>Queensland Spatial Information Infrastructure Council, Department of Natural Resources [DNR 1999]</td>
<td>The Queensland Spatial Information Infrastructure comprises the data sets, institutional arrangements, technical standards, products and services required to meet the needs of government, industry and the community</td>
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<td>Victorian Geospatial Information Stategy 2000-2003 of the State Government of Victoria, Australia [Land Victoria 1999]</td>
<td>A spatial data infrastructure is conceptualised as a comprehensive geospatial information resource—the infrastructure, the value and capability of which are driven into Victoria’s information systems and processes—the benefit, through the strategic elements of custody, metadata, access infrastructure, pricing, spatial accuracy and awareness</td>
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global levels [Chan and Williamson 1999b, Rajabifard et al. 1999, 2000]. SDI development at a state level also suggests that an SDI is a dynamic entity; its identity and functionality change and become more complex over time [Chan and Williamson 1999b]. Failing to acknowledge these characteristics of SDI, the multidimensionality, and dynamic mechanistic and functional roles of the SDI, have rendered many descriptions of SDI inadequate to describe the complexity and the dynamics of SDI as it develops, and thus ultimately constrain SDI achieving developmental potential in the future.

In recent years, researchers have applied the theories of *innovation diffusion* to the study of GIS planning and implementation [Onsrud and Pinto 1991, Masser 1993, Masser and Onsrud 1993, Campbell 1996, Masser and Campbell 1996, Chan 1998]. Rogers [1983] defined diffusion as a process by which an innovation is communicated through certain channels over time among the members of a social system. In 1999, Chan and Williamson [2000] applied the generic principles derived from the study of diffusion of GIS in a complex organisation to the development of SDIs. Based on the diffusion paradigm, understanding of the nature of an innovation is crucial in the success of the progressive uptake and utilisation of the innovation by members of a community [Rogers 1995]. From an engineering point of view, successful designing, building and managing an innovative product requires a sufficient understanding of the nature of the product. This is to help to establish the functions of the product and to determine the engineering characteristics of the product that best meet the customer requirements [Cross 1995].

To better understand the multidimensional nature of SDI, a system of classification is needed to organise the many definitions and various aspects of the nature of SDI. One such system has been developed to organise the definitions for GIS into four different perspectives. It treats GIS as an innovation that is progressing through a process of diffusion in an organisation [Chan and Williamson 1999a]. As GIS technology has had a significant influence on the need for SDI and
the diffusion SDI is undergoing in different communities the system of definition classification for GIS should also be applicable to SDI. SDI is an innovation that is underpinned by many GIS concepts and technologies, as well as the phenomenon of the Internet and related telecommunications and network technology.

3. The Four Perspectives of GIS Diffusion

The definition classification system groups the definitions of GIS into four perspectives: identificational, technological, organisational and productional. The perspectives are not exclusive, rather serve descriptive purposes for different aspects of understanding GIS and at different stages of development. The identificational perspective describes the unique features of GIS that distinguish GIS from other types of information systems. The technological perspective describes GIS as a certain form of technology (database, application, or toolbox) that provides specific functional capabilities (map, database, and spatial analysis). The organisational perspective describes GIS in terms of its generic elements, or building blocks, which specifically include the organisational and/or institutional implementation environment. The productional perspective portrays GIS as the means in the production process undertaken by an organisation to generate the products and services expected by its clients.

Chan and Williamson [1999a] observe that the first three perspectives are useful at different stages of diffusion of GIS when its final purposes, functionality and composition are clearly specified—the focused scenario of diffusion. Under a very dynamic situation, as in the case of the long term development of a corporate GIS, when these details are not clearly defined—the dispersed scenario—the above three perspectives are not applicable. In this regard, an alternative composite view of GIS, namely, the productional perspective, was developed [Chan and Williamson 1999a].
The *productional* perspective applies to GIS in the *dispersed* scenario of diffusion. It takes a high level view of GIS in terms of the environment in which it functions and evolves. The environment is viewed as a mechanism of production. For GIS the environment generally refers to an organisation. GIS in an organisation, under the *productional* perspective, is deemed to be a collection of modules of *infrastructure GIS* and *business process GIS* that interact to promote the development of one another as illustrated in Figure 1 [Chan and Williamson 1999a, 2000]. A module of infrastructure GIS represents the capability of one of a group of GIS suppliers in an organisation, while a business process GIS represents the GIS capability of GIS users. Inherent in the *productional* perspective is an active link or working relationship between the two modules of GIS that ensures the successful development of GIS capabilities by both GIS users and suppliers [see Chan and Williamson 2000 for an example].

The diffusion of GIS in an organisation, also called corporate GIS in the literature, is viewed as the collective outcome of the individual but inter-related processes of diffusion of the GIS modules. In such a process, each GIS module can assume a different identity or even multiple identities at different stages. The outcome of diffusion of one module may have a significant impact on that of one or more other GIS modules by virtue of the links (or working relationships) established. As a result, the *productional* perspective of GIS provides a means for the mapping of
the progressive development of the GIS modules and the associated links over time. It provides a better understanding of not only the nature of GIS but also the dynamics of GIS diffusion in an organisation [Chan and Williamson 2000].

4. The Four Perspectives for SDI

The technology of GIS has recently been incorporated in mainstream database management systems to manage spatial data along with other traditional alphanumerical data [Ower and Barrs 1999]. As GIS becomes a more mainstream corporate technology it underpins the management of spatial data in more organisations and governments. These strive to develop an integrated corporate GIS to maximise the benefit of their spatial data assets. In the context of an SDI hierarchy, Chan and Williamson [1999b] argue that an integrated corporate GIS is in effect a corporate SDI from which SDI at different political and administrative levels can draw data. Similar to the role of SDIs, common problems addressed by a corporate GIS include elimination of duplication, acceleration of development and promotion of data sharing [Levisohn 1997]. Based on the similarities, this paper groups and discusses a range of definitions of SDI, based on the four-perspective system of classification described for GIS. The aforementioned four perspectives of classification, as applied to SDIs, are outlined in the following sub-sections.

4.1 Identificational Perspective

An identificational perspective describes the uniqueness of SDI. This perspective is important in justifying investment in SDI as distinct from other information infrastructure initiatives. In this regard, researchers and practitioners choose to focus on explaining the uniqueness of spatial information rather than SDI itself, as illustrated in the SDI strategies of the European Commission and the State Government of Victoria (Table 1):

The European Geographic Information Infrastructure (EGII) is the European policy framework creating the necessary conditions for achieving the objectives
set out below. It thus encompasses all policies, regulations, incentives and structures set up by the EU Institutions and the Member States in this pursuit [European Commission 1995].

A spatial data infrastructure is conceptualised as a comprehensive geospatial information resource—the infrastructure, the value and capability of which are driven into Victoria’s information systems and processes—the benefit, through the strategic elements of custody, metadata, access infrastructure, pricing, spatial accuracy and awareness [Victorian Geospatial Information Stategy 2000-2003 of the State Government of Victoria, Australia - Land Victoria 1999].

While useful in introducing the basic concept of SDI to the layperson, this approach runs the risk of selling short the SDI initiative to decision-makers.

4.2 Technological Perspective

A technological perspective describes the form and function of SDI. It provides a more tangible image of SDI in an attempt to facilitate its acceptance. A good example is the definition by McKee [1996] where the form (bold) and function (underlined) have been highlighted:

*A global spatial data infrastructure is like a wheel with technology as its hub, each spoke a different country. Each country has SDI components or levels dealing with legacy data, culture, academic resources, professional organisations, governmental agencies, and legal and regulatory structures (for land tenure, privacy, intellectual property, environment, census, etc.)* [McKee 1996].

Another example is the portrayal of an ideal SDI as a hierarchy of spatial datasets that users at different levels can access to meet their needs [Chan and Williamson 1999b, Rajabifard et al.
The Canadian Geospatial Data Infrastructure (CGDI) is also defined using a technological perspective (Table 1) as

the technology, standards, access systems and protocols necessary to harmonize all of Canada’s geospatial data bases, and make them available on the internet [CGDI 2000].

A glance at the definitions in Table 1 [McLaughlin and Nichols 1992, European Commission 1995, ANZLIC 1996, Masser 1998, GSDI 1999, DNR 1999, Land Victoria 1999, CGDI 2000] and those of Chan and Williamson [1999b], FGDC [1999], reveals that an SDI comprises several elements. Three key elements that have gained a high profile in the literature in recent years are the framework data, standards and the delivery mechanism of SDI. Though these elements are only part of the whole SDI, they are often portrayed as one of the several simplified identities of SDI depending on the strategies of the SDI managers. For example, regarding framework data,

The framework forms the data backbone of the NSDI and is designed to facilitate production and use of geographic data, to reduce operating costs, and to improve service and decision making [FGDC 1997, p.v].

The delivery mechanism of SDI is primarily made up of a component that allows searching of spatial data and another that allows browsing and down-loading spatial data over a network, often the Internet. The former is often called a spatial data directory. In the case of Australia,

The Australian Spatial Data Directory (ASDD) is an essential component of the Australian Spatial Data Infrastructure (ASDI) and provides these [sic] search interfaces to geospatial dataset descriptions (metadata) from all jurisdictions throughout Australia [ANZLIC Metadata Working Group 1999].

The latter is often called a clearinghouse. According to FGDC [1999],

The clearinghouse is a decentralized system of servers located on the Internet which … provide(s) access to digital spatial data through metadata.
4.3 Organisational perspective

An organisational perspective describes SDI in terms of its building blocks [Rajabifard et al. 1999, 2000] and in particular the organisational/institutional setting. It is meant to allow SDI practitioners to better plan and coordinate the development of the very complex innovation of SDI. One of the more comprehensive definitions under this perspective is the one by McLaughlin and Nichols [1992] in Table 1:

The components of a spatial data infrastructure should include sources of spatial data, databases and metadata, data networks, technology (dealing with data collection, management and representation), institutional arrangements, policies and standards and end-users [McLaughlin and Nichols 1992].

Examples from Australia [ANZLIC 1996], the European Union [European Commission 1995], and the U.S.A. [Executive Order of the White House 1994] in Table 1 suggest that this perspective is particularly popular among government agencies responsible for SDI development. Other governments such as the Netherlands [Masser 1998], the State of Queensland [Department of Natural Resources 1999] and international organisations such as the Global Spatial Data Infrastructure [GSDI 1999], opt for a composite approach—an amalgamation of the technological and organisational perspectives. In this approach, the form of SDI is described in terms of the building blocks such as those put forward by McLaughlin and Nichols [1992] while the function of the SDI is described as serving the needs of the stakeholders concerned.

4.4 Productional Perspective

Like that of GIS, the diffusion of SDI also takes place in a dispersed scenario in which the final purposes, functionality and composition of the SDI are only vaguely defined as illustrated in the strategies of SDI development of different countries [European Commission 1995, ANZLIC 1996, FGDC 1999]. The experience with GIS suggests that from the similarities of characteristics
of an SDI to a GIS, taking a *productional* perspective for SDI may provide insights into the characteristics of SDI in the context of its evolving environment, resulting in more holistic strategies to manage its diffusion and development within that environment. Chan and Williamson [1999b] propose that such an approach is justified given the characteristics of an SDI are similar to those of a GIS. Based on the experience of development of GIS in the State of Victoria in Australia and Australia as a whole, Chan and Williamson [1999b] cite similarities between SDIs and GIS to include:

1. Like a module of *infrastructure GIS*, an SDI does not develop in isolation but in conjunction with the business activities it supports;
2. It is a multi-levelled entity functionally and administratively;
3. It is dynamic in nature and even well conceived centralised planning will not guarantee the development of an SDI that meets the needs of all users.

As section 3 points out, the two roles of a module of GIS depict the interdependency of the suppliers and users of GIS in an organisation. Likewise, the *productional* perspective of SDI should describe an SDI in terms of a dual-roled module in an environment where business activities or production processes, underpinned by GIS, are undertaken. Chan and Williamson [1999b] propose that a corporate GIS, also constitute a corporate SDI which is a building block of an SDI hierarchy that spans different political/administrative levels throughout the world. Based on this concept the environment for the corporate SDI is identified as the organisation to which it belongs. Each organisation, and the corporate SDI it establishes, can play the role of a supplier or user of spatial data needed to conduct business in a jurisdiction. This concept help to describe the spatial information industry suggested above- the environment for SDIs at other levels in the SDI hierarchy. Figure 2 illustrates a proposed model of the *productional* perspective of SDI. In the model the building blocks are individual corporate SDIs which use and/or supply spatial data and technology, and interact progressively with one another as members of the spatial information
industry, in the production processes of a jurisdiction to fulfil its range of business needs—social, economic and environmental.

![Diagram of the spatial information industry of the jurisdiction](image)

Figure 2. Productional perspective of a SDI

The interaction involves spatial data and technology users adding value to the original raw data provided by spatial data suppliers, and then on-selling the value-added data to other users. This continual value-adding process ends at an ultimate user, often a member of the public, who uses a spatial data product to make decisions. As a result, the interacting stakeholders groups can be visualised as a network of value-adding chains of suppliers and users of spatial data/technology, or alternatively, the different dimensions of the spatial information industry. This industry, in turn, represents the environment in which the SDI functions and evolves.

The productional perspective of SDI, in the model proposed in Figure 2, describes SDI in the context of the spatial information industry of a jurisdiction. It takes into consideration the interests of both spatial data users and suppliers and the way they interact to deliver the products and services to meet the jurisdiction’s business needs. As the reach of the industry is worldwide and recognises no political or administrative boundary, it represents an environment that is generic enough to account for the hierarchy of SDI observed.
5. **Conclusions**

This paper points out that SDI remains an innovation among many practitioners. There is a need to better clarify the nature of SDI to facilitate its development and progressive uptake and utilisation among members of a community (diffusion). A number of the more current definitions of SDI are reviewed within a classification system of four perspectives of SDI, namely, *identificational, technological, organisational* and *productional*. The definitions fall within the first three perspectives with the organisational perspective being the most popular approach adopted by government, regional and global SDI developing agencies.

Based on the research into diffusion of corporate GIS, it is proposed that SDI development and diffusion takes place in a *dispersed* scenario in which the final purposes, functionalities and composition of the SDI change dynamically and can only be specified vaguely. Under this condition, it is the fourth perspective, the *productional* perspective, not the first three perspectives of SDI, that is potentially most useful in facilitating SDI development and diffusion.

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