Networks of Innovation and the Establishment of a Spatial Data Infrastructure in Brazil

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Abstract

Transitional economies with large geographical areas (such as Brazil, Russia, India, and China) represent both a challenge and an opportunity for setting up spatial data infrastructures (SDI). Nevertheless, there is a difference between SDI and more conventional information infrastructures (II). SDI users need to have specific knowledge to navigate the complexities of the different types of spatial data handling and analysis techniques. Because of these added complexities, setting up an SDI in transitional economies is critically dependent on the diffusion of geographical information systems (GIS) technology in public and private institutions. To understand the successful establishment of an SDI in a transitional economy, we use Rogers' diffusion of innovations model to study how GIS technology was introduced in Brazil. We point out a set of institutions whose strategies have had an important role in introducing GIS and SDI in Brazil. These institutions form a collaborative network of early adopters of GIS that provides a 'best practice' example in production and dissemination of spatial data in Brazil. The network was successful because its members combined collective expertise in all areas of spatial information technologies. Therefore, although each institution had a specific focus, the network had unequaled skills in GIS and SDI. All members of the network viewed knowledge as a public consumption good and contributed to establishment of new groups. Finally we conclude discussing the

choices for making the Brazilian SDI sustainable. Brazil is leaning towards a policy that enforces both the open access to data and the use of open software. The Brazilian experience points out that public policies focused on organization of SDI in transitional economies in midsized and large countries should promote the growth of collaborative networks. These networks should be based on complementary skills of the institutions involved and have the potential for improving the quality and the rate of adoption of SDI in transitional economies.

Keywords

Spatial data infrastructures, transitional economies, GIS, information technology.

1 INTRODUCTION

Transitional economies with large geographical areas are both a challenge and an opportunity for spatial data infrastructures (SDI). A good example is the so-called BRIC countries (Brazil, Russia, India and China), which have large populations and research and development (R&D) in geographic information systems (GIS). These countries have significant challenges in handling their natural resources and SDI can play an important role in managing their territories. In practice, the challenges are enormous. One of the key differences between SDI and more conventional information infrastructures (II) is that users need to be knowledgeable to handle the techniques for spatial data handling and analysis. Databases for spatial information are much more complex to handle than conventional database management systems (Shekhar, Chawla et al. 1999). Traditional statistical techniques do not capture important properties of spatial data (Anselin 1989). Thus, GIS uses need specialized skills that need substantial investment in capacity building.

When approaching the idea of an SDI for a transitional economy, there are two competing perspectives. One approach is viewing SDI as an *automated map distribution system*. In this case, SDI implementation focuses on map production and distribution of existing sources on an "as-is" basis. The alternative is viewing SDI as an *enabler for understanding space*. In this case, an SDI does not deliver maps. It disseminates spatial data with associated quality control, metadata information, and semantic descriptions. The SDI user is someone who is able to combine spatial data from different sources to produce new information for a study area. In the authors' view, the second vision is the one where SDI can play an important role in the economic growth of developing nations. While it is important in the long term to provide users with efficient means to feed their own creations, such as digital maps or analysis results back into an overall SDI cataloging, archiving, search and retrieval system, the core of an SDI resides in its source data (Onsrud, Câmara et al. 2004).

SDI is most needed in developing nations as support for decision-making. For example, planning a new hydroelectric power plant requires an assessment of its potential impacts on communities and the environment. This leads to a need for building different scenarios with quality spatial data and adequate spatial analysis techniques. Static map products are unsuitable for such analyses. Thus, SDI will only have an

impact on developing countries if its potential users are knowledgeable in GIS technology. Although the question of how an emerging country, which does not have prior skills in GIS, may leapfrog into an SDI stage is relevant, it is not part of our main discussion in this paper.

Based on the premise that "*GIS predates and enables SDI*", this paper examines the adoption of GIS and SDI in Brazil beginning in 1984. Our theoretical basis is Rogers' diffusion of innovations model (Rogers 1995). We identify a set of leading institutions (*early adopters* in Rogers' terminology) which have played an important role in pioneering GIS and SDI technologies in Brazil. We also point out the links between these *early adopters* and assess the impact of the *early adopters* in promoting GIS/SDI technologies. Similar work on the use of Rogers' theory applied to GIS and SDI include Nedovic-Budic (1998), Chan and Williamson (1999) and Masser (2005). We also complement the analysis with a view of other theories can further explain what happened in Brazilian SDI implementation. We use also Actor-Network theory (Latour 1988; Law 1992) to suggest some other views of the problem.

Our hypothesis is that Brazil has been successful in its SDI development so far largely due to a set of early adopters that combined R&D in spatial information with producing and disseminating spatial data. We have labeled the early adopters of GIS and SDI in Brazil as the "network of innovators". In our view, this collaborative network was instrumental to ensure that such a large country could benefit from spatial information technologies. The network was successful because it combined expertise in different areas of spatial information technology. These *early adopters* viewed knowledge as a *public consumption good* (Dasgupta and David 1994) and openly spread their experience and their results. Our claims are consistent with the literature on economics of science and technology which argues that economic returns of scientific projects are difficult to measure directly (David, Mowery et al. 1992; Dasgupta and David 1994; Nelson 1996; Ruttan 2001). Therefore, investigators on R&D innovation prefer to stress the linkages between research and the market. As David et al. (1992) puts*: "The number and richness of links between the knowledge generated by basic scientific projects…are important determinants of the potential economic returns"*.

We will also discuss how the early adopters of GIS in Brazil have helped to avoid the "lock-in" effects associated to introduction of information technologies in

transitional economies (Arthur 1994) (Mowery 1996). The "lock-in" effect is relevant in GIS software, where two companies (ESRI® and Intergraph®) hold about 50% of the market (Daratech 2003). In Brazil, associating public diffusion of innovation with locally developed no-cost and open source software enabled many institutions to avoid being locked-in a particular vendor's solution.

In what follows, we will first apply Rogers' model of diffusion of innovations to GIS and SDI. In section 3, we give a brief introduction to three of the main players in the Brazilian SDI. Then, we will provide evidence on the applicability of Rogers' model to the extent of the Brazilian case. Next, we show how the network of innovators influenced adoption of GIS and SDI in Brazil. We point to challenges and tensions that remain before Brazil can fully complete a nationwide SDI. Finally, we consider how the lessons from the Brazilian case can be useful to other countries.

2   DIFFUSION OF INNOVATIONS IN GIS AND SDI

The *diffusion of innovations* model was originally articulated by Everett Rogers (1995) and explored in many later research studies (Grubler 1998; Nedovic-Budic 1998; Chan and Williamson 1999; Ruttan 2001; Masser 2005). This model proposes that the rate of adoption of an innovation follows a diffusive equation similar to the spreading of an epidemic disease. In this model, the cumulative number of adopters of a new technology follows a logistic (*S-shaped*) curve and therefore, the number of adopters over time follows a normal distribution (see Figure 1). Rogers (1995) has identified five categories of technology adopters: (1) *Innovators*, who outbound their local circle of peer networks towards more cosmopolite social relationships; (2) *Early adopters*, who are closer to the local social system than innovators; (3) *Early majority*, who embrace innovation just before the average member does; (4) *Late Majority*, who adopts new ideas just after the average members; and (5) *Laggards*, who are the last to adopt innovation.

Rogers considers that rate of adoption of an innovation depends on the adopters' perception of its characteristics. Five *attributes* that aid explanation of the rate of adoption of an innovation include: (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability. To apply Rogers' model to spatial

information technology, we need to understand the *qualities* of GIS and SDI as innovative technologies.

The diffusion of innovations theory (Rogers 1995) assumes an innovation to be an immaterial entity that spreads like an epidemic. Diffusion theory further assumes the innovation is neutral in relation to its adopters. The choice to adopt an innovation considers qualities such as trialability, relative advantage, compatibility, complexity and observability. Rogers' view assumes adopters can be objective when comparing current practices to new ones. His theory has had a significant influence in the literature. As Ruttan (2001) notes: "*The S-shaped logistic curve has remained remarkably robust as a description of the technology diffusion and the substitution processes*" (p.171).

Diffusion theory is not the only explanation for innovation. Other theories, such as actor-network theory (Latour 1988), consider that objective judgment is difficult to achieve in practice. To assess an innovation, would-be adopters have to associate the innovation to their own experiences and worldviews. Actor-network theory discards the view of innovation as a neutral entity, which is fit for use regardless of the actors involved. Instead, actor-network theory sees technologies as networks between actors. Technology only makes sense when used by an 'actor' with interests and roles. In this view, *translation* is more relevant than *diffusion* for adoption of new technologies. What gives meaning to the technologies are the way actors translate them to their worldviews and the way they preserve or confront the status quo (McMaster, Vidgen et al. 1997).

Therefore, *diffusion* and *translation* approaches provide alternative views of GIS technology adoption on transitional economies. We have chosen to discuss first the problem from a diffusion perspective, since the paper focuses on how technically minded institutions introduced GIS technology in Brazil. For these institutions, the fact that GIS technology is disruptive was positive, since it leveraged their influence on more traditional institutions. We recognize that GIS technology is non-neutral. However, since the networks of innovation in Brazil placed a strong emphasis on the public dissemination of information, they helped the other actors succeed in adapting GIS technology to their worldview. The network of innovation also enabled Brazil to reduce the "lock-in" effect and to become software-independent. We consider that translation-based approaches such as actor-network theory (Latour 1988) can bring forth

some other interesting facets in the role of the network described here. We present this complementary view to our discussion towards the end of the paper.

3   A BRIEF REVIEW OF SOME OF THE PLAYERS IN THE BRAZILIAN SDI

Among the many participants in the development of the Brazilian SDI, we chose to focus on three. They belong to different sectors of the economy and have different missions. The first, INPE, is a major research institute funded by the federal government. The second, Prodabel, is a information technology company owned by a local government which has one of the most successful urban GIS projects in Brazil. And finally, Fator-GIS and its spin-off Mundo-Geo which are, today, the most important media companies with interests in GIS in Brazil.

During the 80s, aiming at the protection of the local information technology industry, the Brazilian Government adopted a "market reserve" policy. For eight years, there was a heavy economic incentive provided by the government to produce local information technology (IT) hardware goods. The 'market reserve' law provided a powerful incentive for local development of GIS and Remote Sensing Image Processing technology, insofar as a typical price for a single-seat system at this time was approximately US$ 100,000, including hardware, software and training costs. As a result of this scenario, INPE established its Image Processing Division in 1984 with the following aims: (a) local development and dissemination of image processing and GIS systems in Brazil; (b) establishment of a research program in Image Processing and GIS, and (c) pursuit of co-operative programs with universities, government organizations and private companies. In 1986, INPE brought out Brazil's first GIS+Image Processing based on an Intel platform. The system was used extensively by 150 universities and research labs, up to 1996.

In 1992, given recent advances in hardware and software and the changes in information technology policy in Brazil, INPE started the development of a free GIS software, SPRING, whose first Internet version was made available in late 1996. SPRING provides a comprehensive set of functions for processing of spatial information, including tools for Satellite Image Processing, Digital Terrain Modeling, Spatial Analysis, Geostatistics, Spatial Statistics, Spatial Databases and Map Management.

Currently, in a partnership with Computer Graphics Group at the Catholic University in Rio de Janeiro, INPE is developing TerraLib (Câmara, Souza et al. 2000), an open-source GIS component library. TerraLib enables quick development of custom-built applications using spatial databases. Currently, such capabilities are only available by means of proprietary solutions. As a research tool, TerraLib aims to enable the development of GIS prototypes that include new concepts such as spatio-temporal data models, geographical ontologies and advanced spatial analysis techniques.

The second player is Prodabel, Belo Horizonte's IT company. Belo Horizonte is the fourth largest Brazilian city, with a population of more than 2.2 million people, spread over 335 square kilometers, and is the center of a metropolitan area that houses over 3.5 million people. Belo Horizonte's GIS project which started in 1989 was managed by Prodabel. An interesting fact was that Prodabel also hosted the city's cartography. The main efforts were towards creating the geographic database, the development of the necessary human resources, and the search for partnerships within the city. In the long run, the project became a reference for urban GIS in Brazil. Its team grew out to be participating in the local government activities and play today a major role in the Brazilian scientific community. The project architecture spread from an initially centralized effort to a decentralized service structure. The GIS project for the city of Belo Horizonte has national and international recognition providing applications that deal with important social needs, including education, health, transportation, traffic and environmental control. The results also include over 200 publications, including theses, academic papers and articles in trade magazines (Davis Jr. 1993; Fonseca 1993; Borges and Sahay 2000). Another paper in this special issue gives a longer description of Belo Horizonte's GIS project.

Our third player is Fator-GIS, a media company that started out in 1993 publishing a small magazine on GIS. From the magazine, Factor-GIS started a very successful user-conference series called GIS-Brasil. The series held annual meetings till 2004. The company went through some changes in 1999 which led to an online publication replacing the original paper magazine. It generated also a spin-off called MundoGeo which has a portal, a paper magazine, and its own user-conference series, Geo-Brasil, which has been held annually since 2000.

We will discuss how these players found each other and interacted to create a successful SDI in Brazil. Other important players in this process will be mentioned later and are omitted now only for the sake of clarity. Brazil's path towards a SDI can be summarized in Table 1. There we can see the first GIS software release by INPE in 1986, the first scientific conference in 1990, and the first user conference in 1994. We can also see that after 1997 all these activities are established as permanent events in contrast with their temporary and sparse presence before 1994.

Table 1 - a chronological summary of the main events in the establishment of the Brazilian SDI

	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04
Major Software release	●						●											●	
Scientific conference					●			●		●		●		●	●	●	●	●	●
User conference									●		●	●	●	●	●	●	●	●	●
Joint research papers							●	●	●	●		●	●		●	●	●	●	●

4 EVIDENCES OF SDI ESTABLISHMENT IN BRAZIL

To assess the applicability of Rogers' diffusion of innovation model to the SDI case in Brazil, we have used the number of registered users of the SPRING Brazilian GIS software (Figure 1). SPRING integrates spatial analysis, map algebra, digital terrain modeling and image processing and has been available on the Internet since November 1996 (Câmara, Souza et al. 1996). The number of new registered users of SPRING in Brazil follows roughly a bell-shaped curve, a trajectory that is consistent with Rogers' diffusion model. Starting from 500 registered users in 1997, there was a peak of 7,800 new users in 2002, before declining to 6,300 in 2003 and 5,200 in 2004. We consider that the cumulative number of SPRING users provides an assessment of the extent of the diffusion of GIS in Brazil. We take the years 1986-1994 as the "early adopter" period and the years 1994-2004 as the "early majority" period. The country is now entering Rogers' fourth period, that of the "late majority". The reader should bear in mind that these dates are only approximate.
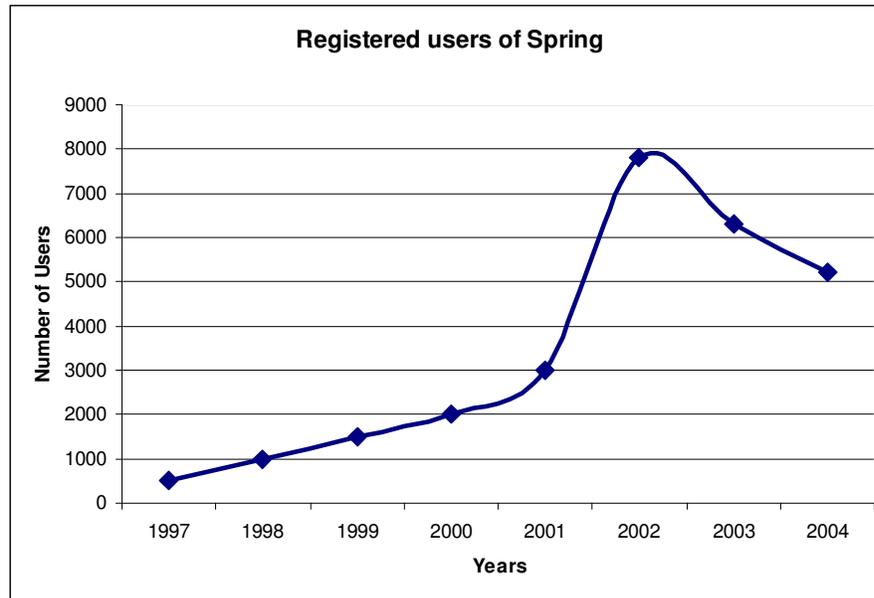
Figure 1 – Evolution of new users of SPRING in Brazil (1997-2004). Source: INPE

Adaptation of GIS software and support to meet the needs of transitional economies may help explain why SPRING has spread at a more rapid rate of adoption and has reached a larger portion of the population of potential users in Brazil than most commercial alternatives. For some adopters, SPRING was replacing commercial GIS to carry out the same tasks at far less cost. It had the relative advantage of needing no capital investment for software, no support or maintenance fees, and free technical support in Portuguese. In addition, switching to SPRING conferred the relative advantage of increased prestige by using locally developed software. SPRING has also the advantage of being more compatible with the language and culture of Brazil. The software interface and documentation are in Portuguese. Software availability has been coupled with extensive investments done by INPE on training material and capacity building. On the 90s, more than 2,000 students attended short courses on SPRING and GIS. To reduce the complexity of GIS adoption to the average user, INPE researchers (with other network members) produced a three-volume reference work on GIS: "Introduction to GIS", "Spatial Analysis" and "Spatial Databases". This material is freely available on the Web. This material has been instrumental in promoting the use of SPRING in Brazil by GIS students, government officials, and private companies. SPRING is also a basic GIS tool for students in undergraduate and graduate courses in GIS in many universities in Brazil.

5   THE NETWORK OF INNOVATION FOR GIS AND SDI IN BRAZIL

This section explores the role played by a collaborative network. First we identify who were the early adopters in setting up GIS/SDI in Brazil. Then, we identify the linkages between these early adopters and point out how they promoted supported new GIS/SDI groups. We also consider the role of the private companies. Although there are other relevant relationships, we opted to focus only on the relations of INPE with other institutions.

5.1 Collaboration between early-adopters of GIS technology in Brazil

The "early adoption" period of GIS in Brazil spans from 1986, when INPE released its first GIS software, to 1994 when Fator-GIS promoted the first major user conference. We have selected some institutions that, in this period, played a significant role in fostering adoption of spatial information technology, as shown in Table 2.

Table 2 – some of the early adopters of GIS in Brazil

	Institution	Main line of business	Funded by	First main initiative in GIS
1	INPE	Research Institute	Government	1984
2	UNICAMP	University	Government	1993
3	Prodabel	IT services	Government	1989
4	EMBRAPA	Research Institute	Government	1989
5	TECGRAPH	Academic Research Laboratory	Private	1987
6	Fator-GIS	Media company	Private	1993

The early adopters worked together in many projects and thus created significant links, which were fundamental for the successful implementation of an SDI in Brazil. We can see in Figure 2 some examples of the relationships of INPE with other members in the network.
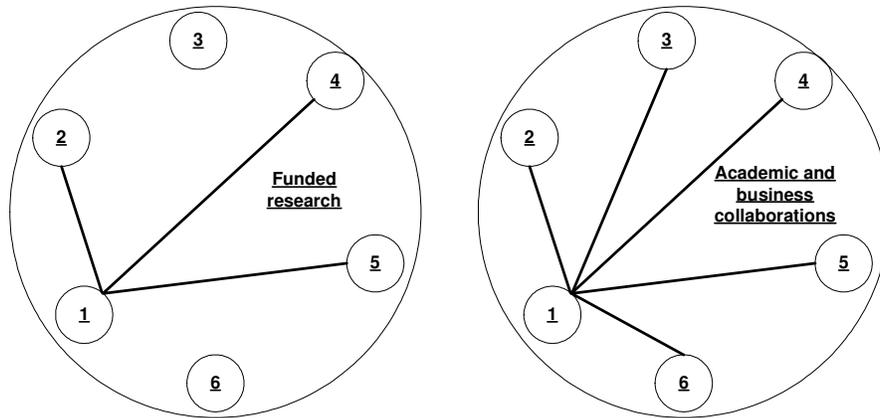
Figure 2 – relations between INPE and other players

As a measure of linkages between the various R&D groups, Figure 3 shows the fully refereed papers and book chapters published by the INPE GIS group in the period 1990-2005. The papers were divided into those whose authors are only from INPE, and those co-authored with researchers from other institutions. There is a clear trend towards the increase of cooperative papers in recent years, a sign of strong links with other R&D groups.
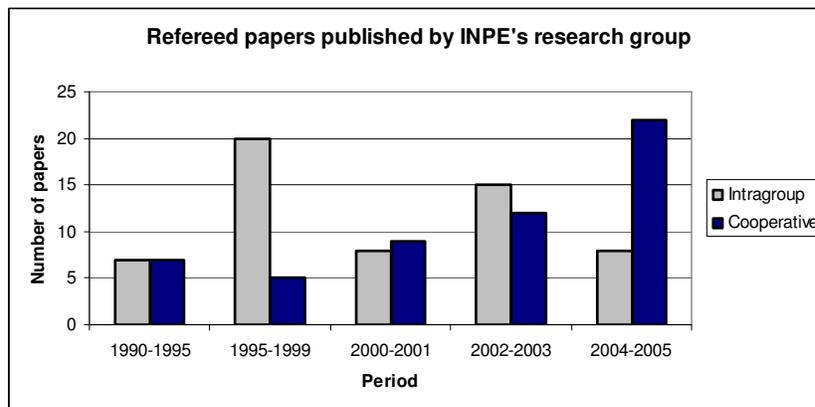

Figure 3 – collaboration between INPE and other players in scientific papers published in geoinformation technology (1990-2005). Source: INPE

In a qualitative sense, the early production of referred papers by INPE described different aspects of the implementation of GIS systems (Câmara, Souza et al. 1996). As the R&D team matured, it felt the need to focus on science, including: (a) environmental modeling, especially land-use changes models in Amazonia (Câmara, Aguiar et al. 2005); (b) interoperability and semantics of spatial data (Fonseca, Egenhofer et al. 2002; Fonseca, Davis et al. 2003); (c) spatial analysis applied to socioeconomic issues

(Câmara, Sposati et al. 2004). This scientific production is supported by international cooperation, as described later in the paper.

5.2 The role of the private companies

Assessment of the role played by the private companies in diffusion of innovations is a major challenge in transitional economies. The case of GIS/SDI Brazil is no different. The available surveys are still incomplete and give only rough indicators. According to the latest survey (Magalhaes and Granemman 2005), there are more than 200 companies working with GIS in Brazil. The total market is estimated in around US$ 150 million, and employee numbers are over 4,000, more than 75% of them with a technical background. Agriculture and facilities management are the largest private application markets; urban cadastre make up 45% of the public customers (Magalhaes and Granemman 2005). Companies offering services based on open source software form 15% of the service provider market. This is an indicator of a reduction on the "lock-in" effect, further discussed in the next section. To discuss the linkages between the networks of innovation and the private companies, we will consider three cases: (a) data providers; (b) service providers based on commercial software; (c) service providers based on open source software.

The *data providers* have settled their business around the failures of the Brazilian mapping agencies to provide basic digital cartographic information. Mostly, their business consisted of digitizing existing topographic maps, as well as high-resolution imagery distribution. The business of data provision will change significantly soon, as a more comprehensive SDI is established.

The *service providers based on commercial software* have based their strategy on the leverage provided by existing proprietary solutions. Usually, they associate software licensing to services such as customization and database modeling. This model has proven successful, but is subject to the same transition as the international GIS market, where the new generation of spatial databases is already having a strong impact. These companies are struggling to adapt themselves, and to hire experts with a strong background on databases and information infrastructures. The "early adopters" are the main providers of qualified personnel for these companies.

The *service providers based on open source software* have appeared more recently. These companies are of small or medium size, and work closely with universities and research institutes, and have in their teams undergraduate and graduate students from top-level schools. Besides relying on the market in general, they also have been taking part in government programs aimed at promoting the Brazilian software industry.

We foresee that in the coming years the private companies will continue to be strongly influenced by the networks of innovators. As the public SDI in Brazil grows, we can expect a reduced market for data providers and an expansion of the market for service providers. The service providers will have to adapt themselves to a geospatial information market centered around building corporate applications based on spatial databases. This will increase the influence of the "early adopters" who are in a privileged position to understand the future of spatial information technology.

5.3 The role of international collaboration

The literature supports the view that industrialized countries refrain from actively supporting the development of advanced technologies in developing countries, and seek to influence decision-makers to remain consumers of Western products (Landes 1999). When sophisticated technological development is at stake, it is difficult to set up fruitful partnerships between institutions in developing and developed nations. The more productive partnerships are person-to-person, as in the case of research collaborations. The GIS early adopters in Brazil have benefited from scientific ties with leading centers of GIS and Remote Sensing research in the USA and Europe, including: (a) The Department of Spatial Information Science and Engineering at the University of Maine; (b) The Department of Geography at the University of California at Santa Barbara; (c) The School of Information Sciences and Technology at Penn State University; (d) The Institute for Geoinformation and Cartography at the Technical University of Vienna; (e) The Institute for Geoinformatics at University of Munster, Germany; (f) The University of Wageningen, Netherlands.

International collaboration has provided the GIS groups in Brazil with exposure to research questions that will influence the future of the technology. In so doing, GIS developers in transitional economics are able to increase the cycle of innovation of their products and even anticipate some of the commercial vendors. For instance, in 1990

Max Egenhofer (U Maine, USA) visited Brazil and presented a lecture on "Object-Oriented modeling for GIS" (Egenhofer and Frank 1989). His talk influenced the design of SPRING (Câmara, Souza et al. 1996), which anticipated in almost a decade the use of object-oriented modeling in commercial GIS software.

6 MOVING FROM GIS TO SDI IN BRAZIL: CHALLENGES AND POSSIBILITIES

6.1 Sustainability of GIS/SDI in Brazil: the rôle of users

In the literature, many authors have argued that disruptive technologies such as GIS are usually actively promoted by software developers and service vendors. Such "push-oriented" actions are not matched by the ability of users to adapt to the technological change. (Sahay and Walsham 1996) (Ramasubramanian 1999). In Brazil, most of the "early adopters" were both users and developers. Institutions such as INPE and PRODABEL are large users of spatial technologies and were involved in the full circle of conception, development, use and maintenance.

One example shows how acquiring GIS technology was motivated by user demands. INPE had operated a LANDSAT remote sensing ground station since 1974 and had established a remote sensing application group since 1975. There was a perceived need for appropriate technology for image processing and GIS that could be used in applications of natural resources management. These needs mandated the creation, in 1984, of an R&D group in image processing to produce technology that was closely linked to users' needs. Development and acquisition of technology at INPE, which culminated in 100,000 satellite images being delivered during the year of 2005, was successful and sustainable because it was all the time "pull-oriented" rather than "push-oriented".

6.2 Paradoxes and tensions in GIS/SDI establishment in Brazil

Although this paper reports a successful story on the establishment of GIS/SDI in Brazil, there are many unresolved issues before SDI can be fully implemented in Brazil. The move towards a nationwide SDI in Brazil has been led by the network of innovators. They recognized the importance of dealing with spatial information as a fundamental part of information infrastructure, and not as a collection of digital maps.

Meanwhile, the civilian mapping agency (IBGE) and the military mapping agency DSG) continue to deal with customers by providing most of their data as paper maps. These mapping agencies neglect the users' capacity for using spatial data to do their own analysis. Even when topographical digital data is made available, it is delivered non-optimally. Digital terrain models are delivered as contour lines instead of grids and there is no associated metadata.

The contrast between the practices of the innovators and the mapping agencies has led to a strained relation between the two groups. This tension is an impediment for a successful nationwide SDI since users need data from the mapping agencies. As a result, many independent data providers have set up a commercial business of selling digitized public maps. The contrasting policies and world-views have also blocked a national consensus around a nationwide SDI infrastructure. In result, Brazil has currently no legislation on access policies for public spatial data sets.

In the coming years, expansion of SDI in Brazil will reach a critical point. As signaled in the paper, the innovators were strongly associated to research and development initiatives. As the user base of GIS/SDI expands in the country, the new users are likely to have a more application-oriented profile. Increasing demand for high-quality spatial data is likely to force all actors to clearly establish their data policies. There will be a strong debate between the mapping agencies and the innovators about which model to adopt nationally. We hope the good results obtained by innovators will serve as basis for an open nationwide spatial data policy.

In the long run, solving this tension requires a new generation of researchers and practitioners in the field. As Max Planck once remarked, "*a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.*" as cited by Kuhn (1996 p. 151). Since the network of innovators of GIS/SDI in Brazil has viewed *knowledge as* a *public consumption good* and has stressed capacity building, we believe their view will prevail.

6.3 Avoiding the lock-in effect: the road to open source SDI

One of the main concerns in SDI establishment in transitional economies is the issue of avoiding the "lock-in" effect in the choice of technology (Arthur 1994). This effect is

well-known in the software industry since the customer may become dependent on proprietary data formats or interfaces, and switching costs might prevent the change to another product (Ruttan 2001). Substantial barriers to entry are created, resulting in effective monopolies. The GIS software market is an oligopoly in which two companies (ESRI® and Intergraph®) have a market share of 50% (Daratech 2003).

In Brazil, the "lock-in" effect was reduced because of several reasons. During the 80s and 90s, locally developed technology could, often, provide an alternative to commercial vendors. In the 80s, INPE developed an Intel GIS at the same time ESRI launched an equivalent product. In the early 90s, PRODABEL and others chose alternative solutions to the mainstream vendors and were successful in their choices. In the same period, INPE's SPRING software provided tight integration of GIS and image processing functions, which is necessary for natural resources applications (Câmara, Souza et al. 1996). The network of innovators created a culture of "digital brains" that understood the basic principles of GIS, and forged a generation of developers that was not locked in to the main vendors. In this decade, this new generation could benefit from the emergence of open source GIS to produce solutions that match user needs and avoid proprietary technology.

For SDI, low-cost or open source software is crucial (Holmes, Doyle et al. 2005). As outlined by Câmara et al. (2000), GIS software development is changing. Coupled with advances in database management systems, rapid application development environments enable building "vertically integrated" solutions tailored to the users' needs. Therefore, an important challenge for the GIS/SDI community is finding ways of taking advantage of the new generation of spatially enabled database systems to build "faster, cheaper, smaller" GIS/SDI technology.

Open source GIS software such as PostGIS, MapServer and TerraLib (Holmes, Doyle et al. 2005) can provide an effective technological base to develop SDI that are independent of proprietary technology. GIS open source software tools allow researchers and solution providers access to a wider range of tools than what is currently offered by the commercial companies. In Brazil, the network of innovators is moving towards open source software. PRODABEL and others have been active in promoting OGC standards (Casanova, Camara et al. 2005). PUC-Rio and INPE are the main developers of the TerraLib open source library (Câmara, Souza et al. 2000). As a result,

many important SDI providers in Brazil are not currently locked in proprietary GIS technologies, and can afford to move directly to open source solutions.

7 LESSONS LEARNED FROM THE BRAZILIAN GIS/SDI EXPERIENCE

The Brazilian experience provides wider implications for other developing (and developed) countries on how to approach the SDI implementation challenge. In this section, we identify some general principles that we have learned from the experience of the network of GIS/SDI innovation in Brazil, and discuss to what extent these principles can be applicable elsewhere.

7.1 Extending the Brazilian experience to other countries

Our lessons are mostly applicable to countries with large territories and GIS R&D communities, such as the BRIC countries (Brazil, Russia, India and China), and to countries with medium-size territories and emerging GIS R&D communities, such as Mexico, Egypt, and South Africa. In contrast to some of these countries, Brazil does not have a tradition of a strong centralized government. As a result, there was no decision to entrust national mapping agencies with the task of setting up a nationwide SDI. As a result, institutions without a strong mapping culture but with understanding of information technology could play a significant rôle in diffusing GIS/SDI culture in Brazil. GIS worked in Brazil only because its innovators worked "outside the system". The contribution of the mapping agencies was limited.

The experience reported in the paper is consistent with the innovation literature, which points out that it is difficult for breakthroughs to occur inside large organizations. An often-cited example is the case of the IBM PC (Ruttan 2001). IBM's internal resistance to the new technology enabled a start-up such as Microsoft to dominate the personal computer software market (Gates, Myhrvold et al. 1996). The Brazilian experience points out that transitional economies willing to succeed on SDI technologies should support institutions that are intellectually independent of the map-production mind-set. We argue the core of these institutions should be people with "digital brains", which are fully aware of the possibilities offered by the digital world. By starting anew and giving the newcomers a mandate for change, these countries are more likely to succeed in setting up a nationwide SDI.

7.2 An alternative theoretical examination of the Brazilian experience

Although we mainly used Rogers' innovation theory to examine the Brazilian experience, some aspects of the Brazilian SDI may be better explained by alternative theories. In this section we use some of the concepts from the Actor-Network theory (Latour 1988; Law 1992) to understand how the Brazilian SDI survived through some of the challenges it has faced. The main actor here is Fator-GIS, a seemingly minor actor and with objectives that at first would seem to be at odds with the other actors. Nevertheless this was the case. This actor, with an apparently minor role, provided the forum where rich interactions among other actors could happen and helped establish a successful network.

The first concept that is useful for our analysis is the *heterogeneous network*, which "is a way of suggesting that society, organisations, agents and machines are all effects generated in patterned networks of diverse (not simply human) materials." (Law 1992). One of the peculiarities of the Brazilian SDI was that three different sectors worked together. INPE is a mainly a research institute while Prodabel is a service company and the third main actor here, Fator-GIS, is a privately owned company. It was in the user-conference series promoted by Fator-GIS the other two could establish and nourish their relationship which later proved so fruitful. Here the different objectives of each company, instead of playing out as a hindrance, came about as synergetic. Prodabel could learn and enhance its research capacities from INPE. INPE could learn the practical side of the trade and expanded SPRING in the direction of urban GIS. People from both INPE and Prodabel gave presentations, courses, and wrote articles in Factor-GIS' outlets. So while Factor-GIS was attending their business interests, it was also helping out INPE and Prodabel to present their capacities to a larger audience and gather more participants to the network.

Another fundamental concept in Actor-Network theory is *translation*, which "implies transformation and the possibility of equivalence, the possibility that one thing (for example an actor) may stand for another (for instance a network)" (Law 1992). By participating in the conference series, the two actors, INPE and Prodabel presented cutting-edge research side by side with introductory courses. While INPE presented SPRING, an instrument to implement GIS, Prodabel showcased its project showing

future actors in the network that establishing and maintaining a GIS project was possible.

Nevertheless just being in the conference per-se did not add anything to the translation process. What was instrumental here was that the two actors, INPE and Prodabel were wiling to expand their roles. INPE was only a research institute. It had also designs of having its products (SPRING and remote sensing associated technology) being effectively used by users which would eventually accomplish the final mission of the institute, which is to disseminate knowledge and technology in Brazil. On its side Prodabel, went beyond its original role of deploying services for a local government. Prodabel turned into a center of excellence for GIS and hosts today many masters and Ph.D. scholars, who in turn helped Prodabel perform better its original mission. What happened was that both INPE and Prodabel transcended their original roles and mission. Both went beyond what was originally expected from them and may here is the key to explain why Brazil succeeded in the establishment of its SDI. The relationships among the many actors were such that they were encouraged to go beyond their original roles.

Further developments include the creation of a new and more specialized forum for interaction. Led by INPE, Prodabel and other actors a new scientific conference series was established in Brazil in the early 90's. The Geoinfo conference series (www.geoinfo.info) is a landmark of the strength of the research in GIScience in Brazil. Currently in its 7th version, Geoinfo is also a forum for the meeting of participants in the Brazilian SDI network more focused on scientific applications.

Although we gave a stronger emphasis in Roger's innovation theory, Actor-Network theory can contribute to the understanding of a successful establishment of a SDI in developing countries. Aspects such as the transcendence of actor roles and the development of parallel networks should be further studied in the case exposed here. Other aspects of the Brazilian SDI need also to be examined. For instance, using Rajabifard et al.'s model (Rajabifard, Feeney et al. 2002; Rajabifard, Feeney et al. 2003) will help a further understanding of the role of what they call a SDI hierarchy. In the Brazilian case, the role of INPE as the main provider of information about deforestation highlights what they call the role of global drivers. The centrality of the environmental concerns in Brazil coupled with INPE's pro-active policy to distribute data support some of Rajabifard et al.'s findings. The role of partnerships for data sharing which was

not discussed here but is reviewed in another paper in this issue ("Considerations from the Development of a Local Spatial Data Infrastructure") also agrees with Rajabifard et al. (Rajabifard, Feeney et al. 2002; Rajabifard, Feeney et al. 2003). In short, a complex case such as the development of a SDI in a developing country needs alternative views to be better understood so that more countries can benefit from successful experiences.

8 CONCLUSION

In this paper we analyzed the establishment of a spatial data infrastructure in a transitional economy. We used Brazil as a case study. The paper had two basic premises. First, that GIS predates SDI. Before spatial data can be exchanged and made available to a larger public, it needs to be organized in spatial databases. Therefore, building a SDI needs an understanding of how GIS technology works. The second premise was that Rogers' diffusion of innovations model helps explaining the Brazilian experience. In Rogers' model, the rate of adoption of an innovation follows a diffusive equation similar to the spreading of an epidemic disease. The cumulative number of adopters of a new technology follows a logistic (S-shaped) curve and therefore, the number of adopters over time follows a normal distribution. Approaches such as actor-network theory (Latour 1988) could clarify other important problems involved in GIS/SDI implementation.

Brazil has been largely successful in setting up qualified institutions that produce and distribute spatial data. We traced these successes to the network of early adopters of GIS in the country. This collaborative network was instrumental in ensuring that such a large and diverse country could benefit from the widespread adoption of spatial information technologies. This collaborative network was successful because its members were able to (1) combine specialized expertise in different segments of spatial information technologies and (2) view knowledge as a public consumption good.

The paper may also provide lessons for other transitional economies with large territories and emerging or established GIS communities. All the groups that comprised the network of innovators in Brazil had a primary background in information technology, rather than mapmaking. GIS and SDI are disruptive technologies which need a new culture. The Brazilian experience shows that it is questionable that institutions with deep-rooted cultures such as most national mapping agencies can be

fully successful in setting up SDI without undergoing major internal changes. As a final recommendation, public policies focused on organization of SDI in transitional economies in midsized and large countries should promote the growth of collaborative networks. Governments in transitional economies are encouraged to set up new teams with backgrounds in information technology and substantive depth in spatial concepts and techniques. These teams should be in charge of the building nationwide SDI.

9 ACKNOWLEDGEMENTS

REFERENCES

Anselin, L. (1989). What's Special about Spatial Data:Alternative Perspectives on Spatial Data Analysis. Santa Barbara, CA, NCGIA Report 89-4.

Arthur, B. (1994). Increasing Returns and Path Dependence in the Economy. Ann Arbor, MI, The University of Michigan Press.

Borges, K. A. V. and S. Sahay (2000). Learning About GIS Implementation from a Public Sector GIS Experience in Brazil. IFIP 9.4, Working Group on Social Implications of Computers in Developing Countries, Cape Town, South Africa.

Câmara, G., A. P. Aguiar, et al. (2005). "Amazon Deforestation Models." Science 307(15 February 2005): 1043-1044.

Câmara, G., R. Souza, et al. (1996). "SPRING: Integrating Remote Sensing and GIS with Object-Oriented Data Modelling." Computers and Graphics 15(6): 13-22.

Câmara, G., R. Souza, et al. (2000). TerraLib: Technology in Support of GIS Innovation. II Brazilian Symposium on Geoinformatics, GeoInfo2000, São Paulo.

Câmara, G., A. Sposati, et al. (2004). Mapping Social Exclusion/Inclusion in Developing Countries: Social Dynamics of São Paulo in the 90's. Spatially Integrated Social Science: Examples in Best Practice. M. Goodchild and D. Janelle. London, Oxford University Press.

Casanova, M., G. Camara, et al., Eds. (2005). Bancos de Dados Geograficos (Spatial Databases). Curitiba, Editora MundoGEO.

Chan, T. O. and I. P. Williamson (1999). "A Model of the Decision Process for GIS Adoption and Diffusion in a Government Environment." URISA Journal 11(2): 7-16.

Daratech (2003). GIS Markets and Opportunities 2003 Survey. Cambridge, MA, Daratech Inc.

Dasgupta, P. and P. David (1994). "Toward a New Economics of Science." Research Policy 23: 487-521.

David, P., D. Mowery, et al. (1992). "Analyzing the Economic Payoffs from Basic Research." Economics of Innovation and New Technology 2: 73-90.

Davis Jr., C. A. (1993). Address Base Creation Using Raster-Vector Integration. URISA 1993 Annual Conference, Atlanta, Georgia, URISA.

Egenhofer, M. and A. Frank (1989). Object-Oriented Modeling in GIS: Inheritance and Propagation. AUTO-CARTO 9, Ninth International Symposium on Computer-Assisted Cartography. Baltimore, MD: 588-598.

Fonseca, F. (1993). GIS for a Two-Million People City in Three Years. URISA 1993 Annual Conference, Atlanta, Georgia, URISA.

Fonseca, F., C. Davis, et al. (2003). "Bridging Ontologies and Conceptual Schemas in Geographic Applications Development." Geoinformatica 7(4): 355-378.

Fonseca, F., M. Egenhofer, et al. (2002). "Using Ontologies for Integrated Geographic Information Systems." Transactions in GIS 6(3): 231-257.

Gates, B., N. Myhrvold, et al. (1996). The road ahead. New York, Penguin Books.

Grubler, A. (1998). Technology and Global Change. Cambridge, UK, Cambridge University Press.

Holmes, C., A. Doyle, et al. (2005). Towards a Free and Open Source (FOSS) Spatial Data Infrastructure. GSDI -8 - From Pharaohs to Geoinformatics - The Role of SDI's in an Information Society, Cairo, Egypt, GSDI Association.

Kuhn, T. S. (1996). The structure of scientific revolutions. Chicago, IL, University of Chicago Press.

Landes, D. S. (1999). The Wealth and Poverty of Nations. New York, W. W. Norton & Co.

Latour, B. (1988). Science in Action: How to Follow Scientists and Engineers Through Society. New York, Harvard University Press.

Law, J. (1992). "Notes on the Theory of the Actor-Network: Ordering, Strategy and Heterogeneity." Systems Practice 5: 379-393.

Magalhaes, G. and E. Granemman (2005). A Survey of Geospatial Market in Brazil. São Paulo, GITA Brasil.

Masser, I. (2005). GIS worlds: creating spatial data infrastructures. Redlands, CA, ESRI Press.

McMaster, T., R. T. Vidgen, et al. (1997). Technology Transfer: Diffusion or Translation? Facilitating Technology Transfer through Partnership. T. McMaster. London, Chapman & Hall.

Mowery, D., Ed. (1996). The International Computer Software Industry: A Comparative Evolution of Industry Evolution and Structure. New York, NY, Oxford University Press.

Nedovic-Budic, Z. (1998). "The Likelihood of Becoming a GIS User." URISA Journal 10(2).

Nelson, R. (1996). The Sources of Economic Growth. Cambridge, MA, Harvard University Press.

Onsrud, H., G. Câmara, et al. (2004). Public Commons of Geographic Data: Research and Development Challenges. Geographic Information Science, Adelphi, MD, Springer-Verlag.

Rajabifard, A., M.-E. Feeney, et al. (2002). "Future Directions for SDI Development." International Journal of Applied Earth Observation and Geoinformation 4(1): 11-22.

Rajabifard, A., M.-E. Feeney, et al. (2003). Spatial Data Infrastructures: Concept, Nature and SDI Hierarchy. Developing Spatial Data Infrastructures: from Concept to Reality. A. Rajabifard, M.-E. Feeney and I. Williamson. London, Taylor & Francis: 17-40.

Ramasubramanian, L. (1999). "GIS Implementation in Developing Countries: Learning from Organisational Theory and Reflective Practice." Transactions in GIS 3(4): 359-380.

Rogers, E. (1995). Diffusion of Innovations. New York, Free Press, 4 ed.

Ruttan, V. (2001). Technology, Growth and Development. New York, Oxford University Press.

Sahay, S. and G. Walsham (1996). "Implementation of GIS in India: Organizational Issues and Implications." International Journal of Geographical Information Systems 10: 385-404.

Shekhar, S., S. Chawla, et al. (1999). "Spatial Databases: Accomplishments and Research Needs." IEEE Transactions on Knowledge and Data Engineering 11(1): 45-55.