

Manuscript submitted to the journal “Information Technology for
Development”, August 2005

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 study how GIS technology was introduced in Brazil, using Rogers' diffusion of innovations model. 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 unequalled 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 mid-sized 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 express 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 GIS research and development (R&D) communities. 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 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 description. The SDI user is someone who is able to combine spatial data from different sources to produce new information for 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 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 analyzes. 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. Even in this case, the country should develop skills in GIS and spatial analysis simultaneously with the SDI implementation.

Based on the premise that “*GIS predates and enables SDI*”, this paper examines the adoption of GIS and SDI in Brazil in the last 15 years. 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).

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 & 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 (Ruttan, 2001) (Dasgupta & David, 1994; David et al., 1992; Nelson, 1996). 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 reduce network externalities and 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. Then, we will provide evidence on the applicability of Rogers' model to the extent of 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 similar countries.

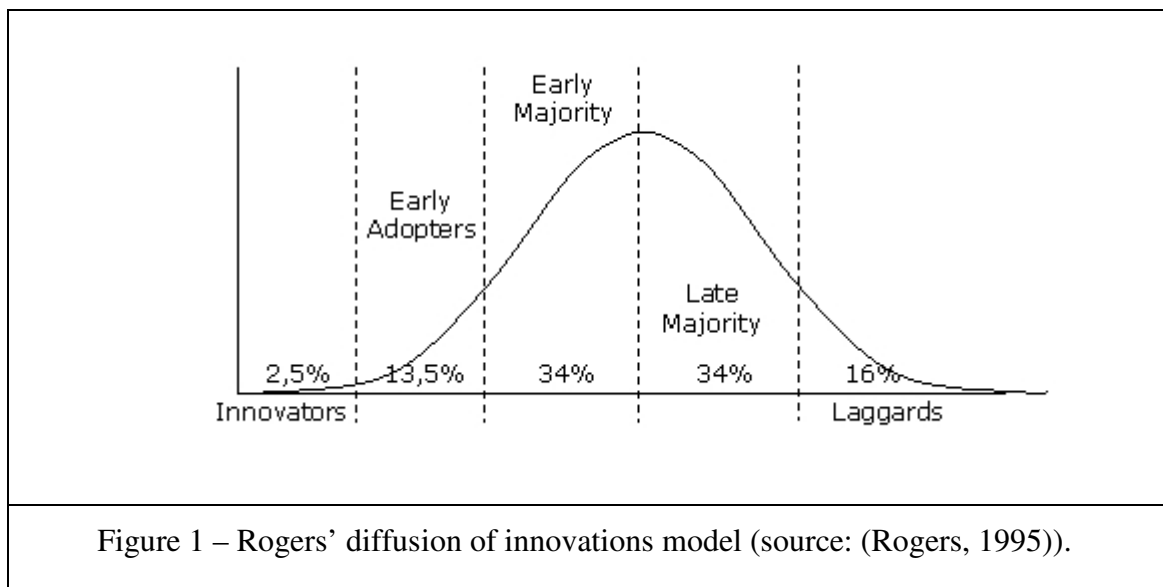
2 DIFFUSION OF INNOVATIONS IN GIS AND SDI

2.1 Rogers' model: application to GIS and SDI

The *diffusion of innovations* model was originally articulated by Everett Rogers (Rogers, 1995) and explored in many later research studies (Nedovic-Budic, 1998) (Chan & Williamson, 1999) (Grubler, 1998) (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:

- *Innovators*: Rogers use the term *venturesome* to define these obsessive adopters. They outbound their local circle of peer networks towards more cosmopolite social relationships. They usually have control of financial resources that allow them greater flexibility to experiment and ability to understand and apply complex technology (p. 263-4).
- *Early adopters*: These adopters are closer to the local social system than innovators. They have the more leadership influence than any other category. Because they are closer to the average individual in innovativeness they are easier for other potential adopters to follow. Even though they are still viewed as risk takers and experimenters by the conservative majority, increased numbers of potential adopters identify with and trust them and thus they have great influence on their peers (p. 264).

- *Early majority*: These adopters embrace innovation just before the average member does. They are an important link between the early and the late adopters. After an innovation has clearly shown its advantages in practice, the early majority adopts it to aim for or keep a competitive edge or advantage over later comers. They have a longer deliberation period than the innovators and early adopters (p. 264-5).
- *Late Majority*: This group adopts new ideas just after the average members. Usually this category makes up for a third of all the members in the system. Adoption in this case is a result of economic and network pressure. Rogers thinks that lack of resources explain their late adoption (p. 265).
- *Laggards*: These are the last to adopt innovation. They have no leadership, are the most *localites*, and are almost isolates in the social network. They have strong tradition values and rely on the past as a strong reference. With a lengthy innovation-decision process they tend to be suspicious of innovations and change agents (p.265).



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. Based on the literature (Onsrud & Pinto, 1991) (Onsrud &

Rushton, 1995) (Ramasubramanian, 1999) (Sahay & Walsham, 1996) (Yapa, 1991) (Yeh, 1991) (Nedovic-Budic, 1998) (Chan & Williamson, 1999) (Masser, 2005) and our experience as reported in this paper, we can state the following general guidelines:

- Relative advantage: "*Relative advantage is the degree to which an innovation is perceived as better than the idea it supersedes*" (Rogers 1995, p 15). With GIS and SDI, the consensus is that spatial information technologies have large advantages over manual mapmaking and nonspatial information production techniques (Masser, 2005; Masser & Onsrud, 1993; Sahay & Walsham, 1996).
- Compatibility: "*Compatibility is the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters.*" (Rogers 1995, p 15). GIS and SDI are disruptive technologies, since they need major changes in established organizational practices (Ramasubramanian, 1999) (Sahay & Walsham, 1996). Therefore, often it is easier to set up GIS and SDI solutions in new or emerging organizations, where tradition is not an issue. This issue is further discussed in Section 5 of this paper.
- Complexity: "*Complexity is the degree to which an innovation is perceived as relatively difficult to understand and to use.*" (Rogers 1995, p 16). Spatial information technologies are more complex and therefore much harder to use than traditional map handling techniques (Nedovic-Budic, 1998) (Chan & Williamson, 1999) (Masser, 2005). See section 5 of the paper for further discussion.
- Trialability: "*Trialability is the degree to which an innovation may be experimented with on a limited basis.*" (Rogers 1995, p. 16). In the Brazilian case, locally developed free and open source GIS software enabled low-investment trialability by prospective GIS users and helped avoid "lock-in" effects (Holmes et al., 2005) (Câmara et al., 2000). For more on this issue, see section 5 of the paper.
- Observability: "*Observability is the degree to which the results of an innovation are visible to others.*" (Rogers 1995, p. 16). In the GIS industry, end user conferences and magazines have a strong role in the spread of the innovation (Parr, 1992). This was also the case in Brazil in which GIS scientific meetings, trade magazines and end user conferences started in the early 1990s, the period of early adoption of GIS.

2.2 GIS technology in transitional economies: diffusion or translation?

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 et al., 1997).

Therefore, *diffusion* and *translation* approaches provide alternative views of GIS technology adoption on transitional economies. We have chosen to discuss 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 nonneutral. 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. This would be a complementary view to our discussion that we leave for future work.

3 EVIDENCES OF SDI ESTABLISHMENT IN BRAZIL

3.1 Rogers' diffusion model and SDI in Brazil: some empirical evidences

To assess the applicability of Rogers' diffusion of information model to the SDI case in Brazil, we have used the number of registered users of the SPRING Brazilian GIS software (Figure 2). 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). Although SPRING is freely available, it is not open source software. The Brazilian project for open source software is TerraLib (Câmara et al., 2000), discussed later in this paper. We define "SPRING user" as anyone that has downloaded the software, including both institutional and individual users.

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 1990-1999 as the "early adopter" period and the years 1999-2004 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.

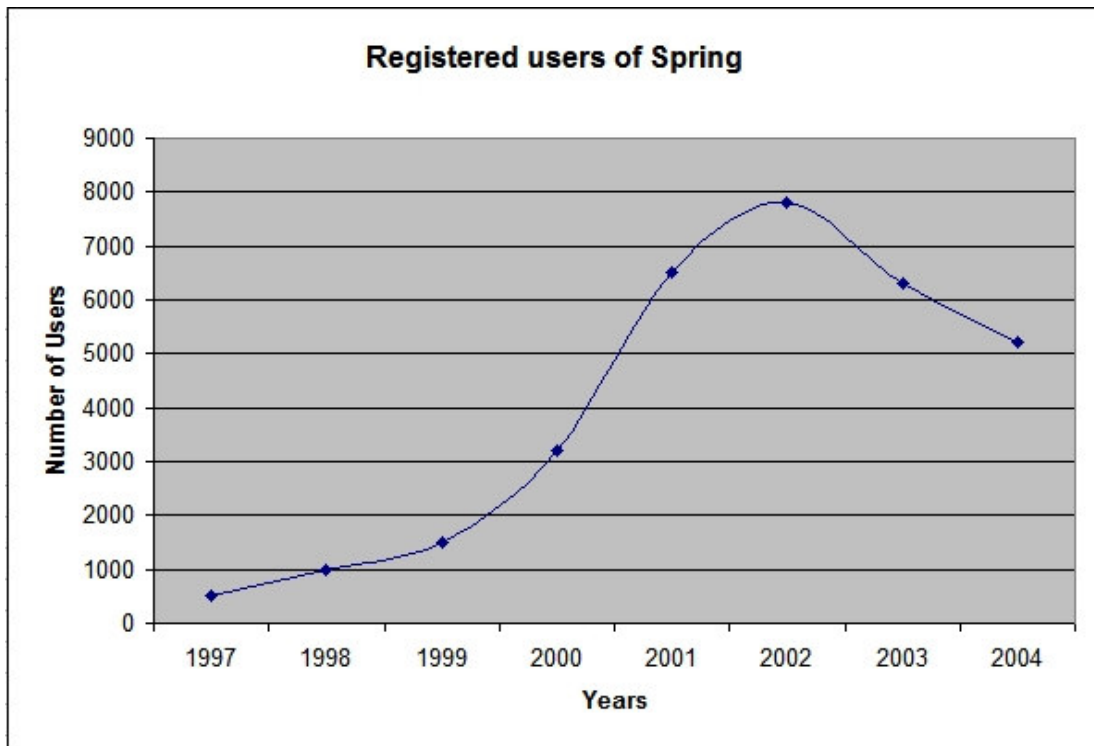


Figure 2 – Evolution of new users of SPRING in Brazil (1997-2004). Source: INPE

Adaptation of GIS software, support and use rights 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. We now consider the diffusion of SPRING in relation to the attributes that, according to Rogers' diffusion of innovation theory, characterize the rate of adoption of an innovation.

Relative Advantage

For some adopters, the idea that SPRING superseded 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 the native language of the nation. In addition, switching to SPRING conferred the relative advantage of increased prestige by using locally developed software.

Compatibility

SPRING has the advantage of being more compatible with the language and culture of Brazil. The software interface and associated 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.

Complexity

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.

Trialability

Because SPRING is freely available, users may try out the full powers of the system without overcoming an economic hurdle for its acquisition. Because the interface, help documentation, support literature and phone help are fully available in Portuguese, users can experiment with SPRING for their specific needs.

Observability

The existence of SPRING on the desktops of peers working on similar spatial information processing tasks made SPRING far more observable to other potential users in Brazil. A second positive reason has been the use of SPRING as a basic tool for students in undergraduate and graduate courses in GIS in many universities in Brazil.

3.2 Geospatial application achievements in Brazil

Further evidence of current GIS and SDI use attainment in Brazil include:

- From May 2004 to May 2005, the National Institute for Space Research (INPE) delivered more than 100,000 CBERS-2 CCD images, which are available free to Brazilian users by Internet access. CBERS-2 is the second of a series of five remote sensing satellites being developed in cooperation between China and Brazil on the

period 1988-2011. Each image covers 120 x 120 km² at 20 m resolution, in three spectral bands (2 visible, 1 near-infrared) with 100 Mb size. These numbers make Brazil the world's largest distributor of remote sensing imagery.

- INPE also leads the PRODES deforestation assessment program, which is the largest forest monitoring project in the world. INPE conducts a yearly wall-to-wall survey of the Brazilian Amazonia using remote sensing imagery, with 200 LANDSAT images and more than 50,000 work-hours of work. PRODES maps are available on-line at <www.obt.inpe.br/prodes>.
- The SAGRE system for telecom network management, developed since 1991 by CPqD Telecom & IT solutions center, and used by many Brazilian telecom operators. At Telefonica, Brazil's largest telecom operator, SAGRE has reached world-class performance levels. Each month, it responds to 1 million geographical queries each month, serving 12 million customers, and supporting 1,300 major engineering projects (Magalhães et al., 2005).
- 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 (Borges & Sahay, 2000; Davis Jr., 1993; Fonseca, 1993).
- Brazil's Ministry for the Environment has produced two major spatial database sets, which support its initiatives for ecological-economical zoning for Brazil. This project, called "*ZEE Brasil*", is a consortium of public institutions, which include IBGE (Bureau of Census), EMBRAPA (Agricultural Research Agency), CPRM (Geological Survey), and INPE. One database set covers the caatinga biome in Brazil's semi-arid Northeast region the other covers the Legal Amazonia area, which includes the rain forest and neighboring areas (Medeiros, 2004). These databases include all publicly available information for these regions.
- The Climatic Risk Agricultural Zoning Project conducted by EMBRAPA (Brazil's Agriculture Research Agency). Brazilian agribusiness is responsible for 29% of the gross domestic product (GDP). Export of commodities has been increasing since the beginning of the last decade and today Brazilian's soybean production is second in

the world. Since 1995, the federal government uses the Climatic Risk Agricultural Zoning Program to finance crop seeding. This program calculates yield risk for 15 different crops in 19 Brazilian states. Areas with high yield risk are not eligible for public insurance on crop production. This policy has promoted a responsible use of land. In the last 10 years, the Brazilian production of commodities increased about 165% while the planted area increased only 37%. The program relies on quality spatial data on climate, soils and crop production (Assad et al., 2001).

4 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.

4.1 A set of relevant early adopters

The “early adoption” period of GIS in Brazil spans the years 1990-1999. We have selected institutions that, in this period, played a significant role in fostering adoption of spatial information technology:

- *INPE (National Institute for Space Research, Image Processing Division)*: this group has developed free GIS technology since the early 80s, including the SPRING system (Câmara, Souza et al., 1996) and the TerraLib GIS library (Câmara et al., 2000). The INPE team has focused its research on spatio-temporal computational models and data analysis techniques (Câmara et al., 2004). Web address: www.dpi.inpe.br.
- *UNICAMP (University of Campinas, Institute for Informatics) and CPqD Telecom & IT solutions*: CPqD is an independent R&D center whose GIS leader is also a professor at UNICAMP. This group has focused on decision support systems and workflows (Seffino et al., 1999) and on ontologies and interoperability (Fileto et al., 2003). Web addresses: www.ic.unicamp.br/~cmbm.
- *PRODABEL (Company for Informatics and Information of the city of Belo Horizonte)*: PRODABEL was one of leaders in adopting GIS in municipalities. Prodabel developed a series of applications to address the information needs of the

citizens of Belo Horizonte. The group's research focus on data modeling (Davis et al., 2002), interoperability (Fonseca et al., 2000) and Web GIS (Fonseca & Davis, 1999). They shared their expertise through consulting, courses, and presentations in major Brazilian and international conferences. Web addresses: www.pbh.gov.br/prodabel.

- *EMBRAPA (Agricultural Research Agency)*: EMBRAPA is one of major research institutions in Brazil, consisting of 50 centers nationwide. One of these is the Center for Agricultural Information Technology, which has developed GIS applications for agribusiness since the late 80s (Assad & Sano, 1998). The group's research focuses on spatial analysis and modeling applied to climate risk assessment for agriculture (Assad et al., 2003). Web address: www.cnptia.embrapa.br.
- *TECGRAF, PUC-Rio (Computer Graphics Group, Catholic University of Rio de Janeiro)*: TECGRAF started in May 1987 in a partnership with PETROBRAS' Research and Development Center - CENPES - and the Catholic University of Rio de Janeiro - PUC-Rio. Its purpose is to develop innovation in information technology. TECGRAF's GIS group combines research in spatial databases (Casanova et al., 2004) and applications such as emergency action plans (Casanova et al., 2001).
- *MundoGEO*: this company publishes the trade magazine InfoGeo and organizes the GeoBrasil annual fair on GIS. Web address: www.mundogeo.com.br.

4.2 Linkages between the groups

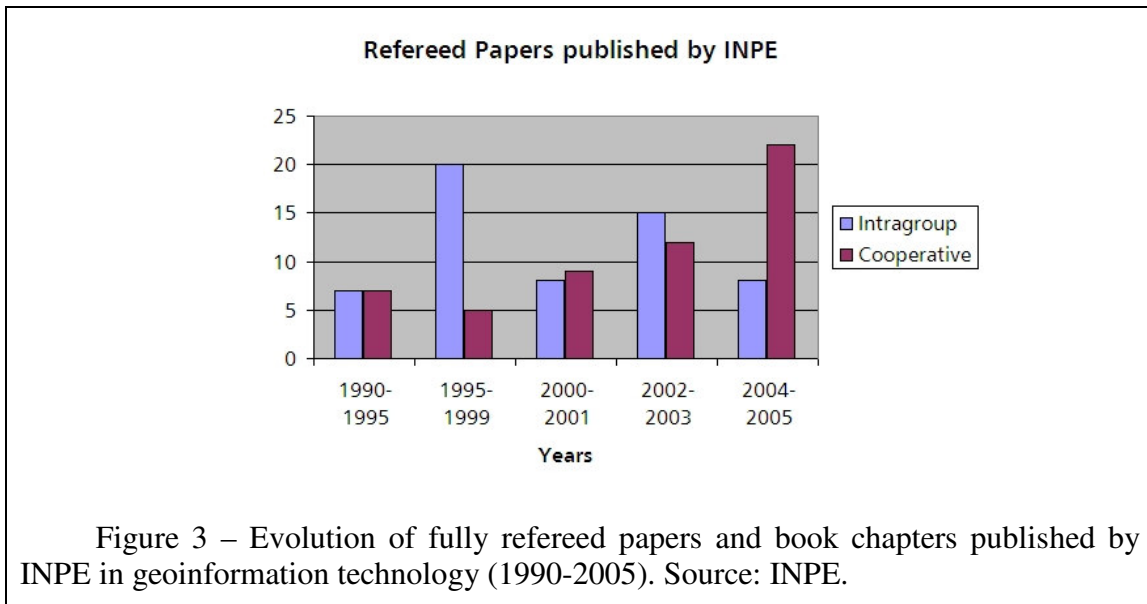
The early adopters worked together in many projects and thus created significant links, which were fundamental for the successful implementation of an SDI in Brazil.

- From 1994 to 1997, UNICAMP led a major cooperative project in Geoinformatics. Financed by Brazil's CNPq (National Research Council), the project had a US\$ 3 million funding, and included the groups in INPE, CPqD, EMBRAPA, and PUC-Rio. Results include *Câmara* (1994) and *Câmara* (1996).
- At the first Brazilian GIS users' conference in 1994, PRODABEL had its first contact with INPE and UNICAMP. Since then, the three have become strong collaborators. Technical visits evolved to presentations and participation on dissertation committees. Today the collaboration includes joint publications at the

national and international level, exchange of technology and of students (Fonseca et al., 2003) (Fonseca et al., 2002). PRODABEL, INPE and PUC-Rio have recently produced a reference work on spatial databases (Casanova et al., 2005).

- The EMBRAPA team has strong partnerships with INPE and UNICAMP. The joint work with INPE has focused on spatial analysis and modeling applied to agriculture (Assad & Sano, 1998) and the work with UNICAMP has focused on interoperability and semantics (Fileto et al., 2003).
- From 2001 to the present date, the research groups at PUC-Rio and INPE have cooperated on joint R&D. An important project is the TerraLib open source GIS library (Câmara et al., 2000), which supports GIS applications in urban cadastre, emergency action plans, dynamical modeling, and social studies (Casanova et al., 2001) (Carneiro et al., 2004).
- Trade magazines and user conferences have also proven important to set up links among the early adopters of GIS in Brazil. The GISBrasil user conference series started in 1993 (later continued as GeoBrasil conference). The trade magazine “FatorGIS” started in 1994, later continued as “InfoGeo”. Many of the early promoters of GIS in Brazil have acted as contributors to *InfoGeo*.

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.



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 et al., 2005); (b) interoperability and semantics of spatial data (Fonseca et al., 2003); (c) spatial analysis applied to socioeconomic issues (Câmara et al., 2004). This scientific production is supported by international cooperation, as described in section 4.5 below.

4.3 Linkages between the early adopters and early majority

To assess the linkages between the early adopters and the early majority, we will consider some key application areas: urban cadastre, socio-economic studies, health, telecom, environment and agribusiness.

The PRODABEL group has been a major influence on urban cadastral applications. They provided guidance on urban GIS for the cities of Salvador, Recife, São Paulo, Fortaleza and Goiânia. The INPE group also works in urban cadastre and has developed systems based on the TerraLib open source library for more than 30 cities in Brazil.

Since 2001, INPE has worked with Catholic University of São Paulo (PUC/SP) on spatially enhanced social studies. Researchers from the two groups have created a nonprofit institute to focus on spatial studies of poverty and exclusion in Brazil (CEDEST – www.cedest.info). Research results include Câmara et al (2004).

From 2001 to 2004, the Brazilian research council funded a cooperative project on spatial epidemiology, focused on urban diffusion of dengue. The project included: Fundação Oswaldo Cruz (Brazil's National Institute for Health), the spatial statistics labs of the federal universities of Minas Gerais and Paraná (UFMG and UFPR), and INPE. For a review of the project see Monteiro et al. (2004).

In 2001, the Brazilian Ministry for Science and Technology set up the GEOMA research network for environmental modeling of Amazonia. The network comprises the INPA (National Institute for Amazonian Research), MPEG (Museu Paraense Emilio Goeldi), LNCC (National Laboratory for Scientific Computing), IMPA (Institute for Pure and Applied Mathematics) and INPE. The GEOMA projects focus on modeling the impacts of the land use and cover change in the Amazon on biodiversity, physical climate, hydrology and biogeochemistry. The objective is to produce computational models that enable public policy makers to foresee scenarios for the future of Amazonia. GEOMA's website is <http://www.geoma.lncc.br>. Results include (Câmara et al., 2005).

In the telecommunications area, the UNICAMP/CPqD group has had a major role in providing support for applications in leading telecom companies in Brazil. As discussed in section 3.2 above, SAGRE's installation at Telefonica in São Paulo is one of the world's largest GIS databases for telecommunications, supporting 100 million spatial objects (Magalhães et al., 2005).

4.4 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 & Granemman, 2005), there are more than 200 companies. 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 & 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 Section 5. 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 national 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.

4.5 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 & 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.

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

5.1 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 & Walsham, 1996) (Ramasubramanian, 1999). In Brazil, most of the “early adopters” were both users and developers. Institutions such as INPE,

PRODABEL and CPqD Telecom 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's 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 CBERS images being delivered in one year, was successful and sustainable because it was all the time "pull-oriented" rather than "push-oriented".

5.2 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 described in section 4. 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, IBGE (the civilian mapping agency) and DSG (the military mapping agency) 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 nonoptimally. 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 (with "digital brains") and the mapping agencies (with "analogue brains") has led to a tensioned 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.*" (Kuhn, 1996). 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.

5.3 Avoiding network externalities: 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 a DOS-based GIS at the same time ESRI launched an equivalent product. In the early 90s, CPqD and PRODABEL 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 et al., 2005). As outlined by Câmara (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 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 described in section 4 is moving towards open source software. PRODABEL and UNICAMP/CPqD have been active in promoting OGC standards (Casanova et al., 2005). PUC-Rio and INPE are the main developers of the TerraLib open source library (Câmara 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.

6 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 what extent these principles can be applicable elsewhere.

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 big 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 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 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 an SDI needs an understanding 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. As a complement to this paper, analyzes based on 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 also provides 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 a marked internal change. 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 that should be charged with building a nationwide SDI.

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