# Toward a User-Centric Peru Spatial Data Infrastructure Based on Free and Open Source Software



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#### ABSTRACT

In the past, we used maps to show where people and assets were located but this has now evolved into a complex digital environment with sophisticated technology (Crompvoets, 2006). Peru has launched in 2003 the Peru Spatial Data Infrastructure (IDEP) to promote and coordinate the development, exchange and use of geospatial data and services between all levels of government, private sector, non-governmental organizations, academic and research institutions (CCIDEP, 2004).

This thesis discusses the progress of the Peru SDI based on the results of a questionnaire that was designed to measure the geospatial technology availability and to apply a multi-view SDI assessment consisting of three methods (SDI readiness, generational approach and SDI components qualitative evaluation). It particularly focuses on the potential of Free and Open Source Software (FOSS) because we believe these solutions can further the implementation of SDIs by allowing the distribution of a proven SDI architecture for organizations on a limited financial budget, without legal constraints and based on international interoperability standards (Steiniger and Hunter, 2010).

A surprisingly high rate of FOSS use has been observed with 78 % of the organizations using a mix of FOSS and proprietary technologies for different purposes. The main tasks realized with FOSS solutions are to interact with spatial databases (query and update information), visualize spatial data from GIS file formats and WMS services and to easily overlay data with online services such as Google Maps. Proprietary software is used in all institutions to create final map products and is believed to be currently far superior in that matter. FOSS has an important market share in some software categories such as metadata cataloging applications (86 % of institutions), database management systems (55 %) and web map servers (38 %). Proprietary GIS products still dominate the desktop GIS (85 % of users) and Web GIS clients market share (87 % of institutions).

The multi-view assessment results indicate that the Peru SDI has established a solid foundation toward a user-centric third-generation SDI and have identified the low available financial resources as the major weak spot. The recommendations are to shift the emphasis from the concerns of data producers to those of data users and give them an active role, focus on processes where geospatial management is crucial (ex: disaster management and land administration), reach out to other participants such as regional and local governments, implement alternative funding models and orient the technological strategy towards FOSS (Delgado et al., 2005).

Finally, most organizations implement departmental GIS and would be better prepared to participate in the Peru SDI if they would migrate to an enterprise GIS built around an integrated database designed to meet the needs of multiple users across multiple units (Harmon and Anderson, 2003). This would allow a better integration with corporate information systems, standardized and less redundant spatial and attribute data, maximum query and analytical functionalities, consistent look and feel of output and centralized geographic information costs (Harmon and Anderson, 2003; Nedović-Budić and Budhathoki, 2006).

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### LIST OF ABBREVIATIONS

CCIDEP:	Peru Spatial Data Infrastructure Permanent Coordinating Committee
DBMS:	Database Management Systems
ESRI:	Environmental Systems Research Institute
FGDC:	Federal Geographic Data Committee
FOSS:	Free and Open Source Software
FOSS4G:	Free and Open Source Software for Geospatial
GIS:	Geographic Information System
GML:	Geography Markup Language
GPS:	Global Positioning System
IDEP:	Peru Spatial Data Infrastructure
INSPIRE:	Infrastructure for Spatial Information in the European Community
ISO:	International Standards Organization
IT:	Information Technology
KML:	Keyhole Markup Language
NSDI:	National Spatial Data Infrastructure
OGC:	Open Geospatial Consortium
SOA:	Service-oriented architecture
US:	United States of America
W3C:	World Wide Web Consortium
WCS:	Web Coverage Service
WMS:	Web Map Service
WFS:	Web Feature Service
WPS:	Web Processing Service
XML:	Extensible Markup Language

### DISCLAIMER

The results presented in this thesis are based on my own research at the Faculty of Earth and Life Sciences of the Vrije Universiteit Amsterdam.

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This thesis has not been submitted previously for a degree at any institution.

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# **1 GENERAL INTRODUCTION**

#### 1.1 Background and Problem Statement

Rapid access to data and information is crucial to the economic, environmental, and social well-being of our global society (National Research Council, 1993). Crime management, business development, flood mitigation, environmental restoration, community land use assessments and disaster recovery are just a few examples of areas in which decision-makers are benefiting from geographic information (Nebert, 2004). In the past, we used maps to show where people and assets were located but this has now evolved into a complex digital environment with sophisticated technology (Crompvoets, 2006). Considerable effort and resources have been devoted to the introduction of spatial data processing and to the construction of geographic information systems (GISs) in a large number of governmental bodies (Bouckaert, 2011).

This has led to the creation of Spatial Data Infrastructures (SDIs) that are enabling platforms developed by many countries to improve access, sharing and integration of spatial data and services (Rajabifard, 2009). For the purposes of this thesis, we will define Spatial Data Infrastructures as the set of technologies, policies and standards that together enable efficient user access to spatial data generated by others in an efficient way (in terms of time and money), reducing the duplication of effort, fulfilling user requirements and improving the quality of products and processes that involve geographic information.

SDIs first emerged in developed countries characterized by high levels of IT, adequate financial resources and huge quantities of digital spatial data. Numerous emerging economies and developing countries have also started SDI initiatives that are generally characterized by the low availability of financial resources and geospatial software technology. One available solution to overcome these obstacles is to orient the SDI technological strategy towards Free and Open Source Software (Delgado et al., 2005) instead of proprietary software and data formats that limit the freedom to use, modify and re-distribute software to the public (in most cases at least) (Steiniger and Hunter, 2012). Although proprietary products such as ArcGIS or MapInfo are mature and powerful GIS products, they also bring major setbacks: the use of non-standard proprietary data formats, the recurring high price of licenses and their difficulty of distribution due to legal constraints.

This thesis discusses the implementation of a National Spatial Data Infrastructure for the emerging economy country of Peru. It assesses the progress of the Peru Spatial Data Infrastructure (IDEP) by applying a multi-view assessment consisting of three different methods: SDI readiness, generational approach and SDI components evaluation. The thesis in particularly focuses on the potential of Free and Open Source Software (FOSS) solutions which may be viewed by many as a revolutionary phenomenon capable of providing the software industry with an alternative and competitive way of doing business (Nasr, 2007). It provides many benefits compared to proprietary software products, including a very low cost of ownership, more frequent updates to the software and its functionality, and the ability to extensively customize the software to meet the needs of the business (Nasr, 2007). Free licenses provide an easier way to collaborate on software development with other companies or institutions (Wheeler, 2007). Also, sharing development allows organizations to combine different (expert) resources on the one hand and reduce development costs on the other (Perens, 2005). Savings in software costs could go towards developing skills and local capacity, instead of paying license fees that tie customers to a single vendor (Holmes et al., 2005)

#### 1.2 Research Objectives and Questions

The first objective of this research is to review the theoretical foundation of SDI in order to provide a common understanding of the complex, multifaceted, dynamic and constantly evolving nature of SDI. To achieve this research objective, the following general research questions are formulated:

- 1. What are the components and characteristics of Geographic Information Systems and how are they implemented in organizations?
- 2. How are Spatial Data Infrastructures defined and how have they evolved since their inception?
- 3. What are the common objectives and components of SDIs?

The second objective is to research the potential of Free and Open Source Software (FOSS) solutions for SDI initiatives in emerging economies and developing countries. The following research questions are formulated:

- 4. What is FOSS and what benefits does it bring?
- 5. Which are the main FOSS spatial software solutions available to realize the software components of a SDI?
- 6. Is FOSS already used in the software components of the Peru SDI and if so, what is the percentage of use?

The third objective is to assess the Peru SDI progress from three different angles, to identify their strengths and weaknesses and offer recommendations. The following research questions are formulated:

- 7. What is the current state of SDI readiness (degree of preparation to deliver geographical information to its community) in Peru and what are the weakest factors?
- 8. Which are the needed changes to move the Peru SDI toward a user-centric third generation SDI that reaches user expectations satisfaction?
- 9. What are the principal characteristics and aspects of the Peru SDI components?

#### 1.3 Thesis Structure

The following UML activity diagram summarizes in a visual way the structure of the thesis:



The first chapter deals with the background of the research topic outlining the problem statement and the objectives and research questions of this research. Chapter two provides a common understanding of what Geographic Information Systems are and how they are implemented in organizations, of the SDI conceptual framework (definitions, objectives, evolution, components) and a review of available FOSS solutions for SDIs. Chapter three will provide insight on the origin and history of the IDEP and on the current progress of the technical workgroups and national spatial policy. Chapter four will discuss the SDI assessment methods that will be applied to the Peru SDI and the data collection and analysis methods that were used to achieve the objectives. Chapter five will present, analyze and discuss the obtained results from the questionnaire and Peru SDI documentation and offer recommendations for each SDI component. Finally, chapter six will formulate conclusions regarding the research objectives and questions and will end with suggestions for further research in SDI. The literature review chapter will answer to questions 1 to 5 while questions 6 to 9 will be answered in the results and discussion chapter.

Question	Subject	Section
1	Implementation of GIS in organizations	2.1 Geographic Information Systems (GIS)
2	SDI definitions and evolution	2.2 Spatial Data Infrastructures (SDI)
3	SDI objectives and components	2.2 Spatial Data Infrastructures (SDI)
4	FOSS characteristics and benefits	2.3 Free and Open Source Software (FOSS)
5	Presentation of FOSS SDI solutions	2.3 Free and Open Source Software (FOSS)
6	SDI FOSS market share	5. Results and Discussion
7	SDI Readiness	5. Results and Discussion
8	Generational approach	5. Results and Discussion
9	SDI components analysis	5. Results and Discussion

# 2 LITERATURE REVIEW

In this section, we will review the available literature to provide a common understanding of GIS, SDI (definitions, objectives, components) and FOSS (presentation of the benefits and main solutions). We will begin with a presentation of how GIS are implemented in organizations.

#### 2.1 Geographic Information Systems (GIS)

#### 2.1.1 Definition and components

Most information in the public sector can be linked to a location (Longhorn and Blakemore, 2008). A GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information (ESRI, 2013c). It allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts (ESRI, 2013c). The core of GIS is a spatial database integrated from various sources and organized to provide maximum query and analytical functionality to the system users (Nedović-Budić and Budhathoki, 2006). According to (Harmon and Anderson, 2003), a GIS is composed of people (the users of the system), applications (the processes and programs they use to do their work), data (the information needed to support those applications), software (the core GIS software) and hardware (the physical components on which the system runs):



#### 2.1.2 GIS Functions

GIS facilitates the three stages of working with geographic data (de By et al., 2001):

- 1. **Data preparation and entry**: the early stage in which data about the study phenomenon is collected and prepared to be entered into the system.
- 2. **Data analysis**: the middle stage in which collected data is carefully reviewed, and, for instance, attempts are made to discover patterns.
- 3. **Data presentation**: the final stage in which the results of earlier analysis are presented in an appropriate way.

Different types of GIS functions are required and different categories of GIS software exist, which provide a particular set of functions needed to fulfill certain data management tasks (Steiniger and Weibel, 2009). Before any geographic analysis can take place the data need to be derived from field work, maps or satellite imagery, or acquired from data providers (Steiniger and Weibel, 2009). Hence, data need to be created (1) and - in case something has changed - edited (2), and then stored (3). If data are obtained from other sources they need to be viewed (4) and eventually integrated (conflation) with existing data (5). To answer particular questions, e.g. who is living in street X and is affected by the planned renewal of a power line, the data are queried (6) and analyzed (7). However, some specific analysis tasks may require a data transformation and manipulation (8) before any analysis can take place. The query and analysis results can finally be displayed on a map (9) (Steiniger and Weibel, 2009).

Some applications are routine and get done multiple times a day, whereas others are less routine but get done with some regularity, and then there are specific analytical applications that might have to be accomplished only rarely or even just once (Harmon and Anderson, 2003). Different types of GIS software exist with different functionality, as not every GIS user needs to carry out all of the above tasks (Steiniger and Weibel, 2009).

#### 2.1.1 Implementation in organizations

There are several levels of GIS implementation in an organization: standalone desktop GIS, departmental GIS and enterprise GIS. The expected result of a standalone desktop GIS is generally a product (ex: a map or report) and has a limited time frame and number of users. Departmental GIS aim to support a well-defined business function and generally involve little integration with attribute databases and sharing with other units. The enterprise model of GIS is a multi-purpose system that is part of the operational information technology framework of an organization. It generally includes the integration of attribute and spatial data into a relational database management system.



Initial investment in GIS is generally made at the division or departmental level, usually as an application purchased to meet a specific goal, with data limited to what was needed to accomplish this task (Bowman, 2005). Typically, individual users create and maintain spatial data datasets on their own desktop computers using standalone desktop GIS software and storing data in individual file formats. These GIS systems eventually grow from a few workstations and dedicated staff members in several departments (Bowman, 2005). These departmental GIS have been built to support the needs of those units only and may be of little utility to other departments in the organization (Harmon and Anderson, 2003). Common setbacks are duplication of data and little congruence of the data sets, duplication of applications, variety in standards for the output of the systems, and generally a unit-centric view of GIS and what it can do (Harmon and Anderson, 2003).

An enterprise GIS is one that is designed to meet the needs of multiple users across multiple units in an organization (Harmon and Anderson, 2003). This approach is based on the concept of delivering software functionality and/or data on demand as a service rather than redundantly housing the same software function or data resource in multiple locations where they may be needed. This approach or model is referred to as service-oriented architecture (SOA). As services, the data and tools may reside in one or more locations, either internal or external to the organization, and can be accessed and used to support business functions of all end users (ESRI, 2007). An enterprise GIS is built around an integrated database that supports the functions of all units that need spatial processing or even mapping. That database, whether centralized for real-time access by all users or replicated across many computers, is the engine of the enterprise GIS. In a well-designed system, users in the departments where GIS already existed will interact with the GIS in ways that are not much different from what they had been doing. New users will interact with the system with custom-designed applications that use the centralized data (Harmon and Anderson, 2003). The system will no longer be a particular department's GIS but will be the organization's GIS. This kind of corporate, or enterprise, GIS is different from a single-unit or project-oriented GIS in several ways: data are standardized and redundancy is reduced, database integrity is maximized, units come together through the database, there is a consistent look and feel to output, geographic information costs are centralized (Harmon and Anderson, 2003).

Generally, there are three types of locations and associated advantages and disadvantages for an enterprise GIS within an organization:

	Advantages	Disadvantages
Direct, front-line working units.	Direct link with operational needs and existing budgets.	Coordination is difficult, no authority of GIS units over other units, possible weak budget position, ownership is concentrated; other units have no stake, lack of visibility.
High-level executive placement.	High visibility, strong authority.	Perception of distance from operational needs, potentially precarious budget position subject to whims.
Support unit (IT/IS)	Brings GIS within existing support structure, budget protection in early (expensive) stages.	Distance from operational needs, difficulties integrating into front-line units.

(Harmon and Anderson (2003)

When an organization reaches the maturity level of an enterprise GIS, it is fully prepared from a technological and organizational point of view to be part of a SDI and to become a node that provides and / or uses spatial data services to / from external organizations. In the following section, we will see that although SDI share various technical aspects of enterprise GIS (ex: the use of spatial databases, web map servers, web map development frameworks, spatial services, standards, etc.), SDI is more concerned with data discovery and delivery issues whether than data analysis and presentation issues. The primary raison d'être of SDI is to encourage and facilitate cooperation and interoperability between multiple participants and technologies (O'Flaherty et al., 2005).

#### 2.2 Spatial Data Infrastructures (SDI): concepts and fundamentals

Generally speaking, GIS is the concept used for managing geo-information within organizations and SDI is the concept mostly used for sharing spatial data between organizations (Koerten, 2008). It is a paradigm and a conceptual foundation for integration, rather than a technology per se (O'Flaherty et al., 2005).

#### 2.2.1 Inception

Spatial data coordination efforts in the United States have been going on for over 100 years with the creation of the US Geographic Board in 1906 to avoid duplication of work and improve the standardization of maps (Robinson, 2008). In the late 1970s, national surveying and mapping agencies recognized the need to standardize the storage of, and access to digital geospatial data and information focusing merely on the technical aspects (Steenis, 2011). SDIs emerged in the early 1990s when advancements in geospatial and communication technologies (Internet in particular) moved the emphasis from stand-alone geographic information systems (GISs) toward networked and collaborative systems and information infrastructures (Nedovic-Budic et al., 2011a). The main conceptual and practical pillars of SDI developments around the globe are probably the United States National Spatial Data Infrastructure (NSDI) created in 1994, Europe's Infrastructure for Spatial Information in the European Community (INSPIRE) adopted in 2007 and the longstanding leadership of the Australia New Zealand Spatial Information Council (ANZLIC) (Nedovic-Budic et al., 2011a).

#### 2.2.2 Definition(s)

For the purposes of this thesis, we will define Spatial Data Infrastructures as the set of technologies, policies and standards that together enable efficient user access to spatial data generated by others in an efficient way (in terms of time and money), reducing the duplication of effort, fulfilling user requirements and improving the quality of products and processes that involve geographic information. There are many definitions proposed in the SDI literature, every definition differing slightly, but no one describing it completely (Steenis, 2011). The fact that there are so many definitions and views is an indicator that there is no universal understanding of what SDI entails (UNECA, 2004 cited from Simbizi, 2007). Furthermore, the variety of interpretations of what SDIs are suggest that it will not be possible to find a single definition of SDI that everybody will agree because of the complex, multifaceted, dynamic and constantly evolving nature of SDIs (Grus et al., 2007). The following table includes representative definitions often cited in the SDI literature:

National Spatial Data Infrastructure (NSDI) means the technology, policies, standards, and human resources necessary to acquire, process, store, distribute, and improve utilization of geospatial data (Clinton, 1994).

The term "Spatial Data Infrastructure" (SDI) is often used to denote the relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data. It provides a basis for spatial data discovery, evaluation, and application for users and providers within all levels of government, the commercial sector, the non-profit sector, academia and by citizens in general. (Nebert, 2004)

The concept of spatial data infrastructures (SDIs) refers to the infrastructure, or basic physical and organizational structures, needed to facilitate efficient use of spatial data (Rajabifard et al., 2006; Hjelmager et al., 2008 cited by Hendriks et al., 2012).

An SDI is a coordinated series of agreements on technology standards, institutional arrangements, and policies that enable the discovery and use of geospatial information by users and for purposes other than those it was created for (Kuhn, 2005).

#### 2.2.1 Evolution

Every country is at a different point in the "SDI development continuum", with the developed world at the front end of the pole, and the developing countries lagging far behind (Williamson et al, 2003b).



The first generation of SDIs that emerged in the 1990s focused mainly on technological issues such as data harmonization, standardized metadata models, standardized web services for data discovery, visualization, download (Hennig and Belgiu, 2011). They were mainly producer-driven aiming at creating a common database and the implementation and coordination governance powers were mainly concentrated in central agencies (Grus et al., 2007).

The second process-based generation of SDIs is essentially a shift in emphasis from the concerns of data producers to those of data users (Masser, 2011).

In the current user-centric third generation, there is a prominent shift from the passive role of the user in the first and second generation (Budhathoki and Nedovic-Budic 2008) into an active role (Sadeghi-Niaraki et al., 2010). The impact of technological innovations has profoundly changed the SDI components by adding a new dimension that is much more user oriented, much more effective in maximizing the added value of a nation's geoinformation assets, and much more cost effective as a data dissemination mechanism (Mapping Science Committee, 1999). SDI has been particularly influenced by the fundamental changes that the World Wide Web (WWW) has seen since it came into existence around the same time the first SDIs came into being. It has evolved from Web 1.0 static websites where people were limited to the passive viewing of content to the introduction of Web 2.0 that allow users to interact and collaborate with each other as creators of user-generated content in a virtual community (Thanuskodi, 2011). GeoWeb 2.0 is the geographic embodiment of Web 2.0 designed to be the next generation of geographic information publishing, discovery and use (Maguire, 2005). Among other aspects, it has evolved from clearinghouses (GeoWeb 1.0) that simply helped users to find information they require to the introduction of Geoportals (GeoWeb 2.0) that allow access to the digital datasets themselves (Masser, 2009).

The following sections will discuss in more detail the common objectives and components of SDI.

#### 2.2.2 Objectives

A uniform definition of the objectives of SDI to allow worldwide benchmarking will be impossible to find due to different views and opinions (Grus et al., 2007 cited from Steenis, 2011). Most SDI literature asserts that SDIs improve decision making, support good governance, foster social equity and development, support disaster prevention and management, help manage environment and environmental risks, and improve planning and sustainability of local communities as well as large cities (Miscione and Vandenbroucke, 2011). From the most often cited objectives of SDI, we can further mention the reuse of data generated by others and for other purposes, the reduction of the duplication of data and effort, the improvement in the efficiency of data producers and users in terms of time and money, the promotion of cooperation between organizations and the enhancement in the quality of products and user needs satisfaction.

A founding principle behind any SDI is that data and metadata should not be managed centrally, but by the data originator and/or owner, and that tools and services connect via computer networks to the various sources (Steiniger and Hunter, 2010). Data custodianship is thus a crucial element which consists in managing data once, and doing it well. It recognizes the authority, responsibilities and mandate of the provider (Social Change Online, 2003). SDI then requires the ability to envision the potential of working with spatial data produced by others and to look beyond the confines of data models and technological dimensions when addressing issues of data usage (Hendriks et al., 2012). The objective is not the use of spatial data extended into user-related or broader goals but to serve those purposes of individuals, groups and organizations for which spatial data are or may become useful (Dessers, 2012).

Especially because geographic data are still expensive and time consuming to produce (Rajabifard et al., 2000), the goal of a SDI is to reduce duplication of effort among agencies, improve quality and reduce costs related to geographic information, to make geographic data more accessible to the public, to increase the benefits of using available data, and to establish key partnerships with states, counties, cities, tribal nations, academia and the private sector to increase data availability (Federal Geographic Data Committee, 2013).

SDI aim to provide a proper environment in which all stakeholders, both users and producers of spatial information can cooperate with each other in a cost-efficient and cost-effective way to better achieve their targets at different political/administrative levels (Rajabifard et al., 2000).

#### 2.2.3 Components

(Rajabifard et al., 2002) and (Mansourian et al., 2005) have proposed the following SDI components:



For this thesis, we will retain a minor adaptation of the previous model by (Steiniger and Hunter, 2010) that distinguishes the following 5 SDI components:

- 1. Spatial Data (or spatial information),
- 2. Technologies, i.e. hardware and software,
- 3. Laws and Policies,
- 4. People, i.e.: data providers, service providers, users, and
- 5. Standards for data acquisition, representation and transfer.

Comparing the SDI components with the GIS components listed in the previous section (people, applications, data, software, hardware), we can easily denote the resemblances and differences between GIS and SDI. Both allow "people" to access "spatial data" through "technology" components (software and hardware). However, while enterprise GIS deal with "standards" and "policies" issues to a certain extent, these are fundamental components of SDI to ensure interoperability between organizations. Concerning the "applications" component present in GIS but missing in SDI, GIS aim to formulate solutions to answer specific spatial questions and problems in various fields where location is important (ex: forestry, agriculture, land management, etc.). On the other hand, SDI is more concerned with facilitating the discovery and delivery of external digital spatial data. Even so, the line between GIS and SDI is fading because of the advent of second and third generations of SDI that shifted the emphasis on processes and users instead of data and the introduction of Web Processing Servers that expose functionalities typically found in desktop GIS software.

The following sections will further describe the content of the five SDI components.

#### 2.2.3.1 Spatial Data

In this section, we will present the different kinds of spatial data that can be found in a SDI (fundamental, thematic and metadata) and the different data structures to store it.

Data sets which may be used for many different purposes and in many different applications are often referred to as base data, core data, fundamental data or reference data (Onah, 2009). Fundamental datasets are themes of spatial information regarded as primary in supporting the key functions of a country or jurisdiction, providing the common spatial reference and context which underpins many other forms of business information (Warnest, 2005). In the context of SDI, themes of spatial information that are required to support the activities of many users; public, private, corporate or individual, may be deemed fundamental. These datasets are widely needed for a variety of purposes and by many agencies. Although fundamental data serve as baseline data for solving many problems, they do not always provide solutions to very specific needs (CCIDEP, 2013). It is recommended that levels of accuracy be consistent with requirements for mapping at the respective scales (Gyamfi-Aidoo et al., 2006) because varying accuracy can negatively affect data sharing and integration (Simbizi, 2007). Themes commonly considered fundamental can include geodetic control, cadastre, administrative boundaries, geographic names and localities, street address, transportation, elevation, hydrology and ortho imagery (Warnest, 2005). Fundamental data are not necessarily uniform for each country and above datasets are not necessarily adapted in their integrity, each country decides on the major datasets according to their needs (Simbizi, 2007). For example, (Gyamfi-Aidoo et al., 2006) has compared the fundamental geospatial datasets for various countries and programmes:

Datasets	Ukraine	Global Map	VMAP	US	Colombia	Mexico	Nigeria	Namibia <sup>2</sup>	Western Australia	South Africa	Botswana	State of Delaware
Transportation <sup>1</sup>								✓				
Administrative boundaries	✓					✓		✓			✓	
Hydrography											$\checkmark$	
Settlements/Population Centres												
Topography/Physiography												
Elevation/Hypsography											✓	
Vegetation												
Land Cover												
Land Use											1	
Geodetic Control											1	
Cadastre and Tenure					V				· 🗹		<b>V</b>	
Imagery <sup>3</sup>											<b>V</b>	
Cultural Environment												
Socioeconomic Data				1. Sec. 1.								
Geographic/Place Names												
Geology				1.1								
Demography												
Coastlines			V					F				
Property Street Address												
Freehold and Crown Tenure												
Electoral Boundaries												
Baselines, Territorial Sea-lanes					1							
Utility networks												
Bathymetry												

1 Includes major road networks, road centreline, rail networks, and airports 2 These "datasets" are identified under 5 broad "feature" classes.

Includes all types of imagery (i.e., aerial photography, digital orthophoto images, and satellite images

The other types of datasets are known as **thematic** datasets which are derived from the fundamental datasets (United Nations Economic Commission for Africa – UNECA, 2004 cited in Onah, 2009). Thematic data corresponds to the stakes of the governments and to the legal aspects, and may include agriculture, roadway infrastructures, forestry, geology, water resources, health infrastructures (Dekeyne, 2012).

**Metadata** is information about the data that is used or generated in a GIS and describes the content, quality, condition and other characteristics of data (CCIDEP, 2013). Aside from documenting the history and characteristics of a dataset, the principal objectives of metadata are to help the searching of information and allow users to determine if a dataset is fit for their purpose (CCIDEP, 2013). This implies that good data management and quality management are mandatory, otherwise metadata may not be up-to-date, data cannot be discovered and the objectives of an SDI cannot be achieved (Crompvoets et al., 2006 from Steenis, 2011). This metadata process is often overlooked because it requires time and recourses but without metadata the value of geospatial data is less (Steenis, 2011). Even though metadata has become widely used recently owing to the popularity of World Wide Web, the concept has been in use for a long time under different forms (Simbizi, 2007). Library catalogues or map legend can serve as examples (Simbizi, 2007).

GIS software store and manage geographic data in a number of formats (Geddes, 2005), most commonly in:

- **Spatial databases**: relational database management systems (RDBMS) that can store and query spatial in addition to typical numeric and character types of data (ex: Oracle Spatial, PostGIS, etc.).
- Vector file formats: commercial formats (ex: ESRI Shapefile and file geodatabase, MapInfo, AutoCAD) and standardized exchange formats (ex: GML and KML)
- Raster file formats: (ex: GeoTIFF, MrSID, JPEG/PNG/GIF)
- Datasets may also be organized and held in **digital tables** which are not necessary GIS format, such as Excel worksheets (Simbizi, 2007).
- Apart from digital formats, **other spatial data** exists as reports, hardcopy tables, and hardcopy maps (Simbizi, 2007).

Sharing spatial data among several systems used to be very difficult because of incompatibilities in spatial data formats and limitations within existing GIS (Piwowar & LeDrew, 1990 cited in Mohammadi, 2008). Efforts have recently been made to minimize the number of geodata formats and to converge towards a reduced set. Currently, most GIS and related access systems support format translation (Nebert, 2004)

#### 2.2.3.2 People

People are the key to transaction processing and decision-making (Rajabifard et al., 2002). They include custodians of spatial data (producers), value-added resellers, users and administrators (Warnest et al., 2002):

- The data custodian is an agency accepting accountability and responsibility for certain information sets. Hence, custodianship assigns certain rights and responsibilities (such as providing metadata) to an agency. These responsibilities cover aspects of data collection, maintenance and revision, standards development, data quality, access, metadata, privacy and negotiations (Brodie et al., 2004). That responsibility is ideally allocated to an agency which is dependent on this data for its operations, and which will prioritize the development and updating of this data (Simbizi, 2007). Custodianship is considered as the heart of spatial information management (Warnest, 2005) and plays the sound role of eliminating unnecessary duplication in spatial data management and promotes partnership with national, regional and local providers and users of spatial data (Rajabifard, 2001 cited from Simbizi, 2007).
- Value-adders play an intermediate role between custodians and users. They use fundamental datasets to develop and supply application data to users (Groot and McLaughlin, 2000).
- Users can be corporate, small or large business groups or individuals, public or private (Simbizi, 2007). The actual objective of an SDI is not to serve the data handling functions per se, but to serve the needs of the user community (Rajabifard et al., 2002). It is argued that to unfold its full potential, a SDI needs to fulfill user requirements (Hennig and Belgiu, 2011).
- Administrators are adequate human and technical resources to collect, maintain, manipulate and distribute geo-information (Warnest et al., 2002). They work for custodians' institutions or value adders agencies.

Traditionally, the data for an SDI have come from official or recognized professional producers of geospatial data using state of the art technology (Cooper et al., 2011b). The emergence of Geobrowsers and Web 2.0 has opened new possibilities for the data collection at the local level (Georgiadou et al., 2011), transforming citizens as voluntary sensors of geometric primitives (points, lines and polygons) that interact with each other, providing spatial data to central sites, and ensuring that data are collated and made available to others (Goodchild, 2007). As a result, custodians of SDIs are starting to admit volunteered geographic information (VGI) into their SDIs (Cooper et al., 2011a) either in the form of revision requests or notices submitted to an SDI through its web site by the public (Guélat, 2009), or potentially even using large quantities of VGI (Cooper et al., 2011b). (Goodchild, 2007) argues that VGI fits in the model of an SDI, facilitating exchange of geographic information between individuals in a community. Therefore, a fifth people category named **Volunteer (contributor / reviewer)** will be considered in the SDI people component of this thesis.

#### 2.2.3.3 Laws and policies

Since the whole scope of SDI is to facilitate better accessibility and exchange of data between different producers and users of spatial data, a well-organized infrastructure for co-ordination and co-operation between different stakeholders is necessary (Simbizi, 2007). Stakeholders will only actively participate if there are certain benefits or advantages to win for their organizations and should be involved closely in developing supportive policy (Steenis, 2011).

The institutional framework defines the policy and administrative arrangements for building, maintaining, accessing and applying the standards and datasets (Onah, 2009). Policies and institutional arrangements define other components of SDI such as governance, data privacy and security, data sharing, and cost recovery (Nebert, 2009). It is the policies and organizational components that make it possible for the realization of aims and objective of SDI. Even when data and other components are in place, without enabling policies, and institutional arrangements, coordination, cooperation and sharing will not be achieved (Onah, 2009).

The framework is to cover issues like leadership, custodianship, funding, capacity building, policies and legislations (Simbizi, 2009):

- Leadership: it is convenient to form some kind of organizational body to manage all issues. The organization structure comprises the following elements as suggested by (United Nations Economic Commission for Africa – UNECA, 2004 cited in Simbizi, 2007):
  - a. A Ministry in Charge: it is advisable that the SDI be under a ministry in charge of development of sectors of geo-information, surveying, mapping and remote sensing. The ministry in charge must provide a strong support at policy level, and ensure that the concept of SDI is understood in the high organs of decision making like government and parliament.
  - b. A Lead Agency: this will be an institution which is in charge of geospatial data management. This organ will host a geospatial data service centre. As explained by Groot and McLaughlin (2000), the geospatial data service is a facility which acts as a broker between data users and the providers of the applications data. It will play the role of coordinating the actions related to administrative functions, resources management, and technical aspects.
  - c. A forum of data producers and data users reinforces the concept of participation essential for the involvement of all the stakeholders in the SDI process.
  - d. **A steering committee**: this organ is made by a sample of stakeholders in charge of analyzing the outcome of activities undertaken and making recommendations.
  - e. **Technical Working Group** deals with specific problem areas of SDI development and operation such as drafting standards, policies and suggesting capacity building programs.
- Policies and legislations: spatial data related policies and legislations are of fundamental importance, even though these take more time and effort to establish (Janssen and Dumortier, 2007). In the context of SDI, spatial data policy aims at providing basic principles specific to spatial data to be observed by all stakeholders when generating, collecting, transforming, disseminating and making use of spatial data (United Nations Economic Commission for Africa – UNECA, 2004 cited in Simbizi, 2007).

- 3. **Custodianship**: the criteria for assigning custodianship to an agency include (Brodie et al., 2004):
  - a. Has sole statutory responsibility for the capture and maintenance of the spatial information;
  - b. has the greatest operational need for the spatial information;
  - c. is the first to record changes to the spatial information;
  - d. is the most competent to capture and/or maintain the spatial information;
  - e. is in the best economic position to justify collection of the spatial information at source;
  - f. requires the highest integrity of the spatial information.
- 4. Funding: The majority of the first generation SDIs were funded through the budgets of national mapping agencies or specially funded projects and evolved without long term financing mechanisms (Garfield, 2003). These sources are no longer sufficient to finance the next generation of SDI and structured long term financing mechanisms are required (Garfield, 2003). The concept of SDI financing models is even more important to emerging and transition countries that have very limited financial resources which must be shared amongst other projects that have more tangible and short term benefits such as health and education (Garfield, 2002). Innovative funding models include funding from the budgets of ministries, special taxation, non-monetary contributions (personnel, equipment, etc.), partnerships, alignment to special projects and contribution from large stakeholders such as utility companies (Garfield, 2003). Funding mechanisms must be adapted to the economic context of every SDI implementation environment (Simbizi, 2007). The ANZLIC argues that SDI should be founded by the governments, since it is an essential infrastructure (Nasirumbi, 2006).
- 5. Capacity building: Capacity is the power/ability of something a system, an organization or a person to perform and produce properly (Enemark and Williamson, 2004). Capacity issues can then be addressed at these three levels. The concept is closely related to education, training and human resource development. Capacity development for SDI at the people or individual level includes a whole range of activities such as (Rajabifard and Williamson, 2004):
  - a. short courses including web delivery
  - b. components of university degree programs
  - c. conferences, seminars and workshops
  - d. research training (Master's degrees and PhD students) i.e. training people to do SDI research
  - e. preparation of books, articles and reports

#### 2.2.3.4 Standards

Agencies invest significant resources, including time and money, each year in collecting and maintaining data. Despite this investment, data collected by different agencies often use different standards to collect, store, document and provide access to data. The resulting inconsistencies may create major inefficiencies and limit effectiveness (Australian Local Government Association, 2007).

Standards are defined as collective agreements on technical aspects, data and organization with as goal interoperability and optimization of the SDI (Steenis, 2011). They ensure interoperability of data, datasets, technology, access mechanisms, processes and workflows (Smith and Kealy, 2003). Data standards are required for quality, reference systems, models, data dictionaries, metadata, formats (Crompvoets et al., 2004). Bishr (1998) recognizes six levels of technical interoperability: network protocols, hardware and operating systems, spatial data, database management systems (DBMS) data models and semantics.

Benefits of standards for data include increased data sharing, improved data consistency, increased data integration and interoperability, better understanding of data, improved documentation of information resources, improved control over data updating activities and development of new versions of datasets and improved data security (Australian Local Government Association, 2007).

At least 4 categories of standards can be enumerated (Mansourian et al., 2005):

- 1. Interoperability: capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units (OGC, 2013). There should be no heterogeneity between data custodians, value adders, and users system. In this respect, there are three sources of heterogeneity that should be brought into consideration during standardization: semantic, syntactic, and schematic heterogeneities (Groot and McLaughlin, 2000). Semantic heterogeneity is relevant for differences in definition, structure and coordinate systems of data layers. Syntactic heterogeneity relates to differences in software, hardware, data base management systems, and data format which are used by the data provider and analyzer. Schematic heterogeneity relates to differences in deta provider and analyzer. Schematic heterogeneity relates to differences in data model, data coding, and topology (Groot and McLaughlin, 2000).
- 2. **Guides and specifications:** must describe how to do a task in a standard way and provide the procedures standards. It includes data collection, data storage, data presentation, data access, data integration procedure, data analysis procedure, quality control, quality assurance.
- 3. **Data quality:** having quality standards and producing data based on them is very important within an SDI. It includes accuracy, currency, coverage, lineage, completeness.
- 4. Metadata: In order to make metadata easily readable and understandable by different users, there should be a standard that provides a common terminology and definition for the documentation of geospatial data (Simbizi, 2007). The ISO standard 19115:2003 defines the schema required for describing geographic information and services (ISO, 2009). It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of digital geographic data. It is applicable to the cataloguing of datasets, clearinghouse activities, and the full description of datasets. ISO/TS 19139:2007 defines Geographic MetaData XML encoding, an XML Schema implementation derived from ISO 19115 (ISO, 2010).

The development of standards is the duty of national standards bodies, as well as international standards organizations on which other countries can adhere to as members (Simbizi, 2007). Several technical standards defined by the Open Geospatial Consortium (OGC) and the International Standards Organization (ISO 19xxx series) play an important role in the dissemination and processing of spatial data (Steiniger and Hunter, 2010). In general, these standards describe communication protocols between data servers, servers that provide spatial services, and client software, which request and display spatial data. In addition, they define a format for the transmission of spatial data. (Steiniger and Hunter, 2010) identifies the following OGC standards that are required to build an SDI:

- OGC data delivery standards: Web Mapping Service (WMS), Web Feature Service (WFS) and its transactional equivalent (WFS-T), and the Web Coverage Service (WCS);
- OGC data format standards: Simple Feature Standard (SFS), Geography Markup Language (GML), Keyhole Markup Language (KML);
- OGC data search standards: Catalogue Service (CSW), Gazetteer Service (WFS-G); and
- Other OGC standards: Web Processing Service (WPS), Coordinate Transformation Service (CTS), Web Terrain Service (WTS), Styled Layer Descriptor (SLD), Symbology Encoding (SE), Web Map Context (WMC).

GeoJSON is another geospatial data interchange format based on JavaScript Object Notation (JSON) (Butler et al., 2008) that has become the defacto data transfer expression language for web applications posting data to a web browser (OAGI, 2011). This is mainly due to the fact that it is more compact and human readable than XML (Andrews, 2007). The example architecture diagram below illustrates how the OGC interfaces can simply be used to provide controlled access to existing GIS and database systems (Social Change Online, 2003):



A Web Map Service (WMS) provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases (OGC, 2013d) while a Web Feature Service (WFS) offers direct fine-grained access to geographic information at the feature and feature property level (OGC, 2013d). Geography Markup Language (GML) is an XML grammar for expressing geographical features and serves as a modeling language for geographic systems as well as an open interchange format for geographic transactions on the Internet (OGC, 2013a). Data can be stored in relational databases or file formats and accessed through desktop GIS, mobile devices or web clients.

#### 2.2.3.5 Technologies

A Spatial Data Infrastructure should enable the discovery and delivery of spatial data from a data repository (Crompvoets et al., 2004), ideally via one or more web services. Additionally, it is often desirable that the data provider is able to (remotely) create and update spatial data stored in a repository. The technologies component, sometimes called access network by early authors, contains hardware, software, networks, databases and technical implementation plans (Nebert, 2009).

According to (Steiniger and Hunter, 2010), the basic software components of an SDI consist of:

- (i) a **software client** that can interact with spatial data services,
- (ii) a catalogue service for the discovery, browsing, and querying of metadata,
- (iii) a **spatial data service** that enables the delivery of the data via the Internet, and/or processing services such as datum and projection transformations,
- (iv) a (spatial) data repository, and
- (v) **GIS software (client or desktop)** that permits the creation and maintenance of data.



In the following section, the characteristics and benefits of Free and Open Source Software (FOSS) will be presented and the major available options to build a SDI will then be reviewed.

#### 2.3 Free and Open Source Software (FOSS)

#### 2.3.1 Introduction

Presented before the Peruvian Congress in December 2001, Law Proposition 1609 proposed the mandatory adoption of the use of free software in all areas of Peru's government, making exceptions only where a developed enough free software application was not yet available (Chan, 2004). It stressed that states' reliance on computational processing in nearly all administrative activities forced governments into "a situation of dependency... [on] technology created in other countries" (Chan, 2004). The bill further cited the rapidity of software update cycles, stressing that the frequency of new releases forced governments to make choices between continually purchasing new licenses, operating with outdated software, or pirating programs (Chan, 2004). It also referenced a government study that estimated Peruvian government's own use of pirated programs at 90% and the cost of legalizing the situation at millions of dollars (Chan, 2004).

The aim of the bill was not directly related to the amount of direct savings that can be made by using free software in state institutions (Villanueva, 2002). Instead, the basic principles which inspire the bill are linked to the basic guarantees of a state of law (Villanueva, 2002), such as:

- Free access to public information by citizens: it is indispensable that the encoding of data is not tied to a single provider.
- Permanence of public data: it is necessary that the usability and maintenance of the software does not depend on the goodwill of the suppliers, or on the monopoly conditions imposed by them.
- Security of the State and citizens: it is indispensable to be able to rely on systems without elements which allow control from a distance or the undesired transmission of information to third parties.

The proposed 2001 bill was never approved but after three years of effort, the Peruvian Congress finally passed a bill in 2005 that prohibits any public institution from buying systems that tie users into any particular type of software or that limits "information autonomy" (The Register, 2005).

#### 2.3.2 Benefits

For all categories of GIS software required for the implementation of an SDI, a free software product able to compete with proprietary software is available. This enables adopters to implement an SDI on a limited financial budget, and allows the distribution of a proven SDI architecture without legal constraints of proprietary software licenses (Steiniger and Hunter, 2010). FOSS solutions often implement a wide range of industry standards that ease interoperability between SDI components, and if not, at least permit the implementation/addition of components that are OGC/ISO standard compliant (Steiniger and Hunter, 2010). Another benefit of the open source license model is that it allows the simple deployment of SDI components to other locations (so-called up-scaling) at no additional cost (Steiniger and Hunter, 2010). Finally, helpful user and developer communities exist, and support and maintenance service options are offered by various companies which are similar to that currently offered by proprietary software vendors (Steiniger and Hunter, 2010).

#### 2.3.3 Definition

FOSS is an inclusive term that covers both free software and open source software, which despite describing similar development models, have differing cultures and philosophies (Feller et al., 2005).

The term Open Source (OS) refers to a set of licenses that require unfettered access to the humanreadable source code from which all computer programs are made (Holmes et al., 2005).

The idea of 'free software' has its origin in the idea of freedom (as in free speech) and not in the idea of free-of-cost (Steiniger and Hunter, 2012). This also includes that a distinction between 'free software' and 'commercial software' is neither correct nor expresses the thinking of the creators of free software. Rather, a distinction should be made between 'free software', that grants freedoms of use, modification and re-distribution to the public, and 'proprietary software', that takes these freedoms away (in most cases at least) (Steiniger and Hunter, 2012). A program is free software if the program's users have the four essential freedoms (GNU, 2012):

- 1. The freedom to run the program, for any purpose (freedom 0).
- 2. The freedom to study how the program works, and change it so it does your computing as you wish (freedom 1). Access to the source code is a precondition for this.
- 3. The freedom to redistribute copies so you can help your neighbor (freedom 2).
- 4. The freedom to distribute copies of your modified versions to others (freedom 3). By doing this you can give the whole community a chance to benefit from your changes. Access to the source code is a precondition for this.

Software such as Google Earth, Google Maps or ESRI ArcExplorer are free (gratis) software products for download but are not considered FOSS (Steiniger and Bocher, 2009) because they not comply with the four freedoms mentioned above.

One can imagine software as a very complex LEGO house, a functional unit built up from individual pieces that is used by consumers (Holmes et al., 2005). Most commercial software is sold already built into its final form – similar to an already built house, (or a car, a firetruck, or a school). Unlike LEGO sets, which include a detailed instruction booklet, proprietary software does not include instructions for its inner workings (Holmes et al., 2005). This is satisfactory for most people, since they just want a house for their LEGO people to live in. But it's antithetical for anyone who plays with LEGOs, or who might want to modify their house after they buy it, or use the parts to build an entirely new type of structure (Holmes et al., 2005).

The Open Geospatial Consortium (OGC) is an international industry consortium of several companies, government agencies and universities participating in a consensus process to develop publicly available interface standards (OGC, 2013). OGC's mission is to serve as a global forum for the collaboration of developers and users of spatial data products and services, and to advance the development of international standards for geospatial interoperability (OGC, 2013). The OGC does not create Open Source software but rather specifies open standards (defined as freely and publicly available, non-discriminatory, no license fees, vendor neutral, data neutral, agreed to by a formal member based consensus process (Trakas, 2008)). Giving some basic rules about how the house can integrate with other houses (Holmes et al., 2005), anyone can then choose to implement the standards, to build a house like the one they specify (Holmes et al., 2005). And to build it they can choose to buy a private company's LEGO blocks, to completely build their own blocks, or to use and build upon Open Source blocks (Holmes et al., 2005).

#### 2.3.4 FOSS4G Software for building a SDI

Many of the most important technical pieces needed to implement a Spatial Data Infrastructure indeed are already stable, moving towards even more maturity (Holmes et al., 2005). Fundamentally, successful OSS projects are not created by releasing free source code – they are created through the growth of communities of shared interest (Ramsey, 2007). In particular, the **Quantum GIS** project, the **PostGIS** project, and the **OpenLayers** project have been able to attract users and developers, which has subsequently influenced software functionality and support and as a consequence raised their attractiveness to new users of free software (Steiniger and Hunter, 2012).

The following diagram, loosely inspired by the works of (Steiniger and Hunter, 2010) and (Steiniger and Hunter, 2012), depict the 5 SDI components along with the principal FOSS alternatives and software categories that are generally part of a Spatial Data Infrastructure architecture:



As we can see, the policies component glues together people, technology, standards and data issues. Client technology allows people to access data by communicating with server technology. This is made possible by agreeing to various types of standards. For the remaining purposes of this thesis, the following software categories have been retained: client technology (Desktop GIS and Web Map Development Frameworks), server technology (Web Map Servers and Server GIS), spatial data storage (Spatial Database Management Systems), and cataloging applications. Two additional categories that integrate various components will also be described: collaborative mapping and SDI software packaged solutions. In order to have a better understanding of the more relevant FOSS alternatives available to build an SDI, we will review in the next sections the main software categories and FOSS solutions that could be appropriate to realize the software components of the Peru Spatial Data Infrastructure.

#### 2.3.4.1 Client technology

#### 2.3.4.1.1 Desktop GIS

Desktop GIS software is probably the most common GIS software in use (Steiniger and Hunter, 2010). ESRI (2012) defines desktop GIS as "a mapping software that is installed onto and runs on a personal computer and allows users to display, query, update, and analyze data about geographic locations and the information linked to those locations". (Steiniger and Bocher, 2009) add: "That is, the software is not executed on a server and remotely accessed or controlled from or by a different computer". The most relevant and mature FOSS desktop GIS projects are GRASS, QGIS, gvSIG and uDig.

Geographic Resources Analysis Support System, commonly referred to as GRASS GIS, is a Geographic Information System (GIS) used for data management, image processing, graphics production, spatial modeling, and visualization of many types of data (OSGeo, 2012). Originally developed by the U.S. Army Construction Engineering Research Laboratories, a branch of the US Army Corp of Engineers, as a tool for land management and environmental planning by the military, GRASS GIS has evolved into a powerful utility with a wide range of applications in many different areas of applications and scientific research (OSGeo, 2012). GRASS is currently used in academic and commercial settings around the world, as well as many governmental agencies including NASA, NOAA, USDA, DLR, CSIRO, the National Park Service, the U.S. Census Bureau, USGS, and many environmental consulting companies (OSGeo, 2012).

As a response to the expert oriented design of GRASS, a group of volunteers started to develop QGIS (Quantum GIS) in 2002 as the QGIS project evolved the idea emerged to use QGIS as a simple Graphical User Interface (GUI) for GRASS itself (Steiniger and Bocher, 2008). Like GRASS, it owns one of the largest user communities (Steiniger and Bocher, 2008). It has a growing developer base and the software itself and the development process are well documented (Steiniger and Bocher, 2008).

GvSIG (generalitat valenciana Sistema d'Informació Geogràfica) started in 2002 when the Regional Ministry of Infrastructure and Transport (CIT) of Valencia started to analyze the process of migrating the whole organization computer system to an open source system (Anguix and Diaz, 2008). gvSIG project is developed along with the fact that SDI are becoming the infrastructures being deployed everywhere where users need to share and integrate spatial information (Anguix and Diaz, 2008). gvSIG application wanted to integrate its powerful geoprocessing functionality and diverse tools into Spatial Data Infrastructures playing an important role, giving users complete access to SDI services and being able to work with this remote information using the power of a rich client (Anguix and Diaz, 2008). gvSIG is now an European Commission project supported by many government agencies and private companies that are providing support at national and international level (Anguix and Diaz, 2008). gvSIG has been successfully used in SDI deployments at all levels as entry points to the infrastructures, applications that have been customized for every user needs (Anguix and Diaz, 2008).

uDig stands for "User-friendly Desktop Internet GIS", and the goal is to bring internet mapping technologies such as WMS and WFS transparently to ordinary GIS users desktops (Ramsey, 2007).

#### 2.3.4.1.2 Web Map Development Frameworks

Three projects are worthy of mentioning: OpenLayers, MapFish and the promising Leaflet.

OpenLayers implements a JavaScript API for visualization of spatial data in a web browser without the need for server-side components. It implements industry standard methods, WMS, WFS, etc., for accessing geospatial data (Steiniger and Hunter, 2012). OpenLayers has close tie to other projects such as TileCache (for speeding access to dynamic map services like WMS) and FeatureServer (for standard access to database and other backends) (Ramsey, 2007).

Several development toolkits exist that include not only a viewer (often OpenLayers) but also other tools that help to build web map pages for display and query (or even editing) of spatial data (Steiniger and Hunter, 2010). MapFish is an example of this kind of project.

Leaflet is a JavaScript library for the creation of interactive maps by the founders of OpenStreetMap (Steinger and Hunter, 2012) that is recently gaining popularity. Interesting for developers is probably the focus on desktop and mobile web browsers, and its use of HTML5 (Steinger and Hunter, 2012).

#### 2.3.4.2 Server Technology

#### 2.3.4.2.1 Web Map Servers

Web Map Servers usually serve spatial data and images based on three OGC standards: WMS for the display of maps as image, WFS for vector data, and WCS for raster data (Steiniger and Hunter, 2010). Web map servers rarely allow interaction with the data in terms of processing or editing. However, if standards such as the OGC WPS (processing) and OGC WFS-T (editing) are implemented, then this is possible (Steiniger and Hunter, 2010).

The best-known web map servers are MapServer and GeoServer (Steiniger and Hunter, 2012). Both solutions are comparable to similar proprietary solutions with respect to functionality (Aime and McKenna, 2009 cited from Steiniger and Hunter, 2012) and tile–caching capability. A recent review by (Ballatore and Tahir, 2011) suggests that MapServer is preferred in terms of performance, scalability, and stability, whereas GeoServer is easier to extend, and follows the various web mapping standards more closely.

Autodesk also offers a widely adopted open source web map server, MapGuide Open Source (mapguide.osgeo.org), which has evolved out of Autodesk's proprietary MapGuide 6.5 software (Steiniger and Hunter, 2010).

A fourth server software, with a strong European user base, is the deegree server/application framework (Steiniger and Hunter, 2010).

#### 2.3.4.2.2 Server GIS

Web-GIS servers for data processing does not refer to web servers for web mapping applications, but rather to server software that expose GIS functionality typically found in desktop GIS software (Steiniger and Hunter, 2010). This functionality does not require direct interaction from a user via a user interface (Steiniger and Hunter, 2010). Server GIS is software that (i) is used remotely, and (ii) provides access to functionality via web protocols such as the OGC Web Processing Service (Schut, 2007) and (iii) allows for the provision of data and input parameters from other web-based services (i.e., allows service chaining) (Steiniger and Hunter, 2012).

The 52 North WPS is an OGC WPS conforming implementation of a server GIS developed by 52 North (Schaeffer & Foerster, 2008).

A second implementation of the WPS standard is offered by "deegree" as part of their deegree3 web services architecture (Steiniger and Hunter, 2012).

PyWPS also implements the OGC WPS standard (Cepicky & Becchi, 2007).

GeoServer, originally a web mapping server software, implements the WPS standard since version 2.1 (Steiniger and Hunter, 2012). This will allow users to access spatial analysis functions of spatial analysis libraries (Steiniger and Hunter, 2012).

#### 2.3.4.3 Spatial Data Storage

Spatial DBMS provide an alternative to storing geographical data in files (Steiniger and Hunter, 2012). We can describe a Spatial Data Base Management System (Spatial DBMS) as (i) a DBMS, which (ii) offers spatial data types in its data model, i.e., geometry data types defined in the Open Geospatial Consortium (OGC) Simple Features Specification for SQL3 (Herring, 2010), that (iii) offers a query language, and offers (iv) spatial analysis operations as defined in the OGC Simple Features Specification (Herring, 2011), such as intersection, union, etc. (Steiniger and Hunter, 2012).

The dominating product, i.e., the free DBMS with the largest user group, is PostGIS (Obe & Hsu, 2011; Sherman, 2012 cited from Steiniger and Hunter, 2012), which provides spatial data types and analysis functions for the free PostgreSQL database.

Two other FOSS DBMS projects include spatial data capabilities. They are the MySQL Spatial extension, which adds spatial support to MySQL, and the SpatiaLite project for SQLite (Steiniger and Hunter, 2010).

#### 2.3.4.4 Cataloging applications

GeoNetwork Opensource is a catalog application to manage spatially referenced resources that provides powerful metadata editing and search functions as well as an embedded interactive web map viewer. It is currently funded and used in numerous Spatial Data Infrastructure initiatives across the world including the Food and Agriculture Organization of the United Nations, the World Food Programme, the United Nations Environment Programme, and the United Nations Office for the Coordination of Human Affairs (Steiniger and Hunter, 2010).

MDweb is a project initiated by research institutes in France and the software is used in several environmental projects and institutions (Steiniger and Hunter, 2010).

The deegree framework also provides metadata services for the creation, storage, query, retrieval and display of metadata (Steiniger and Hunter, 2010).

The fourth software is not a server-based catalogue software, but a metadata editor for desktop computing: CatMDEdit which allows creation and editing of metadata for several types of GIS file formats and is used by a number of public agencies such as the EUs Statistical Office EuroStat, the National Geographic Institute of Spain and the French National Mapping Agency (Steiniger and Hunter, 2010).

#### 2.3.4.5 Collaborative Mapping

Inspired by the success of Wikipedia and the preponderance of proprietary map data, OpenStreetMap was founded in 2004 as a free editable map of the whole world that allows free access to the full map dataset (unlike proprietary datasets like Google Map Maker) (OpenStreetMap, 2013). Since then, it has grown to millions of contributors who collect data with GPS devices, aerial photography, and other free sources (OpenStreetMap, 2013). This massive amount of data can be downloaded in full, but also is available in immediately-useful forms like maps and commercial services (OpenStreetMap, 2013). OpenStreetMap is not only open data, but it's built on open source software (OpenStreetMap, 2013). The web interface software development, mapping engine, API, editors, and many other components of the map are made possible by the work of volunteers (OpenStreetMap, 2013). According to a model proposed by (Cooper et al, 2011b), OpenStreetMap can be seen as a SDI, contributors having the role of data providers and National Mapping Agencies the role of data aggregator/integrator according.

There has been a recent trend for open source and crowd-source maps to be developed immediately post disaster (Farthing and Ware, 2010). For example, after the 2010 Haiti earthquake, contributors from around the world helped to improve the amount of geographic detail on the OpenStreetMap and Google Map Maker web sites (Zook et al, 2010). The volunteers mostly relied on aerial images and traced features from them; few volunteers knew Haiti or had actually been there and there was little time or resource for ground-truthing the GI (Farthing and Ware, 2010).

#### 2.3.4.6 SDI Software Packaged Solutions

Recently, FOSS software has been packaged as global solutions including tools that can be used together to build a SDI software solution (Deleurme, 2010). Those new projects are examples of a new trend that aim to cover most SDI functionalities and needs for setting up a complete SDI (Deleurme, 2010).

For example, EasySDI is a simple and ready-to-use solution to deploy a Spatial Data Infrastructure (SDI) based on ISO/OGC standards (EasySDI, 2013). The solution is particularly designed for setting up discovery, view and download services in a secured environment with rights management and multilingual support. EasySDI do not aim to replace existing tools but act as aggregating technologies to offer an interoperable and OGC compliant solution. It is based on GeoServer, Geonetwork Open Source and the open source Content Management System Joomla.

Another open source solution is GeoNode which is a platform that facilitates the creation, sharing, and collaborative use of geospatial data (GeoNode, 2013). It is a complete spatial data infrastructure solution with catalog functionality and a sophisticated user experience. Highly customizable and extendable, it is also a powerful platform on which to build your domain specific analysis applications. It is based on Django, GeoNetwork, GeoExt, GeoServer and GeoWebCache. Features include:

- Upload and manage data security through a web application interface
- User profiles for all geospatial team
- A complete metadata catalog solution
- Participatory map creation and editing using built-in GIS tools
- Publish and share maps and data
- Browse spatial resources at blazing speed
# **3** CASE STUDY: THE PERU SPATIAL DATA INFRASTRUCTURE

## 3.1 Location of the study area

The field work of this research was conducted in Peru, a country located in western South America as showed on the following map from (CIA, 2013):



Peru is considered a high human development index country by (United Nations Development Programme, 2011), a lower-middle-income economy by (World Bank, 2013) and an emerging economy by (International Monetary Fund, 2012). According to (United Nations, 2013), South America remains a developing region and Peru's poverty level is still low around 30 percent (Central Intelligence Agency, 2013). The Peruvian population, estimated at 29.5 million, is multiethnic, including Amerindians, Europeans, Africans, and Asians. The main spoken language is Spanish, although a significant number of Peruvians speak Quechua or other native languages. Its main economic activities include agriculture, fishing, mining, and manufacturing of products such as textiles (Wikipedia, 2013a). Ancient Peru was the seat of several prominent Andean civilizations, most notably that of the Incas whose empire was captured by the Spanish conquistadors in 1533 (Central Intelligence Agency, 2013). Peru is a representative democratic republic divided into 25 regions. Its geography varies from the arid plains of the Pacific coast to the peaks of the Andes Mountains and the tropical forests of the Amazon Basin (Wikipedia, 2013a).

In the following section, we will present the initial situation of the production of geographic information by Peruvian public institutions that have led to the creation of the IDEP.

## 3.2 Initial situation

Since the implementation of the first GIS in Peruvian public institutions in 1985, the number of public institutions involved in the generation, development, management, administration and use of spatial data has increased dramatically. This process was conducted without proper coordination, so that each institution has been operating for the capture and management of spatial data according to their particular needs, without considering the developments of other institutions. Until the formal creation of the IDEP in 2003, there was no organizational and regulatory framework governing the production, exchange and access spatial data. The dismantling and overlapping inter-institutional roles in managing geographic information is clear and is a result of weaknesses in the dissemination of information that causes isolated efforts by public entities to meet the unmet demand of geographic information. This situation has generated an overlap of powers and functions between state agencies regarding their roles, creating duplication of effort and resources, resulting in the generation of spatial data for their own needs and requirements without considering the needs of external spatial information users. The scales of mapping information currently available are not suitable for use by public entities to develop projects and development activities, thus having to use isolated solutions such as third party service contracts and / or using self-generated funding (CCIDEP, 2013).

The creation of the Peru Spatial Data Infrastructure was first proposed in 2001 as a result of an environmental & land management national commission. In 2002, a pilot project was realized by seven public institutions to share cartographic and statistical information.

In 2003, a diagnostic was published where 14 public institutions were identified as spatial data producers and highlighted the following issues:

- 1. Partial and uneven cover of digital data in the country, with a low level of updating
- 2. Lack of knowledge on the available information and the quality of the source data
- 3. Isolated information production which prevents data exchange due to different technical specifications
- 4. Lack of standardization of formats and regulations in the cartography process
- 5. Lack of a mechanism that enables to users the access and exchange of cartographic and statistical information in an updated and automated way
- 6. Autonomous production of data by each entity without consideration of common national priorities with partial user requirements analysis
- 7. Lack of regulation and standardization in the use of the national geodetic network parameters and lack of official transformation between geodetic networks
- 8. Lack of communication mechanisms between entities that produce and use spatial information
- 9. Absence of a legal device that establishes the roles of public institutions regarding data generation

#### 3.3 Creation of a permanent committee to lead the Peru SDI

As already discussed in the policies component section, it is convenient to form some kind of organizational body to manage all issues related to leadership, custodianship, funding, capacity building, policies and legislations. In response to the growing needs of standardized spatial data and to tackle the problems enumerated in the previous section, the Peru Spatial Data Infrastructure Coordination Committee (CCIDEP) was created in 2003. Its mission is to promote and coordinate the development, exchange and use of data and spatial data services across all levels of government, private sector, nonprofit organizations profit, academic and research institutions. The Peru Spatial Data Infrastructure (IDEP) is defined as a set of policies, standards, organizations and technology resources that facilitate production, collection, use and access to georeferenced information of national coverage, to support the country's socioeconomic development and facilitate timely decision-making. From those issues, the committee identified a vision of four critical problems that must be addressed:

- **Geographic information national policies**: define, disseminate and implement basic policies for geographical information management topics including production, information exchange, access, security and copyright, among others
- **Data production:** user-driven and to obtain national data coverage with clear specifications that are easy to integrate and use in different projects
- **Documentation of data**: for which each entity must implement geographic and statistical metadata to document products (both geographical and attribute information)
- **Mechanisms of access for users**: where producers must define the conditions and mechanisms under which the spatial information developed by the public sector will be available for the service of society.

The committee became permanent in 2007 and its name was changed to the Peru Spatial Data Infrastructure **Permanent** Coordination Committee to reflect this change. The CCIDEP acronym from the Spanish initials remained though. The CCIDEP is attached to the high organ of the Presidency of the Council of Ministers, who provides technical and administrative assistance through the National Office of Electronic Government and Information – ONGEI (CCIDEP, 2013). The Peru Spatial Data Infrastructure Permanent Coordination Committee currently has 21 members, all of them from the national public sector (CCIDEP, 2013).

The specific objectives are stated as follows:

- Define guidelines and strategies to order the production and dissemination of geographic information
- Establish a framework for cooperation between producers and users of geographic information.
- Document the basic and thematic map data produced and facilitate access to them (metadata)
- Deliver products and online geographic information services, to support decision making
- Improve the technological management capacity of the entities
- Harmonize information systems to ensure data interoperability

In the following section, we will present the Peru National Spatial Data Policy to gain understanding on the priorities of the IDEP.

## 3.4 National Spatial Data Policy

In 2012, the Peru Spatial Data Infrastructure Permanent Coordination Committee - CCIDEP - unanimously approved the National Spatial Data Policy, which consists of a set of guidelines that should be implemented in the short term and that will guide the work of CCIDEP. This document consists of five basic policies and their respective guidelines that serve as a framework for the actions and activities of CCIDEP and Working Groups:

- **Policy 1:** Order and integrate spatial data production processes and strengthen the role of information producing institutions.
- **Policy 2.** Promote the production, use and exchange of spatial data according to the priorities of public policies
- **Policy 3.** Prioritize the production and exchange of sensitive fundamental data or of massive use by the regional and local governments.
- Policy 4. Boosting cataloging of spatial data as a sustained process.
- Policy 5. Promote the implementation of spatial information services citizen-oriented.

## 3.5 Technical Workgroups

Technical working groups are an important aspect of SDI and deals with specific problem areas of SDI development and operation such as drafting standards, policies and suggesting capacity building programs. These working groups are formed to propose solutions to specific problems depending on their nature and can be permanent or temporary. There are currently 7 workgroups and 2 subgroups:

- **GT-01: Fundamental Data**: facilitate public access to the fundamental data of the state, in order that all production of spatial data is based on this information
  - **GT-01-A: Population Centers**: coordinate the development of a unique database of population centers and geographical location code for public entities.
  - **GT-01-B: Referential Boundaries**: create a unique political and administrative boundaries spatial database and allow the proper management of resources and benefits based on the country's political divide
- GT-02: Metadata: elaborate the proposal of metadata, catalogs and services standards
- **GT-03: Standards and Interoperability**: develop and promote the collection, use and efficient management of standards for geographic information at national, regional and local levels
- **GT-04:** Administrative and Statistical Records: determine consensus policies and propose guidelines to ensure the upgrade, maintenance and quality of administrative and statistical records that will be associated and linked to a graphical database.
- **GT-05: Remote Sensing**: organize and propose recommendations for the management and administration of spatial information obtained through such instruments as the sensors and satellites
- **GT-06: Interagency Agreements and Policies**: determine consensus policies and propose data policies, prices of products, services and licenses in the field of producers, distributors and brokers of geographical data and services
- **GT-07: Cadastre (land management)**: determine the integration in relation with the production, use and dissemination of cadastral mapping produced by the state

#### 3.6 Example of a sectoral SDI: Online Environmental Assessment Information System

The Peru SDI participants could learn some lessons from the experience of the Ministry of Energy and Mines and from the Peru Canada Mineral Resources Reform Project (PERCAN) that took place between 2003 and 2011. At the beginning of the project, all departments of the Ministry (mining, electricity, hydrocarbons, and environmental affairs) had departmental GIS and GIS experts under their direct supervision. Some of the problems that were observed in the initial situation included the duplication of the same data with inconsistencies (it was obtained from different sources at different times and even maintained in parallel), different standards for data structures, different output templates for final map products, different software versions, etc. Only file formats were used (shapefiles and personal geodatabases) making it impossible for users to query and view spatial data without a desktop GIS. Also, there was no integration with the institutional information systems and with the integrated corporate Oracle database.

A decision was made in 2004 to migrate to an enterprise GIS based on proprietary ESRI software technologies (ArcGIS, ArcSDE, ArcIMS). The central IT office became responsible of the institutional GIS and spatial data. Agreements where then signed with some institutions to directly exchange digital data between themselves through web services and database links. This can be considered a sectoral SDI and became possible mostly because each institution was the custodian of some specific information that was needed to support the processes of the other institutions. For example, the Ministry needed the mining rights (claims) and the Mining Cadaster Institute (INGEMMET) needed the processing plants and abandoned mines information. Automated Extract-Transform-Load tools were developed to access the external data and import it daily into the Oracle database in ArcSDE geodatabase native format. Even though some benefits were gained in the process such as the sharing of fundamental spatial data between departments, it remained difficult to integrate data between the GIS data stored in ArcSDE format and the tabular data from the institutional information systems. This was in part due to the impossibility of using standard SQL to edit tables that use geodatabase functionality and to the impossibility of implementing DBMS referential integrity.

After 5 years, problems began to arise when the Ministry had not paid the yearly recurring costs to ESRI and the purchased versions became obsolete. A new decision was then made to migrate the spatial data from native ArcSDE format to the Oracle SDO format. It became possible to integrate easily tabular data (string, number, dates) with spatial data (points, lines, polygons) into the same tables. Programmers with minimal knowledge of GIS issues began to be able to use standard SQL to query spatial data or include spatial analysis into standard Web applications.

Among other e-government systems that were later developed, this allowed the design and development of the successful Online Environmental Assessment Information System (SEAL) which must be used by mining companies to obtain approval for their mining projects totally online without presenting any paper (MINEM, 2011a; MINEM, 2011b; MINEM, 2011c). The process begins when companies use Web forms to indicate the coordinates of their mining project. Using standard SQL spatial analysis queries, the system then detects automatically if the mining project is located within the mining concessions of the company, if they are in a restricted or protected area, which districts are intersected to organize informative workshops for the population, etc. These systems were developed using a mix of free and open source software (Plone / Zope / OpenLayers / TileCache) and proprietary software (ArcGIS, Manifold, Oracle). Tens of thousands of dollars were saved in license fees but the main benefit for the Ministry is to be independent from proprietary technologies and formats and the integration of spatial and attribute data into a single database.

## 3.7 Conclusion

We have now reviewed how GIS evolves within an organization from standalone and departmental GIS to enterprise GIS designed to serve the needs of multiple units. We have then reviewed from the literature the definitions, objectives, components (data, people, standards, policies, technology) and 3 generations of SDI (data-centric, process-centric, user-centric).

Special attention has been taken to present the benefits of FOSS (financial savings, freedom, independence from vendors and technology, compliance with standards), the main software components of a SDI (desktop GIS, web map development frameworks, web map servers, server GIS, spatial DBMS, cataloging applications) and the main FOSS spatial software solutions available to realize it (Quantum GIS, gvSIG, Open Layers, Map Server, Geo Server, PostgreSQL, GeoNetwork opensource).

The Peru SDI (IDEP) has been introduced (presentation of Peru, initial situation of geographical information, objectives of the permanent committee, presentation of the national policies and guidelines and of the technical workgroups). An example of a successful project that implemented an enterprise GIS and was able to reach to agreements with other institutions to share data based on mutual needs and sectoral processes was then presented. For the remainder of this thesis, the Peru SDI will serve as a case study as we will inquiry the current FOSS market share in Peru and apply various SDI assessment methods to observe the progress of the Peru SDI. The next chapter will provide more details on the methods that were used to obtain the expected results.

# 4 METHODOLOGICAL OVERVIEW

SDIs are mainly established by government bodies and resourced by public funds hence the need to assess their progress (Grus et al., 2007). This is especially true for emerging economies like Peru where available financial resources for SDI are low or lacking and the resources spent on those infrastructures must be justified.

Due to the complex, dynamic and evolutionary nature of SDI, one SDI assessment strategy is to use multiple assessment approaches and methods (Grus et al., 2007). By analogy with the barometer used to measure air pressure, researchers need some instruments to measure the population they are studying (Goddard and Melville, 2001). For this research, primary and secondary data collections methods have been applied using quantitative and qualitative methods.

More precisely, we will discuss in this section the methodology that has been applied to answer the four following questions:

- 1. Is FOSS already used in the software components of the IDEP and if so, what is the percentage of use?
- 2. What is the current state of SDI readiness (degree of preparation to deliver geographical information to its community) in Peru and what are the weakest factors?
- 3. Which changes are needed to move the Peru SDI toward a user-centric third generation SDI that satisfies user expectations?
- 4. What is the evaluation of the main Peru SDI components aspects?

The following table summarizes the approaches and methods that will be used to answer the research questions:

Approach	Question	Data collection method	Quantitative / qualitative	Primary / secondary
FOSS and Geospatial Technology Availability	1	Questionnaire survey	Quantitative	Primary
SDI Readiness	2	Questionnaire survey	Quantitative	Primary
Generational Approach	3	Public information review	Qualitative	Secondary
SDI Components Evaluation	4	Questionnaire survey / public information review	Qualitative and quantitative	Primary and secondary

## 4.1 Data collection methods

## 4.1.1 Primary data collection methods

Questionnaire surveys normally aim at drawing accurate information from the respondents (Hague, 1993). With the goal of assessing systematically the development and status of the Peru SDI, a questionnaire survey was conceived for this research. The main purposes of the questionnaire were to obtain quantitative information on the technological aspects and FOSS software components use, to obtain further information for the SDI components evaluation (especially concerning data and people) and to assess the SDI readiness of participating institutions. The works of (Steiniger and Hunter, 2010), (Steiniger and Weibel, 2009), (Delgado et al., 2005) served as an inspiration for the questionnaire design which can be found in the appendices section. Questions were elaborated in five different sections:

- 1. Identification of the respondent
- 2. Technology
- 3. Data
- 4. People
- 5. SDI Readiness Assessment

The questionnaire consists of 25 questions that aim to gain specific understanding of SDI component aspects or of SDI software. The following table summarizes the links between the questionnaire section and questions with the respective SDI component and reference of the literature review section.

Questionnaire section	Questionnaire question	Thesis literature review reference	SDI Component
1.General information	1.Person who completed the questionnaire	2.2.3.2 People	People
2.Technology	2. Types of desktop GIS software	2.3.4.1.1 Desktop GIS	Technology
	3.Number of desktop GIS software users	2.3.4.1.1 Desktop GIS	People
	4.Frequency of GIS tasks performed	2.2.3.5 Technology	Technology
	5.Types of web server software	2.3.4.3.1 Web Map Servers	Technology
	6.Number of web server software users	2.3.4.3.1 Web Map Servers	People
	7.OGC standards	2.2.3.4 Standards	Standards

	8.Spatial data formats	2.2.3.1 Spatial Data	Data
	9.Databases	2.3.4.4 Data storage software: spatial DBMS	Technology
	10.Metadata software	2.3.4.2 Cataloging applications	Technology
3.Data	11.Custodianship	2.2.3.2 People	Data
	12.Needed fundamental data from other institutions	2.2.3.1 Spatial Data	Data
4.People	13.GIS experts	2.2.3.2 People	People
	14.GIS office	2.1.3 Implementation in organizations	People
	15.Number of users	2.2.3.2 People	People
	16.Number of programmers	2.2.3.2 People	People
5.SDI Readiness	17.SDI Vision	2.4.2 SDI Readiness	Policies
	18.Institutional leadership	2.4.2 SDI Readiness	People
	19.Legal framework	2.4.2 SDI Readiness	Policies
	20.Availability of digital data	2.4.2 SDI Readiness	Data
	21.Willingness to share	2.4.2 SDI Readiness	People
	22.Metadata availability	2.4.2 SDI Readiness	Standards
	23.Human capital	2.4.2 SDI Readiness	People
	24.Capacity building and SDI awareness	2.4.2 SDI Readiness	People
	25.Funding	2.4.2 SDI Readiness	Policies
-	26.Comments	-	-

To compile the survey results, a decision was made to use the Survey Monkey application (<u>http://www.surveymonkey.com</u>), which offers web tools to create online surveys, collect responses and analyze results. The questionnaire was pilot-tested first with the Ministry of Energy and Mines because the researcher knows several of their key GIS experts. It started in September 2011 and two answers were obtained to obtain comments on the ease of filling and clarity of questions. The respondents worked for two different administrative units (information technology department and mining department). Major findings included:

- 1. One of the questions was to indicate the percentage of GIS functions performed by their administrative unit. Both of them answered that they performed all GIS tasks and all the same percentage (around 20 %). This question was very important but was not sufficiently understandable. For this reason, instead of a percentage 5 columns were added for each GIS function (everyday, frequently, sometimes, rarely, never).
- 2. One of the questions was "what GIS client software does your institution use" followed by a text area question "please specify the quantity of users for each marked software of previous section". One of the respondents suggested that instead of a text area, text boxes must be available to specify quantity for each software option.
- 3. The number of users was difficult to estimate.
- 4. One of the two did not realized there was an SDI readiness question and did not fill it until I asked him.

At the time of the survey, there were 20 CCIDEP committee members and 10 work group members with their contact information publicly available. An invitation email was sent using SurveyMonkey to these 30 persons officially participating in the CCIDEP. In spite of the fact that the CCIDEP is currently only constituted by national government civil servants, an effort was done to try to reach to other stakeholders such as regional government's civil servants and private companies GIS experts. In some cases, people preferred to fill the survey in Word format instead of the online Survey Monkey web form, some of them for security reasons. As the research was coming to an end, a second attempt was done in early 2013 to reach out to new appointed members of the IDEP.

The results were compiled and analyzed using standard Microsoft Excel tools.

#### 4.1.2 Secondary data collection methods

In addition to the primary data collection method, all documents available from the CCIDEP website (<u>www.ccidep.gob.pe</u>) were read. Several books, journals, conference proceedings, articles available on internet were also consulted. The information gathered through these documents served to build the literature review. This documentation will be analyzed in the discussion section and serve as a basis for the generational approach. Finally, semi-structured interviews were carried on with key stakeholders and pioneers of the IDEP to obtain their views concerning the results obtained so far and future direction of the IDEP.

#### 4.2 Questionnaire answers

Data collection lasted one month (from September 10 to October 19, 2011) for the first attempt and also one month for the second attempt (from January 31 to February 28, 2013). In the first attempt, 16 answers were received by Survey Monkey. 3 of the 16 were discarded because of inaccuracies. An additional 5 answered by email for a total of 18 answers. The answers represent 8 different national institutions (12 people), 2 regional institutions (3 people) and 3 private companies. In the second attempt, 5 answers were received (4 from national institutions and another from academia). In conclusion, we retained 23 respondents, 16 from national institutions (11 institutions), 3 from private companies (3 institutions), 3 from regional governments (2 institutions), and 1 from an academic institution.

After the compilation of the results, additional questions were sent by emails to some of the respondents that already had a high level of FOSS use to obtain further information on the reasons why their institutions chose FOSS and to obtain their opinion on the advantages and disadvantages according to their experience.

Level	Acronym	Description	Number of
			Respondents
Academia	CISMID	Japanese Peruvian Center for Seismic Research and	1
		Disaster Mitigation	
National	CEPLAN	Strategic Planning National Center	1
National	IGN	National Geographical Institute	1
National	INGEMMET	Mining Geological and Metallurgical Institute	2
National	MINAG	Ministry of Agriculture and Irrigation	1
National	MINAM	Ministry of Environment	2
National	MINEDU	Ministry of Education	2
National	MINEM-	Mining Environmental Affairs General Bureau of the	1
	DGAAM	Ministry of Energy and Mines	
National	MTC	Ministry of Transport and Communications	2
National	OEFA	Agency for Environmental Assessment and Control of the	2
		Ministry of Environment	
National	PCM-ONGEI	National Office of Electronic Government and	1
		Information Technology of the Presidency of the Council	
		of Ministers	
National	SENAMHI	National Meteorology and Hydrology Service	1
Private	Anabi	Mining company	1
Private	S&Z	Engineering consulting company	1
Private	Terra	Engineering consulting company	1
	Planning		
Regional	Callao	Regional Government	1
Regional	Piura	Regional Government	2

The following table summarizes the origin of the questionnaire survey respondents:

#### 4.3 SDI Assessment Methods

Assessments are made for many specific reasons, for example to measure and account for the results and efficiency of public policies and programmes, or to gain explanatory insights into social and other public problems, or to reform governments through the free flow of evaluative information (Chelimsky, 1997). In this section, we will review some of the available SDI assessment methods.

## 4.3.1 Multi-view SDI Assessment

Assessing SDI, especially in worldwide comparison or benchmarking studies, remains problematic due to the nature of SDIs, particularly their multifaceted (multiple SDI definitions) and dynamic nature, complexity and vaguely defined objectives (Grus et al., 2007). To deal with these issues, (Grus et al., 2007) has proposed a multi-view SDI assessment based on the principles of assessing Complex Adaptive Systems: using multiple assessment strategies, a flexible framework and a multi-perspective view of the assessed object. The essence of this framework is that it accepts the multiple views on SDI and thus accepts its complexity in terms of multiple definitions (Grus et al., 2007).

The following figure illustrates the framework and two of the approaches that we have applied in this research:



In the following sections, the SDI readiness and generational approaches will be presented with the objective of applying them to assess the Peru SDI development.

## 4.3.2 SDI Readiness

SDI readiness index is an approach available to assess SDIs that could be defined as the degree to which a country is prepared to deliver its geographical information in a community (Delgado et al., 2005).

When building a SDI readiness index, various factors that cover SDI components such as organization, information, access network, people and financial resources are taken into account. Each of these factors can be quantitatively measured by collecting and analyzing predefined indicators based on surveys. SDI readiness index integrates factors from several points of view: organizational (politicians vision-commitment-motivation, institutional leadership, national legal (umbrella) agreements); information (providers' motivation, digital cartography availability, knowledge of standards); access network (web connectivity; technological infrastructure, geospatial software availability/in-house development); people (educational level, SDI culture, individual leadership) and financial resources (government sources, private sources, national geospatial initiatives).

(Delgado et al., 2008) assumes the following propositions:

- A country is ready to undertake an SDI if and only if it has an appropriated level of the global factors: Organizational, Informational, People and Financial Resources, and any level of Access Network.
- A country has an appropriated level of organization to undertake SDI if and only if it has an appropriate level of: vision on SDI, institutional leadership and legal framework
- A country has an appropriated level of information to undertake SDI if and only if there is an appropriated availability of digital cartography and metadata or if there is not an appropriated availability of digital cartography then it has a strong level of metadata.
- A country has an appropriated level of people to undertake SDI if and only if there is an appropriated level of: national human capital, SDI culture and individual leadership.
- A country has an appropriated level of financial resources to undertake SDI if and only if there is an appropriated level of funding from the Government or from private sector or an appropriated level of return on investment from geospatial industry.
- A country has an appropriated level of access network to undertake SDI if and only if there is an appropriated level of technological infrastructure, web connectivity and an appropriated availability of Geospatial software or own geoinformatics development or open source culture.

This model falls within the knowledge and developmental evaluation purposes. An assessment of SDI readiness is meant to serve as an advisory tool and aims at: raising awareness in order to assure a reasonable basis for success in the SDI development process; discovering the main weaknesses of the environment in which SDI development takes place, as well the strengths; comparing levels of SDI readiness among countries or initiatives; and providing a monitoring and evaluation tool to assess the evolution of the conditions in a same country as well as the comparison of different countries regarding SDI development (Delgado et al., 2008).

#### 4.3.3 Generational Approach

The Generational Approach is another assessment method based on the generational development of SDIs described by (Rajabifard et al., 2003a). The generational assessment approach also falls into the developmental class of evaluation which purpose is to measure and recommend changes in organization activities and to monitor how projects are being implemented across a number of different sites. The results of such an assessment will help the countries concerned to position themselves on the worldwide arena and to indicate directions for future development. The measurement of transitions through generations may help to capture the factors that strengthen or weaken the development of SDIs. In this approach, data collection methods may include surveys and document study.

The worldwide development of SDI can be measured according to the identified indicators of first, second and third generations of SDI development (Grus et al., 2007). Based on the SDI literature, transitions through generations are most visible in the following areas: user/producer orientation (from less to more user oriented/driven infrastructure), governance/players roles (decrease of National and increase of subnational and private roles in SDI activities, technology (from database to services oriented applications), standards (steady harmonization of International GI – standards (e.g. metadata).

The following table gives more details on the characteristics of each generation (Hennig and Belgiu, 2011):

	1st SDI generation Product-based	2nd SDI generation Process-based	3rd SDI generation User-centric
Level/Focus	Explicitly national	National; including hierarchical context	Cross-scale
Driving forces	Integration of existing data, data management Gov.agencies	Establishing the linkage between people and data; Spatial data application	User-driven Private sector organizations & individuals
Expected results	Linkage into a seamless database	Knowledge infrastructures, interoperable data and resources	Platform for a spatially enabled society
Development participants	(Mainly) data producers	Cross-sectors: provider, integrators, users	Users: producers, consumers
Funding/ resources	Mainly no specific or separate budget	Mostly include in national mapping program, or having separate budget	Incorporating governmental, private initiatives, including crowd-sourcing
Involved actors	Mainly national mapping organizations	More independent organizational committees, partnership groups	Consortia, representing the target user groups
Number of SDI initiatives	low	increasing number	Numerous initiatives
User domain	government	Various stakeholders	everyone
tasks	Mainly administrative	Different applications	Different applications
GI Expertise	GI experts	GI experts	Every level, GI expert to laymen
Rel. between SDI initiatives	Low	Increased cooperation	Integrated SDIs
Measuring SDI value	Productivity, savings	Holistic socio-cultural value, expense of not having an NSDI	Usability criteria

# 5 **RESULTS AND DISCUSSION**

# 5.1 FOSS Market Share in Peru SDI and Geospatial Technology Availability

The following section will try to answer the following research question: "Is FOSS already used in the software components of the Peru SDI and if so, what is the percentage of use?"

# 5.1.1 Client Technology

# 5.1.1.1 Desktop GIS

Desktop GIS software is probably the most common GIS software in use (Steiniger and Hunter, 2012). (ESRI, 2012) defines desktop GIS as "mapping software that is installed onto and runs on a personal computer and allows users to display, query, update, and analyze data about geographic locations and the information linked to those locations." (Steiniger and Bocher, 2009) adds: "that is, the software is not executed on a server and remotely accessed or controlled from or by a different computer." The following graph illustrates the results of desktop GIS market share in terms of number of institutions use in Peru:



From the obtained results, we can observe the following facts:

- ESRI products (ArcGIS) are used by each and every institution.
- Although it is not a GIS, AutoCAD is used by many institutions to create map products.
- Other proprietary GIS software have very low market share.
- Quantum GIS and gvSIG are the most popular FOSS solutions with respectively 6 and 5 out of 23 institutions using them. Other FOSS options such as uDig, GRASS and Ilwis only have 1 or 2 institutions using them.
- Among the 3 private companies that answered, none of them use FOSS desktop GIS.
- Only 35 % of Peruvian institutions use at least one kind of FOSS desktop GIS solutions.



In terms of users, proprietary software represents an astounding 85 % of market share (this includes ESRI/AutoCAD/MicroStation/MapInfo/GeoMedia/Erdas/Manifold/Envi):

From the 6 institutions that reported the use of Quantum GIS (QGIS), we can observe that the number of QGIS users represent 20 % or less of the total number for most institutions. Among those, only SENAMHI has more QGIS users than ArcGIS users.

	ArcGIS	QGIS	ArcGIS	QGIS
	# of users	# of users	% users	% users
CISMID	15	2	88 %	12 %
INGEMMET	80	1	99 %	1%
MINAG	10	2	83 %	17 %
MINEDU	17	2	89 %	11 %
Piura Regional Government	4	1	80 %	20 %
SENAMHI	6	20	23 %	77 %

Different functional categories of GIS software can be identified with respect to the tool sets that GIS software offers, and with respect to the tasks that can be accomplished. Typical GIS tasks include data encode (input and editing), retrieval (explore and query), analysis (spatial analysis, transformations, modeling and simulation), storage and display (map creation). All traditional GIS tasks, i.e., not tasks related to web and remote processing applications, can be accomplished with a desktop GIS.

According to the results, the most frequent GIS tasks performed are display, map production and spatial data query. The following diagram shows the results obtained in the questionnaire regarding the frequency of use of the different GIS tasks in Peru:



Everyday 🔲 Frequently 🗆 Sometimes 🔲 Rarely 📕 Never 🗆 Did not answer

The obtained results revealed higher frequencies of GIS tasks performed every day or frequently by the respondents that use QGIS in their institution compared with all respondents:

GIS Function	All respondents	Only respondents that	Difference
		reported QGIS use	
Display	83 % every day or frequently	100 % every day or frequently	+ 17 %
Map products	87 % every day or frequently	100 % every day or frequently	+ 13 %
Query	78 % every day or frequently	83 % every day or frequently	+ 5%
Analysis	74 % every day or frequently	100 % every day or frequently	+ 26 %
Input / editing	83 % every day or frequently	83 % every day or frequently	
Transformations	57 % every day or frequently	83 % every day or frequently	+ 26 %
Modeling and	30 % every day or frequently	67 % every day or frequently	+ 37 %
simulation			

The only two organizations that perform "modeling and simulation" every day also use QGIS. The increase in frequency is also significant in the "spatial analysis" and "transformations" advanced functions. We can conclude that the organizations that use QGIS perform in general advanced tasks more frequently than the others who do not. Unfortunately, it is not possible to know precisely which software is used to perform each GIS function (because of the questionnaire design). This could have been done by linking the desktop GIS and GIS functions questions together. It is probable that QGIS is mostly used by seasoned GIS experts for advanced tasks. In the case of the SENAMHI, it is probably the opposite with 77 % of users using QGIS.

ArcGIS is widely recognized to be one of the best desktop GIS especially to create nice final map products, for spatial analysis and for modeling and simulation. For users that not perform those map creation tasks every day or frequently, FOSS options such as Quantum GIS or gvSIG could represent interesting alternatives worthy of evaluation. Also, those products have the advantage that they can directly connect to spatial databases like Oracle or PostgreSQL, unlike ArcGIS which needs the use of costly proprietary middleware ArcSDE to store and access spatial data in relational database management systems.

#### 5.1.1.2 Web Map Development Frameworks

16 respondents have reported the use of web mapping software. Among those, 14 use ESRI's web mapping stack (ArcGIS Server and it's JavaScript API/Flex/Silverlight). Because, the questionnaire design mixed "web map servers" with "web map development frameworks" into a single question, it is unfortunately impossible to know precisely the number of respondents that use ESRI's own web mapping framework. However, we will assume that the 14 institutions that reported ArcGIS server use to publish spatial data on the Web also use ESRI's framework as a web client.

FOSS Web Development Frameworks (OpenLayers and MapFish) have very scarce market share, with respectively only two and one respondents using it.

Therefore, we will consider that only 13 % reported the use of FOSS web map development frameworks and that all other respondents use solely use ESRI's framework.



# Web Map Development Frameworks

## 5.1.2 Server Technology

## 5.1.2.1 Web Map Servers

Under this category, we include software that enable the delivery (via server software) and view (via client software) of geographic data and maps using standard internet protocols (Steiniger and Hunter, 2012). In particular, we address software that supports the OGC Web Mapping Service (WMS) and Web Feature Service (WFS) standards. The following graph illustrates the results in terms of number of institutions that use web servers and web development frameworks:



- 70 % of respondents publish geographic information on the Web using web map servers.
- The percentage of institutions that implement FOSS Web Map Servers is slightly higher than desktop GIS but still low at 38 %.
- ESRI products (ArcGIS Server/ArcIMS) also have a very high market share in internet web mapping, with 14 institutions out of the 16 that publishes geographic information (88%).
- None of the four private companies that answered the survey implement web map servers.
- MapServer and GeoServer are the most popular FOSS solutions with respectively 4 and 3 out of 16 institutions using them.
- Only two other proprietary web mapping tools (Manifold and JMAP) have been reported (each in only one institution).
- No institution has reported the use of other popular FOSS options such as Deegree and MapGuide Open Source.
- Most institutions that publishes geographic information on the Web implement the WMS standards (15 institutions) and to a lesser extent WFS (10) and WCS (4). In other words, most institutions return static maps rendered as pictures by the server.

#### 5.1.2.2 Server GIS

No institution has reported to implement Web Processing Services (WPS), whether with FOSS or proprietary software.

## 5.1.3 Spatial Data Storage

It is possible to store spatial data in various data formats. Standalone and departmental GIS usually use file data formats while most enterprise GIS and SDIs use spatial database management systems. The following diagram illustrates the obtained results in Peruvian institutions:



- The Shapefile format is the most used format according to the survey results (19/23). Although it can be considered a de facto standard since its introduction by ESRI in the 1990s, it is aimed at standalone GIS and for manual data exchanges between different GIS software products.
- The second most popular spatial data formats are ESRI's personal and file geodatabases, the primary data format used in ArcGIS for editing and data management. It consists of a proprietary native data structure which uses an object-relational database approach for storing spatial data (ESRI, 2013d). This format is not adequate for multiuser environments and its popularity probably implies that most institutions implement GIS as standalone or department GIS instead of enterprise GIS that must reside in a spatial DBMS.
- To implement the proprietary ESRI geodatabase into a multiuser environment and integrate descriptive and spatial data into a single relational database management system such as Oracle or SQL Server, the ArcSDE geodatabase format must be used (ESRI, 2013d). It is puzzling that as much as 43 % (10/23) of institutions store data in native proprietary ArcSDE format because this represents a high amount of recurring yearly licenses costs that could be avoided if for example the Oracle SDO format available in Oracle databases would be used. According to (ArcGIS Resource Center, 2013), standard SQL must not be used to edit tables that use geodatabase functionality. Therefore, ESRI specialized GIS tools must absolutely be used to access data stored in a proprietary geodatabase instead of standard programming technologies. This makes interoperability with other institutional information systems difficult and generally has the effect of separating GIS and IT tools and data structures for the management of spatial data and descriptive data.

 Spatial database management systems have very low market share with PostGIS (5/23), Oracle Spatial SDO (3/23) and Spatial GIS SQL Lite formats (1/23). An enterprise GIS is built around an integrated database that supports the functions of all units that need spatial processing or even mapping (Harmon and Anderson, 2003). This is an indicator that very few GIS are implemented as enterprise GIS.

On the other hand, many institutions use database management systems to support their information systems as shown in the following diagram:



- According to the results, 10 institutions out of 23 uses a PostgreSQL database, while only 5 of them store spatial data in PostGIS extension. The same observation applies to Oracle, while 10 institutions have an Oracle database, only 3 reported to store their spatial information natively in Oracle Spatial SDO geometries.
- At the same time, 8 institutions have a Microsoft SQL Server and MySQL databases but do not use the spatial extensions of these databases and probably prefer to store data in ESRI's geodatabases.

The ratio of number institutions that already use FOSS databases is very high at 55 %. This represents a good opportunity to store spatial data directly in proper relational database management systems and integrate well with corporate institutional information systems.

#### 5.1.4 Cataloging applications

Among the 15 institutions out of 23 that maintain metadata, a huge majority (12) uses GeoNetwork opensource. The market share of FOSS cataloging applications is extremely high at 86 % and no proprietary cataloging application apparently competes with GeoNetwork opensource.

## 5.1.5 FOSS use versus proprietary use analysis

The majority of organizations that have chosen FOSS for desktop GIS use it for specific tasks but still use ArcGIS for most common tasks. Here is a summary of the advantages and disadvantages of FOSS that have been reported by the interviewed Peru SDI stakeholders:

	FOSS	Proprietary software
Principal reasons cited for use	<ul> <li>Directly access spatial data from databases such as PostgreSQL, SQLite and Oracle</li> <li>Overlay spatial data easily with Google Maps and Bing Maps as a base map to verify locations</li> <li>Use advanced scripts made available by the community of users</li> <li>Visualize shapefiles and WMS services</li> </ul>	<ul> <li>Creation of final map products</li> <li>Automation of processes</li> <li>Use of extensions such as Network Analyst</li> </ul>
Advantages	<ul> <li>Cost</li> <li>PostGIS allow better possibility of integration with corporate databases and information systems, allowing programmers with SQL skills to incorporate mapping applications into a corporate web information system without extensive knowledge of GIS issues (just have to learn the points/lines/polygons data types and common spatial analysis keywords)</li> <li>Interact directly with a spatial database (query and update)</li> <li>Overlay data easily with available online services</li> <li>Use advanced specialized scripts developed by the community that do not exist in ArcGIS</li> <li>Constant improvement of software</li> </ul>	<ul> <li>Better intuitive mapping and cartography tools (extensive symbology, optimized options for printing and paper publication, etc.)</li> <li>Availability of ESRI's model builder that can automate processes</li> <li>Availability of specialized extensions (ex: Network analyst)</li> <li>Better availability of documentation and examples</li> <li>All Peruvian GIS experts are well-trained with the use of ESRI's tools.</li> <li>Guarantee of corporate technical support when needed</li> </ul>
Disadvantages	<ul> <li>There is an evident lack of a critical mass of GIS experts with FOSS knowledge.</li> <li>No tangible support from an official source (community support is not seen as sufficient and is not always available in the Spanish language)</li> </ul>	<ul> <li>Recurring high price of licenses</li> <li>Dependence on software vendors</li> <li>Poor integration with other information systems because of the use of proprietary GIS formats</li> <li>Difficulty of distribution due to legal constraints</li> <li>High level of complexity of specialized ArcObjects and ArcSDE technologies</li> </ul>

## 5.1.6 Summary and recommendations to improve FOSS market share

As a conclusion, FOSS is already used in the software components of the Peru SDI. Among FOSS technologies already present with significant market share, we can mention GeoNetwork, PostgreSQL, GeoServer, MapServer, Quantum GIS and gvSIG. The following table summarizes the percentage of use of FOSS alternatives in the five main software categories that were presented.

Software	FOSS	Observations
Category	Use	
Desktop GIS	35 %	For desktop GIS, all institutions use costly proprietary ESRI products. We recommend that ArcGIS should be limited to GIS experts that create map products frequently or daily. For the others that want to perform other tasks such as query and browse spatial data, alternatives such as Quantum GIS should be examined more closely. The amount spent on ESRI licenses could be used to fund at least a small part of the SDI workgroups.
Web Map Development Frameworks	13 %	Institutions that already have ArcGIS server licenses usually use the same line of products for internet mapping applications. For those institutions that do not have this kind of expensive licenses, OpenLayers could be a very good alternative as a Web GIS client.
Web Map Servers	38 %	The same observation concerning organizations with ArcGIS server licenses also applies to the Web Map Servers category. GeoServer and MapServer are the leading FOSS alternatives to publish spatial data on the Web.
Database Management Systems	55 %	Even though the market share of FOSS databases is high, many institutions do not take advantage of storing data in spatial databases and still use file formats. Institutions that already use PostgreSQL could benefit of the PostGIS spatial extension. The same applies to institutions with an Oracle database, data could be stored in Oracle Spatial SDO geometries instead of ArcSDE proprietary format.
Cataloging Applications	86 %	GeoNetwork opensource is already the principal metadata cataloging technology.

78 % of the respondents use at least one type of FOSS software and most organizations use a mix of both. The following table compares the number of respondents by software category that strictly use proprietary or FOSS software, and those who use a mix of both.

Software Category	Strictly proprietary	Strictly FOSS	Mix of both
Desktop GIS	65 %	0 %	35 %
Web Map Development Frameworks	88 %	6 %	6 %
Web Map Servers	62 %	13 %	25 %
Spatial Databases Management Systems	64 %	22 %	14 %

There are generally 60 % of respondents that use solely proprietary software for a given software category. No institution only uses FOSS for desktop GIS but a significant number (35 %) use both. Concerning spatial databases, it is the type of software that has the higher number of respondents (22 %) that rely entirely on FOSS. An astonishing 39 % did not use spatial databases and reported only file based formats and were not included in the numbers of the previous table.

The following section will try to answer the following research question: "What is the current state of SDI readiness in Peru and how can the weakest factors be improved?"

# 5.2 SDI Readiness

## 5.2.1 Introduction

The SDI readiness assessment approach (Delgado et al., 2005) aims to measure the degree to which a country is prepared to deliver its geographical information to its community. The application of the SDI readiness model can contribute to identify critical factors to undertake an SDI (Delgado et al., 2005). According to (Delgado et al., 2005), the SDI readiness index can be defined as a composite measurement of the capacity and willingness of countries to use SDI. A country is ready to undertake an SDI if and only if it has an appropriated level of the global factors: organizational, informational, human resources (people) and financial resources, and any level of technology. Each of these factors can be quantitatively measured by collecting and analyzing predefined indicators based on surveys.

- The 'organization index' is a composite score consisting of three primary factors: politicians' SDI vision, institutional leadership and legal framework. The SDI vision deals with the awareness of politicians on the importance and development of a National SDI. Institutional leadership can be expressed as the coordination by one or more institutions of the national agenda regarding SDI.
- The 'information index' focuses of the availability of core spatial data sets (for example geodesy, elevation, cadastral, administrative boundaries, hydrography, transport, orthoimages and place names) as well as metadata.
- The 'human resources index' is a composite score that incorporates the: human capital index, culture/education on SDI and individual leadership.
- The 'financial resources index' is a crucial index that focuses on the sources of funding in order to develop an SDI.
- The 'technology index' focuses on how access networks and technologies facilitate the use of data and services from SDIs. The 'technology index' is composed by the communication infrastructure, the Web connectivity, the availability of commercial or in-house spatially-related software and the use of open source resources related to SDI.

For the purposes of this thesis, the technology index has not been measured by the usual factors (web connectivity, technological infrastructure, geospatial software availability/in-house development, open source culture) because of the more specific questions that were presented in the previous sections.

For each indicator, a basic seven tier classification system was used that ranged from Extremely High to Extremely Low. For example, for the first organizational factor 'Political vision regarding SDI' a score in box Extremely Low means that the respondent view is that 'No vision exist as well as no intention exist to formulate a vision regarding the importance and development of the national SDI', while a score in box Extremely High indicates that there is an 'Extremely high vision regarding the importance and development of the national SDI' according to the respondent.

#### 5.2.1 General SDI readiness

After the compilation of the results, the SDI Readiness Index has been calculated for each indicator as explained in the methodology chapter (extremely low is considered a 0 score while extremely high equals to 1). The following table summarizes the obtained results for each factor:

Number of Answers	SDI Index							
Factors	Extremely Low	Very Low	Low	Medium	High	Very High Ex	tremely High	Totals
Organizational	6		10	21	16		10	63
Institutional Leadership	3		2	4	9		3	21
Political Vision Regarding SDI			1	6	7		7	21
Umbrella Legal Agreements	3		7	11				21
Informational		6	9	17	5	1	6	44
Digital Cartography Availability	/	1	4	7	5	1	4	22
Metadata Availability		5	5	10			2	22
People	4		14	27	14		7	66
Human Capital	1		1	8	8		4	22
SDI Culture	3		4	11	3		1	22
Willingness to Share			9	8	3		2	22
Financial Resources	4		12	3	1		1	21
Government Central Funding	4		12	3	1		1	21
Totals	14	6	45	68	36	1	24	194

Summing all factors, the Peru SDI has obtained a general index of 51 %. Therefore, we conclude that the Peru SDI degree of preparation to deliver geographical information to its community is average (medium) and that some adjustments are needed to make progress. The total distribution of answers is as followed:



# **Peru SDI Readiness**

#### 5.2.1 Analysis by factor

If we organize and summarize the factors by categories, we can observe that the weakest spot of the Peru SDI is clearly the low financial resources factor while the strong spot is the high organizational factor.



The following gauge diagrams give more details on the obtained results for each factor and indicator.

#### Organizational

The political vision regarding SDI and institutional leadership are very high. However, improvements are needed in the umbrella legal agreements field.



#### Informational

Digital cartography availability is high but improvements must be done in respect to metadata.



#### Human resources (people)

Human capital has been reported as very positive but improvements are needed to promote SDI culture and willingness to share.



#### **Financial Resources**

Central government funding has been reported as very low. If asked if there are enough financial resources, it is expected that most people may answer that financial resources are insufficient. However, the fact that a vast majority of respondents (76 %) perceive that the central government funding is extremely low to low is an indicator that it might really be the case.



#### Technology

The 'technology index' indicators have not been included in the questionnaire design. It is usually composed by the communication infrastructure, the Web connectivity, the availability of commercial or in-house spatially-related software and the use of open source resources related to SDI. Concerning geospatial technology availability, it does not seem to be a concern of the Peru SDI participants. However, some concerns have been mentioned by several stakeholders concerning the fiber optic network that only cover small part of the Peruvian territory. This can be problematic especially for the regions of the Andes and Amazon basin and will therefore be considered as a weakness.

#### 5.2.1 Summary

The following table summarizes the strengths and weaknesses of the Peru SDI. Indicators that obtained an index below 50 % are considered as weaknesses.

- **Strengths:** geospatial technology availability (proprietary and FOSS), political vision regarding SDI, institutional leadership, digital cartography availability, human capital
- Weaknesses: umbrella legal agreements, metadata availability, SDI culture, willingness to share, central government funding, communication infrastructure



#### 5.2.2 Recommendations to improve Peru SDI Readiness

(Delgado et al., 2005) has made recommendations for countries to improve SDI readiness depending of the weak spots. For countries characterized by the low availability of financial resources, the following 5 recommendations have been proposed:

- 1. Associate the SDI to other national programs where geospatial management could be crucial (e.g., Information Society, disaster management, land administration).
- 2. Conduct cost/benefit analysis to emphasizing the merits of SDI to convince decision makers about the importance to invest in geospatial matters.
- 3. Orient the technological strategy towards Open Source in order to obtain free implementations of the geospatial standards necessary to build an SDI (Web Map Servers, Web Coverage Servers, Plug and Play GeoPortals, etc).
- 4. Find cheaper alternatives to share geospatial data bypassing the technological bottleneck (Delgado, 2005).
- 5. Explore alternative funding models for emerging nations (UNECA, 2004).

The first recommendation goes exactly in the same vain as one of the Peru SDI guideline which is to promote the production, maintenance and exchange of spatial data to support the disaster risk management. Another similar guideline of the same policy is to support the public sector investment system to obtain sectoral information to focus investments according to the priorities of public policies. Land administration and cadastre is another subject of importance that unites many levels of government (national, regional, municipal). The Peru SDI already focuses on the construction of a geographic information system where investment projects are georeferenced with associated information on the pre investment and execution of the health and education sectors.

The second recommendation is to present the results of the Peru SDI to decision makers, namely the actual impact on the exchange and use of spatial data (Vancauwenberghe et al., 2009b). This is especially true for emerging economies such as Peru, where some would even debate the assumption that information systems and infrastructure are of value or have priority over resolving basic needs such as basic sanitary infrastructure and housing (Cavric et al, 2003).

The third and fourth recommendations are directly in line with the objective of this thesis and of the previous FOSS market share section. Focusing on FOSS technological components could help save precious resources in software costs that could go towards developing skills and local capacity, instead of paying license fees that tie customers to a single vendor (Holmes et al., 2005).

Concerning the last recommendation to explore alternative funding models for emerging nations, this could include funding from the budgets of ministries, special taxation, non-monetary contributions (personnel, equipment, etc.), partnerships, alignment to special projects and contribution from large stakeholders such as utility companies (Garfield, 2003).

The following section will try to answer the following research question: "Which characteristics of the Peru SDI could be improved to move towards a user-centric third generation SDI that reaches user expectations satisfaction?"

## 5.3 Generational Approach Assessment

## 5.3.1 Generational Indicators Analysis

In this section, we will apply 12 generational approach indicators to the Peru SDI and evaluate in which generation can be considered each indicator (data/product-based first generation, process-based second generation or user-centric third generation).

Indicator	Observations	SDI Generation
		Generation
Level / focus	The level and focus are explicitly national, with no documented hierarchical or cross-scale fundamental dataset (with the possible exception of urban cadastre).	1 <sup>st</sup>
Driving forces	The driving forces are the integration of existing data mostly within national government agencies (ex: populated places, administrative boundaries, etc.). Some efforts have been made to establish the linkage between people and data and focus on spatial data applications. There are actually no private sector organizations individuals in the Peru SDI.	1 <sup>st</sup>
Expected results	The expected results are to link all data in a seamless spatial database. The Peru SDI is still far from being a platform for a spatially enabled society.	1 <sup>st</sup>
Development participants	The participants are mainly data producers (ministries) and users and consumers are not yet involved.	1 <sup>st</sup>
Funding / resources	Even if the CCIDEP is located into a high organ, it has no specific or separate budget. It does not incorporate private initiatives or crowd-sourcing nor is included in a national mapping program	1 <sup>st</sup>
Involved actors	Even if one of the national spatial data policy mentions regional and local governments, the involved actors are currently mostly national stakeholders. The Peru SDI definition states "all levels of government, private sector, non-governmental organizations, academic and research institutions", but it is apparently currently not the case.	1 <sup>st</sup>
Number of SDI initiatives	The number of SDI initiatives is mainly limited to the technical workgroups interests.	1 <sup>st</sup>
User domain	Only government institutions are currently involved and target user groups are not represented with Peru SDI.	1 <sup>st</sup>

Tasks	Actual tasks are mainly administrative.	1 <sup>st</sup>
GI Expertise	Mainly national GIS experts and IT decision makers are currently involved in the technical workgroups and permanent committee.	1 <sup>st</sup>
Rel. between SDI initiatives	There are very scarce relations between SDI initiatives at different levels and sectors.	1 <sup>st</sup>
Measuring SDI value	There is no public documentation of showing productivity improvements or resources savings after the creation of the Peru SDI.	1 <sup>st</sup>

In summary, the Peru SDI is still considered a first generation product-based SDI focusing on data management but is pushing toward a second generation SDI (process-based).

	ist SDI generation	2nd SDI generation	3rd SDI generation
	Product-based	Process-based	User-centric
Level/Focus	Explicitly national	National; including hierarchical context	Cross-scale
Driving for es	Integration of existing data, data management Gov.agencies	Establishing the linkage letween people and data; Spatial data application	User-driven Private sector organizations & individuals
Expected results	Linkage into a seamless database	Knowledge infrastructures, interoperable data and resources	Platform for a spatially enabled society
Development participants	(Mainly) data producers	Cross-sectors: provider, integrators, users	Users: producers, consumers
Funding/ resources	Mainly no specific or separate budget	Mostly include in national mapping program, or having separate budget	Incorporating governmental, private initiatives, including crowd-sourcing
Involved actors	Mainly national mapping organizations	More independent organizational committees, par nership groups	Consortia, representing the target user groups
Number of SDI initiatives	low	increasing number	Numerous initiatives
User domain	government	Various stakeholders	everyone
tasks	Mainly administrative	pifferent applications	Different applications
GI Expertise	GI experts	GI experts	Every level, GI expert to laymen
Rel. between SDI initiatives	Low	Increased cooperation	Integrated SDIs
Measuring SDI value	Productivity, savings	Holistic socio-cultural value, expense of not having an NSDI	Usability criteria

(Hennig and Belgiu, 2011)

#### 5.3.1 Recommendations to help move toward a user-centric third generation SDI

The following recommendations are formulated to help move toward a user-centric SDI:

- 1. The level/focus must include regional and local governments and be cross-scaled. It is recommended that levels of accuracy be consistent with requirements for mapping at the respective scales (Gyamfi-Aidoo et al., 2006) because varying accuracy can negatively affect data sharing and integration (Simbizi, 2007).
- 2. The driving forces must be user driven and include private sector organizations and individuals.
- 3. The expected results must be to develop a platform for a spatially enabled society. This is in line with one of the Peru SDI policy which is to promote the implementation of spatial information services that are citizen-oriented. These services must be designed to meet the most important needs of the population, improve decision-making and assist in the management of government.
- 4. The participants must include not only data producers but also users and consumers.
- 5. Funding must incorporate governmental and private initiatives and include crowd sourcing (volunteered geographic information).
- 6. Involved actors must include representatives from the target user groups.
- 7. Different levels and sectors of SDI initiatives must be formed and integrated into the national SDI.
- 8. Common citizens must be granted free access to fundamental Peru SDI digital data.
- 9. Tasks must be driven toward real user applications and processes.
- 10. Not only GI experts must be involved.
- 11. Usability criteria must be used to measure Peru SDI value and justify investments.
- 12. Constitute sectoral SDIs of institutions with mutual needs and dependencies in specific processes (ex: land administration-cadastre and disaster management)

The following section will try to answer the following research question: "What are the main characteristics of the different Peru SDI components and which improvements must be made?"

## 5.4 Peru SDI Components Evaluation

## 5.4.1 Data

The data component includes fundamental data, thematic data, metadata and data formats aspects.

#### 5.4.1.1 Fundamental data

One of the national spatial policies is to prioritize the production and exchange of sensitive fundamental data or of massive use by the regional and local governments. There is one CCIDEP technical workgroup which objective's is to facilitate public access to the fundamental data of the state, in order that all production of spatial data is based on this information. The workgroup has proposed following layers as fundamental data: coordinate reference system, hypsometry (elevation data), digital terrain model, transport network, hydrography, political-administrative boundaries, population centers, geographical names, ortho images and photos, urban cadastre. The same workgroup has harmonized the hydrography and hypsometry (elevation data) layers.

Many of those layers are maintained in parallel by several institutions depending of their specific needs. For instance, the population centers are maintained by the rural electrification department of the Ministry of Energy and Mines, by the ministry of Education and by the National Statistics Institute. This is apparently also the case of at least the political and administrative boundaries (regions, provinces, districts), urban cadastre, hydrography and hypsometry. A national spatial data model for fundamental data has been proposed for those layers and integration of content is currently under way. With the purpose of creating a unique and integrated spatial database respectively of population centers and referential boundaries, two sub workgroups have been created and have made significant progress.

Concerning the ortho images and photos, there is one technical workgroup that focuses on remote sensing. In respect to cadastre, there is also a technical workgroup that is in the final phase of developing a national cadastre information system to publish information and coordinate with municipalities in cadastral issues. Datasets are currently characterized by national focus but one of the national spatial data policies is to prioritize the production and exchange of sensitive fundamental data or of massive use by the regional and local governments.

#### 5.4.1.2 Thematic data

According to the survey, thematic data produced by some institutions and needed from others include schools, health centers, watersheds, groundwater, archeological and protected areas, native and rural communities, agricultural cadastre, tourism areas, mining cadastre and projects, geology, police stations, parishes, etc.

#### 5.4.1.3 Data formats

The prominence of file dataformats (shapefiles, personal/file geodatabases, DWG, IMG, TIF, KML) have already been observed in the FOSS market share section as an indicator that most GISs are probably implemented as standalone or departmental GIS. Very few institutions store data in proper RDBMS format such as Oracle Spatial, PostGIS or SpatialLite. To successfully exchange spatial data with other institutions, it is expected that spatial data must be stored in a relational database system.

## 5.4.1.4 Digital cartography availability

Many developing countries have difficulties with the availability of digital data and some are undergoing major efforts to convert their analogue data to digital data (Eelderink, 2005). This is not the case of Peru where most data is available digitally. This has been perceived as very positive by 46 % of the respondants that qualify digital cartography availability as high, very high or extremely high. Still, it is not possible for institutions to access automatically updated fundamental data from a geoportal. At the national level, 9 out of 11 institutions publish geographical information using the WMS protocol. None of the 3 private companies that answered the survey publish spatial data.



The following table summarizes the datasets that are maintained by each institution along with the implemented OGC standards.

Level	Organization	Datasets managed	WMS	WFS	WCS	WPS
Academia	CISMID	Seismic risks, seismic zones	-	-	-	-
National	CEPLAN	-	Х	-	-	-
National	IGN	Hypsometry (elevation data and contour lines), digital terrain model, hydrography network, transport network, geographical names, political-administrative boundaries	X	X	X	-
National	INGEMMET	Geology, mining cadaster, mining resources, restricted areas to mining, geological risks	X	X	-	-
National	MINAG	Agriculture	-	-	-	-
National	MINAM	Deforestation, natural heritage, watersheds, physical vulnerability	-	Х	-	-
National	MINEDU	Populated places, education centers	Х	Х	-	-
National	MINEM- DGAAM	Environmental studies: mining projects areas, direct and indirect influence zones, monitoring points, mining activity component areas	X	-	-	-

National	МТС	Transport and communication network, airports, bridges, toll and weighting stations, rural communication projects, satellite stations transmission	x	x	-	-
National	OEFA	Air and water quality monitoring, environmental noise, supervision of mining, hydrocarbons, electricity, fines	X	-	-	-
National	PCM-ONGEI	-	Х	Х	Х	-
National	SENAMHI	Meteorology and hydrology	Х	Х	Х	-
Private	Anabi	Drilling platforms, project areas, access, components	-	-	-	-
Private	S&Z	Engineering	-	-	-	-
Private	Terra Planning	-	-	-	-	-
Regional	Callao	Roads, populated places, blocks, lots, education, health, citizen security, tourism, companies, public services	-	-	-	-
Regional	Piura	Ecological and economical zoning	Х	Х	Х	-

# 5.4.1.5 Metadata availability

One of the challenges faced by users of data is the lack of information about information sources that might be relevant to their needs (Eelderink, 2005). Appropriate metadata services can help them to find this information. The use of metadata services needs to be encouraged in almost all countries. One of the Peru national spatial policy is to boost the cataloging of spatial data as a sustained process. It states that "all state institutions spatial data producers implement a system of cataloging data (metadata)" and there are rules about it. There is a national geonetwork metadata catalogue portal, which is a step in the right direction. However, it would be very useful to document the metadata of all fundamental and thematic data mentioned in the two previous sections. In spite of the geonetwork portal, metadata availability was judged poorly by survey respondents with 46 % having a low or very perception.



The perception in metadata availability seems to be directly related to the use of metadata cataloging software. From the 54 % that reported medium to extremely high metadata availability, 93 % maintain metadata (50 versus 4 %). On the other hand, 61 % of respondents that perceive low or very low metadata availability do not maintain metadata themselves (28 versus 18 %).

Metadata availability perception	Medium / extremely high	Low / very low
Maintain metadata	50 %	18 %
Do not maintain metadata or did not answer	4 %	28 %

32 % of respondents do not maintain any kind of metadata. On that matter, one of the respondents indicated that very few institutions produce metadata or use cataloging applications because of the lack knowledge and established standards, among other problems.

## 5.4.2 People

The people component includes custodians, value-adders, users, administrators and volunteers.

#### 5.4.2.1 Peru SDI participants

The Peru SDI's mission is to promote and coordinate the development, exchange and use of geospatial data and services **between all levels of government, private sector, non-governmental organizations, academic and research institutions**. Also, it is a national spatial policy to prioritize the production and exchange of sensitive fundamental data or of massive use by the **regional and local governments**. In practice, all members of the permanent committee are from national institutions.

#### 5.4.2.2 Location of GIS experts within the institution (department vs. GIS / IT office)

An outstanding 70 % of GIS experts work in direct front-line working units. This is another sign that most GISs are implemented as department GIS. Discussed disadvantages are the difficulty of coordination is difficult, no authority of GIS units over other units, possible weak budget position, ownership is concentrated; other units have no stake, lack of visibility (Harmon and Anderson, 2003).

Only 17 % of respondents have declared to have dedicated GIS offices and a smaller amount of GIS experts work in a central IT office (13 %). This ensures high visibility and strong authority, brings GIS within the existing support infrastructure and protects budgets (Harmon and Anderson, 2003).

#### 5.4.2.3 Users

There were many questions in the questionnaire asking for estimations of users, but many institutions were not able to estimate the number of users of their systems or were using different indicators (number of visits, internal vs. external users, number of licenses, etc.). Therefore, it is impossible to present a graph to illustrate and compare the number of users between institutions. If one of the goals of the Peru SDI is to satisfy user needs and expectations, it would be important to implement qualitative client surveys and to use standard tools to analyze the number of spatial data users.

## 5.4.2.4 Volunteers and value adders

There are few signs of voluntarily geographic information and value adders in Peru. Noteworthy is the Peru Ruteable portal (<u>http://www.perut.org/</u>) and Guiacalles (<u>http://www.guiacalles.com/</u>). It is a nonprofit project whose objective is the creation and maintenance of GPS maps of Peru. The maps are free of charge with frequent updates and contribution made thanks to anyone who agrees to the terms of this project. The national coverage and the level of detail vary by city. There are few private GIS companies that could be categorized as value adders.

## 5.4.2.5 GIS experts

From the following graph, we could deduce that medium-sized institutions have 4 to 5 GIS experts while large-sized have 6 and more and small-sized have 3 to less GIS experts:



#### 5.4.2.6 Programmers

Almost 34 % of programmers available in surveyed Peruvian institutions master .NET framework technologies (including C#, VB and ASP). Java and PHP follow respectively obtained 24 % and 19 % of the total number of programmers. Because of the availability of programmers, the Microsoft .NET and Java related technologies could therefore be considered to program SDI information systems.

From the following graph, we could deduce that medium-sized institutions have 4 to 9 programmers while large-sized have 10 and more and small-sized have 3 to less programmers:


#### 5.4.2.1 Human capital

Although many SDI national coordinators around the world mention the lack of well-trained human resources (Eelderink, 2005), the general perception is that there are a lot of qualified GIS experts in Peru.



The following table compares the number of GIS experts versus the number of programmers (prog.), along with the GIS size cluster (medium-size is 4-5 GIS experts) and the office where they work.

Level	Organization	# GIS Experts	# Prog.	% GIS experts / Prog.	GIS Cluster Size	Prog. Cluster Size	Location
National	CEPLAN	1	-	100 %	Small	Small	Department
National	CISMID	5	8	38 %	Medium	Medium	GIS Office
National	IGN	10	3	77 %	Large	Small	GIS Office
National	INGEMMET	7	10	41 %	Large	Large	IT Office
National	MINAG	2	11	15 %	Small	Large	Department
National	MINAM	5	3	63 %	Medium	Small	Department
National	MINEDU	13	4	77 %	Large	Medium	Department
National	MINEM- DGAAM	4	-	100 %	Medium	Small	Department
National	MTC	7	4	64 %	Large	Medium	Department

National	OEFA	5	12	29 %	Medium	Large	Department
National	PCM-ONGEI	1	11	8%	Small	Large	Department
National	SENAMHI	6	7	46 %	Large	Medium	Department
Private	Anabi	4	-	100 %	Medium	Small	Department
Private	S&Z	2	4	33 %	Small	Medium	GIS Office
Private	Terra Planning	3	2	60 %	Small	Small	GIS Office
Regional	Callao	5	2	71 %	Medium	Small	IT Office
Regional	Piura	3	1	75 %	Small	Small	Department

The average ratio is 59 % of GIS experts, with a smaller 49 % ratio in offices considered as small in the number of GIS experts (3 and less).

There not does seem to exist a direct proportion between the number of GIS experts cluster size and the number of programmers cluster size as demonstrated in the following table:

Number of organizations Programmers Cluster	-			
GIS Experts Cluster 🕞 Large		Medium	Small	Total
Large	1	3	1	5
Medium	1	1	4	6
Small	2	1	3	6
Total	4	5	8	17

However, the number of programmers is not very trustable because the objective of the question was to know the most used programming languages. If a programmer knew more than one language, he is likely to be counted more than once.

#### 5.4.2.2 Willingness to share

The challenges related to the willingness to share spatial data can be noticed in both developed and developing countries (Eelderink, 2005). 59 % of the respondents perceive the willingness to share of other institutions as medium to extremely high.

#### 5.4.3 Policies

The policies component covers issues like leadership, custodianship, funding, capacity building, policies and legislations. One of the national spatial policies is to order and integrate spatial data production processes and strengthen the role of information producing institutions. This policy is based on three essential aspects that every state must set for the proper functioning of an SDI: 1) clear custodianship of spatial data producers 2) transparent, accessible and sustainable standards and 3) validation of fundamental and thematic map production. This policy's main objective is to lay the foundations for an adequate management of spatial data, primarily ordering production processes data and promoting integrated management of information based on standards and certified mapping processes. There is one Interagency Agreements and Policies technical workgroup which aim is to determine consensus policies and propose data policies, prices of products, services and licenses in the field of producers, distributors and brokers of geographical data and services. They have proposed a supreme decree to exchange geospatial information that is currently in the second phase of the review process by the concerned ministries. Also, the workgroup is preparing a document to identify citizen services that uses geographic information. Almost all SDI initiatives consider institutional arrangements as challenges (Eelderink, 2005)

There are still many layers of fundamental data that is not clear who is the custodian (populated centers, administrative boundaries, etc.). The criteria for assigning custodianship to an agency include (Brodie et al., 2004):

- 1. Has sole statutory responsibility for the capture and maintenance of the spatial information;
- 2. has the greatest operational need for the spatial information;
- 3. is the first to record changes to the spatial information;
- 4. is the most competent to capture and/or maintain the spatial information;
- 5. is in the best economic position to justify collection of the spatial information at source;
- 6. requires the highest integrity of the spatial information.

Funding for the future has not been secured and institutional arrangements are still missing to publish fundamental data. Innovative funding models include funding from the budgets of ministries, special taxation, non-monetary contributions (personnel, equipment, etc.), partnerships, alignment to special projects and contribution from large stakeholders such as utility companies (Garfield, 2003).

(Masser, 2005 from Eelderink, 2005) described that the need for capacity building activities to be developed in parallel with the processes of NSDI implementation is often underestimated. This is particularly important in developing countries where implementing NSDI initiatives are often dependent on a limited number of staff that has the necessary geographic information management skills. Even though human capital has been judged very positively, the Peru SDI could be fostered by capacity building activities such as: short courses including web delivery, components of university degree programs, conferences, seminars and workshops, research training (Masters degree and PhD students) i.e. training people to do SDI research, preparation of books, articles and reports (Rajabifard and Williamson, 2004). Also, we believe that technical training in the use of FOSS solutions (Quantum GIS/gvSIG, Open Layers, GeoServer/MapServer, PostgreSQL/PostGIS, Geonetwork opensource) would improve the capacity of stakeholders at other levels than national public institutions (regional and local governments, private sector companies, public in general, academic and research institutions, non-governmental organizations) to eventually contribute in the Peru SDI.

#### 5.4.3.1 Institutional leadership

Sometimes national mapping agencies are the key contributors to SDI development, while other entities have the political influence and funding that drives the initiatives (Eelderink, 2005). The fact that CCIDEP is a permanent body lead by the high organ President Council of Ministers ensures the political will of the IDEP to continue.

#### 5.4.3.2 Political vision regarding SDI

In the dynamic NSDI environment, a long-term strategic vision is considered as very relevant (Eelderink, 2005). The SDI vision has been stated as a very positive aspect and the CCIDEP technical workgroups and the 2012 national spatial policy and guidelines are probably the reason behind this perception.

#### 5.4.3.3 Umbrella legal agreements

This aspect is apparently one of the Peru SDI weakest points that will need improvements.

#### 5.4.3.4 Central government funding

To secure funding is a relevant issue not only in developing countries as NSDIs requires constant accomplishments and financial input over a long period of time (Eelderink, 2005). However, chances to obtain funding for an SDI is limited in developing countries and stability cannot be guaranteed. Although many countries have NSDI initiatives, it is not prominent on the political agenda due to other critical issues.

#### 5.4.3.5 SDI culture

Understanding and being aware of the concepts and benefits of a SDI is very important before and during its implementation and establishment (Eelderink, 2005). For example, the concepts could be not well understood and seen just a 'tool' to prevent data duplication – people were not aware of, and did not understand, other SDI components and principles. If countries undertake actions to increase SDI understanding, a greater willingness to participate in the initiative might be achieved (Eelderink, 2005). SDI culture is an aspect that could be improved and half of respondents perceive it as neutral (medium). Capacity building is part of this and it would be recommendable for the CCIDEP to organize more events and trainings on SDI and GIS matters to improve the SDI culture in Peru.

#### 5.4.1 Standards

The standards component covers issues like interoperability, guides and specifications, data quality and metadata. The ability to successfully understand and share various data, software and hardware across a broad spectrum of organizations and users is relevant for any SDI (Eelderink, 2005).

A spatial data model has been proposed which will reduce semantic heterogeneity and schematic heterogeneity.

Basic metadata profile based on the ISO 19115 – 19139 for the IDEP will be implemented by the institutions that published nodes of metadata information. 13 institutions publish metadata with the geonetwork software.

# 6 CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

#### 6.1 Conclusions

This thesis has discussed the implementation of a National Spatial Data Infrastructure for the emerging economy country of Peru. The first objective of this research was to review the theoretical foundation of SDI in order to provide a common understanding of the complex, multifaceted, dynamic and constantly evolving nature of SDI. The second objective was to research the potential of FOSS solutions for SDI initiatives in emerging economies and developing countries. The third objective was to assess the progress of the Peru Spatial Data Infrastructure (IDEP) from three different angles (SDI readiness, generational approach and SDI components evaluation), to identify their strengths and weaknesses and offer recommendations to move toward a more user-centric SDI.

#### 6.1.1 Theoretical foundation (GIS, SDI, FOSS)

Generally speaking, GIS is the concept used for managing geo-information within organizations and SDI is the concept mostly used for sharing spatial data between organizations (Koerten, 2008). GIS facilitates the three stages of working with geographic data: data preparation and entry, data analysis and data presentation (de By et al., 2001). This allows the formulation of answers and solutions to answer specific spatial questions and problems in various fields where location is important (ex: forestry, agriculture, land management, etc.). Spatial Data Infrastructures have been defined as the set of technologies, policies and standards that together enable efficient user access to spatial data generated by others in an efficient way (in terms of time and money), reducing the duplication of effort, fulfilling user requirements and improving the quality of products and processes that involve geographic information. The primary raison d'être of SDI is to encourage and facilitate cooperation and interoperability between multiple participants and technologies (O'Flaherty et al., 2005), especially spatial data discovery and delivery issues.

When an organization grows to a certain point where several departments have introduced GIS in their processes and begin to employ a significant number of dedicated GIS experts, an enterprise GIS must be implemented. Moving away from the file formats typically found in standalone GIS, an enterprise GIS is built around an integrated database that supports the functions of all departments needing spatial processing or mapping and provides maximum query and analytical functions to the system users. Aside from the common components that can be found in both GIS and SDI (people, spatial data, technology), SDI are characterized by the presence of organizational issues (standards and policies) that are needed to ensure interoperability between different institutions and foster sustainable cooperation. While a GIS usually respond to the needs of users in a specific field of application, this is not necessarily the case for a SDI. Indeed, the first generation of SDIs that emerged in the 1990s focused on the efficient exchange of spatial data between spatial data producers organizations. Recent generations of SDIs have seen a shift of emphasis from data producers to the needs and concerns of users, giving them a more active role and focusing on their processes instead of simply exchange data.

Proprietary GIS software used to implement most SDIs bring major setbacks: the use of proprietary data formats that tie organizations to a single vendor, the recurring high price of licenses and their difficulty of distribution due to legal constraints. The principal benefits of FOSS are the freedom of distribution without legal constraints, the compliance with standards that ease interoperability between organizations, the improved independence from software vendors and the direct financial resources savings that could be directed to the development of local capacity instead of paying license fees to foreign companies.

For all categories of GIS software required for the implementation of an SDI, a free and open source software product able to compete with proprietary software is available. The major FOSS spatial software solutions able to compete with commercial GIS software are: Quantum GIS (desktop GIS), Open Layers (web map development framework), Geo Server and Map Server (web map servers), GeoNetwork opensource (cataloging applications) and PostgreSQL/PostGIS (spatial database management systems).

#### 6.1.2 Peru SDI assessment

A surprisingly high rate of FOSS use has been observed with 78 % of the organizations using a mix of FOSS and proprietary technologies for different purposes. The main tasks realized with FOSS solutions are to interact with spatial databases (query and update information), visualize spatial data from GIS file formats and WMS services and to easily overlay data with online services such as Google Maps. Proprietary software is used in all institutions to create final map products and is believed to be currently far superior in that matter. FOSS has an important market share in some software categories such as metadata cataloging applications (86 % of institutions), database management systems (55 %) and web map servers (38 %). Proprietary GIS products still dominate the desktop GIS (85 % of users) and Web GIS clients market share (87 % of institutions).

The purchase of proprietary desktop GIS is justified for some GIS experts that need to perform frequently complex GIS tasks such as the elaboration of final map products or specialized spatial data analysis. For users that need to perform tasks such as display, browse or query spatial data, FOSS desktop GIS products such as Quantum GIS or gvSIG could represent interesting alternatives worthy of evaluation. In the internet mapping applications categories, a conjunction of MapServer or GeoServer with Open Layers could be used by institutions to publish their geographic information on the Web at a small cost. Capacity building on these technologies would deliver interesting benefits to Peruvian public institutions, especially for the regional and local governments that have lower IT resources and legacy information systems to maintain and that should join the Peru SDI more actively.

Another observed result was the prominence of file formats (shapefiles, personal and file geodatabases) to store spatial data. File formats are not designed to meet the needs of multiple users and to handle large data sets. The full potential of a GIS materializes when spatial data is stored in relational database management systems, allowing multiple users to query and edit data simultaneously, the storage of large volumes of data, referential integrity, integration with the other tabular data of an organization, as well as common benefits of administration tools that can be found in most DBMS (security, backups, restore, etc.). After file formats, the format of choice for many Peruvian institutions is the proprietary ESRI ArcSDE geodatabase, a native data structure which uses an object-relational database approach to store and manage data. Aside from the need of purchasing an expensive ArcGIS Server license, it has several disadvantages such as the impossibility of using standard SQL to edit tables that use geodatabase functionality and the impossibility of implementing DBMS referential integrity. This has the effect of tying organizations exclusively with ESRI technologies (ArcGIS, ArcSDE, ArcObjects), making geodatabases difficult to integrate with other standard applications. The Peru SDI stakeholders should take advantage of the fact that PostgreSQL already has an important market share in the database category to migrate from file and geodatabases formats to the PostGIS format. This would unleash all benefits of storing spatial data in relational databases management systems while at the same time allowing the integration of tabular and spatial data and the use of standard query and programming languages to access and manipulate data. PostgreSQL allow typical types of data (numbers, strings, dates) while PostGIS add geographic types such as points, lines and polygons.

It then becomes possible for programmers without extensive GIS knowledge or specialized technologies such as ArcObjects/ArcSDE to integrate spatial data and even use spatial operators into their applications using standard SQL. A combination of Quantum GIS with PostgreSQL would give more freedom to Peru SDI organizations from software vendors, facilitate integration with other non-GIS technologies as well as increase collaboration and sharing.

Also, we conclude that most organizations that are part of the Peru SDI implement Geographical Information Systems as standalone or department GIS instead of integrated enterprise GIS. Aside from file formats, another indicator that points toward this conclusion is the fact that 70 % of respondents work in direct front line working units. Departmental GIS increase the probability of data redundancy and lack of standards, inconsistent look and feel of map outputs and non-optimal geographic information costs. If an organization does not implement an enterprise GIS, it may not be totally ready to join a spatial data infrastructure.

From the application of the SDI readiness assessment method to the Peru SDI, we conclude that the degree of preparation to deliver geographical information to its community is average (medium). The results have identified the following strengths and weaknesses:

- **Strengths:** geospatial technology availability (proprietary and FOSS), political vision regarding SDI, institutional leadership, digital cartography availability, human capital
- Weaknesses: umbrella legal agreements, metadata availability, SDI culture, willingness to share, central government funding, communication infrastructure

According to (Delgado et al., 2005), a country is ready to undertake an SDI if and only if it has an appropriated level of the global factors: organizational, informational, human resources (people) and financial resources, and any level of technology. Concerning the level of technology, we have seen that the Peru SDI has an appropriate level of geospatial software availability and open source culture but some stakeholders have mentioned that telecommunication infrastructures must be improved (especially the fiber optic network in the regions far from the Lima capital). From the survey results, we can conclude that the levels of organizational, people and informational factors are also appropriate. However, the weak spot of the Peru SDI is clearly the low financial resources. The following recommendations have been proposed by (Delgado et al., 2005) to improve SDI readiness for countries such as Peru characterized by the low availability of financial resources:

- 1. Associate the SDI to other national programs where geospatial management could be crucial (e.g., Information Society, disaster management, land administration).
- 2. Conduct cost/benefit analysis to emphasizing the merits of SDI to convince decision makers about the importance to invest in geospatial matters.
- 3. Orient the technological strategy towards Open Source in order to obtain free implementations of the geospatial standards necessary to build an SDI (Web Map Servers, Web Coverage Servers, Plug and Play GeoPortals, etc).
- 4. Find cheaper alternatives to share geospatial data bypassing the technological bottleneck (Delgado, 2005).
- 5. Explore alternative funding models for emerging nations (UNECA, 2004).

The first recommendation goes exactly in the same vain as one of the Peru SDI guideline which is to promote the production, maintenance and exchange of spatial data to support the disaster risk management. Another similar guideline of the same policy is to support the public sector investment system to obtain sectoral information to focus investments according to the priorities of public policies. Land administration and cadastre is another subject of importance that unites many levels of government (national, regional, municipal). The Peru SDI already focuses on the construction of a geographic information system where investment projects are georeferenced with associated information on the pre investment and execution of the health and education sectors.

The second recommendation is to present the results of the Peru SDI to decision makers, namely the actual impact on the exchange and use of spatial data (Vancauwenberghe et al., 2009b). The third and fourth recommendations are directly in line with the objective of this thesis to explore the potential benefits of FOSS technologies benefits of FOSS (financial savings, freedom and independence from vendors and technology, compliance with standards). Concerning the last recommendation to explore alternative funding models for emerging nations, we recommend funding from the budgets of ministries and non-monetary contributions (personnel, equipment, etc.).

Peru has built a solid foundation toward an efficient SDI by establishing a permanent coordinating committee, technical workgroups and a national spatial policy. The IDEP can be considered a first generation SDI because it is centered on products and spatial data. The IDEP is now ready to embark in the implementation of second and third generation SDIs that are respectively based around processes and users. The following recommendations are made:

- 1. The level/focus must include regional and local governments and be cross-scaled.
- 2. The driving forces must be user driven and include private sector organizations and individuals.
- The expected results must be to develop a platform for a spatially enabled society. These services must be designed to meet the most important needs of the population, improve decision-making and assist in the management of government.
- 4. The participants must include not only data producers but also users and consumers.
- 5. Funding must incorporate governmental and private initiatives and include crowd sourcing (volunteered geographic information).
- 6. Involved actors must include representatives from the target user groups.
- Different levels and sectors of SDI initiatives must be formed and integrated into the national SDI.
- 8. Common citizens must be granted free access to fundamental Peru SDI digital data.
- 9. Tasks must be driven toward real user applications and processes.
- 10. Not only GI experts must be involved.
- 11. Usability criteria must be used to measure Peru SDI value and justify investments.

#### 6.2 Summary of findings

The Peru SDI would benefit if its leading members would implement enterprise GIS within their own organizations using spatial database management systems and creating an integrated team of GIS experts located in a central IT office or specialized GIS unit offering services to departments. This would allow a better integration with corporate information systems, standardized and less redundant spatial and attribute data, maximum query and analytical functionalities, consistent look and feel of output and centralized geographic information costs (Harmon and Anderson, 2003; Nedović-Budić and Budhathoki, 2006). PostgreSQL already has an important market share and PostGIS could be used in conjunction with Quantum GIS for most GIS tasks without the need of proprietary software. This way, organizations would not only save direct financial resources but more importantly would be liberated from being tied to foreign software vendors and specialized GIS proprietary formats that do not integrate easily with the corporate IT infrastructure. Savings should go toward developing local capacity. The Peru SDI has an average degree of preparation to deliver geographical information to its community. Although the level of available financial resources is actually very low, some recommendations have been proposed to improve SDI readiness (be more user-centric, demonstrate results to decision makers, focus on FOSS technologies, and explore other funding mechanisms than direct central government funding). More stakeholders than national government public institutions should participate actively in the Peru SDI: private companies and value adders, academic institutions, regional and municipal governments, citizens in general.

#### 6.3 Suggestions for further research

#### 6.3.1 Retrospection on the methodological framework and questionnaire survey

Mainly because of the multifaceted, dynamic and complex nature of SDI, assessment remains problematic. To deal with these issues, (Grus et al., 2007) has proposed a multi-view SDI assessment based on the principles of assessing Complex Adaptive Systems: using multiple assessment strategies, a flexible framework and a multi-perspective view of the assessed object. In line with existing research in this field, our methodological framework involved the use of three different evaluation methods to scrutinize the Peru SDI through various angles: SDI readiness, generational approach and SDI components evaluation. The works of (Steiniger and Hunter, 2010), (Steiniger and Weibel, 2009), (Delgado et al., 2005) served as an inspiration to design a questionnaire survey to apply those methods and to obtain information on the use of the different categories of spatial software required to realize the software components of SDI, taking special attention to FOSS alternatives. The SDI readiness method has already been applied to various countries but we have slightly adapted it to assess organizations within a SDI instead of comparing countries. To our knowledge, the generational approach has been described theoretically by (Grus et al., 2007) but had not been applied before. The qualitative SDI components evaluation has been proposed as a new thorough method to analyze the various components and aspects of SDI.

We received answers by 23 different respondents from 17 different institutions, including almost all of the principal Peru SDI stakeholders. This includes 12 national public institutions, 2 regional governments and 3 private companies. For a thesis that investigates the transition towards 3rd generation SDIs, it would have been beneficial to extend the questionnaire to other important stakeholder groups such as private companies and regional governments, as well as other groups of users such as municipalities, private value adders and academic institutions. The principal reasons for this are that 3rd SDI generation (user-centric) are typically characterized by cross-scale level / focus, private sector organizations as driving forces, participants such as users / producers / consumers and incorporate governmental / private / crowd sourcing initiatives.

#### 6.3.2 Limitations of this approach

We obtained valuable numbers on the quantity of institutions that use various types of geospatial technology tools. Unfortunately, we were unable to understand the deep reasons why some organizations are using a mix of FOSS and proprietary software and why FOSS has less market share. In-depth interviews would have given more insight on these issues. Additions to our methodological approach could have included a SWOT analysis to further analyze the strengths, weaknesses, opportunities and threats of FOSS over proprietary software. Even if the primary advantage of FOSS is generally not the financial savings it can bring, a cost-benefit analysis would have also been beneficial to compare the costs and benefits in monetary terms.

We have adapted the SDI readiness method by applying it to individual institutions instead of countries. This has given some good results but we were unable to know the reasons why some factors were so low (ex: metadata availability, central government funding) or surprisingly high (ex: willingness to share, digital cartography availability, human capital). For example, most institutions perceive funding as a major weakness but we have no tangible quantitative factor to confirm that it is the case. Questions could have been added to complete the obtained perceptions (improvements to metadata) and quantitative numbers (number of published datasets and total programmers).

For the generational approach, the sole use of secondary methods has resulted in sometimes general recommendations for some of the indicators because of incomplete data. It would have been advisable to include in the questionnaire design the generational factors as listbox questions, thus obtaining the perception of participants if the Peru SDI is in the first, second or third generation. Concerning the SDI components evaluation, the questionnaire included specific questions on three out of five SDI components (technology, data, people). As SDI focus is on the standards and policies components, it would have been wise to include questions on issues such as the legal framework, custodianship, guides and specifications, etc.

This thesis has tried to evaluate from a conceptual and qualitative perspective the relationship between GIS and SDI. GIS are the building blocks of SDI and both share many software components together, especially when a GIS matures in an organization as an enterprise GIS using spatial databases, web services and agreed standards. Further research could be conducted to better clarify this relationship, especially by defining more precisely the characteristics of the 3 levels of GIS implementation that we have described and by investigating the average GIS levels of organizations that are part of SDI and the advantages/disadvantages on the location of GIS experts.

#### 6.3.3 Suggestions to improve the questionnaire design

Some improvements would be needed to the questionnaire design to be able to answer more precisely some of the questions and can be summarized as follows:

- 1. Make the desktop GIS software and GIS functions questions dependent
- 2. Instead of having a single "software for internet mapping" section, separate the server side (web map servers) tools from the client side (web map development frameworks)
- 3. Add a question to obtain the perceived needed improvements to metadata
- 4. Make the managed datasets and implemented OGC protocols questions dependent
- 5. Add a question to ask the number of maintained datasets
- 6. Add a question to ask the number of programmers
- 7. Instead of having an open question for the GIS office, provide a closed list

#### 6.3.4 Promising technological developments

Traditionally, the data for an SDI have come from official or recognized professional producers of geospatial data using state of the art technology (Cooper et al., 2011b). Compared to former SDI concepts that had their emphasis on data issues, the development of third-generation SDI is increasingly driven by users (Hennig and Belgiu, 2011). There is a prominent shift from the passive role of the user into an active role (Sadeghi-Niaraki et al., 2010).

Initiatives of Voluntary Geospatial Information (VGI) such as Wikimapia and OpenStreetMap (OSM) are empowering citizens to create a global patchwork of geographic information (Goodchild, 2007). At the same time products such as Google Earth have been developed that make it possible for a new generation of non-professional users to add their own data relating to the surface of the earth for their own applications (Butler, 2006 cited in Masser, 2011). The emergence of these Geobrowsers and Web 2.0 has opened new possibilities for the data collection at the local level (Georgiadou et al., 2011), transforming citizens as voluntary sensors of geometric primitives (points, lines and polygons) that interact with each other, providing spatial data to central sites, and ensuring that data are collated and made available to others (Goodchild, 2007).

Custodians of SDIs are starting to admit Voluntarily Geographic Information (VGI) into their SDIs (Cooper et al., 2011a). This could be in the form of revision requests or notices submitted to an SDI through its web site by the public (Guélat, 2009), or potentially even using large quantities of VGI (Cooper et al., 2011b). This revolutionary phenomenon might change the evolving concepts of SDI. An obvious concern with VGI that researchers should investigate is how its quality compares with official information (Haklay 2010) and how data can be incorporated into a traditional SDI with appropriate metadata and validation. Trust issues can be raised with regard to the absence of metadata for geographic information supplied through Google Earth and other commercial actors who control the data, its quality and, and its accessibility (Craglia et al., 2008).

Also, further developments are needed in the software components of SDI to simplify and extend their use to the general public. The advent of content management systems (CMS) at the end of the 1990s has revolutionized the way of publishing information on the Web. Suddenly, common users without any knowledge of HTML programming became able to publish information themselves through those CMS tools. This has yet to happen with the current SDI packages solutions mainly benefiting GIS experts and national institutions. Many FOSS tools are already available (EasySDI and GeoNode) but the gap is still missing to allow non-programmers to contribute to a SDI freely and openly.

## 7 **APPENDICES**

#### 7.1 Questionnaire (translated English version)

#### 7.1.1 General Information

#### 1. Person who completed the questionnaire

Date:	
Name:	
Position:	
Institution:	
Email:	
Telephone:	

### 7.1.2 Technology

#### 2. What client software do your institution use?

	Checkbox
ESRI ArcGIS/ArcInfo/ArcView	
AutoCAD	
MicroStation	
SmallWorld	
MapInfo	
Manifold	
GeoMedia	
GRASS	
Quantum GIS	
gvSIG	
uDig	
Other (specify):	

3. Specify the number of users for each client software

	Number of Users
ESRI ArcGIS/ArcInfo/ArcView	
AutoCAD	
MicroStation	
SmallWorld	
MapInfo	
Manifold	
GeoMedia	
GRASS	
Quantum GIS	
gvSIG	
uDig	

4. Specify the frequency of GIS tasks that your institution perform

	Every day	Frequently	Sometimes	Rarely	Never
Data input / editing (digitizing from source GPS, aerial images, satellite imagery, maintenance of datasets, updating of attributes)					
Display (viewing / exploration of spatial data for example by zooming)					
Creation of final map products (digital output or printed maps)					
Data query (attribute filter, query builder)					

Spatial analysis (distance measurements, buffers, intersections, etc.)			
Transformations (coordinate systems, raster/vector, format conversion, for example from Oracle Spatial to shapefile)			
Modeling and simulation			

5. Do your institution serve spatial data on the Web or use a web development toolkit? If so, what software?

	Checkbox
ESRI ArcServer/ArcIMS	
MapServer	
GeoServer	
MapGuide Open Source	
Deegree	
Manifold	
OpenLayers	
MapFish	
Other (specify):	

6. Specify the number of users for each web GIS software

	Number of Users
ESRI ArcServer/ArcIMS	
MapServer	
GeoServer	

MapGuide Open Source	
Deegree	
Manifold	
OpenLayers	
MapFish	
Other (specify):	

### 7. What OGC standards do you implement?

	Checkbox
Web Map Service (WMS)	
Web Feature Service (WFS)	
Web Coverage Service (WCS)	
Web Processing Service (WPS)	
Other (specify):	

## 8. How do you store spatial data?

	Checkbox
Oracle Spatial	
ESRI ArcSDE	
PostGIS	
ShapeFile	
Personal/File Geodatabase	
Other (specify):	

9. What databases do you use in your institution?

	Checkbox
Oracle	
SQL Server	
MySQL	
Postgres	
DB2	
Other (specify):	

10. Do you keep metadata of the data you publish and / or create? If so, what software do you use?

	Checkbox
GeoNetwork Open Source	
FGDC Metadata Editor	
Other (specify):	

#### 7.1.3 Data

11. What are the spatial layers that your institution create and / or maintain?

12. What core data sets do you obtain (or would need to obtain) from other institutions:

	Checkbox
Elevation (points and contour lines)	
Transport and infrastructure	
Hydrographic network	
Administrative boundaries	
Populated places	
Cadastral parcels	
Education centers	
Health centers	
Protected areas	
Satellite imagery	
Aerial photography imagery	
Others (specify):	

#### 7.1.4 People

- 13. How many Geographical Information Systems experts work in your institution? Please specify their specialization and level of education degree.
- 14. Do you have a GIS department within you institution? Please explain where GIS experts work (GIS department, Information Technology Office, other offices).
- 15. How many users do you have? Please explain the kind of users.
- 16. What development technologies do your institution use? Please consider the total number of analysts/programmers in general of your institution (do not consider only GIS experts).

	Checkbox	Number of developers
.NET		
Java		
РНР		
Python		
Other (specify):		

#### 7.1.5 SDI Readiness

17. **SDI Vision.** A practical and organizational issue to take is the development of a vision, detailing a vision of the desired future and a clear sense of how SDI components could serve that future and help to realize it. This also involves setting clear priorities and defining a strategy or policy to accomplish this vision. Check (X) one box only.

Extremely high vision regarding the importance and development of the national SDI (top level of management of your institution participate in defining a strategy of the national SDI)

Very High vision regarding the importance and development of the national SDI (important experts of your institution are strongly involved in setting strategies for the national SDI)

High vision regarding the importance and development of the national SDI (vision formulated forms a crucial starting point for launching the national SDI and is already useful for your institution)

Medium vision regarding the importance and development of the national SDI (a formulated vision does exist, but has low impact on the development of the national SDI and the responsibilities of your institution)

Low vision regarding the importance and development of the national SDI (a vision is being formulated but has no impact on your institution)

Very Low vision regarding the importance and development of the national SDI (a few sectors show interest in having a vision)

No vision exist as well as no intention exist to formulate a vision regarding the importance and development of the national SDI

18. **Institutional leadership.** How would you qualify the leadership of your institution within the institutional framework? Check (X) one box only.

Maximum leadership of your institution to coordinate the activities relating the national SDI

Very High leadership of your institution to coordinate the activities relating the national SDI

High leadership of your institution to launch the crucial activities relating the development of a national SDI

Medium leadership of your institution to coordinate partly the activities relating the national SDI

Low leadership of your institution to start to set up the institutional framework

Very Low leadership of your institution that show interest to set up the

institutional framework

No leadership of your institution

19. Legal framework. This factor refers to the creation of a legal environment that leads to national SDI being legally embedded. The legal framework of a SDI consists of legal instruments such as laws, policies, directives and commitments. Check (X) one box only.

Maximum level of legal support to the national SDI-initiative (existence of a legal framework that support legally the SDI at a maximum level)

Very High legal support to the national SDI-initiative (applying legal instruments that motivate strongly all the activities relating the national SDI)

High legal support to the national SDI-initiative (an established legal framework that support the national SDI is under construction)

Medium level of the legal framework (existence of a framework, but it is incapable to support the national SDI)

Low legal support to the national SDI-initiative (creating legal instruments isolated that might support the national SDI)

Very Low legal support to the national SDI-initiative (not existing legal instruments at a national level, but at organizational or sector level, which have a very low impact on the national SDI)

No existence of any legal framework (including instruments) that might support the national SDI initiative

20. Availability of digital data. This factor refers to the availability of core spatial datasets in digital format crucial for the national SDI. Check (X) one box only.

Maximum availability of core spatial datasets in digital format

Very High level of core spatial datasets in digital format (availability of core spatial datasets with an appropriate scale level that cover the whole country

High level of core spatial datasets in digital format (availability of core spatial datasets with an appropriate scale level that the main regions of the country

Medium level of core spatial datasets in digital format (partial availability of core spatial datasets at levels that are insufficient for being a decisive factor)

Low level of core spatial datasets in digital format (availability of some core spatial datasets for some regions in the country

Very Low level of core spatial datasets in digital format

No availability of any core spatial datasets in digital format

21. Willingness to share. Institutions that are part of the Peru SDI are willing to freely share their data. Check (X) one box only.

Maximum will willingness to share

High willingness to share

Medium willingness to share

Low willingness to share

There is no willingness to share

22. Metadata Availability. This factor refers to the availability of metadata that describe the existing datasets in Peru. Check (X) one box only.

Maximum availability of metadata describing spatial datasets

Very High level of metadata describing spatial datasets

High level of metadata describing spatial datasets

Medium level of metadata describing spatial datasets

Low level of metadata describing spatial datasets

Very Low level of metadata describing spatial datasets

No existence of metadata describing spatial datasets

23. **Human capital.** There are enough qualified staff in Geographical Information Science in Peru. Check (X) one box only.

Maximum capacity

High capacity

Medium capacity

Low capacity

There is no capacity

24. **Capacity building and SDI awareness.** What is the level of investment of your institution in significant resources to build capacity and to raise community awareness of spatial data and technologies such as courses, workshops and seminars in order to realize the full potential of SDIs. Check (X) one box only.

Maximum level of SDI-culture and education (capacity building) among the stakeholders

Very High level of SDI-culture and education (capacity building) among the stakeholders

High level of SDI-culture and education (capacity building) among the stakeholders

Medium level of SDI-culture and education (capacity building) among the stakeholders

Low level of SDI-culture and education (capacity building) among the stakeholders

Very Low level of SDI-culture and education (capacity building) among the stakeholders

No existence of any SDI-culture and education (capacity building) among the stakeholders

**25. Funding.** This factor refers to the government's role (level) as source to finance the national SDI-initiative. Check (X) one box only.

The national SDI is only funded by the central government and no other funds are needed.

Very High level of funding by the central government to finance the national SDIinitiative

High level of funding by the central government to finance the national SDIinitiative

Medium level of funding by the central government to finance the national SDI-initiative

Low level of funding by the central government to finance the national SDI

Very Low level of funding by the central government to finance the national SDI

No funding by the central government to finance the national SDI

#### 26. Comments

#### 7.2 SDI Readiness Results

#### 7.2.1 SDI Vision



### 7.2.2 Institutional leadership



#### 7.2.3 Umbrella legal agreements



#### 7.2.4 Availability of digital data



#### 7.2.5 Willingness to share



## 7.2.6 Metadata Availability



#### 7.2.7 Human capital



#### 7.2.8 SDI Culture





## 7.2.9 Central government funding

#### 7.3 Definition of Geographical Information Systems versus Spatial Data Infrastructures

#### 7.3.1 Introduction

In the last few decades, armies, governments, non-governmental organizations and multinational enterprises have devised new methods of data capture and analysis to satisfy their different requirements (Van Manen et al., 2009). Particularly with the development of the Internet, this has resulted in an increasingly wide range of geospatial tools, geospatial data and geospatial services available to a widening body of users (Van Manen et al., 2009). Spatial Informatics is the umbrella term for studying theories, methods, and applications of spatial analysis/modeling; and spatial data handling, management, and visualization (University of Illinois, 2013). It includes disciplines such as surveying, geodesy, remote sensing, photogrammetry, cartography, Geographic Information Systems (GIS) and Global Positioning Systems (GPS) (Maartens, 2006). A Spatial Data Infrastructure (SDI) is a rapidly evolving concept that aims to facilitate the discovery and exchange of geospatial data and services between organizations. In this focused-task paper, we propose to review the distinct characteristics, uses and underlying structures of GIS and SDI. We will first describe the content of frameworks in support of spatial informatics, then review GIS and SDI, and finally discuss the recent Voluntarily Geographic Information (VGI) phenomenon and how it might change the concept of SDI.

#### 7.3.2 Frameworks in support of spatial informatics

Since the advent of Spatial Informatics, many technologies, techniques, information types, analyses, communications and rules / regulations have been developed with a connection to this discipline (GIS and SDI being two). To grasp their distinct characteristics and specific contribution, we will use the frameworks include in the following figure as a basis for the discussion to follow:



#### 7.3.3 Geographic Information System (GIS)

A GIS integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information (ESRI, 2013). According to (Harmon and Anderson, 2003), it is composed of five components:



The applications component is paramount to GIS and includes the processes developed by organizations to answer spatial questions such as create reports and maps and apply their skills to get the work done (Harmon and Anderson, 2003). Some applications are routine and get done multiple times a day, whereas others are less routine but get done with some regularity, and then there are specific analytical applications that might have to be accomplished only rarely or even just once (Harmon and Anderson, 2003). Analyses and models allow to grasp the nature of the problem/question and to formulate answers/solutions. Then, the outcomes of geospatial analysis can be visualized or communicated in other formats in order for the end user to be able to understand and act on the proposed answers/solutions. Thus, GIS focuses on the analytical and visualization / communication frameworks.

Examples of geospatial technology tools that can be part of a GIS include desktop GIS, web map development frameworks, web map servers and spatial databases management systems. Common GIS functions are data input / editing, display, creation of final map products, data query, spatial analysis, transformations, modeling / simulation, data storage.

There are several levels of GIS implementation in an organization: standalone desktop GIS, departmental GIS and enterprise GIS. The expected result of a standalone desktop GIS is generally a product (ex: a map or report) and has a limited time frame and number of users. Departmental GIS aim to support a well-defined business function and generally involve little integration with attribute databases and sharing. The enterprise model of GIS is a multi-purpose system that is part of the operational framework of an organization. It generally includes the integration of attribute and spatial data into a relational database and is based on the concept of delivering software functionality and/or data as a service. When an organization reaches the level of an enterprise GIS, it is fully prepared to be part of a SDI and can become a node by incorporating external data to its GIS and / or publishing information for other SDI nodes. The organization and data (especially metadata and data formats) frameworks begin to take more importance when a GIS enters the level of an enterprise GIS.

#### 7.3.4 Spatial Data Infrastructures (SDI)

Mainly because geographic data are expensive and time consuming to produce (Rajabifard et al., 2000), an organization typically develops some, but not all, of its own spatial data content and has to incorporate at least some of its layers from external sources (Bank, 2004). SDI are the set of technologies, policies and standards that together aim to enable efficient user access to spatial data generated by others. The primary raison d'être of a SDI is to encourage and facilitate cooperation and interoperability between multiple participants and technologies (O'Flaherty et al., 2005). It is a paradigm and a conceptual foundation for integration, rather than a technology per se (O'Flaherty et al., 2005). GIS constitutes the installed base and building blocks of SDIs (Nedović-Budić and Budhathoki, 2006). One SDI can be part of another SDI, either functionally or hierarchically.

According to (Steiniger and Hunter, 2010), SDI are composed of the following components:

- (i) Spatial Data,
- (ii) Technologies (hardware and software),
- (iii) Laws and Policies,
- (iv) People
- (v) Standards

From the frameworks in support of spatial informatics discussed before, the organization framework is the key to Spatial Data Infrastructures. This covers two of the SDI components, namely the standards and policies. Concerning standards, issues such as OGC/ISO interoperability standards (data delivery, data formats, data search), guides and specifications, data quality and metadata must be considered. The laws and policies component covers issues like leadership, custodianship, funding, capacity building, policies and legislations (Simbizi, 2009).

Most of the Geospatial Technology Tools used in SDI are very similar to GIS (especially the desktop GIS and spatial databases). Even if they can be found in some GIS, cataloging applications take a very special place in SDI for the search and discovery of data. Also, because of the nature of SDI which aims to transfer geographic data through networks, tools such as web development toolkits and web map servers are generally found in SDI while it is not always the case for a conventional GIS. As we will see in a coming section, public users can also contribute to a SDI using collaborative mapping tools.

The analytical and visualization / communication frameworks are not generally part of SDI.

#### 7.3.5 GIS and SDI comparison

Comparing the 5 SDI components (people, data, technology, standards, policies) with the 5 GIS components listed in the previous section (people, data, software, hardware, applications), we can easily denote the resemblances and differences between GIS and SDI. Both allow "people" to access "spatial data" through "technology" (software and hardware). One of the key differences is the inclusion of the "applications" component in GIS that is missing in SDI. While GIS makes heavy use of the analytical and visualization capabilities of GIS, SDI focus on the "standards" and "policies" components to ensure interoperability between organizations (Organizational Framework). Those two SDI components are the backbones of SDI but are sometimes present in an enterprise GIS to a certain level.

#### 7.3.6 Voluntarily Geographic Information (VGI)

Traditionally, the data for an SDI have come from official or recognized professional producers of geospatial data using state of the art technology (Cooper et al., 2011b). However, recent developments like Web 2.0 platforms, GPS enabled cell phones and sensor technology make capturing of geographic data no longer the exclusive domain of well trained professionals, but opens new possibilities for involvement of citizens (Bregt, 2010). Interactive platforms such as Google Maps or OpenStreetMap allow anyone to use and disseminate their own maps and geographic information.

Custodians of SDIs are starting to admit VGI into their SDIs (Cooper et al., 2011a). This could be in the form of revision requests or notices submitted to an SDI through its web site by the public (Guélat, 2009), or potentially even using large quantities of VGI (Cooper et al., 2011b). (Goodchild, 2007) argues that VGI fits in the model of an SDI, facilitating exchange of geographic information between individuals in a community. According to a model proposed by (Cooper et al, 2011b), OpenStreetMap can be seen as a SDI, contributors having the role of data providers and National Mapping Agencies the role of data aggregator/integrator according.

#### 7.3.7 Conclusion

Generally speaking, GIS is the concept used for managing geo-information within organizations and SDI is the concept mostly used for sharing spatial data between organizations (Koerten, 2008). SDI interconnects GIS nodes across the Internet to share information with one another according to agreed standards and policies. Even if GIS and SDI share some components (people, data, technology), their uses and underlying structures are different. A GIS generally aim to provide solutions and answers to specific spatial problems and questions (applications), and SDI aim to provide an interinstitutional cooperation framework focusing on policies and standards issues. Both share the Data Framework and Geospatial Technology Tools with some minor differences. While GIS primary focuses are the Analytical and Visualization / Communication Frameworks, SDI is more concerned with the Organizational Framework. Even so, the frontier between GIS and SDI is thinning with the advent of user-centric third generations of SDI and the introduction of Web Processing Servers that expose functionalities typically found in desktop GIS software.

# 7.4 Relationships and correlations between SDI-readiness indicators within organizations

#### 7.4.1 Introduction

The aim of this focused task paper is to a) extract additional / new information from the data collected through the questionnaire by way of correlation and quantification, and b) improve the questionnaire by shortly discussing possible extensions and additions. This assignment is split in two parts; the first set of questions aims to find interesting / relevant correlations between different sets of answers whereas the second set aims to quantify some of the found "soft" perceptions by using quantitative information (e.g. number of programmers) collected elsewhere in the questionnaire.

#### 7.4.2 Part 1 - Correlations

# 7.4.2.1 What is QGIS mostly used for? What is ArcGIS mostly used for? Is QGIS used for other tasks that ArcGIS? Are organizations that perform modeling and simulation using QGIS?

The obtained results reveal higher frequencies of GIS tasks performed every day or frequently by respondents using QGIS compared with all respondents:

GIS Function	All respondents	Only respondents that reported QGIS use	Increase
Display	83 % every day or frequently	100 % every day or frequently	17 %
Map products	87 % every day or frequently	100 % every day or frequently	13 %
Query	78 % every day or frequently	83 % every day or frequently	5 %
Analysis	74 % every day or frequently	100 % every day or frequently	26 %
Input / editing	83 % every day or frequently	83 % every day or frequently	-
Transformations	57 % every day or frequently	83 % every day or frequently	26 %
Modeling and simulation	30 % every day or frequently	67 % every day or frequently	37 %

The only two organizations that perform "modeling and simulation" every day also use QGIS. The increase in frequency is also significant in the "spatial analysis" and "transformations" advanced functions. Organizations using QGIS perform advanced tasks more frequently than the other who do not. Unfortunately, it is not possible to know which software is used to perform each GIS function because of the questionnaire design. This could have been done by linking the desktop GIS and GIS functions question together.

In the following table, we can observe that the number of QGIS users represent 20 % or less of the total number for most institutions.

	ArcGIS	QGIS	ArcGIS	QGIS
	# of users	# of users	% users	% users
CISMID	15	2	88 %	12 %
MINAG	10	2	83 %	17 %
INGEMMET	80	1	99 %	1 %
Piura Regional Government	4	1	80 %	20 %
SENAMHI	6	20	23 %	77 %
MINEDU	17	2	89 %	11 %

It is probable that QGIS is mostly used by seasoned GIS experts for advanced tasks. In the case of the SENAMHI, it is probably the opposite with 77 % of users using QGIS.

# 7.4.2.2 To what degree does the organization use a mix of FOSS and non-FOSS technologies?

The following table compares the number of respondents that strictly use proprietary or FOSS software, and those who use a mix of both.

	Strictly proprietary	Strictly FOSS	Mix of both
Desktop GIS	65 %	0 %	35 %
Web map servers	62 %	13 %	25 %
Spatial databases	64 %	22 %	14 %

Between 62 to 65 % of respondents only use proprietary software. No institution only uses FOSS for desktop GIS but a significant number (35 %) use both. Concerning spatial databases, it is the type of software that has the higher number of respondents (22 %) that rely entirely on FOSS. An astonishing 39 % did not use spatial databases and reported only file based formats and were not included in the numbers of the previous table.

# 7.4.2.3 Do organizations that use the ArcGIS web mapping stack (ArcGIS Server and its JavaScript API/Flex/Silverlight) also use FOSS mapping frameworks?

Out of 14 respondents that reported the use of the ArcGIS web mapping stack, only one of them mixes proprietary ArcGIS and Manifold servers with FOSS web map development framework.

7.4.2.4 Is the low usage of FOSS web mapping frameworks due to absolute reasons (i.e. organization simply do not use web maps) or because most organizations use ESRI's own web mapping framework that is part of ArcGIS Server? In other words, what percentage of the organizations use web mapping frameworks for displaying geographical information?

70 % of respondents publish geographic information on the Web using web map servers. In absolute numbers, 38 % have reported the use of FOSS web map servers and only 13 % reported the use of FOSS web map development frameworks. All other respondents are expected to solely use ESRI Javascript API/Flex/Silverlight.

Because of the questionnaire design that mixed in a single question web map servers and web map development frameworks, it is not possible to know with precision the number of respondents that use ESRI's own framework. One improvement would have been to separate Web Map Servers (that serve data and images) from Web Map Development Frameworks used to build browser-based clients.

# 7.4.2.5 Do people who report low quality of metadata also report a low degree of metadata cataloging software use?

Metadata availability has been reported as a weakness of the Peru SDI with 46 % of respondents perceiving metadata availability as low or very low.



The perception in metadata availability seems to be directly related to the use of metadata cataloging software. From the 54 % that reported medium to extremely high metadata availability, 93 % maintain metadata (50 versus 4 %). On the other hand, 61 % of respondents that perceive low or very low metadata availability do not maintain metadata (28 versus 18 %).

	Medium / extremely high	Low / very low
Maintain metadata	50 %	18 %
Do not maintain metadata or did not answer	4 %	28 %

# 7.4.2.6 What improvements have to be done to the metadata? Quantity? Quality? The process of metadata collection?

To be able to directly answer this question, an additional question should have been included in the questionnaire design to obtain more precisions on the perceived needed improvements. According to the previous question and answer, the problem is probably the process of metadata collection that is not widespread because 32 % of respondents do not maintain any kind of metadata.

#### 7.4.3 Part 2 – Quantification of the "soft" perceptions

# 7.4.3.1 Data vs. availability of digital data: how many datasets does each organization manage? How many datasets does each organization make available through their infrastructure?



Digital cartography availability has been reported as a strength of the Peru SDI.

At the national level, 9 out of 12 institutions publish geographical information using the WMS protocol. Private companies do not publish their own information. The questionnaire design does not allow knowing precisely which datasets are published through the various protocols and which are public or only available through their local networks. An improvement would be to relate the OGC protocols and managed datasets questions. Also, the fact that the managed datasets question was open does not allow knowing the exact number of maintained datasets because some institutions have answered in a general way.

The following table summarizes the datasets that are maintained by each institution along with the implemented OGC standards.

Level	Organization	Datasets managed	WMS	WFS	WCS	WPS
National	CEPLAN	-	Х	-	-	-
National	CISMID	Seismic risks, seismic zones	-	-	-	-
National	IGN	Hypsometry (elevation data and contour lines), digital terrain model, hydrography network, transport network, geographical names, political-administrative boundaries	X	X	X	-
National	INGEMMET	Geology, mining cadaster, mining resources, restricted areas to mining, geological risks	X	Х	-	-
National	MINAG	Agriculture	-	-	-	-
National	MINAM	Deforestation, natural heritage, watersheds, physical vulnerability	-	Х	-	-
National	MINEDU	Populated places, education centers	Х	Х	-	-
National	MINEM- DGAAM	Environmental studies: mining projects areas, direct and indirect influence zones, monitoring points, mining activity component areas	X	-	-	-
National	МТС	Transport and communication network, airports, bridges, toll and weighting stations, rural communication projects, satellite stations transmission	X	x	-	-
National	OEFA	Air and water quality monitoring, environmental noise, supervision of mining, hydrocarbons, electricity, fines	X	-	-	-
National	PCM-ONGEI	-	Х	Х	Х	-
National	SENAMHI	Meteorology and hydrology	Х	Х	Х	-
Private	Anabi	Drilling platforms, project areas, access, components	-	-	-	-
Private	S&Z	Engineering	-	-	-	-
Private	Terra Planning	-	-	-	-	-
Regional	Callao	Roads, populated places, blocks, lots, education, health, citizen security, tourism, companies, public services				
Regional	Piura	Ecological and economical zoning	Х	Х	Х	-
#### 7.4.3.2 People vs. human capital: how many GIS experts does each organization harbor? How many programmers? What is the percentage of GIS experts / programmers in an organization?



Human capital has been reported as another major strength of the Peru SDI.

The following table compares the number of GIS experts versus programmers, along with the size cluster (medium-size is 4-5 GIS experts) and the office where they work.

Level	Organization	GIS	Programmers	% GIS	Cluster	GIS Office?
		Experts		experts /	Size (#	
				Programmers	GIS	
					experts)	
National	CEPLAN	1	-	100 %	Small	Department
National	CISMID	5	8	38 %	Medium	GIS Office
National	IGN	10	3	77 %	Large	GIS Office
National	INGEMMET	7	10	41 %	Large	IT Office
National	MINAG	2	11	15 %	Small	Department
National	MINAM	5	3	63 %	Medium	Department
National	MINEDU	13	4	77 %	Large	Department
National	MINEM-	4	-	100 %	Medium	Department
	DGAAM					
National	MTC	7	4	64 %	Large	Department
National	OEFA	5	12	29 %	Medium	Department
National	PCM-ONGEI	1	11	8 %	Small	Department
National	SENAMHI	6	7	46 %	Large	Department
Private	Anabi	4	-	100 %	Medium	Department
Private	S&Z	2	4	33 %	Small	GIS Office
Private	Terra	3	2	60 %	Small	GIS Office
	Planning					
Regional	Callao	5	2	71 %	Medium	IT Office
Regional	Piura	3	1	75 %	Small	Department

The average ratio is 59 % of GIS experts, with a smaller 49 % ratio in offices considered as small in the number of GIS experts (3 and less). However, the number of programmers is not very trustable because the objective of the question was to know the most used programming languages. If a programmer knew more than one language, he is likely to be counted more than once. An additional question to ask for the number of programmers could have been included in the questionnaire. The GIS office question could also be improved, by making a closed list (central IT office, GIS office or directly from an operational department) instead of an open question and avoid confusion.

## 7.4.4 Conclusions

New information has been extracted from the questionnaire data by making new correlations on the GIS functions versus desktop GIS, mix of FOSS and non-FOSS technologies, web map development frameworks and metadata. An attempt has also been made to better quantify two SDI readiness "soft" perceptions (digital cartography availability and human capital). Some improvements would be needed to the questionnaire design to be able to answer more precisely some of the questions and can be summarized as follows:

- 1. Make the desktop GIS software and GIS functions questions dependent
- 2. Instead of having a single "software for internet mapping" section, separate the server side (web map servers) tools from the client side (web map development frameworks)
- 3. Add a question to obtain the perceived needed improvements to metadata
- 4. Make the managed datasets and implemented OGC protocols questions dependent
- 5. Add a question to ask the number of maintained datasets
- 6. Add a question to ask the number of programmers
- 7. Instead of having an open question for the GIS office, provide a closed list

## 7.5 Suggestions for further research

## 7.5.1 Introduction

This focused task paper will discuss further research that could / should be done in order to further enhance our understanding of SDI implementation in developing economies like Peru. The task will be divided into three parts:

- 1. summary of the methodological framework and survey
- 2. limitations of our approach
- 3. summary of technological and organizational developments

## 7.5.2 Part 1 – Summary of the methodological framework and survey

Our methodological framework involved the design of a questionnaire which first aimed at gaining insight on the use of the different categories of spatial software required to realize the software components of SDI, taking special attention to FOSS alternatives. A second objective was to assess the Peru SDI through 3 different angles: SDI readiness, generational approach and SDI components evaluation. We received answers by 23 different respondents from 17 different institutions, including almost all of the principal Peru SDI stakeholders. This includes 12 national public institutions, 2 regional governments and 3 private companies. The contacts for the participants were taken on the public Peru SDI public web site and included high ranking officials from the steering committee and technical experts which are members of the different workgroups. It would have been interesting to extend the questionnaire to more private companies and regional governments, as well as other groups of users such as municipalities, private value adders and academic institutions.

#### 7.5.3 Part 2 – Limitations of this approach

We obtained valuable numbers on the quantity of institutions that use various types of geospatial technology tools. Unfortunately, we were unable to understand the deep reasons why some organizations are using a mix of FOSS and proprietary software and why FOSS has less market share. In-depth interviews would have given more insight on these issues. Additions to our methodological approach could have included a SWOT analysis to further analyze the strengths, weaknesses, opportunities and threats of FOSS over proprietary software. Even if the primary advantage of FOSS is generally not the financial savings it can bring, a cost-benefit analysis would have also been beneficial to compare the costs and benefits in monetary terms.

We have adapted the SDI readiness method by applying it to individual institutions instead of countries. This has given some good results but we were unable to know the reasons why some factors were so low (ex: metadata availability, central government funding) or surprisingly high (ex: willingness to share, digital cartography availability, human capital). For example, most institutions perceive funding as a major weakness but we have no tangible quantitative factor to confirm that it is the case. Questions could have been added to complete the obtained perceptions (improvements to metadata) and quantitative numbers (number of published datasets and total programmers).

For the generational approach, the sole use of secondary methods has resulted in sometimes general recommendations for some of the indicators because of incomplete data. It would have been advisable to include in the questionnaire design the generational factors as listbox questions, thus obtaining the perception of participants if the Peru SDI is in the first, second or third generation.

Concerning the SDI components evaluation, the questionnaire included specific questions on three out of five SDI components (technology, data, people). As SDI focus is on the standards and policies components, it would have been wise to include questions on issues such as the legal framework, custodianship, guides and specifications, etc.

## 7.5.4 Part 3 – Technological and organizational developments

Traditionally, the data for an SDI have come from official or recognized professional producers of geospatial data using state of the art technology (Cooper et al., 2011b). Custodians of SDIs are starting to admit Voluntarily Geographic Information (VGI) into their SDIs (Cooper et al., 2011a). This could be in the form of revision requests or notices submitted to an SDI through its web site by the public (Guélat, 2009), or potentially even using large quantities of VGI (Cooper et al., 2011b). This revolutionary phenomenon might change the evolving concepts of SDI. An obvious concern with VGI that researchers should investigate is how its quality compares with official information (Haklay 2010) and how data can be incorporated into a traditional SDI with appropriate metadata and validation.

Also, further developments are needed in the software components of SDI to simplify and extend their use to the general public. The advent of content management systems at the end of the 1990s has revolutionized the way of publishing information on the Web. Suddenly, common users without any knowledge of HTML programming became able to publish information themselves through those CMS tools. This has yet to happen with the current SDI mainly benefiting GIS experts and national institutions. Many FOSS tools are already available (EasySDI and GeoNode) but the gap is still missing to allow non-programmers to contribute to a SDI freely and openly.

# 7.5.5 Conclusions

We have offered various suggestions to improve our methodological approach and questionnaire that might be extended in further research (extensions to our geospatial technology tools approach, additional questions to complete SDI readiness results, questionnaire to test SDI generational factors and additional questions on standards and policies). Finally, two of the recent developments worth researching in the SDI field include the VGI phenomenon and the advent of SDI packages solutions.

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