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Research Article

Actor-networks and implementation: examples from conservation GIS in Ecuador

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Abstract. Recommendations for implementation and evaluation of Geographical Information Systems (GIS) can benefit from a broader theoretical foundation to support investigation, understanding and improvement. This paper discusses Actor-Network Theory (ANT) as a framework to delineate and evaluate the social and technical interactions involved in GIS implementation. The proposed process traces actor-network interactions through texts, technical objects, people, money and control. Actor alignment, actor-network stability and obligatory points of passage are evaluated to compare actor-networks. Case study research on conservation GIS implementation in Ecuador illustrates these methods. The strength of these actor-networks is examined through analysis of actors' interactions and the presence and function of an obligatory point of passage. Stronger actor-networks exhibit alignment among actors, co-location of an obligatory point of passage with the center of calculation and credit sharing.

1. Introduction

Recommendations for implementation and evaluation of geographical information systems (GIS) can benefit from a broader theoretical foundation to support investigation, understanding and improvement. Traditional prescriptions for GIS implementation frequently consist of sequential steps to guide establishment of GIS primarily in local municipal organizations (Huxhold 1991, Antenucci 1991). Evaluations of success in GIS implementation have been based on accomplishment of organizational objectives (Guptill *et al.* 1988), data availability and data accuracy (Budic 1994). Other measures of success are subject to perspectives and judgments based on personal effects of GIS implementation and may change with the passage of time (Campbell and Masser 1995, 110). Examination of GIS diffusion, social networks and 'technical communities' (Assimakopoulos 1997) emphasizes the roles played by people, often leaving the larger influences and details of funding, politics and technology interactions by the wayside. These research efforts have contributed greatly to identifying the factors that play significant roles in affecting GIS implementation.

Research on GIS implementation contexts have expanded understanding of the prescriptive approach to implementation and explored the role of the organization

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and its politics. Campbell (1991) identifies three preconditions for the effective utilization of computers for urban planning: a clearly defined information management strategy, commitment of organization personnel and organizational and environmental stability. Campbell and Masser (1995) introduce three implementation perspectives that shape organization's efforts to establish GIS: technological determinism, managerial rationalism and social interactionism. With respect to politics, Pinto and Azad (1994) demonstrate the potential of Public Organization Theory to advance positive management of GIS implementation. Like the implementation step approach, these efforts remain focused on the public institution and municipal agency contexts. This emphasis on the organization as the implementation context hinders treatment of the multifaceted relationships that exist between internal and extended elements of the organization in social, technical and political arenas.

The difficulty in guiding and evaluating GIS implementation stems from the social-technical interaction nature of GIS. The importance of interaction between social and technical elements has been recognized in implementing information technology (Orlikowski and Robey 1991, Orlikowski 1992) and GIS (Innes and Simpson 1993, Campbell 1996). Orlikowski (1992) introduced a 'structural model of technology' as a conceptual and theoretical model to allow a deeper understanding of technology and organization interactions. Similarly, Pinto and Onsrud (1997) consider evaluating successful system implementation using approaches from Information Systems and Management Information Systems and point out their utility with respect to GIS. Again, these approaches are limited in their ability to treat interactions that extend beyond organizational boundaries to include specific contextual elements such as coalitions of organizations, interactions with hardware, software and data providers, and end users' information needs and capabilities.

This paper discusses Actor-Network Theory (ANT) as an alternative framework to identify and examine the extended collection of actors and interactions associated with a GIS implementation process. By removing the limitations imposed by categories and compartmentalization of human activities, ANT extends the analysis scope to include a greater range of entities and influences affecting GIS implementation. By considering the actors participating in the implementation and operation of GIS as components of an actor network, ANT is shown to support a broader understanding of the context for GIS implementation as well as contributing institutional, political and technical linkages.

Theory development to support analysis and understanding of GIS must be applicable in all contexts of implementation and application. Research on GIS implementation has frequently focused on established public and government agencies situated in western industrialized countries where the majority of GIS deployments have been concentrated. Outside of this realm the diffusion and adoption of GIS in new implementation contexts is increasing. The challenges encountered while employing GIS in non-western contexts are well known (Dunkerly 1986, Taylor 1991, Fox 1991, Hastings and Clark 1991, Yeh 1991, Poole 1995, Warren 1995, Dunn *et al.* 1997) and the use of GIS by grassroots conservation organizations is being investigated (Sieber 1997). In light of these developments, current research and construction of theoretical frameworks must be capable of addressing the diversity of actors and interactions that are encountered in expanding implementation contexts.

The applied portion of this paper focuses on GIS supporting conservation and natural resource management activities based in Quito, Ecuador. This implementation context is representative of efforts to resolve growth and resource management issues in countries where GIS is new technology. Conservation initiatives in Ecuador are introduced followed by the case study methods. The case study results and analysis include descriptions of the four participant GIS implementations, their actors and interactions, associated actor-network diagrams and a comparative analysis. The final section presents conclusions and suggestions for new research directions.

2. How to trace actor networks

Actor-Network Theory (ANT) is a framework for investigating society-technology interactions. This research framework was developed by studies in Science, Technology and Society (STS) for tracing heterogeneous networks of actors and their interactions involved in the production of science and technology (Latour 1987, Callon *et al.* 1996). In expanding the scope of analysis to include any influential element associated with the production of technology the creators of ANT emphasize description at the expense of explanation. They advocate approaching technology research without the limiting artificial divisions other disciplines erect between human, non-human, science, nature and society. To apply ANT is to assert that knowledge is local and socially constructed and society is created by science and vice versa.

One of the most important works on ANT is *Science in Action* by Bruno Latour (1987). In this book, Latour addresses the interaction of technical and social content in scientific activity and lays out a coherent research methodology for following scientists at work. Investigators utilizing ANT have engaged in empirical studies of science and society aimed at uncovering the processes that produce scientific representations (Callon 1985, 1991, Law 1985, 1991, Latour 1987, 1992, Akrich 1992, Bijker and Law 1992).

Since all interactions between humans are mediated through objects of one type or another (Law 1992, p. 383), ANT accepts humans, non-humans and their intermediaries as actors. By removing the analytical divide between humans and objects, we are better able to examine the nature of interactions that are the building blocks of networks both within and beyond organizations (Latour 1991, 1992, Law 1992). The perspective shifts the analytic focus from the organization to the characteristics and behaviour of actor interactions between elements of society and techno-science. The justification in this radical view is that if we want to know the origins of power and structure, then we must consider a broader range of components that collaborate and cooperate in their creation, proliferation and persistence.

As a recently developed research framework being applied to the diverse and often controversial topics of science and society, ANT is in a state of flux (Law 1997, Latour 1999). Another STS approach related to ANT that considers interactions between science and society is social worlds and arenas theory (Strauss 1978, Becker 1982, Clarke 1990, 1991). While both of these theoretical approaches are 'constructionist, relativist and focused on relations among actors' (Clarke and Montini 1993, p. 45), ANT encourages examination of specific actors' interactions. Social worlds and arenas theory adopts a broader perspective concerned with negotiated social order and the distribution of power (Clarke 1990, 1998). The components of ANT put forth and employed in this paper are strongly influenced by social worlds and arena theory, especially with regard to issues of control and power. Despite this extension of the theory, this research endeavor remains an ANT analysis because the fundamental unit of analysis is the actor-network, and not the larger overarching social structure.

2.1. *ANT components and supporting concepts*

Literature on the development and application of ANT offers a suite of useful and practical elements to delineate and characterize actor networks. While some of these concepts are longstanding in the practice of ANT, their derivation, interpretation and development are not entirely without contention. The interpretation of ANT concepts presented herein reflects an effort to bring their utility to bear for investigation of GIS actor-networks. Anticipating that most of these concepts are new to readers unfamiliar with ANT, I briefly introduce them here.

Interactions between actors are the primary building blocks of actor-networks and their many manifestations are called 'translations' (Callon 1985, Latour 1987, 1997). Between human actors, the translation of interests is roughly analogous to commitment and the negotiation of shared interests. Between humans and objects, translation occurs, for example, during design when the object is imbued with its purpose, program or script in how it interacts or affects other actors (Akrich 1992). Further translation takes place between the object and the actors it encounters as the initial program or script is altered through interaction. Actors that are strongly aligned through translation each share a vested interest in the activities of the other and form durable interactions. Poorly aligned actors require frequent negotiation of their interactions or may cease to interact. Challenges to the alignment between actors in a network are termed 'trials by strength' (Latour 1987, pp. 74–79).

Interactions between actors related to the production or support of technology are segments that together form an actor network. Convergence is a special case of translation that aligns the elements in a network (Callon 1991). In some cases, actor-networks can become so transparent or accepted that they are no longer recognized. In this case, alignment and durability lead to punctualization, a point where the network supporting an actor disappears from view. This takes place when the network components that are responsible for the production of objects or performance of functions are summed up in symbols or artefacts that encapsulate the network (Callon 1991). In the case of technology, punctualization takes the form of a 'black box' (Latour 1987).

ANT employs a number of conceptual elements that connect actors and transcend predefined categorizations. Star and Griesemer (1989, p. 393) introduce boundary objects as 'objects which are plastic enough to adapt to local needs and the constraints of several parties employing them, yet robust enough to maintain common identity across all sites'. Harvey and Chrisman (1998) demonstrate the utility of the boundary object concept to understand the interwoven relationships between people and organizations in the localized construction of GIS. They explore wetlands and technical standards as boundary objects that connect multiple agencies despite persistent disagreements over definition, measurement and implementation. Although they may be contentious, boundary objects play an important role in stabilizing institutional relationships.

Latour introduces the 'center of calculation' as a location where the accumulation, synthesis and analysis of observations to yield greater understanding (Latour 1987, pp. 215–57). He illustrates this concept with La Pérouse's voyage of cartographic exploration and the collection of 'immutable mobiles' (Latour 1990). La Pérouse is shown to be successful only when his inscriptions of the landscape are returned to

France where they can be presented and combined with other observations. Today's cartographic centres of calculation are often supported by GIS technology where data layers are inscriptions that are '...mobile, flat, reproducible, still and of varying scales, they can be reshuffled and recombined' (Latour 1990, p. 45).

Inscription devices are technical artifacts that record, and thus translate, nature, particularly in a visual representation (Latour 1987). Scientists use a multitude of instruments that make nature 'accessible' through the inscription of measurements as graphs, illustrations or maps. Inscription devices often punctualize the inscription device's actor-network and natural phenomenon being inscribed in the resulting graphic representation. In relation to a GIS actor-network, inscription devices are potent boundary objects that extend the collection of actors participating in an actor network. Information derived from satellite imagery is common in land use data sets, yet the process, techniques and actor-network that accountable for the data are commonly punctualized as a citation or reference to data sources.

Another important theoretical element in describing an actor-network is the 'obligatory point of passage', a node which acts as an intermediary between networks or network components. A strong obligatory point of passage exercises control over resources and is able to claim responsibility for the success of the network (Law and Callon 1992, p. 46). As a connective and controlling feature, the presence and function of an obligatory point of passage varies from network to network yet plays an important role in alignment and durability (table 1).

Co-location of the obligatory point of passage with a the centre of calculation, where control over resources coincides with the management and analysis of multiple data sources, may result in an especially strong actor network depending on the nature of constituent actors' interactions. In assessing the contribution of the obligatory point of passage to the nature of an actor network, the strength and nature of interactions among individual actors must be taken into account.

2.2. *What circulates?*

The methodological approach to investigate actor-networks is to observe and record the interactions, connections and effects of actors involved in the production of techno-science (Latour 1987). The difficulty in accomplishing this task is the overwhelming multitude of possible interactions and circulating entities that

Table 1. Potential advantages and disadvantages in the function of an obligatory point of passage in an actor-network.

	Strong	Weak
Advantage	Controls the network Perpetuates network existence Maintains interaction with participating actors	Distributed responsibility greater circulation Flexibility of interaction
Disadvantage	Network success inextricably linked to Success of the obligatory point of passage	Competing channels between actors circumvent resource control and responsibility for success Competing obligatory points of passage can fracture a functioning network

constitute an actor-network. Michel Callon (1991) has identified four main types of action intermediaries that circulate, align and define scientific networks:

- Texts
- Technical artefacts
- Human beings
- Money

In relating interest and arranging support for a particular perspective on a phenomenon, the scientific text defines 'the skills, objects and relations of heterogeneous entities' (Callon 1991, p. 136). Latour (1987) recognizes scientific publications as means to enrol, support, and extend networks. These scientific texts represent network associations through the citations and references that support the research. Scientific publications also document credit for success in research and investigation, an important factor in acquiring or maintaining control over resources (Latour and Woolgar 1979). Non-scientific texts such as contracts, internal reports, memos and progress reports also serve as intermediaries that can document actor interactions and establish credit. Information products such as graphs, maps and data base records can be considered texts for their ability to represent relationships between heterogeneous entities.

Technical objects align networks through programs of action (Akrich 1992, Latour 1992). A program of action dictates the resources required for the object to function, the skills an operator must possess to control and direct the object and the intended task the object was designed to accomplish. Examining the program of action of a technical object can serve as a means to identify inefficient, inappropriate or counter productive linkages that weaken a network. Human actors' programs of action derive from multiple sources such as social position, job description, responsibility, credit among peers, acquired skills and knowledge, desire, belief and even biological need. Position and function of human actors in an actor-network is predicated upon an appropriate set of acquired or innate abilities and the responsibility to interact with specific actors in the network.

Money as an action intermediary bridges the gap between actors with a vested interest in an actor-network and capacity to do work (Callon 1991). Money in the context of direct funding, sales or venture capital becomes translated into orders, actions and recommendations. The circulation of money transformed into action is representative of alignment between those actors providing the financial resources and the output or work accomplished by the actor-network. Money in and of itself is a powerful boundary object that may be traced through textual action intermediaries such as receipts, bills of sale and contracts.

In 'Aramis, or, The Love of Technology', Latour (1996) describes a failed transportation initiative in France, demonstrating the multiple levels of interactions and influences upon a network. Latour found that taken individually, money, politics or technological reasoning was insufficient to explain the failure of the network. Learning from this example, control should be a consideration in tracing an actor-network. The need to address and assess control or power relationships between actors has been recognized within social worlds and arenas theory (Clarke 1991, Fujimura 1992, Garrety 1997). The power relationships examined through social worlds and arenas theory revolve around the human social activities that lead to the construction of legitimacy, negotiation of social order, representation of others, and imposition of perspectives. In some situations control may be an action intermediary, in others it might be better considered as an interaction modifier. The multiple levels and degrees of control present in an actor-network make exhaustive tracing of control impossible, but remaining sensitive to the presence and effects of control upon portions of a network is a valuable contribution. The purpose of including control as an intermediary in delineation of an actor-network is to expose power relationships that might otherwise be ascribed to technology.

2.3. *Applying ANT to GIS*

The first step in applying ANT is to generate an initial functional sketch of the various actors, human, non-human, social, cultural, and technical, that interact in an actor-network. With respect to GIS, examination of interactions surrounding the hardware and software boundary objects will identify many important actors. The relationships between people, institutions and resources that support and perpetuate these technical artefacts constitutes the core portion of a GIS actor-network and is accountable for its operation. Data resources in a GIS are inscriptions that link the technology core actor-network to displaced landscapes and landscape processes through representation. Finally, the circulation of maps, data layers and reports generated at the GIS centre of calculation links information consumers to the GIS actor-network.

Thus far, the delineation of a GIS actor-network is principally a descriptive exercise and is generally consistent with traditional applications of ANT (see Law 1997). The principal accomplishment at this point is in recognizing the linkages between social and technical actors that comprise an operating GIS. Considered within the larger contexts of the actor-network, culture and society, specific actor interactions can be identified as more important than others in stabilizing an actor-network. Taken as a whole, examination of the actor-network's interactions can identify and characterize the presence and function of an obligatory point of passage. With structural analysis of an actor-network, it is possible to identify problematic translations between actors and consider their impact upon a GIS actor-network.

3. Case study setting: Ecuador

Before relating the research methods employed to apply ANT in studying GIS, a contextual foundation to the case study setting is required. This section introduces the importance of Ecuador's biological resources, the emergence of conservation organizations and their motivations to acquire and implement GIS.

3.1. *Biological resources*

Ecuador is a small country (283 560 km^2) with a population of about 12 million that straddles the equator on South America's west coast between Peru and Colombia. Possessing portions of the upper Amazon basin, the Andes Mountains, Pacific coastal lowlands and the Galapagos Archipelago, Ecuador is one of the most biologically diverse countries on Earth (Myers 1988, USAID/Ecuador 1989). Efforts to protect this biodiversity have resulted in the establishment of twenty state owned national parks and protected areas with plans to establish more. Combined, these areas cover more than four million hectares, roughly 16% of the nation's territory, and have significant national and international importance (Ponce and Huber 1982, Figueroa 1995, Varea *et al.* 1997) (figure 1).

Activities to preserve, conserve and manage Ecuador's protected areas have been undertaken by the Government of Ecuador, local and international Non

Figure 1. Ecuador's main geographic regions and system of national protected areas (Original map Instituto Geografico Militar, 1996).

Governmental Organizations (NGOs). Management of Ecuador's protected areas was the responsibility of the Ministerio de Agricultura y Ganaderia (MAG) until August 1992 and is now the responsibility of the Instituto Ecuatoriano Forestal y de Areas Naturales y Vida Silvestre (INEFAN) (INEFAN/World Bank 1993). Financial and technical support has been offered to INEFAN from a variety of international sources, principally USAID, CARE, The Nature Conservancy, and Wildlife Conservation International, to increase this agency's effectiveness in administering the protected areas (INEFAN/World Bank 1993, pp. 7–8).

3.2. *Environmental NGO's*

In addition to the expansion of governmental and international conservation initiatives in Ecuador (USAID/Ecuador 1989, USAID/Ecuador 1994, pp. 97–104) there has been explosive growth in number of conservation oriented NGOs. Fundación Natura, Ecuador's first environmental NGO, was founded in 1978 and at least 24 more NGOs were established between 1984 and 1993 (Meyer 1993, pp. 200–202). The arrival of these groups in the local conservation arena in Ecuador indicates that there were voids not addressed by existing conservation efforts. The proliferation of these organizations can also be attributed to the availability of funding from a variety of international sources interested in the conservation of tropical biological resources (Meyer 1993). International and donor agencies saw the appearance of Ecuadorian environmental NGOs as a means to circumvent institutional barriers in local government and a chance to broaden their impact in communities. These organizations participate in a broad spectrum of activities including environmental education, legal reform, buffer zone management, alternative income generation, promotion of agroforestry, biological monitoring and investigation, ecotourism and sustainable ecosystem management. While many of these activities are focused on areas other than the national parks and protected areas, some of these organizations work directly in the protected areas. A great number of projects conducted by NGOs are done under contract for or in co-operation with INEFAN (USAID/Ecuador 1994, p. 98). Examples of these are the creation and implementation of management plans, delimitation of park boundaries, socio-economic studies of communities within park boundaries and training programs for park personnel.

3.3. *Enter GIS*

In Latin America, initiation of GIS implementation and use began in the early 1970s (Smith 1992). Early GIS technology transfer in this region during the past decade was facilitated by the Organization for American States (OAS), International Development Bank (IDB), United Nations Developmet Program (UNDP), and the United States Agency for International Development, and was mainly associated with natural disaster planning (Smith 1992). In 1996 there were twenty organizations with GIS capability in Ecuador (CEPEIGE-PUCE 1996).

The growth and development of conservation GIS initiatives in Ecuador is the result of increased demand for information gathering and analysis services to support conservation planning and decision-making processes. Activities such as prioritizing areas for conservation efforts, design of management plans for national parks, improving administration of protected areas and establishing baselines for monitoring projects are locally recognized as able to benefit from analysis of geographic information (Fundación Natura 1991a, 1991b, 1995). GIS is viewed as an effective solution to managing and visualizing information resources for the benefit of conservation initiatives and the desire to acquire GIS technology and products among conservation NGOs is widespread (Troya 1997). International funding organizations are also interested in the potential of GIS to promote effective planning and monitoring of Ecuador's protected areas and biological resources. A number of organizations are providing resources or participating in the use of GIS to meet conservation objectives through the support of local governmental or NGO projects, including The Nature Conservancy (TNC), US Agency for International Development (USAID), The World Bank, Conservation International (CI), World Wildlife Federation (WWF), and CARE.

4. Case study methods

The concepts and methods related earlier in this paper were applied to investigate four conservation GIS initiatives in Quito, Ecuador. Quito, Ecuador's capital, was selected as the location for this case study because it is the centre of activity for much of the nation's conservation movement. Fieldwork, conducted during July and August of 1997, included preliminary research, selection of participant organizations, informant interviews and collection of supporting texts.

4.1. *Organizations, informants and interviews*

Preliminary research consisted of asking prominent members of Ecuador's conservation community to identify conservation organizations utilizing GIS to support their activities. In addition to a list of conservation GIS initiatives, the preliminary research stage also identified funding sources, clients, and other end users of GIS information products. From this information, four conservation GIS initiatives, three private non-profit and one government contract were selected and invited to participate based on their importance in the conservation community and their level of involvement with GIS. Each of the four organizations agreed to participate (table 2).

Each organization identified individuals that were the best informed about their ongoing GIS activities for initial interviews: technicians and the project managers. These persons provided information relating to the institutional context, history, training, funding sources, clients and future directions of the individual projects. Additionally, these informants identified others who might be able to offer alternative perspectives on their GIS activities from an administrative, client or funding perspective. Organization administrators addressed the utility of GIS in the institution's greater goals, changes in the institution's organizational structure as a result of GIS implementation, changes in operational practices, internal uses of the results or products from their GIS and future directions in the growth of their GIS. Clients and end users were interviewed to learn how they were making use of GIS information products and if they were effective. Funding source representatives provided information on their conservation agenda in Ecuador, their reasons for supporting the development of GIS initiatives, their role as owners or creators of information and data and how they were benefiting from their support of GIS. Three local private GIS contractors providing data preparation services were also interviewed concerning their activities and involvement with the participant conservation GIS initiatives. Twenty-five informants participated in thirty interviews. Some informants had multiple relationships with one or more of the participant GIS initiatives (table 3).

Table 2. Conservation GIS initiatives that participated in the case study.

Name	Status
EcoCiencia	Private non-profit
Fundación Natura	Private non-profit
Corporación Centro de Datos para la Conservacion (1998)	Private non-profit
CECIA/FEDEMA (1998)	Private non-profit Government Contract

Table 3. Categories of informant relationships to the participant conservation GIS initiatives.

Informant relationship:	
GIS manager/technicians	8
Organization administrators	4
Clients/end users	10
Funding source representatives	5
Contributing private contractors	3

4.2. *Supporting documentation*

Every effort was made to acquire texts documenting these projects' histories, institutional arrangements, funding, acquisition of technology resources and the established roles of people. Of particular interest were interoffice memos, and contract terms of reference that detailed the negotiations and contract governing a GIS project. Project proposals, interim reports and summaries, particularly for the larger funding sources and their local partners, were useful in illustrating various institutional perspectives on GIS as well as the rationale and means for supporting GIS technology transfer. Examples of map output from the projects were photographed or photocopied when available.

4.3. *Network diagrams*

The interviews and supporting texts were examined to identify the actors participating in the implementation or operation of a specific GIS and to characterize their action intermediaries. These actors and their interactions were sketched in an association diagram presenting a two dimensional visual overview of the actor-networks supporting the individual GIS initiatives. While there are no established methods for visual representation of actor-networks, the diagrams in this paper are loosely based on the actor-network diagrams of Law and Callon (1992). Following Orlikowski's positioning of technology at the centre of organizational structure (Orlikowski and Robey 1991, Orlikowski 1992), GIS technology is treated as a closed black box at the centre of each actor-network (see figure 2). The actors accountable for the GIS actor-network are located inside a grey square in the middle of the diagram. Additional supporting actors that provide input resources are arranged on the left and the recipients of information products or benefits produced by the GIS are on the right. Four categories of double-ended arrows signify the four action intermediaries that connect the actors to the GIS technology and to each other. These relationships are strictly topological: the length and direction of the vectors representing action intermediaries have no meaning. In some cases, multiple arrows are used to represent multifaceted interactions. Interactions that are characterized by the same action intermediary should not be considered equal within or across diagrams; each interaction is defined by the reciprocating exchange that takes place between the involved actors.

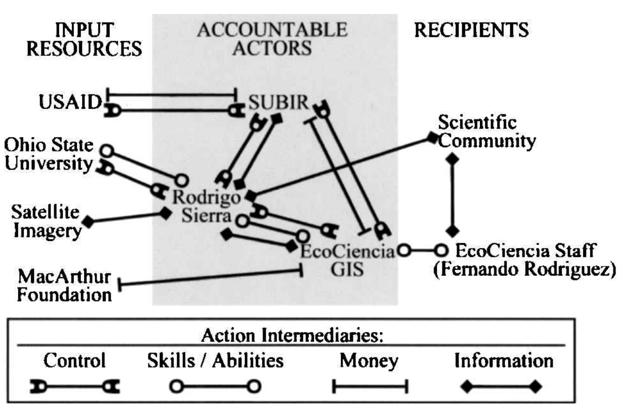

Figure 2. EcoCiencia's GIS implementation actor-network.

5. Case study results and analysis

The actor-networks of the four participant conservation GIS initiatives are presented in the following sections. Although the field research investigated several projects accomplished by these GIS initiatives, only the implementation actor-networks are described and analysed here. A section is devoted to each organization and presents a brief historical sketch, descriptions of each initiative's actors and interactions and an assessment of the actor network.

5.1. *EcoCiencia*

EcoCiencia is a non-profit organization that supports ecological/biological investigation, environmental education and natural resource management in Ecuador. Begun in 1990, they have grown into a multidisciplinary institution with a holistic approach to conservation initiatives incorporating studies in anthropology, sociology, economics and communication in their efforts. EcoCiencia has been a longtime cooperating partner with Sustainable Use of Biological Resources (SUBIR). SUBIR was a project funded in part by USAID and managed by a consortium of CARE International with The Nature Conservancy (TNC) and The Wildlife Conservation Society (WCS). Primary objectives of SUBIR were to provide a model for effective natural resource management and institutional strengthening of local conservation organizations. SUBIR Phase II (SUBIR II) began in 1994 and is managed solely by CARE which provides technical support to local NGOs who in turn provide implementation (USAID/Ecuador 1994, EcoCiencia 1997).

The actor-network that initiated the GIS laboratory at EcoCiencia is stabilized by the strong interdependent relationships among a few actors. Initiated in 1992 during doctoral dissertation research by Rodrigo Sierra, the network is composed of actors with a vested interest in each other's success (figure 2). Sierra, a student at Ohio State University under Larry Brown and Douglas Southgate, was investigating land use and deforestation in north-western Ecuador (Sierra 19940. EcoCiencia hosted Sierra's research and received funding from USAID administered through SUBIR to provided technology and data resources for this research. Ecociencia staff, led by Fernando Rodriguez, also used the GIS and image technology to conduct several small scale biological assessments utilizing remotely sensed data (Rodríguez *et al.* 1994a, 1994b, 1995). These additional projects were funded by SUBIR with resources from USAID and the MacArthur Foundation.

The common accomplishment of this actor-network is the establishment and operation of a GIS lab at EcoCiencia, but each actor engages in this network for different reasons. USAID fulfills its contract with SUBIR, SUBIR satisfies its mandate to lead and strengthen local environmental organizations, Rodrigo Sierra completes his dissertation and EcoCencia staff become trained in GIS and produce their own research. Alignment through funding is strong due to the compatible agendas of the funding institutions (USAID, SUBIR and the MacArthur Foundation) and the recipients (EcoCiencia and Sierra) who produce the work.

Another source of strength in this actor-network is the sharing of credit and circulation of information products. The activities of this actor-network are punctualized in several text documents: Sierra's dissertation (1994), a book version of Sierra's research (1996), three reports from GIS supported ecological analyses (Rodríguez *et al.* 1994a, 1994b, 1995) and numerous maps. Publication of literature for consumption by the scientific/academic community is the frequent end product of research and doing so legitimizes this GIS actor-network. Alignment with the scientific/academic community is strong due to association with and support from Ohio State University.

Rodrigo Sierra functions as a weak obligatory point of passage that is co-located with the centre of calculation (EcoCiencia's GIS laboratory). His research activities mobilize interactions with the other actors, a role analogous to the GIS champion, but they do not interact exclusively with him. Interactions between USAID, SUBIR and EcoCiencia predate the GIS actor-network and persist after conclusion of Sierra's research. These pre-established institutional relationships prove to be the most durable interactions of the actor-network as they continue to sustain operation of the laboratory after Sierra's departure.

5.2. *Corporacion Centro de Datos para la Conservacion Ecuador*

The Corporacion Centro de Datos para la Conservacion—Ecuador (CDC Ecuador) was created in 1993 as a private non-profit NGO by The Nature Conservancy (TNC), TNC local partner Fundación Natura, and Fundación Jatun Sacha. CDC Ecuador is a member of the South American Conservation Data Centers sponsored by TNC (The Nature Conservancy 1998). The mission of CDC Ecuador is to support the management and conservation of protected areas and rare ecological communities at risk of disturbance through the collection, generation, processing and diffusion of information (CDC Ecuador 1998). Initial activities consisted of Rapid Ecological Assesments (REA), a systematic method for gathering baseline biodiversity information for selected ecologically sensitive areas. As CDC Ecuador grew, a state of the art GIS was implemented with funding from TNC to support spatial presentation and analysis of biological data. Marcelo Guevarra, a technician with experience in remote sensing and GIS in European agencies and CLIRSEN, the military space agency of Ecuador, was hired by CDC Ecuador to lead the new GIS laboratory.

The fact that CDC Ecuador was fully funded and operational prior to engaging in contracts with other organizations changes the dynamic of the supporting actor-network. Without the significant barriers of cost associated with training and acquisition of equipment, the CDC is motivated more by an institutional mandate to circulate information than a need to acquire resources and develop technical capabilities and resources. This shifts the importance of the interactions in the actor-network from the translation and alignment of funding sources to those interactions that affect the production, delivery and use of information products developed by CDC Ecuador.

The first use of CDC Ecuador's GIS was to support the preparation of the new management plan for Podocarpus National Park in southern Ecuador (Guevarra 1997, personal communication) (figure 3). Fundación Natura, the organization responsible for developing the management plan for INEFAN, contracted with CDC Ecuador to conduct a REA of the park and prepare the required cartographic resources for the management plan. Specifications for the spatial information products supporting the management plan were established in the contract terms of reference between Fundación Natura and INEFAN. These terms of reference required eight thematic maps drawn to a scale of 1:100 000: base map, vegetation, hydrology, geology and soils, ecosystems, land use, critical areas and management zones.

The resource inputs for this initiative came from a number of diverse actors. Funding for the REA was provided by USAID while the cost of the cartography was shared between the CDC and Fundación Natura. Aeromapa, a private firm in

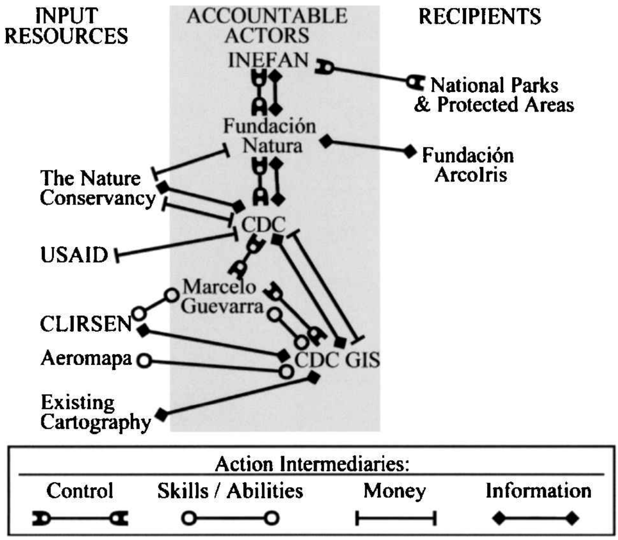

Figure 3. The CDC implementation GIS actor-network.

Quito, differentially corrected the field positional data. Satellite imagery acquired from CLIRSEN supported the creation of vegetation maps while data for geology, soils and infrastructure were digitized from paper maps.

The primary end users of the information products produced by this actor-network are Fundación Natura and INEFAN. Additional informal end users include the CDC who retains the database, TNC who operate the Conservation Data Center Network and Arco Iris, a conservation organization active in and around the national park. Beyond the information products produced, the staff members of the CDC gained experience from the process and demonstrated their ability to manage a complex project and produce professional results.

The strongest alignment in this GIS actor-network is between the CDC and its funding source, TNC. They both share a vested interest in success of the project as this will further the missions of both organizations and justify further funding. The weakest alignment is between the CDC and INEFAN as they disagreed over the specifications in the maps to be delivered. The CDC produced vegetation maps that went beyond the minimum information content detailed in the contract terms of reference raising objections from INEFAN. A letter responding to the objection explained the reason for the departure and the improved utility of the map supplied (Ortiz 1996). In addition to the eight maps specified by the terms of reference, the CDC produced an additional map of land occupancy, an intermediate layer produced during analysis for the final land use map. INEFAN's resistance to progress and cartographic innovation by the CDC is an expression of conflict between institutional agendas: national park management versus analysis and dissemination of information about natural resources.

Fundación Natura serves as an obligatory point of passage for this actor network in their control over resources in the network and responsibility for production of the management plan. The strength of this position is weakened since the final products are subject to review and approval by INEFAN. CDC Ecuador constitutes the centre of calculation in its dual role of gathering and processing the information resources about the park. Although important, this role is ancillary as it is encapsulated within the larger effort to create the management plan. This relationship is evident in the division of credit for products of the actor-network. The CDC is credited for the mapping effort and their logo appeared on the maps. In the official final document authored by Fundación Natura and approved by INEFAN, the efforts of the CDC are summed up in a single line of credit to the 'Technical Team' (INEFAN/Fundación Natura 1997).

CDC Ecuador and their GIS laboratory continues to be funded by TNC and has engaged in several other projects, including support for two other national park management plans. In these subsequent activities the alignment with the funding source remains stable and durable, but the obligatory point of passage and control over the actor network is substituted, as other organizations were responsible for authoring these management plans. The weak and renegotiated alignment between the centre of calculation and the end users of the information products suggests that this GIS actor-network could benefit from changes in interaction between these actors. CDC Ecuador and INEFAN would both benefit from dialog where cartographic standards are discussed and the potentials for information products to support management decisions are explored. Terms of reference for the delivery of information products reflecting the understanding between CDC Ecuador and INEFAN would help to stabilize this weak interaction link in the network.

5.3. *Fundación Natura*

Fundación Natura, Ecuador's oldest environmental NGO, is known for its focus on the social and political aspects of natural resource management. Their activities include promoting sustainable development, environmental education, lobbying political and legal initiatives, effective management of Ecuador's protected areas, conservation of biodiversity, promoting management of urban environmental resources and engaging in research to support these activities (Fundación Natura 1998). The organization's national office is located in Quito and they have three local chapters in Quito, Guayaquil and Azogues.

Fundación Natura's GIS was established in 1994 to meet the needs of their Amazonia Project, which started in 1992. Roberto Cruz, a consultant to Fundación Natura in charge of this project, proposed a GIS be established to incorporate existing cartographic resources with other regional data to design comprehensive management zones for Ecuador's Amazon region (figure 4). Nixon Narvaéz, a geography student at the Pontificia Universidad Catolica del Ecuador (PUCE) studying land use zoning in the Amazon, contributed to the design and implementation of the GIS. The Amazonia project was originally funded by the IUCN (REDLAT 1996) and supported purchase of a computer for the GIS. The rest of the system was assembled using resources from within Fundación Natura.

The Amazonia Project and development of the Amazonia database was cut short when the IUCN suspended funding for the project in 1996. In an attempt to finish the project, a contract for additional funding was negotiated with the government organization Instituto de Ecodesarollo de la Amazonia (ECORAE). This funding support was also cut short, ending the project. Existing results of the project and the database were delivered to ECORAE, local municipal governments in the Amazon region and indigenous communities with GIS capabilities.

The actor network that initiates Fundación Natura's GIS exhibits co-location of the centre of calculation with the obligatory point of passage, but the potential

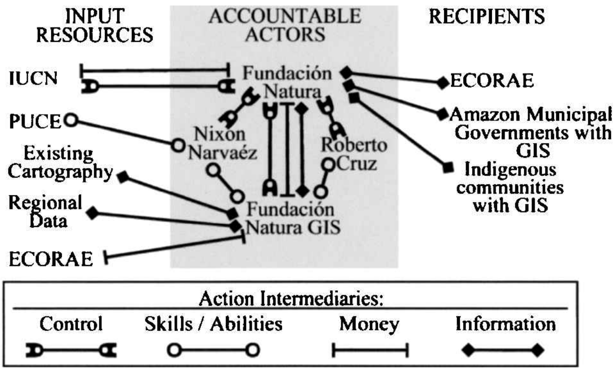

Figure 4. Fundación Natura's GIS implementation actor-network.

strength of this arrangement is undermined by alignment difficulties with funding sources and the information product end users. Fundación Natura's ability to continue the project during an interruption of funding and finally complete the project using internal resources illustrates the strength of this co-location. Although Fundación Natura has distributed digital data from the Amazonia project, alignment with these end users appears to be weak. By providing funds, ECORAE had a vested interest in the results, but not enough to see the project to completion. Likewise, local municipal governments and indigenous communities were recipients of the information products, but did not actively contribute to the productive activities of the actor-network. In spite of these weak alignments, Fundación Natura has a vested interest in circulating the project results to demonstrate success and accept responsibility for completion of the project.

At the close of the Amazonia Project, Fundación Natura redirected the focus of the GIS lab to internal information needs using internal resources. This change helped to stabilize the GIS actor-network by removing unstable interactions with actors from beyond the organization, but placed limitations on access to resources for continued operation.

5.4. *FEDIMA/CECIA*

In 1995, INEFAN, with support from the Global Environmental Facility (GEF) put out a request for proposals through the United Nations Development Program (UNDP) to identify and evaluate protected forests and private, community and state owned lands in southern Ecuador as potential protected areas. The contract required a multidisciplinary approach incorporating biological, economic, social and legal data with satellite imagery in a GIS. Two organizations, Fundación Ecuatoriana de Investigación y Manejo Ambiental (FEDIMA) and La Fundación Ornitologica del Ecuador (CECIA) teamed together and won the contract based partly on their strength in using bird species as indicators of ecosystem health. CECIA is a local partner of BirdLife International, an international ornithological conservation action organization based in England (CECIA 1998). FEDIMA biologists participated in the first biological assessment of the Cordillera del Condor in 1993 and 1994 (Conservation International 1998). The contract was awarded in January of 1996, but work did not begin until eight months later.

Christopher Canaday and Clemencia Vela, the authors of the FEDIMA/CECIA proposal, assembled an actor-network with the required skills and resources to complete the project (figure 5). Biological inventories conducted by FEDIMA/CECIA specialists, existing data from avifauna surveys (Conservation International 1998), and recent work by the Missouri Botanical garden were included in an analysis of biodiversity. The locations of species occurrences were combined with Holdridge life zone maps to identify concentrations of endemic species. Members of the FEDIMA/CECIA technical team conducted social, economic and legal field surveys to assess the potential impacts of human activity on the success of potential protected areas. Satellite images of southern Ecuador were acquired from CLIRSEN and analysed to locate the remaining large tracts of undisturbed vegetation in the region. Topographic maps from Ecuador's Instituto Geografico Militar (IGM) were used as base maps for the project providing a common spatial reference for GPS field observations. The biological and socio-economic data were compiled in a digital database by INFOESPACIO, a private GIS consulting firm in Quito.

This GIS actor-network had numerous technical interactions that required re-negotiation to maintain alignment. An initial set back to the project was difficulty acquiring promised satellite imagery from CLIRSEN. An antiquated data tape drive and lack of writable CD's caused an eight-month delay in delivery of the satellite images. Without another alternative cost-effective source for the imagery, there was no choice for the management team but to wait for the images to be delivered.

Unlike the three other GIS actor-networks investigated, this initiative did not have a single centre of calculation. At the time of the contract, neither the funding or contract organizations supported a functional GIS lab. Access to GIS technology was made possible through a contract with INFOESPACIO and with equipment owned by INEFAN, but had never been used. INEFAN's hardware had been purchased by GEF at the recommendation of a consultant, but no one at INEFAN was qualified to set up the system. Upon learning that this equipment was available, the technical coordinator for FEDIMA/CECIA, Chris Canaday, was granted access to conduct the satellite image analysis for the contract providing he set up the workstation. While alignment with CLIRSEN as a data provider and access to GIS technology were eventually stabilized, they required repeated negotiation. These interactions undermine the strength of the FEDIMA/CECIA leadership as the obligatory point of passage because they cannot effectively control these resources and success of the project hinges on their availability.

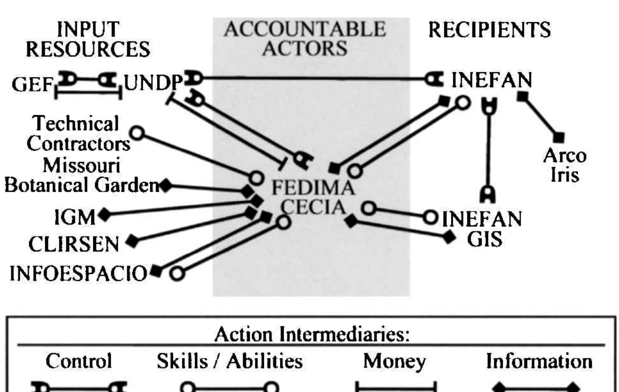

Figure 5. The FEDIMA/CECIA/INEFAN/GEF GIS actor-network.

Poor alignment was also observed in interactions with the information end user, INEFAN, through conflicts in the contract terms of reference on potential protected area criteria and cartographic specifications. The criteria were established in the contract terms of reference authored by the UNDP using content from INEFAN (INEFAN/GEF 1996). Use of GIS to support the analysis was required, but the specific nature of the analysis procedure using GIS was not fully detailed. Thirteen criteria in four categories were identified to support comparison of the potential protected areas (table 4) exactly how to measure these criteria was not addressed. While criteria such as uniqueness, naturalness, and social acceptance are important to consider in planning a protected area, applying these criteria is situation specific and defies standardization.

Six maps were specified for the final results: base map (drainage, topography, population centres and roads), ecology (ecosystems and related wildlife), land use, negative environmental impacts, proposed protected area boundaries, and tourism/recreation value. All maps were required to be 1:100 000 scale with an acceptable margin of error no more than 50 m. During preparation of the final cartographic products, the contract team determined these scale and accuracy requirements were excessive for the project information content. The strict cartographic specifications were seen as an attempt by INEFAN to pursue a data development strategy at the expense of the contracting organizations.

At the conclusion of the project, the disagreements over measurement criteria and information specifications threatened acceptance of the results by INEFAN. Despite the criteria to standardize analysis and delivery of information resources, the contracting organizations felt that the FEDIMA/CECIA team placed too much emphasis on biological factors and the information resources and analysis of social, economic and legal aspects were not sufficient. This disagreement illustrates competition between FEDIMA/CECIA and INEFAN/UNDP/GEF as the obligatory points of passage in this actor-network. FEDIMA/CECIA controls the execution of the project yet it must operate under standards set in the terms of reference and final products are subject to approval by INEFAN/UNDP/GEF. Credit for the accomplishments of the actor-network cannot be shared because the results are in dispute and neither party wants to recognize the contributions of the other.

Table 4. INEFAN/GEF evaluation criteria for potential protected areas (INEFAN/GEF 1996).

Criteria category	Criteria
Ecological	Uniqueness
	Diversity
	Disturbance
	Size
Educational/scientific	Access
	Monitoring
	Investigation
	Demonstration
Social/economic	Recreation
	Tourism
	Scenic value
Pragmatic	Urgency
	Opportunity

The unstable technical interactions and competing centres of calculation in this actor-network place the productivity of this actor-network in jeopardy. Like the CDC Ecuador actor-network, standards and technical specifications become contentious and require repeated negotiation between the information provider and end user. These difficulties might be avoided if the information product specifications were established with participation of the information provider. Alternatively, the underlying goals behind information product specifications could be made public and transparent so a contractor could make suggestions on the best means to accomplish them. Uninformed parties who write unreasonable terms of reference into a contract should expect difficulty during execution and potential contractors should know enough to avoid such contracts. Informed strategic planning on the part of INEFAN to develop coherent geographic information policies to support their needs in management of Ecuador's protected areas would help to improve their alignment with the GIS actor-networks in which they interact.

6. Conclusions and new directions

This investigation has demonstrated that application of ANT to study GIS implementation produces useful insights into the effects and impacts of social interactions surrounding GIS technology. ANT opens analysis of GIS to include diverse social and technical actors that affect the nature of GIS implementation. Tracing actor-networks permits examination of these actors' interactions that contribute to the durability and function of a GIS actor-network. Examination and comparison of these networks show that they are all different despite similar topical domains. This illustrates the important role that context plays in configuring GIS. Explanation of why similar GIS implementations produce different outcomes is predicated on detecting differences in the constituent actors and their interactions.

Although this investigation only examined four GIS actor-networks that focus on conservation issues in Ecuador, there are some patterns that are worth mentioning. Unlike other actor-networks that converge to produce a technical artefact (see Bijker and Law 1992), GIS actor-networks converge to produce information artefacts that circulate. All of these actor-networks managed to produce information artefacts, but there are marked differences in their alignment with the various the end users. Rodrigo Sierra and EcoCiencia produced information artefacts for the scientific community with which they are well aligned while Fundación Natura made their own efforts complete their project and deliver the results to users who might find it of value. Both CDC Ecuador and FEDIMA/CECIA struggled with expectations set forth in contract language in delivery of their information artefacts. While all of these implementations can be considered successful in circulating their work, they exhibit degrees of success.

Alignment with resource actors and effective substitution of actors is another pattern that may contribute to a GIS actor-network's ability to create and circulate information artefacts. The ability to substitute actors in a network is an effective means to survive trials by strength (Latour 1987). Rodrigo Sierra leaves EcoCiencia after completing his research, but the GIS lab continues to function as the institutional relationships remain intact and other staff takes over his responsibilities. CDC Ecuador maintains alignment with its funding source and continues to contribute to the preparation of other national park management plans. Fundación Natura experienced three substitutions of funding sources yet still manages to produce data products. In these examples, a weak obligatory point of passage and the ability to substitute actors and resources is an important GIS actor-network quality. The weak obligatory points of passage competing for strength in FEDIMA/CECIA actor-network had few options for substitution of resources (satellite image access, technology access) and disputed acceptance of the final information products.

Successful circulation of information artefacts that credit the responsible actors could be considered a measure of success and may lead to continuation or expansion of the actor-network. Effective geographical information products are potent allies contributing to the creation of facts (Latour 1987, 1990). An actor-network that can claim responsibility for the creation of an information artefact is proof that the actor-network is operational. Sharing credit across the actors in the network is an important contribution to stabilizing actor-interactions where credit is valuable. Circulation of an information artefact extends the GIS actor-network and further legitimizes its existence. This circulation also acts like advertisement of the GIS actor-network's abilities and may lead to future stabilized interactions with funding sources and clients that bring more resources to the actor-network. In the EcoCiencia GIS actor-network, credit is important because the information artefacts are aimed at the scientific community. CDC Ecuador is willing to accept less credit for their work with Fundacíón Natura and INEFAN because their funding source is more secure and part their mission is the diffusion of information. Fundacíón Natura works hard to circulate their information artefacts after repeated funding difficulties to because it is a part of their mission statement and to demonstrate that their GIS is operational.

While stability in actor interactions is certainly an important contribution to the stability of the entire actor-network, overall network structure plays a complimentary role. These two aspects of actor networks need to be considered simultaneously to understand why one actor network withstands its trials of strength and another does not. Strong alignment with multiple and redundant interactions between constituent actors can result in an actor network that lacks an obligatory point of passage, yet is better able to withstands trials by strength. Presence of an obligatory point of passage can contribute to network strength if it can mediate between actor-networks, maintain interactions between actors and successfully promote circulation. This is the case with EcoCiencia where Rodrigo Sierra, a weak obligatory point of passage, can be effectively replaced with a new laboratory director. Sierra initiated interaction among actors and a new lab manager will inherit these interactions. A strong obligatory point of passage may be the Achilles heel of a network during a trial by strength if the actor interactions cannot be maintained or substituted.

With respect to overall GIS actor-network structure, co-location of the obligatory point of passage was observed as a possible indicator of network stability. While the actual impact of co-location or separation on GIS actor-network stability depends on context and actor interactions, examining this relationship is revealing about the behaviour of a GIS actor-network. The GIS actor-networks for CDC Ecuador and FEDIMA/CECIA exhibited separation and they both experienced difficulties in alignment with the intended end user. If the obligatory point of passage is a management node that is not well versed in the capabilities and resource requirements of GIS, then repeated negotiation with the centre of calculation will be required to complete the objectives of the network. Conversely, co-location means the mobilization of resources is informed by system requirements and credit for production of information is more explicitly linked to the GIS.

Finally, this research suggests several new directions towards investigation of GIS social-technical interactions with ANT. GIS actor-networks positioned in a variety of social contexts should be traced to verify repeatability and refine the use of ANT for this topic area. I expect other researchers would encounter a wider variety of actor interactions that influence the stability and durability of GIS actor-networks than those observed in this investigation. Generalizing patterns of actor interaction as predictive of GIS actor-network instability would require a large body of research to establish correlation. It is worth noting that the use of ANT for predictive or diagnostic purposes is quite unfaithful to ANT's founding precepts (Law 1997). For the moment, the best use of ANT for investigating GIS may be to continue exposing the social interactions behind GIS operations so practitioners, managers, theorists and researchers will be more sensitive to building stable GIS actor-networks.

Adopting a longitudinal approach, ANT could support investigation of actor interactions in response to shifts in GIS use, incorporation of new technologies, developments in public policy or fluctuation in availability of resources to sustain GIS operations. Some of the most important challenges facing existing GIS installations are changes in technology and data resources. How these changes are introduced to a GIS actor-network and how they affect network stability remains to be investigated.

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