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PRAGMATIC INFORMATION MANAGEMENT FOR ENVIRONMENTAL MONITORING IN OIL AND GAS

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Abstract

The oil and gas industry has an installed base that is characterized by local fragmented approaches for data management. Inside this information infrastructure, real-time monitoring of the subsea environment remains an unexplored arena that demands a cross-disciplinary and cross-organizational data integration layer. Semantic technologies have been proposed in the literature as a possible standardization solution. Their development depends on collaborative processes involving business partners from different industrial domains, thus requiring that an equifinal level of understanding is reached and boundaries of knowledge sharing are overcome.

We describe an ethnographic study from an inter-organizational project in an oil and gas company, where the objective is to develop an integrated solution for real-time subsea environmental monitoring. We identify the challenges that emerge when sharing knowledge at a boundary on a syntactic, semantic, and pragmatic level. (i) The different backgrounds of the organizations involved and (ii) the unresolved issues affecting semantic-based solutions influence the possibility of reaching a shared understanding at a syntactic and semantic level. We open the black box of semantic technologies thanks to an information infrastructure perspective and conclude that collaboration can be carried out on a pragmatic level by addressing the implications of the specific technology.

Keywords: Information infrastructures, Semantic technologies, Environmental monitoring, Knowledge sharing.

1 Introduction

Since the discovery of oil in the North Sea in the late 1960s, Norwegian industries have continued to make technological discoveries that have brought them to the forefront of innovation. Subsea operational facilities are now being installed on the Norwegian Continental Shelf (NCS) for exploration, extraction, and production of oil and natural gas, and these facilities are connected via fiber-optic infrastructures to control centers onshore. A compound element of novelty characterizes this unexplored scenario. Not only are there modern sensors in place to measure various parameters, but the real-time availability of the data opens the door to solutions that were previously unconceivable. However, this process has to fit a reality that is the result of at least 40 years of activities. According to the Norwegian Petroleum Directorate, 70 oil and natural gas fields are in production on the NCS (NPD, 2012). Each of the operational assets connected to them has its own historical background, and its employees have developed diverse local work practices (Rosendahl and Hepsø, 2013). Over the years, massive amounts of heterogeneous information have been accumulating in large databases (or "silos") spread over different systems and different operational fields that can be connected to several wells at the same time. No integrated solution is currently available for standardizing and accessing information across technological, professional, and geographical boundaries (Hepsø et al., 2009). Nevertheless, operators in the sector have learned how to co-exist with this reality and have cultivated daily heuristics and workarounds to cope with it (Monteiro et al., 2012, Østerlie et al., 2012).

The monitoring of the marine environment surrounding the field remains an immature discipline among the many activities performed on an oil and gas asset. Traditionally, environmental samples and data are collected offshore via bi- or triennial campaigns. Physical, chemical, and biological data are shipped to shore, stored, and analyzed, often with a temporal gap of 9-12 months (KLIF, 2011). This methodology may be adequate to report the status of polluted areas and the effects on local fauna. However, it is not suitable to proactively prevent possible environmental damage from current or future activities. A standardization effort is required to achieve a cross-field overview of the status of the marine environment within the information infrastructure of the oil and gas operations. Even when blended into a well-established installed base, real-time environmental monitoring represents a unique opportunity for the industry to abandon the chronically local, silo-based methods of handling information and move towards more global, integrated, and networked practices.

Semantic technologies emerged in computer science as a promising solution to provide standardized and consistent storage and access to real-time multi-sensor data (Gulla, 2009). The development of these technologies is an inter-disciplinary and inter-organizational achievement. In practice, they tend to reproduce the struggle to find a balance between older and newer methods used to manage information that is representative of the information infrastructures they support. On the one side, the oil and gas industry is a conservative and strictly regulated domain that is considered a fertile terrain to apply the standard-based, top-down information modeling solutions to realize architectures for data integration and interoperability (Gulla, 2009, Verhelst et al., 2010). These approaches are endorsed by institutions and non-profit organizations promoting the development of data specifications. On the other side, new tools are being developed, inspired by the Linked Open Data set of best practices (Bizer et al., 2009), to share and reuse community-approved vocabularies that begin to question the role of former approaches.

Understanding how information is transformed into meaningful knowledge is therefore the key when addressing the challenges of standardization processes in situations where the inter-organizational setting does not allow shared communication practices. In this paper, our objective is to provide a better understanding of how collaboration can be organized around *equifinal meanings*, i.e., by relying solely on approximate or sufficient levels of shared understanding (Donnellon et al., 1986). We set the following research question: *How can a collaborative process be performed at an equifinal level?* Our answer highlights the need to include the implications of the technological choices and to adopt an information infrastructure perspective to encompass the absent presences into the culture of an organizational reality.

The remainder of this paper is organized as follows. In section 2, an overview of the theoretical basis underpinning our analysis is presented. In section 3, the method we adopted is described. Section 4 presents the results of the ethnographic study on which our analysis is grounded. The results are further discussed in section 5. Section 6 presents the conclusions and some implications of the study.

2 Towards equifinality in information infrastructures

The availability of real-time environmental data presents an element of novelty in the complex scenario of oil and gas operations. In a recent working article by Carlile and Lakhani (2011), innovation is said to have its "sweet spot" in the tradeoff between the exploitation of older elements and the exploration of newer ones. The innovation cycle is inherently distributed across the relationships between social and technological actors. They form an interconnected socio-technical system, labeled *information infrastructure* by a stream of literature (Monteiro and Hanseth, 1995), to stress the fundamental role of information flows and to acknowledge the importance of understanding the interplay of heterogeneous aspects in design, implementation, and use of technology.

2.1 The top-down/bottom-up tension of standardization

The realization of an information infrastructure in practice is a matter of knowledge management, in that it consists of collecting information from different sources and transforming it into relevant knowledge for diverse audiences. In a complex scenario such as that of an oil and gas company, this process has been depicted as a continuous tension between *top-down* institutional requirements for more global integration and *bottom-up* reliance on information generated locally by heterogeneous disciplines and devices (Hepsø et al., 2009). The addition of a semantic capability to an information infrastructure has emerged in literature as a possible alternative to assigning a unique value to data (Gulla, 2009, Verhelst et al., 2010), thus bringing to the forefront the supporting role of semantic technologies. In practice, semantic capabilities mirror the continuous top-down/bottom-up tension characterizing information infrastructures by enabling different paradigms of knowledge management. One of the features of semantic technologies is the machine-usable content; however, the level of standardization, i.e., *how* information is actually put into the machine is at the heart of the confusion around this definition (Uschold, 2003). Indeed, two distinct and separate camps can be found in the literature. With respect to the first camp, many expectations have arisen around ontologies as a top-down approach to achieve "overall standardization", and several IT companies have plunged into this new emerging market. For example, the "oil and gas ontology", based on the ISO 15926 standard, has been used to model oil and gas production plants (Gulla, 2009). Nonetheless, such a methodology is struggling to gain momentum, and experience shows that moving from prototype solutions towards relevant industrial applications is an underestimated problem (Hausenblas, 2009, Hepp, 2008). Top-down semantic information models developed by experts rely on a strong expressive power and predetermined meta-data structures. However it is difficult to make their utility visible to end users who do not directly require them (Hepp, 2008). The fragmented reality of oil and gas information systems and the challenges imposed by the unexplored context of real-time environmental monitoring demand more flexible solutions to account for the local users' practices and natural characteristics of an operational site. Knowledge about the submarine environment is constantly evolving, and newer generations or combinations of technologies become available on a daily basis. Propositions to integrate the emerging technical and social aspects through bottom-up approaches (e.g., by adopting folksonomies) have been proposed in computer science; see, e.g., Mika (2007). A tradeoff between the power of expressivity and the usability of a semantic data model is necessary in an information infrastructure where the requirements for stricter control must co-exist with the need to find new directions in an open scenario. With respect to the second camp, Linked Open Data have recently come to the fore as a set of best practices for data modeling to connect community-approved vocabularies and datasets (Bizer et al., 2009). They provide the conditions to make (a possibly huge amount of) data available on the Web in a standardized and reusable format, even though to date, few datasets with a clear connection to real-world problems exist (Hausenblas, 2009).

2.2 Negotiation at a boundary

To exit the top-down/bottom-up dichotomy, the formalization of the knowledge flows within an information infrastructure requires an in-depth analysis of the interwoven and dynamic relationships between its elements. Information infrastructures emerge through a socio-technical process of *negotiation* among human and non-human actors. For instance, actor-network theory (ANT) provides a well-known language in the information system research community to delve into complex phenomena and to unwrap an information infrastructure at different levels (Monteiro and Hanseth, 1995). Even if this article relies on an ANT-inspired vocabulary, the argument that it brings forth seeks to avoid a side effect of this approach, i.e., the black-boxing of the technological element in organization studies (Monteiro and Hanseth, 1995, Orlikowski and Scott, 2008). However, the members of an infrastructure have problems that go beyond the technology and encompass economic, political, and organizational factors (Ribes and Finholt, 2009). Later versions of ANT allow for a flexible representation of the mutable interplay between more or less visible actors as well as relationships distributed in time and space (Mol, 2002). The formalization of knowledge is therefore understood to be *dependent on* and *generative of* a set of necessary absent elements brought to presence (Law and Singleton, 2005). To further complicate things, the participants in collaborative practices in the oil and gas industry belong to heterogeneous disciplinary domains and worlds of thought. Nevertheless, they can relate to each other through either material or immaterial artifacts called *boundary objects* (Star and Griesemer, 1989). The difference between the actors' knowledge at a boundary of communication can be divergent, and the consequences of integrating knowledge across domains are not necessarily worth the cost expended. The incompatibility is due to differences in the knowledge regimes, i.e., the combination of artifacts, work practices, and conventions of each actor (Howard-Grenville and Carlile, 2006). A boundary object should be endowed with a common denominator that each community can refer to, but it can play different roles or have "extra meaning" within each separate community (Star and Griesemer, 1989). Objects can be depicted not only as instruments to achieve the successful management of knowledge at a boundary (Carlile, 2004) but also as triggers of contradictions and further negotiation (Nicolini et al., 2012). Their original purpose is enabling a shared level of understanding of the context of action between the communities involved. The exact amount of sharing is difficult to measure, if it occurs at all, but it should at least happen at an *equifinal* level (Donnellon et al., 1986), as quoted by (Berntsen, 2011). *Equifinal* is a term that originated in system theory and is also used in software engineering to describe a situation where a given end state in an open system can be reached by many potential routes. Interpretations might be totally dissimilar but have similar behavioral implications thanks to short-lived and highly situated forms of collaboration and knowledge sharing. Based on the type of knowledge available at a boundary, there are increasing levels of complexity in the communication process: *syntactic* (a common lexicon is sufficient for knowledge transfer); *semantic* (different domains generate interpretive differences); and *pragmatic* (different interests emerge such that finding common knowledge is a political process of negotiation and alignment). Carlile (2004) proposes a well-established theory of practice that consists of three progressively complex capabilities to create enough common ground to unpack the challenges of collaboration in practice: knowledge transfer, translation, and transformation. Innovation in collaborative settings can therefore happen if all three types of capabilities are iteratively developed. It is important to emphasize how for Carlile, translation is only one of the steps to enact collaboration, while in ANT's terminology, it has a more general meaning, i.e., that every process can be decomposed into a translation process.

3 Study context and method

Subsea installations can be integrated with environmental observatories based on existing technologies (e.g., landers equipped with sensor networks, remotely operated vehicles, or floating buoys) to assess on-line the environmental impact of operations. Human presence and direct intervention are not possible on subsea facilities, so sensors are the only source of data available. They might be faulty and differ significantly, e.g., in terms of data representation and accuracy. In addition, the oil and gas industry has no standardized knowledge about how to handle sensor-based real-time environmental data. The Deepwater Horizon blowout in 2010 is a notorious example showing that the availability of information does not directly imply its efficient interpretation by the different groups working on a platform. Initiatives to address this problem have already been taken elsewhere, e.g., the Alaska Ocean Observing System (http://www.aoos.org/) and the Monterey Bay Aquarium Research Institute (http://www.mbari.org).

A relevant project in the oil and gas domain was started in late 2011 by NorthOil[1], a multinational energy company. NorthOil awarded a consortium of international companies a three-year contract to design and develop a hardware and software solution to aid in the acquisition, elaboration, interpretation, modeling, and usage of sensor-based environmental data collected from the subsea fields. NorthOil's goal was to enable a cross-asset, standardized data representation and simultaneously to open the system to on-line environmental data. The added business value would allow NorthOil to more readily gain access from authorities to harsh Arctic areas where there are new discoveries of oil and natural gas. The project, EnviroTime, states that the process of real-time data handling from acquisition facilities to control centers should include *"the development of a semantic model (or ontology) to describe concepts, relations and properties within the EnviroTime domain."* Given the unexplored scenario, NorthOil purposefully left some uncertainty as to the end users. Members of the consortium are:

- *O&G Solutions*, a major supplier of IT solutions and sensor and communication technologies for the oil and gas industry, seeking a stronger business value in software and hardware integration;
- *ITCorp*, a world-wide provider of corporate technologies, with a long experience in realizing large systems for different business sectors, interested in broadening its role in semantic modeling by leveraging its own proprietary technology;
- *QualityCertificationBody* (*QCB*), a global service provider for certification and risk assessment, aiming at setting the standards for offshore environmental monitoring compliant with technological and modeling standards from international standardization bodies.

According to the shared documentation, the ad-hoc Design&Modeling group had the mandate to "*supervise the technical implementation during the project.*" For the purpose of our research, while keeping an eye on the overall situation, we focus primarily on what happens inside the Design&Modeling group to negotiate the realization of a semantic model.

The first author is a researcher from a Norwegian university who was granted full access to the offices of NorthOil beginning in March 2012, a few weeks after the official start-up of the EnviroTime project. Since then, she has been spending 2-3 full working days a week in the NorthOil offices. The second author has been an employee of NorthOil for 20 years as a senior researcher. This paper relies on the empirical data that the first author has been collecting over a period of one year as part of an ongoing longitudinal case-based study conducted in parallel with the design and development activities within the project. The study is ongoing as of March 2013. The findings are supported by the collaboration with the second author, thanks to his long experience in the oil and gas sector. Specifically, the activity took the form of ethnographic field work. Table 1 provides an overview of the main modalities of data gathering, the type of sources used, and the topics covered.

[1] All proper names have been dubbed for the sake of anonymity

As a strategy to data processing and sense making, we adopted a temporal bracketing of the data collected during the ethnographic study into four phases to provide a unit of analysis and to identify the constraints of and reasons for the actors' actions (Langley, 1999). An interpretive approach has guided the process of data evaluation and interpretation (Walsham, 1995), informed by the seven principles presented by Klein and Myers (1999). The overarching principle of the hermeneutic circle, in particular, considers the interdependent meaning of the parts and the whole that they form. Given the number and the heterogeneity of the elements involved in the project we have analyzed, this principle guided our iterative data collection. For instance, since the beginning of the activity, the author has analyzed internal documents available on the NorthOil intranet, not only regarding the project itself but also with reference to the long-term strategies and views of the company. Having a broader knowledge about the actors helped the author to understand their choices. The entry point for the author's research activity was one NorthOil project manager. This may have affected the direct interactions with the other companies that subsequently occurred in semi-formal and formal settings. We acknowledge that this might be a limitation to the research, but having a key actor introducing us to the project was fundamental. In addition, we do not underestimate the value of allowing an outsider to be involved in the daily informal life and activities of an oil and gas company. This let us develop an understanding of the context that would most likely be impossible otherwise.

SOURCE	TOPIC/DESCRIPTION
Digital data sources	

- MS SharePoint team sites (Intranet):
  - Internal to NorthOil
  - Shared with partners
	- Long-term strategies and views of NorthOil
	- Private emails exchanged during the project (either internally or with partners)
	- Official reports and deliverables
	- Internal notes and presentations

Internet-based public information	- Official online information about NorthOil and its partners - Official guidelines and reports from the Norwegian Petroleum Directorate, the Norwegian Ministry of the Environment, standardization and certification bodies (e.g., W3C, ISO, etc.) - Reports on past environmental accidents
Semi–structured and unstructured interviews (transcripts)	
4 project managers from the GlobalMapping project	- Semantic technologies - Evaluation of GlobalMapping
9 participants in EnviroTime with different roles	- EnviroTime project, environmental monitoring in oil and gas - Relations between the EnviroTime project and past projects
Unobtrusive or participatory observations (field notes)	
- NorthOil internal briefing sessions - 9 teleconferences (1-6 h) with other NorthOil offices and with the partners - 3 workshops about EnviroTime	- Exchange of ideas - General issues in the EnviroTime project - Development of the semantic model
Other (field notes)	
- Informal chats - 3 conferences on science and practice in oil and gas - 4 full-day seminars at research centers	

Table 1. Overview of the empirical data sources.

4 Results

PHASE 0 – Background and context – In late 2011, NorthOil was executing a project in partnership with ITCorp to implement the GlobalMapping infrastructure to provide a global semantic model of production and asset data. The goal was to overcome the locality of data that is intrinsically due to the peculiar geological properties of the drilled terrain, the different structures of the wells and equipment, and the historically weakly coupled nature of the operations. In addition, different naming conventions have been established to refer to data stored on local information systems, causing a high level of fragmentation not only across fields but also across different disciplines. Standards are available for storage, but when a new or non-standard type of measurement is retrieved, it has to be handled manually by engineers to ensure quality and communication with other systems. The global model was intended to be based on a top-down ontology containing concepts from a number of well-recognized industrial standards. The need for a data integration solution was so great that many competitors showed a continual interest in the advancement of GlobalMapping. The project had been progressing for a few years, and, even though its start had been "fair enough", it was now struggling to move forward, mainly because of two factors. First, the technological choices did not allow scalability of the solution, thus constraining NorthOil developers to the proprietary pieces of code provided by ITCorp. Second, the lack of data standardization at the level of a single asset made the mapping of the data from local storage to the global model an obstacle. In addition, NorthOil management had difficulty mobilizing resources for the project, i.e., the local assets that were intended to finance the integrated solution did not recognize its utility. The NorthOil IT department took an active role in the development and testing activities performed by ITCorp and some misunderstandings arose between the developers at ITCorp and NorthOil. In spite of that, NorthOil hoped that the GlobalMapping solution would become a part of the installed base in a few months.

PHASE 1 – Lack of a common/shared terminology – In an interview conducted in October 2012, a NorthOil marine biologist tells about her experience with data management: "*I used for instance two months to get access to some videos. Depending on who did the service it was stored in different systems and to some extent the videos are not stored in any system at all because there is a link to find them on disks. So […] I see we definitely have no good system to get access to the existing data either. Of course those who use these data and collect these data on a daily basis then know where to find it. But for environmental-related issues there is already a large amount of information that is collected […], but for different purposes than environmental purposes then environmental people do not have access to it or it is very hard to get access to it because […] you need to know people to get access to hard disks or you need to know the system well to access these data. […] It is even worse to have data that are not accessible than to not have data at all.*" In 2011, NorthOil had performed preliminary tests in two fields at different geographical locations to remotely assess the impact of drilling activities on coral reefs on the sea bottom. The following practical issues emerged: How to make sense of mismatched readings from neighboring sensors? How to predict if the water current will take a discharge close to corals using a limited number of readings? To answer these questions, NorthOil initiated the EnviroTime project in early 2012. O&G Solutions was hired as the main partner and enrolled ITCorp and QCB. The contract the parties signed was composed of two sub-sections: a technical specification and a legal statement. According to a NorthOil project manager, the terminology used in the legal part to refer to the final product was left as open as possible because of NorthOil's intention to be the legal owner of the final product regardless of its format. The technical section of the contract required "*the development of a semantic model (or ontology)*" and made explicit reference to ITCorp's architecture currently under development for the GlobalMapping project. Additional shared documentation clarified the hierarchy of the project responsibilities. In the first version of the contract, ITCorp was intended to be the only partner in charge of implementing the semantic model. However, QCB demonstrated a strong interest in participating, and provided its own funding. A lack of a common definition of the concepts of "semantic" and "ontology" emerged early in the Design&Modeling group. It was not only a syntactic problem (using the word "ontology" as a synonym of "semantic model") but also a semantic problem in the meaning assigned by the actors to these labels. The following is an excerpt from the researcher's field notes taken during a chat with Rick from NorthOil: *"This done in a vacuum has allowed them to create a local terminology… QCB uses one, and ITCorp uses another […] We are at two completely different levels of communication."*

PHASE 2 – Negotiating the technology – A few weeks after the project's inception, NorthOil shared the descriptions of a few use cases that the EnviroTime solution should be able to handle. In particular, one case related to the long-term monitoring of a spectrum of ecological parameters in sensitive areas, and another to the detection of oil leakages in the production phase. The model had to be flexible enough to allow the end users to understand sensor data in specific situations, e.g., by integrating other vendors' systems, or despite missing information because of a lack of infrastructure (e.g., during the exploration phase). Rick issued a proposal to adopt a methodology based on Linked Open Data, which, in a nutshell, consisted of developing a "flat" graph of the data by describing common concepts by referring to other community-approved and publicly available graphs. He grounded his suggestions on the call for a use-case-based approach as defined in the technical part of the contract. As he stated during a meeting, *"We do not want to develop things that already exist but are slightly different*." On the other hand, Jim (ITCorp) and Martin (QCB) recommended that the development of an ontology represented in formal languages grounded on the aforementioned "oil and gas ontology" was the solution to obtain a standard-compliant model. They were making extensive reference to the legal part of the contract, liable to multiple interpretations. According to Jim: *"Maybe the use-case-based approach limits our view".* ITCorp's proposed design was based on the same software tools used previously in GlobalMapping, which would hinder NorthOil's aim to openly share data with research institutions to foster collaboration with other disciplines. Hans had a well-developed experience as a leading IT advisor in NorthOil. Doubtful about the approach to adopt, he expressed some practical concerns: *"With open source it is difficult to get dependable support when you need it. Many open source products are often very small… With a real support system you can call them always. (...) You get developers flown with helicopters to a platform (...) When you get [open source solutions]… they need to have the capability to fix any problem. You can run in emergency for no more than 10-12 hours. (...) When we buy things from ITCorp we know that we get this kind of support; but my concern is… where is the tradeoff with the issues of scalability, interoperability, etc.?"*

PHASE 3 – A need to focus on the data – After approximately half a year since the start of EnviroTime, the news was heard at the NorthOil research center; a decision had been made at the management level to stop the GlobalMapping project. This empirically confirmed how an excess of generification introduced too much disorder in the local assets. According to some NorthOil representatives, this new situation would leave the door open for new approaches to develop the semantic model for EnviroTime. However, on the other hand, this could suddenly halt the development process. Nonetheless, meetings and conference calls continued on a more or less regular basis. Based on the field notes, the researcher perceived quite clearly that ITCorp and QCB representatives continued to support their initial ideas. This is part of a conversation that occurred during a teleconference involving the members of the Design&Modeling group, specifically Hans and Rick from NorthOil and Martin from QCB:

Hans (NorthOil): *"We don't need an ontology; we need to be able to find out where to get the data. If it turns out that we need an ontology to do that then OK. But, I don't want an ontology until I know that I need one."*
Martin (QCB): *"Then you are not really interested in semantic web technologies."*

At the end of 2012, NorthOil settled for an approach inspired by Linked Open Data to foster a more efficient data combination in different contexts. For example, as the descriptions of the use cases proved, during the exploration phase preceding the drilling of a new well little or no infrastructure is in place, thus making metadata about the equipment less critical as they might be during the drilling phase. More focus was also set on the role of time in the use cases. The model should indeed support long-term tasks (e.g., monitoring the health of marine mammals) and shorter-term ones (e.g., the concentration of particles in water at a given time).

5 Discussion: mobilizing actors at a pragmatic level

When NorthOil first issued the invitation to tender a scope of work, its *problematization* (Callon, 1986), i.e., "how to achieve a semantic model of the environmental data?", placed the company as a passage point to solve the problem of developing integrated techniques to protect the environment during all oil and gas activities. NorthOil assumed that the development of a "semantic model" was the right solution and thus led the other organizations to find the answer in semantic technologies and to dynamically align around NorthOil's target. Under the light of their business and historical background, their representatives have developed an experience and shaped their knowledge and understanding of concepts for which there remains a debate in literature and in the IT community. Participants faced a new and emerging type of knowledge, the management of real-time environmental data, and should adapt their background to it.

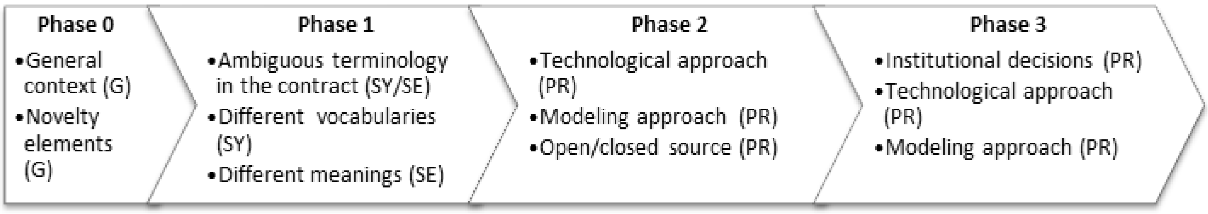

Figure 1 *The boundaries at each phase and their nature (G=general; SY=syntactic; SE=semantic; PR=pragmatic)*

Overcoming boundaries at a pragmatic level. The first step towards the successful management of knowledge is to overcome the syntactic barrier by transferring knowledge between communities (Carlile, 2004). In the analysis above (see Figure 1) a syntactic boundary emerges during phase 1, when different terms are used to refer to the same tools and no common vocabulary has been successfully shared at the start of the project. The second step would thus require translating knowledge to overcome semantic barriers. Our findings show no successful accomplishment of this process because the actors continue to assign different meanings to items that are labeled in the same way (phase 1). The words "ontology" and "semantic model" are used by each organization to imply different technological stacks and different modeling paradigms. The reach for shared terminology and sets of meaning is further disabled by the fact that the representatives of the organizations involved in EnviroTime seldom meet, and when they do, it generally occurs through situated arrangements (teleconferences or formal settings) where ambiguities can only be addressed temporarily, i.e., at an equifinal level. These first two obstacles mirror the present situation regarding semantic technologies reflected in the literature and in the IT community. The consequence is a lack of capability of the shared artifacts to foster a discussion of the impact of technological choices on the final outcome in situations where the future remains unclear. A successful design phase entails predicting the role of given artifacts as boundary objects. However, they often emerge in use (Levina and Vaast, 2005) and can only be observed after a pragmatic test. The semantic model thus acts as a boundary object to catch the tensions emerging in the EnviroTime project; it is the battlefield where collaboration plays out, the reason for further negotiations, and the trigger for an improved understanding of key environmental aspects. Interestingly, semantics themselves also constitute a semantic limitation to collaboration. The lack of a syntactic and semantic capability within the negotiation process could thus be seized at a pragmatic level. This step requires the transformation of knowledge so that political barriers (interests) are set (at least temporarily) aside (Carlile, 2004). In phase 2, actors' different explicit and implicit agendas are revealed from the historical background and the business sectors of each company. If and when they meet, the organizations' representatives must act at a pragmatic level. During an informal chat, Rick (NorthOil) argues: "*I suppose the big picture is that the partners are misaligned. That the understandings and approaches diverge greatly, and that there is no way to mediate between them because NorthOil views this as a research project and O&G Solutions view it as an engineering project. This is evidenced at the small scale by various things. But oddly not semantics, where everything is reversed. NorthOil is "this isn't the research part, it is engineering" and ITCorp + QCB want to create new knowledge*." Innovation can happen through collaboration by the inscription of the actors' interests on the final outcome; however, such capability was not enough in the analyzed case until Hans clearly reminded the partners of the final outcome, i.e., the possibility of representing real-time environmental data in different contexts and time windows. Figure 1 shows how syntactic and semantic misalignments trigger pragmatic obstacles, which are, in turn, to be motivated on a more abstract level by accounting for the institutional and historical backgrounds both of the actors involved and of the technology adopted. No first-level obstacle (like a lack of a common terminology) can be understood without digging beneath the surface for pragmatic and institutional discrepancies with deeper roots.

The information infrastructure rationale of environmental monitoring. Semantically enabled solutions (and ontologies in particular) are, after all, technological artifacts. They are a technology in use (Orlikowski, 2000) that should represent information in a manner both recognizable by and enabling of the knowledge of the specific social context they attempt to target. Indeed, evolving forms of collaboration continue to exist in each of the communities of users of an information infrastructure. Communities tend to maintain their own tasks, practices, and pre-existing information systems, thereby often refusing a standardized model or not recognizing their own knowledge in it (Hepsø et al., 2009). As Hepp (2008) noted, “ontologies are not just formal representations of a domain, but much more *community contracts* about such formal representations” (p.6, emphasis in original); they are supposed to be the result of a negotiation process, a temporary state of shared knowledge that reveals meaningful insight in a given context. The technological element has therefore to be considered as a primary actor and analyzed by the way the users and the broader IT community use and understand it. In line with ANT, the view of technology in use as a socio-technical network allows us to conceptualize semantic technologies as more than just part of an information infrastructure. They can be considered information infrastructures themselves. Their development follows a process of translation comprising not only developers and users but also the overall background in which the technology was born, and the domain whose knowledge it represents. Semantics are an especially interesting case because of their troublesome story and their explicit attempt towards the representation and management of the knowledge of a domain. At a higher level of abstraction, our case represents a shift for the entire oil and gas business domain. Well-established practices and standards co-exist in the tasks related to operation and management (Hepsø et al., 2009, Monteiro et al., 2012, Rosendahl and Hepsø, 2013) and a degree of irreversibility (Monteiro and Hanseth, 1995) in the traditional approach has already been reached. The addition of novelty elements lets new invisible actors emerge in the socio-technical network hidden under a technological artifact. In our story, underneath the semantic model lies what Law and Singleton (2005) call an *absent presence*, the environment. Within the EnviroTime project, the marine environment is made physically present thanks to the deployment of heterogeneous sensors on the sea bottom to capture the behavior of the marine ecosystem. Its progressive incorporation in the traditional oil and gas ecosystem is the rationale for adopting a perspective based on information infrastructure. The semantic model was motivated from the beginning as the key instrument to give a real-time voice to the environment, even if corals and fish are never physically present in the Design&Modeling group meetings. It is one of the socio-technical (or, more broadly, sociomaterial) artifacts (Orlikowski and Scott, 2008) that should enhance the process of mediation through which environmental knowledge is made part of the oil and gas culture (Latour, 2004). The ability of the semantic model and of other actors’ agendas to speak on behalf of the environment could represent the very outcome of the innovation project described in our story; hence, a pragmatic achievement of knowledge transformation (Carlile, 2004). There lies what Carlile and Lakhani (2011) call the “sweet spot” of innovation. This can be described as a problem of mobilizing actors by pushing disagreements back far enough, or *equifinally*, by giving a voice to those elements that should be the main motivation for innovation, but are often forgotten.

6 Conclusions and implications

In this article, we described the innovative attempt of an international oil and gas company (NorthOil) to enhance its real-time environmental monitoring capabilities as a consequence of the latest technological advances. This scenario represents a unique opportunity for the domain to abandon the local, fragmented practices in information management and head towards more integrated, cross-organizational networked solutions for more efficient decision making. We depicted the trajectory of a collaborative project to reach an *equifinal* level of understanding in spite of the unresolved ambiguities that arose. The following question now remains: What are the implications for the sociomaterial practices through which environmental information is daily handled by oil and gas operators? The project we studied spans across three years and is therefore ongoing; nevertheless, we are able to draw some conclusions. Each of the approaches proposed by the participants to the design process has consequences on the capabilities of the final result. On the one hand, the path towards a top-down, standard-based semantic model could lead to the re-establishment of a degree of irreversibility because of the inability to conceal heterogeneous distributed information sources. We illustrated how a previous project demonstrated the practical and technological complications of this approach. On the other hand, a solution based on the Linked Open Data set of practices was proposed as the right tradeoff between a top-down modeling methodology and a bottom-up categorization based on the data managed locally by users. The test field for this latter approach is even more interesting because environmental monitoring has historically remained almost virgin to oil and gas traditions. Even so, this path could be practically, or pragmatically, unfeasible. It could either be misunderstood in the domain where it has to be used, or it could be viewed as immature because, after all, the oil and gas sector is an intrinsically closed domain. As we illustrated, the attempt by NorthOil to cover every possible final product of the project in the bureaucratic sections of the contract attracted the attention of the partners and opened the box of ambiguities about the nature of the final product. To conclude, a pragmatic (or, again, equifinal) conceptualization of the role of semantic technologies as information infrastructures is relevant at three levels. For the oil and gas sector (i), to understand *how* a given modeling methodology can enable the effort of extrapolating a timely meaning from the punctuated sensor network through which the environment is made present. Symmetrically, it is fundamental for IT developers within oil and gas (ii) to clearly realize how a given technology could enable or disable future improvements, e.g., by taking into account newer combinations of data to make sense of natural phenomena. Finally (iii), our analysis is an indication to the information systems research community to focus more on the implications of specific technological elements inside information infrastructures.

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