SOCIOMATERIAL CAPABILITIES IN INTEGRATED OIL AND GAS OPERATIONS – IMPLICATIONS FOR DESIGN

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Abstract

Organisations must design and innovate capabilities in a symbiotic evolution between social and technical elements. Information Systems (IS) literature has successfully demonstrated the relationship between the material technology and the social organization, and how both influence each other. However, research has tilted in terms of favouring the explanatory power of either social or material agencies. To address this we suggest viewing the relationship as a sociomaterial capability addressing key organisational objectives. To understand the role of IS in such a capability, an approach addressing the bi-directional and flexible relationship is needed. We explore sociomateriality and draw empirically on a holistic case study in an international oil and gas company. The result shows how two sociomaterial capabilities, convergence and maintenance, are performed to contain tensions between global requirements and local contexts and between rigidity and flexibility. Second, bridging capability with the information infrastructure design theory, we derive seven principles for information system design to support organisations.

Keywords: Sociomateriality, socio-technical, capability, flexibility, convergence, maintenance, case study, design and innovation, information infrastructure.

1 Introduction

Modern subsea oil and gas exploration and production are characterized by particularly expensive and risky operations across complex information infrastructures, including exploring potential underground and/or subsea oil and gas fields, drilling exploratory wells, and subsequently drilling and operating production wells. To operate safe and cost effective, the oil and gas industry has turned its attention to the notion of *Integrated Operations*, as a strategy towards the integration of people, work processes, governance, and technology with the goal of improved decision-making and better execution. To achieve these goals, ubiquitous real-time data, collaborative techniques, and multiple expertise across disciplines, organizations, and geographical locations are sought utilised (Rosendahl and Hepsø 2013). In operations that “integrate” the social (people) and the material (technology), the Information Systems (IS) literature has demonstrated the mutual influence between the social and the material. Technologies alter the "*social dynamics*" of organizations; be that change in organizational structures, decision-making and power relationships in formal organizations (Barley 1990), or change in informal communication networks (DiMaggio et al. 2001). Reversed, research also documents the malleability of technology, explaining how technologies emerge as products of a social process; negotiations, human agency and personal interest (Leonardi and Barley 2008). It is well established in practice-based perspectives that the use of information systems is subject to local tinkering and adaptations (Suchman 2006; Monteiro et al. 2012b).

While these unidirectional influences are well rehearsed, it has proven more of a balancing act to account for how the social and the material, through a bi-directional network, dynamically perform together. Instead, tilting has occurred, giving more explanatory power to either social or material agency, resulting in "*theoretical accounts that are epistemologically and ontologically unable to handle the entwining of the material and the social and that cannot speak with precision about degrees of agency and constraint*" (Leonardi and Barley 2008, p.161). Since Orlikowski started questioning the separation between the social and material (Orlikowski 2007), a wave of contributions on sociomateriality has come (Constantinides and Barrett 2012). It is now suggested to consider contributions on sociomateriality along a continuum ranging from "hard" sociomateriality to "soft" sociomateriality according to how they conceptualise the relationship between the social and the material (Mikalsen 2014). On the hard end of the scale we find Orlikowski type contributions, building on Barad´s agential realism (Barad 2007), asserting that the social and the material are "*inextricably related – there is no social that is not also material, and no material that is not also social*" (Orlikowski 2007, p. 1437). Toward the softer end of the continuum we find studies that conceptualise sociomateriality as a coupled or linked relationship between two separate entities. Kautz and Jensen (2013) see Leonardi as being one of the main proponents of this end of the continuum, using the concept of imbrication "*to capture the simultaneous interdependence and specificity of each the digital and the non-digital. They work on each other but they do not produce hybridicity. Each maintains its distinct irreducible character…*" (Leonardi 2011, p. 151). Both the hard and the soft versions of sociomateriality is at the centre of current IS debate (Mikalsen 2014). Mutch (2013), has argued from a critical realism stance that Orlikowski-type studies where the material and the social is not seen as separate entities (hard sociomateriality) lead to "*confusing levels of analysis*". Leonardi-type studies, perhaps closer to the actor-network theory (ANT) roots (soft sociomateriality) (see (Latour 2005) for a recent summary of ANT), is also critiqued, albeit on contrasting grounds. Pollock and Williams for example argue that such ANT based contributions with their focus on following local actors fail to explain how sociomaterial imbrications are shaped across space and time, and that we need a more "*contexted view*" (Pollock and Williams 2011).

The concept of sociomaterial capabilities that we explore here reverberates with the softer and perhaps performative stream of this sociomaterial research that acknowledges that both social and material agencies have the capacity to exercise a great deal of flexibility (Leonardi 2012; Parmiggiani and Mikalsen 2013) in the way the imbrications play out and are performed in practice. In fact, it is only through flexible imbrications they can be considered *capabilities*. This becomes evident as we view capabilities, as Henderson et al. (2013) do, explain capabilities as an extension of process thinking in organisations that has been limiting in terms of trying to define "*perfect*", "*to be*" processes that in effect fail to reflect a complex organisational and technical reality. In order to prevail, process thinking needs to account for sociomaterial imbrications as *"…alignment of process, people, technology and governance. […] The notion of a capability emerged as an explicit attempt to cope with this complexity.*" (ibid, p. 5) Capabilities are configured to reach a defined business objective, e.g. to find oil and/or natural gas. Key to capability thinking is that value comes from the combination of factors, not the individual factors alone. People, processes, technology, and governance (strategies) are configured to create an organisational capability and business value. As a consequence, designing information systems to be a part of a capability, and consequently business value requires an understanding of the capability context – the way those four elements are combined in existing and new configurations. In this view, technology is not dismissed as static and fixed representations, but rather something performed. The meaning and use of technology is not something given, but rather emerges in practice. Human and material agencies interact directly, but they still are distinct phenomena, that, at certain points in time, for a given purpose, become imbricated. Sociomaterial capabilities are people and technology "*interlocked in particular sequences*" that can "*produce, sustain, or change*" routines and technology (Leonardi 2011). We will show how the imbricative formation of a capability does not happen in a vacuum, but is rather the result of balancing conflicting goals and containing dynamic tensions (Smith and Lewis 2011). This becomes particularly clear in Integrated Operations as the capability reaches out of the local and situated (Suchman 2006), integrating social and material actors across dimensions of space and time, extending our notion and understanding of "situated" knowledge (Pollock et al. 2009).

Succeeding in innovating and designing capabilities consequently require insight in the tensions faced, and practical strategies applied in capabilities to deal with these tensions.

The two research questions addressed in this article is therefore; *i*) how is flexibility performed in sociomaterial imbrications (forming capabilities)? And, following from the first, *ii)* what are the implications for designing the information system part of such a capability?

To answer these research questions a holistic case study of two capabilities from the upstream oil and gas industry is reported. These cases' critical characteristics make it particularly attractive to study the performativity of sociomaterial capabilities. The only way that people can know anything about what happens deep down subsea and subsurface – without actually performing an expensive and potentially hazardous drilling – is *indirectly*, through sensor data brought to them through information systems. Based on these data, professionals need to make their decisions. Is it oil down there? Can we drill safely? The empirical setting is NorthOil (an acronym), a large international oil and gas company that perfectly illustrates the tensions facing this kind of operations, and, equally important, how the tensions are contained.

The first case presents tensions between the local sites and the global infrastructure in an initiative for environmental monitoring that NorthOil is running due to the necessity of drilling in an environmentally sustainable manner, particularly when moving into diverse and fragile biological habitats. We conceive of the capability to keep this balance between local and global as *convergence*, a notion openly defined by Bowker and Star (1999) as the process by which infrastructures and the social world come to fit to each other. It hermeneutically stresses the fundamental role of the imbrication between humans, technology and nature at the local site to generate a global result.

The second case presents tensions between the need for formal procedures to assure the quality of work and the flexibility needed in order to keep up or improve performance. These tensions result in containment strategies in NorthOil´s exploration department. We conceptualise this containment as the capability *maintenance* (Graham and Thrift 2007). Maintenance in this regard is the invisible (until breakdown) processes and tools that are perhaps seemingly mundane but indeed necessary components in discovering oil and gas.

The article is structured as follows. Next, in section 2, we introduce the case studies at NorthOil and explain how we study the sociomaterial capabilities. In section 3 our main findings are spelled out in terms of two central tensions observed in the empirical cases; the tension between the local and the global, and the rigid and the flexible. We show how the containment of these tensions forms two sociomaterial capabilities, *convergence* and *maintenance*. In the discussion section we explain six IS design implications that the designers for sociomaterial capabilities in organizations should adhere to; *i*) opting for value-driven design, *ii*) utilizing the information legacy, *iii*) accounting for multiple materiality, *iv*) KIS (keep it simple), *v*) ensuring sociomaterial modularity and frictionless data and finally, *vi*) including the maintainer in the design process. We conclude by drawing some implications for practice and further research.

2 Method and study context

2.1 Empirical setting

NorthOil is an international oil and gas company established in the 1970s and headquartered in Northern Europe, currently employing over 20000 people with activities in 35 countries, with a focus on the Norwegian continental shelf. NorthOil's primary activities are the exploration of new oil and gas fields and the operation and maintenance of a number of offshore production installations. We theoretically sampled two case sites in NorthOil, also guided by pragmatic concerns of access. Our study is therefore a multiple-case holistic study, in that we studied one phenomenon in each of the two cases (Yin 2009). The two cases can be defined as critical cases, as they have strategic importance in relation to the general problem (Flyvbjerg 2006). They illustrate how capabilities meet tensions in practice in a domain like that of offshore oil and gas where the objects of interest – the subsurface reservoir and the subsea operational area – are only accessed through sensors and information systems.

In the first case, we look at NorthOil's effort to develop an infrastructure for real-time subsea environmental monitoring. Over 60% of the oil production on the Norwegian continental shelf comes from facilities installed on the sea floor. As the company´s activity moves towards environmentally fragile areas (e.g. the Barents Sea), authorities require the prevention of environmental damage caused for example by the possible discharge of drill cuttings during drilling, or by the deployment of rigs and pipelines. That implies that the traditional preventive approaches involving bi- or triennial campaigns where ships go out and collect data are no longer sufficient. With the traditional procedure, data are usually collected offshore and later analysed onshore, with temporal gaps of 9-12 months. The process of monitoring the marine environment is today undergoing a development process, boosted by new technologies and integrated collaborative tools. Sensor networks to measure several operational and environmental parameters are deployed and data can be accessed in real-time thanks to fibre-optic cables, radio and satellite communication. To enable a more proactive assessment of environmental risk, in late 2011 one department at NorthOil's research centre initiated the EnviroTime (an acronym) project to leverage the recent technological improvements and integrate subsea equipment with environmental observatories for the real-time surveillance of the marine ecosystem.

In the second case, we look at the process of maintaining the infrastructure for supporting data interpretation in NorthOil's exploration department, where geologists and geophysicists ("G&G personnel" or simply "G&G") are essential to interpret the company's vast amount of subsurface data. Geologists know rocks and the formations they make in the earth crust. Geophysicists focus on physical characteristics, such as magnetics and gravitation to analyse subsurface rocks and formations. To do this, all available data from previous and on-going exploration projects are sought used in order to extrapolate a model of the area of investigation, and try to find the presence of hydrocarbons. Drilling is the only sure way to find out if oil and gas exist somewhere down in the earth crust. However, since drilling is highly expensive and potentially hazardous, they try to keep drilling to an absolute minimum. Instead, they apply information systems combined with human expertise to make interpretations of the subsurface, thereby attempting to predict, to the best of their ability, the presence of hydrocarbons.

2.2 Data collection and analysis

This article draws on the empirical data that the first two authors have been collecting as part of two ethnographically inspired longitudinal case studies. We were granted access to NorthOil research centre in April 2012, and the second author has been spending there an average 2-3 working days a week since then doing participatory observations, interviews, and studying internal documentation. In March 2013 we were granted access to the NorthOil exploration case, and the first author has been present there in five periods for 14 days total, combining participatory observation and interviews. Both cases are still ongoing. Table 1 below provides an overview of the modes of data collection. In particular, the observations include participating in meetings, conferences, being co-located at the workplace, and talking informally over lunch and coffee. We have hundreds of pages of field notes. The interviews are all semi-structured (Myers and Newman 2007) and have been generally conducted by asking few initial questions about the interviewee's experience in NorthOil or in the domain considered (environmental monitoring; oil and gas exploration). Thus, the script was intentionally left flexible to allow the researchers span across different topics following the interviewee's answers and reactions, but making sure that the planned points were covered during the available time (1 to 1.5 hours on average). Interviews have been audio recorded and selected parts were transcribed.

SOURCE	TOPIC/DESCRIPTION
Digital data sources (documents)	
MS SharePoint team sites (Intranet)	Long-term strategies and views of NorthOil Private emails exchanged either internally or with vendors Official reports and deliverables Internal notes and presentations
Internet-based public information	Official online information about NorthOil and its vendors Official guidelines and reports from Norwegian and international authorities
Semi–structured and unstructured interviews (transcripts)	
5 data managers in the exploration	Data and data management
18 participants in EnviroTime with different roles (project managers;	EnviroTime project, environmental monitoring in oil and gas Relations between the EnviroTime project and past projects

environmental advisors; IT advisors) 3 participants to EnviroTime from partner companies (1 project manager; 2 environmental advisors)	State of the art in environmental monitoring Data modelling solutions
Participatory observations (field notes)	
14 full days with NorthOil data managers	Sharing key documents, presentations showing systems and processes
2-3 full days a week (April 2012 – December 2013) with EnviroTime participants EnviroTime weekly briefing sessions (variable length) 13 teleconferences (1-6 h) with other NorthOil offices and/or vendors 4 workshops about EnviroTime	Exchange of ideas General issues in the EnviroTime project Application of data modelling techniques Usage of environmental data together with operational data
Other (field notes)	
Informal chats over lunch and coffee 3 conferences on science and practice in oil and gas 4 full-day seminars at the research centre	

Table 1. Overview of the four modes of data collection: document study, semi-structured interviews, participatory observations, and informal chats.

An interpretive approach has guided the data analysis process (Walsham 1995). In practice, we subscribed to the principles proposed by Klein and Myers (1999). The first principle is that of the hermeneutic circle. It helps to account for the interdependent meaning of the parts (e.g. the participants' understandings) and the whole that they form (e.g. the meanings emerging from the interactions between the parts). We followed this principle in our strategy to data analysis and sense making by iteratively adopting an inductive-deductive approach. As mentioned, the initial choice of the case material was based on theory, in particular on sociomateriality as a theoretical lens. According to Walsham (1995): "*The motivation for the use of theory in the earlier stages of interpretive cases studies is to create an initial theoretical framework which takes account of previous knowledge, and which creates a sensible theoretical basis to inform the topics and approach of the early empirical work.*" (p. 76). Walsham later invites interpretive researchers to remain open to new ideas from the field data. An inductive approach was thus followed as we open coded the material to identify the emerging themes inside the material and to progressively refine them through the discussions between the authors. Subsequently, the sociomaterial capabilities have been identified out of the data. This process has been complemented by deductively drawing on theoretical concepts that inspired the labelling of the two capabilities.

The second principle is that of contextualization. It underlines the importance of understanding the subjects of a study as a part of broader social and political contexts. The study of the design and implementation of information systems and infrastructures cannot be decoupled from the bureaucratic, business, and technological context where it is happening. We operationalized this principle thanks to a constant collection of official and informal documentation both from NorthOil and the competent authorities, to gain an historical overview of the policy regime under which NorthOil operates and the management's past and future strategies. The documents include access to NorthOil team sites (intranet), selected documents sent to us, and public information. The third author, thanks to his 20 years of experience as a senior researcher in NorthOil, gave an important contribution by facilitating the access to relevant documentation and to get a more thorough overview of the company's background and context.

The third principle deals with the interaction between the researchers and the subjects in a study. It acknowledges how data are produced by the social interaction between the researcher and the participants, in that the participants have a role in interpreting and analysing information. We put this principle in practice by making extensive use of participatory observations. As our access to the empirical settings improved, we have been increasingly accepted by NorthOil's employees and have been asked for feedback or to take part in small tasks (e.g. commenting on the draft of a document; helping in formatting a report).

The fourth principle guides the drawing of abstractions from the particulars. Abstraction can take several forms (Walsham 1995). We chose to draw specific design implications (see section 5).

The fifth principle requires openness to the prejudices that guided the original research design. We applied it by iteratively discussing our findings with the research group we belong to and by constantly interacting with the participants in our case studies (see principle three above). In addition, this principle accounts for our adoption of narratives to focus on interesting aspects of the relationship between the emerging tensions and the sociomaterial capabilities required to address them (see next section). Narratives help to reproduce observed situations characterized by variable temporal embeddedness, eclectic data, and no clear boundaries (Langley 1999).

Principle six warns against ignoring the broader social context conditioning the observed human actions. Accordingly, we chose to let different types of informants speak. This strategy is apparent in our choice of interviewing participants with different roles in the case studies. In the EnviroTime project, we could for instance interview also one project manager and two environmental advisors from two vendor companies.

3 Tensions require Convergence and Maintenance

3.1 Tensions between the local and the global require convergence

Several wells can be drilled in an oil or gas field. As of 2012, NorthOil was operating hundreds of productive wells in the world. The geographical distribution of wells entails a stark heterogeneity in the geological characteristics of each site. As stated by the commission in charge of investigating the Macondo blowout in the Gulf of Mexico, each well has its "own personality": knowledge about local conditions of the rocks to be drilled, the particular installation, and the surrounding marine environment have to be developed and tailored to the local setting (OSC 2011). Different technological configurations must also be adapted to local environmental constraints. Expensive solutions for harsh weather in the Arctic North might not be suitable for the sea floor off Brazil. In addition, technological innovation is an important factor. Operations are becoming increasingly dependent on lightweight subsea installations completed on the sea floor and remotely operated and monitored from a control room via e.g. fibre-optic cables (Hepsø 2008). NorthOil has been in business for over 40 years. In spite of the recent call for Integrated Operations, four decades of divergent activities have resulted in the accumulation of a wide spectrum of heterogeneous information over several diverse and often overlapping information systems and operators have created local strategies and workarounds to carry out their tasks (Østerlie et al. 2012).

National governments and international organizations issued guidelines and regulations to monitor and assess subsea risk (NME 2008; OSPAR 2009). Oil and gas companies must develop devices and methodologies to predict possible effects on the biological resources to be granted a "permission to drill" in environmental sensitive areas. However, no comprehensive regulatory framework is today available. Environmental monitoring is therefore a task characterized by uncertainty and complexity. First of all, uncertainties remain with regard to the technology and the monitoring practices to use in the local biological ecosystems. For example, the Norwegian continental shelf is home to the world's largest population of cold-water corals. In 2011, NorthOil performed some preliminary tests to simulate the environmental impact of a new well onto a protected coral reef in the vicinity and to assess the viability of the EnviroTime project. Oceanographic parameters (e.g. water currents, pressure, particle sedimentation rate) had to be monitored in order to predict whether discharges of particles would be taken close to the corals by the current. As no data-transfer cables were available in the chosen point, a surface buoy had been connected to the sensors on the seabed to send real-time data onshore through to a satellite link. The real-time data transfer was initially successful, but the buoy went suddenly lost after a few days. NorthOil had to plug in third-party software to model oceanic currents and infer the missing data to provide the authorities with a sufficient report:

> *"*So in that way we were able to fulfil the real-time environmental modelling during this whole drilling period. So this modelling was updated every hour so we could have a new picture of the current situation at the location, the concentration of particles in the water column at different coral structures and also sedimentation of particles on the seabed at different locations. At least we have that overview. This worked very well with this backup solution but in the future of course we should have it as current

> data that have to be in place. (…) But this is the typical problem we do have, it is not the first time, I think it has happened 3 or 4 times before, this happens because we are still working on having equipment on the sea that are robust enough."
>
> (Environmental advisor, Interview, December 2012)

This empirical snippet is a good example of the difficulty to control infrastructures as pointed out by Ciborra (2000). They are made to standardize natural or social phenomena that are themselves uncontrollable. A daily bricolage work is required to cope with situated constraints and to fulfil top-down standardization requirements by integrating the new systems (e.g. real-time data collection, wireless communications) with the old infrastructure (real-time calculation of risk with well-known modelling systems). Subsea environmental monitoring has a performative nature. It is the result of an emerging interlocked sequence of material elements (the sensors; the modelling systems; the corals and the water currents; the particles discharged while drilling); human knowledge required to interpret the sensor-filtered data; national or regional norms to be fulfilled; and the establishment or adaptation of standardized work processes. All these elements get imbricated to make a decision regarding a possible state of risk of a specific submarine area. In particular, nature plays a key role in this imbrication for at least two reasons. First, the technical equipment must be "robust enough" against the local weather conditions. In the excerpt above, a company internal assessment concluded that the buoy had most likely been cut away by vessels passing the area during bad weather. Second, the types of data to be collected and managed depended on the presence of given species of protected fauna in that specific area where NorthOil wanted to drill new wells, making the monitoring activities also a complex work. Corals are a static resource and can be inspected through sensor racks and cameras from a fixed position. Fish is instead more unpredictable, as its movements have to be tracked not simply along three axes. As indicated by a leading advisor in the EnviroTime project:

> "So in order to build the complexity of the EnviroTime solution I think it is important that you select a different type of resource [in addition to] corals, I think it is important a pelagic resource like fish, plankton, that lives in the water masses, and it has a 5 dimensionality, not only 3. Because they have a position, and they are at a certain depth, they have also a concentration, and at a certain time. (…) What parameters do you need to collect, what should be the resolution of the parameters you collect, how many [subsea sensor networks] will you need to get sufficient amount of data to plan your operation? Will you need one lander location? Will you need 4? 10? To say something about the resources in these 5 dimensions. And of course that would give some challenge to the data management because it's a lot of data, complex data, and how should it be visualized"
>
> (Leading Advisor, Interview, 2013)

It is difficult to predict the behaviour of moving marine biomass or their reaction to the devices used for inspection. In November 2013 we were interviewing an IT advisor involved in the development of a web portal to display real-time data retrieved by a test sensor installed off the Norwegian coasts next to a coral reef. On his computer screen was the browser, open on the web interface displaying the incoming real-time data. At one point the interviewee was distracted by a fish coming out of the reef and stopping in front of a live camera images. The fish stopped for a short time, and then disappeared again. The IT advisor told us that it was not the first time that fish did so, and the analysis of the acoustic data indicated that it also used to "say" something:

> "And that's what happens, he gets really angry so he says "Shshshshsh! (…) Or maybe he gets annoyed. Maybe he gets used to it. And that's also one of the things. Will we influence, will the local fauna get used to the sounds when we do the stuff?"
>
> (IT advisor, interview, November 2013)

3.2 Tensions between the rigid and the flexible require maintenance

The geologist and geophysicist (G&G) personnel in the exploration department must cope with enormous amounts of subsurface data. The three main types of data used by G&G are seismic data, well data, and production data from existing wells. Seismic data are gathered using ships equipped with air guns firing acoustic pulses down through the ground. The echoes that come back show different rock layers and depths. Well data are logs gathered while drilling a well, showing the well characteristics. Production data are data from wells that already are in production. Taken together these data sources form a base of data upon which the G&G personnel can create interpretations.

The amount of data is huge. Data are primarily gathered from two main sources, the corporate raw data store and a national database where all oil and gas companies operating on the Norwegian Continental Shelf are required by the law to store all of their seismic, well, and production data. The database has thousands of tables and thousands of attributes. Central data managers (CDMs) administer the corporate data store. G&G (and other interpreters) need to extract data through queries that involve joining 20 to 30 tables that are run overnight. In-house IT specialists (such as e.g. "GIS experts" and project data managers or PDMs) are called for in order to formulate and execute these queries. These experts are co-located in the same physical office space as the G&G personnel to be close to the exploration operations. The goal is to facilitate cooperation and to build knowledge of the work that the G&G do, in order to better understand what the G&G actually need. Another issue is the number of systems involved. There are 35 different systems, ranging from petrophysical evaluation to corporate data stores and data integration tools. IT experts (in house and external) are needed in order to enable the data to flow to and from this ecosystem of tools.

Overall, and simplified for descriptive purposes, the process of exploring a certain geographic area consists of three main steps. First, a new exploration project is created and is populated of existing data from the national database and the corporate data store. PDMs and IT specialists assist the G&G in this process. Second, G&G start working on the data, doing their interpretations. More data can be called for, e.g. more or new seismic surveys, and data can flow into the system in real time, e.g. from exploration wells that are drilled. These data are taken care of by PDMs and consultants. Finally, when the project is finished (found oil or not), data are tied up, quality assured, and entered into the corporate data store for future use. This is a complex process involving a lot of different people, roles, processes, and technology. There is a tension between the obvious need for NorthOil to define proper processes for this, and the actual dynamics of the operation.

The rationale for having well-defined processes is clear and sensible. A NorthOil process owner explains why the need is there:

> "If not it would be chaos. Too many applications and solutions, it would be very hard to support all of them. Also, it is about standardization. A person should be able to leave one business area and go to another one, and then start working immediately, with the same machinery and tools he is used to″
>
> (Process owner, from field notes)

Immediately that makes sense, and at critical parts of the exploration process definitions are indeed followed. One reaches for example certain decision gates (e.g. to do drill an exploration well), where one makes a decision, documents the rationale for that decision, and stores it into the data stores. But, in order to make it work, there is a need for a dynamic (that is; not predefined and rigid) activity of people and technology. A PDM explains the relation to the process definitions:

> "We lack a good enough process for data management. There is no standardised way of entering data into the system, for instance well data from an exploration well. The real data flow is known to a PDM after two to three years of practice. You start to know what is happening, but then things change, and you do not necessarily get notified. We have a community portal, but it does not suffice, particularly not for inexperienced people"
>
> (Project data manager, from field notes)

The formal process description defines how at the beginning of the exploration of an area, a new project should be started in the project data store, where new data should be propagated. However, rather than following this protocol, the G&G extend existing ones in geographical proximity to the area of interest. This has a very practical reason. The G&G know that they have a lot of relevant information in the existing projects and want to make sure to bring all of that with them into the new project as well, to make sure nothing is lost.

To be able to deal with this rather "messy" reality and lack of well-defined processes and tools, flexibility is observed in both people and information systems. There are many roles in NorthOil exploration solely working on providing the G&G personnel with the data they need. The PDMs for example are co-located in the same physical department as G&G personnel. Until recently they were even co-located in the same offices. The reason for this is to have a proper understanding of what the G&G personnel need and to understand "*what they really are asking for*" (from field notes). The PDMs attend meetings; receive e-mails, phone calls, and in-office requests from the G&G data access and maintenance. The PDMs exercise flexibility in terms of answering to requests from the G&G. Below is an example where the ideal process is not followed, but flexibility is exercised to overcome the contingencies in the situation:

> "A PDM has earlier that day received an email about preparing some well paths in the project data store, so that it is ready to receive real time data from the drilling. The PDM calls me over and says that he shall be very open. It is something about communication. He tells me that during a [coffee] break outside, he has met with a G&G person that told him that it is one week until SPUD (drilling shall start) and that the names of the wells are set. Four well paths must be prepared in the project data store and the PDM is somewhat frustrated that he has to learn this accidentally in a break, and he feels that the original email sender should have informed him about the fact that SPUD is in one week, and that a name etc. has been set. He says, it will work out anyway, I would have gotten notice maybe a day or two before SPUD, but then it would get very hectic. I ask him why he did not get the message that SPUD was in one week, and he says it is '*a new guy*'"
>
> (Project data manager, from field notes exploration, 2013).

The ICT tools must exercise flexibility too. In the absence of inter-tool application interfaces, IT specialists, such as GIS experts, are co-located with the G&G personnel to ensure data flow into GIS tools such as ArcGIS. They write SQL queries to interface the corporate database and Python scripts to extract the data. The data they extract are tailored for presentation in the GIS tools in a way feasible to the G&G personnel. Since the G&G cannot do this directly, and in order for the IT specialists and PDMs to be able to do this, the tools have at least a minimum kind of flexibility that enables them to take data out of one system, work with it (format and quality assure), move it to another system, and present it in a certain tailored way in another tool.

4 Implications for Design

4.1 Designing sociomaterial capabilities

Investigating the bi-directional relationship between the social and the material is key to IS knowledge, but it has proven challenging as researchers have treated "*human and material agencies as having a unidirectional relationship*" (Leonardi 2011, p. 148). Now, more technology is designed with flexibility (customisability and adaptability) in mind, either by the users themselves or by IT savvy personnel (developers and/or IT support) in the organisation (ibid.). Instead of addressing the social and material as separate entities, many scholars now view and try to explain them in the form of "*constitutive entanglement*" of the social and the material, that is, sociomaterial (Orlikowski and Scott 2008). This insight is arguably not new, and has been found to be influenced by works such as actor-network theory (Latour 2005), and Law's concept of relational materiality (Law and Mol 1995). Sociomateriality then continues in the tradition of science and technology studies, that has demonstrated empirically the "*constitutive entanglement of use/ technology"* (Monteiro et al. 2012a, p. 93). Recent studies have shown how technologically enabled representations are actually the result of empirically driven representational practices rather than passive readings of sensors (Almklov and Hepsø 2011; Østerlie et al. 2012). This symmetrical practice is also central in capability design thinking: "*No single dimension is more important than another. One may be easier to achieve, e.g., it may be easier to deploy technology than to change culture, but both are required for success. This is a critical concept because value arises from the synergy of the four dimensions, not the singular effect of each individual one. A debate over the relative value of people versus technology misses the point that both are required and can needlessly side-track the transformation effort*." (Henderson et al. 2013, p. 5) How this imbrication is best practiced, is not known a priori. Ciborra explains how we need to design to enable a flexible *bricolage*, which is characterized by; "*flexibility, movement and transformation obtained from intersecting, penetrating and collating different organizational arrangements, such as the network, the matrix, and even the hierarchy*." (Ciborra 1996, p. 104)

In the cases presented above we have also shown how tensions are dealt with by exercising considerable flexibility. We find that flexibility takes the shape of two capabilities that involve the social and the material: *convergence* and *maintenance*. We consider these to be sociomaterial capabilities, since they require flexibility from both the organization and the technology, or the social and material. The flexibility must always be performed, but also continuously developed; "*The central dynamic driving in this transformation is the process* *wherein digital technologies, physical phenomena, and work processes for monitoring and controlling these phenomena evolve together in continuous interplay*" (Østerlie 2012, p. 108). Designers of information systems should therefore pay consideration to the "*continuous interplay*". Different scholars have addressed it using different names. Starting from a capability viewpoint, Henderson et al. (2013) explain how we should build "*... on a view that a capability platform is an information ecology, the dynamic nature of capabilities allow for innovation emerging from these capabilities. Technology in a capability platform is an enabling device for people, processes and governance*" (p.4). Anderson (1999) argues that such organisations are far from equilibrium; "*Adaptation is the passage of an organization through an endless series of organizational microstates that emerge from local interactions among agents trying to improve their local payoffs.*" (p. 228) Information infrastructure research explain the evolutionary dynamics of information infrastructures by drawing upon complex-adaptive systems theory (Hanseth and Lyytinen 2010). Their approach is relevant in terms of showing how distributed, large-scale information infrastructures like those for oil and gas unfold and self-organise, in spite of the apparent lack of standardized data management system or the major constraints imposed by the local contexts, as shown in the previous section. To design for sociomaterial capabilities means to consider and contain the tensions existing between the global and the local (through convergence), and the formal and dynamic (through maintenance).

First, convergence is a concept used by Bowker and Star (1999) in science and technology studies, to label the result of the ever local, ever partial sequence of translations within infrastructures, as a co-construction of nature (corals, fish, rocks) and society (the oil and gas business, authorities). Social, political, and economic interests are embedded into the bricolage work of modelling subsea environmental risk. Convergence is the capability to leverage the performative aspects of operations in order to overcome the dichotomy between the local context (presence of corals with given characteristics in an area) and the global corporate infrastructure with its formal requirements and work processes. Indeed, our cases show how the "location" has the same sociomaterial properties of the infrastructure, in the sense that it stretches across space (subsea and onshore) and time (real-time data to inform long-term environmental monitoring). According to Monteiro et al. (2012b): "*Work practices are local in the sense of being shaped by local social, historical and material circumstances but not local in the sense of being confined in time and space to a particular locale*." (p. 171) As illustrated above, real-time environmental monitoring today implies finding situated, temporary, and ad hoc – in a word, *performed* – heuristics to fit the institutional requirements and, at the same time, the need for a more cross-organizational infrastructure.

The second sociomaterial capability, identified from the case of oil and gas exploration, is *maintenance*. Maintenance is all the often invisible work (Star and Strauss 1999), done by the many, that seldom comes into the foreground, until something breaks, then it becomes extremely visible and urgently needed. Consider our modern societies and cities, and all the continuous maintenance work that goes into keeping roads, water, electricity up and running. The same is required in sociomaterial capabilities. What many designers arguably get wrong is that they do not have a full picture of the complete set of stakeholders that is needed to have the organization running. Maintenance is often neglected "*But it is in between breakdown and restoration of the practical equilibrium – between the visible (that is, "broken") tool and the concealed tool – that repair and maintenance, makes its bid for significance*" (Graham and Thrift 2007, p. 3). In oil and gas exploration, it is, as we have shown above, not just the ingenious geologist that strikes oil, but also less visible work of the unsung maintainers that keep the nuts and bolts going.

Below, drawing on and extending information infrastructure work, we give some design implications of this insight.

4.2 Design principles for Convergence and Maintenance

IS designers should *opt for value-driven design* (I)**.** This principle is about allowing scalability of local phenomena. Doing so can help overcome the bootstrap problem encountered by early adopters of a new system, when costs and risks outnumber the actual benefits (Hanseth and Lyytinen 2010). The need to design for direct value has also been advocated for engineering data representations and models, like ontologies that have been very popular in the last decade. Data models are an integral part of the standardization of cross-organisational infrastructures, but often present underestimated challenges at the level of the local implementation (Hepp 2008). A capability platform thinking (Henderson et al. 2013) suggests overcoming this paradox by fostering an infrastructure's scalability and at the same time focusing on the local value. The EnviroTime case showed how the discrepancies at the local level would not allow the creation of a fixed and overall representation applicable to every operational field for environmental monitoring. Central and local decision-making must converge into something considered as valuable, for instance to decide how many parameters are actually needed and at which resolution to track fish: "*Because one of the big discussions we have had in the project is 'Ok, so what are the data, what kind of decisions are the collected data serving?' Because if you do not have any actions you can do, then one can raise the question: 'Is there a value of the data at all having real-time data if you are not making decisions on it?'*" (Environmental advisor, interview 2013) As the infrastructure is being built around real-time environmental monitoring, the social and natural worlds are necessarily inscribed into it. How much of these worlds is in fact a bootstrapping operation (Bowker and Star 1999), where part of the work of convergence is done by splitting the worlds into useful categories. Will you need to track all the 5 dimensions about a fish at a high time granularity? Or will these more complex data be mirrored by the availability of algorithms to properly analyse them? Or maybe for the sake of getting a long-term trend of the fish's behaviour it is enough to know their concentration in few points of the water column, say, every hour?

As stated above, the development of new information infrastructures within the oil and gas upstream sector is never a tabula rasa. A second principle is therefore to build upon the information *legacy* (II), or installed base. The EnviroTime project is an illuminating case of this requirement. NorthOil being a 40-year-old energy company, it owns a distributed infrastructure for its daily operations, made of pipelines, cabled or wireless data transfer systems, devices, subsea or traditional installations, and, equally important, practices, regulations, and professional knowledge. For example, more than 30000 formal work processes are stored in the corporate databases. The work processes must now be complemented or modified to account for the flow of real-time environmental data that must be coupled with the flow operational data (e.g. exploration, drilling, production). But the necessary technology can be missing – as is for instance the case of the exploration phase, where no investment can be made to install permanent equipment as there is no certainty for profit yet – thus demanding the organisation to reconfigure its capabilities to the new reality, and possibly create new ones. In the example above on the tests done by NorthOil, no physical infrastructure was in place yet, so temporary solutions (buoy, satellite connection) had to be deployed. When that equipment was lost, the traditional installed base was leveraged by adapting the existing capabilities (modelling systems, operators' knowledge) to successfully perform the monitoring activity. The way environmental and technical capabilities get combined is often not possible to foresee a priori and depends on emerging conditions.

The third principle is to *account for multiple levels of materiality* (III). Finding information and taking decisions in the oil and gas business combines several levels of materiality. Sensors for instance take an active role in shaping a reality that cannot be directly accessible to humans (Østerlie et al. 2012). That is also true for the data models or the simulation models that re-combine sensor data to represent or predict reality based on specific parameters, as it happens in climate science (Edwards 1999). Strong currents or vessels might cut off the sensor networks. A well-functioning capability in such a scenario consists in finding a convergence between the materiality of physical properties (failing technology) and the materiality of system intelligence (the models). In the story of NorthOil's tests, when the physical robustness of the buoy failed, the modelling systems came into play to supplement critical missing data from the real world. In NorthOil's tests a surface system could not be decoupled from an efficient real-time onshore modelling system. "*So in that way in places where you have a limitation on the deployment of sensors using modelling is very important because you can predict – based on little information you can predict the spreading of the discharge and you can predict the concentration of particles and the sedimentation on the sea bed. (...)This is a system you have onshore in your office to run this continuously based on input on current and discharge...*" (Environmental advisor, interview, 2012) In addition, the examples we have described in section 3.1 clearly indicate that sociomaterial design must not only include the interaction between the user and the interface and the remote sensors. It should also encompass the way this machinery gets imbricated with another level of materiality: that of nature, which must be recognized its own agency. Convergence therefore means encompassing humans, technology, *and* nature. For instance the robustness of subsea devices should be proven against water currents or challenging weather conditions based on the geographical area. In addition, EnviroTime was motivated by the strong presence of corals offshore Norway, but also the fish living inside the corals should have their say in the system.

Einstein is quoted stating "*Make things as simple as possible, but not simpler*". This is indeed true for a sociomaterial maintenance capability as well. Our fourth design principle (IV) to support sociomaterial maintenance is therefore to *keep it simple*. Although well known, it is far too often forgotten, with subsequent failure. The IS components of a capability must be as simple as possible in order for maintenance work to be possible and cost efficient. "*What makes a collection of IT capabilities simple or complex is a function of its* *technical complexity as defined by the number of its technical elements, their connections and rate of change*" (Hanseth and Lyytinen 2010, p. 13), quoting (Edwards et al. 2007). We would add also organisation complexity. As we have seen in exploration, with at least 35 different systems, that are themselves complex, it should be stressed that it is not only the "end user", the geologist or geophysicist that must experience simplicity (not to say that they necessarily do). It must also be implemented at the many levels of maintenance, the project data manager, the central data manager, and so forth. In a situation where new layers are added to the information infrastructure, with ever-new functionality, simplicity must cut across layers as a key architectural and design concern. In so doing, the organisation can release an additional benefit of keeping it simple, which has proven more cost effective to explore new designs with small and lean artefacts. In so doing, one can prove value through simple and "*low-cost probes*" (Brown and Eisenhardt 1997). This is central to a capability platform design strategy where the goal is to build option value by utilising existing layers in the platform. Each layer must have clearly defined and shared interfaces with adjacent layers. Often termed standards, the interfaces provide the mechanism to decouple layer and enable independent yet scalable innovation. There may be competing standards although as a layer matures, one or two dominating standard interfaces normally emerge (Henderson et al. 2013, p. 9).

A sociomaterial capability is successful when it enables an organisation to *"link products together over time through rhythmic transition processes from present projects to future ones, creating a relentless pace of change*" (Brown and Eisenhardt 1997, p. 3). As we have seen, oil and gas exploration involves a complex assemblage of information systems, maintainers, and end users. A key task for the maintainers is to apply different kinds of tools to search for, move, and archive data in and between these systems, in effect, linking the products together, enabling the essential flow of data. Our fifth design principle (V) is to ensure modularity and fluidity of "small" data. Modularity is recognised in the infrastructure literature as a key success criterion behind the Internet: "*One reason for the speed of innovation in Internet was its initial modular design (...). The Internet's simple end-to-end architecture, which puts the 'intelligence' into the end nodes, has proven to be a critical for its adaptive growth."* (Hanseth and Lyytinen 2010, p. 14) Modularity, in the data sense, would entail that data can be split apart and transported between those actors needing it. We see this in the empirical material where the GIS experts run SQL queries and use Python scripts on the results to shape the results into something feasible for the G&G to consume and interpret. Ideally perhaps, all data would be collected in one giant database or silo that is easily indexed, queried and accessible for all. As long as this is not the case, and given the nature of flexible work, a practical strategy is to enable information to flow between systems by facilitating the data moving and tinkering work done by the maintainers (or perhaps "bricoleurs" to use Ciborra's terminology (Ciborra 1996)). Standards are key to such an achievement, but standards must also be kept simple and pragmatic. The standardisation must strike a balance between being lean enough to support flexibility, while still rigid enough to avoid chaos (Brown and Eisenhardt 1997). Incentives must be given, or requirements set, to vendors to make their data interoperable and enable data move frictionless between systems.

Last, but not least, the sixth design principle (VI) is *to include all required stakeholders in the design process*. Too often, projects fail because they simply overlook more mundane roles and tools, such as the maintenance workers or the PowerPoint application, and rather focus on an end-user-developer relationship. The sixth design principle then is to bring the seemingly mundane and everyday into the limelight. It is essential to get an understanding of the role they play as mediators and maintainers of data and information. Emergent design processes, such as DevOps (Loukides 2012) are extending the agile movements customer-developer paradigm. Full appreciation of the sociomaterial capability thinking requires extending the notion of the customer, to include all relevant stakeholders, including but not restricted to roles such maintainers. In an oil and gas setting, such as in the EnviroTime project, other stakeholders that are easy to keep out of the design process are "silent" (non-human) stakeholders in terms of nature, such as corals.

5 Concluding remarks

Successful organisations manage to balance the exploitation of existing capabilities and the development of innovative competencies. A capability platform approach seeks to provide a general framework to address this target by emphasizing the dynamic recombination of people, governance issues, work processes, and technologies. Sociomateriality gives a framework to further understand how a capability platform for innovation performs and how to deal with and design for tensions that must be observed when building information system capabilities in organizations.

In this paper, we have observed two sociomaterial capabilities in the upstream oil and gas sector. Based on an extensive empirical research in two different disciplines, subsurface resource exploration and environmental monitoring, we outlined convergence and maintenance as two strategies to contain and possibly overcome global/local and formal/flexible tensions. These sociomaterial capabilities should be seen as the beginning of a sociomaterial capability platform, encompassing evolving configurations of social and material actors performing at different scales. From this understanding we derived six design principles designers should take into account when realizing sociomaterial capabilities for the organisation.

This work is a step to bridge concepts that belong to different disciplines. The notions of convergence and maintenance are not in themselves novel in IS; however, this contribution's aim has been to take an additional step into the performative nature of sociomaterial capabilities. In so doing we have demonstrated how to adopt such a lens to the notions of capability platform, traditionally part of the strategic management literature, bridging it with the IS literature. Practical implications can then be drawn for the designers of information systems. We listed a set of guidelines to address the realization of systems that aim to become an integral part of a possibly highly complex installed base, of which the upstream oil and gas sector is a highly representative case.

The work we have presented should be seen as an on-going empirical activity. Future research should analyse the sociomaterial performativity of the bits of information – the data – that constantly flow across information infrastructures and thus constitute them. Another interesting direction might be to investigate how development process (like agile methods) fit with the sociomaterial insight of information system design.

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