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When Are We Going To Address Organizational Robustness and Collaboration as Something Else Than a Residual Factor?

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Abstract

We see an increasing acknowledgement of the importance of work processes and change management in e-field initiatives. However, it is argued in this paper that the E&P business in general tends to lack a framework and the concepts to approach the social nature of work and collaboration. Several studies show the challenges of realizing global concepts, standardized work processes and seamless integration of data. The paper discusses how the social nature of work must be addressed. It also shows what a more open-ended understanding of the work practices of subsurface professionals' can mean for "intelligent energy". Seven propositions based on an understanding of integrated collaborative environments as information ecologies are set up and presented using examples from ongoing e-field/integrated operation projects. The work practices presented are from the subsurface and production optimization domain. Examples are from Statoil, using my company as an example of an industry that has particular work practices also found elsewhere in the business. This kind of work is knowledge intensive, highly dependent upon information and communication technology for the retrieval and presentation of data and information. A shared understanding among professional subsurface and petroleum engineering professionals of this information is enabled with the help of primary and articulation work. These two types of work enable communication, collaboration and decision making. Finally, in the conclusion some suggestions for development work within integrated collaborative environments based on the propositions will be presented.

Introduction

Most major oil companies and globally operating service companies have e-operations, smart operations or e-field initiatives. Even though the scope varies among actors in the industry most of the initiatives evolve around planning and implementation of new work processes/practices enabled by the latest real-time information and communication technologies. Real time data and information are made available from a remote location, typically the down-hole reservoir/well of an oil and gas asset's or from a process facility through a high-capacity fibre-optic infrastructure. Various professionals with multidisciplinary backgrounds onshore-offshore, inside or outside the oil companies/vendors analyse the data in collaborative environments and take decisions on corrective actions to support and optimize the production of oil and gas, see **Fig 1.**

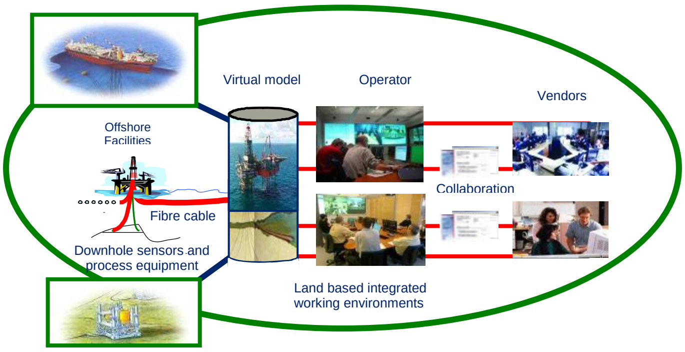

Fig 1 - Integrated operations, from reservoir and process facility sensors to integrated collaboration among operators and vendors. Figure courtesy of OLF (Norwegian Oil Industry Association)

A typical definition an e-field is an instrumented and automated field that utilizes people and technology to remotely monitor, model and control processes in a safe and environmentally friendly way in order to maximize the life value of the field.

This paper addresses integrated operations mostly from a Norwegian setting, a part of the industry that has had considerable focus on the quality of working life, good union-management relations and egalitarian industrial relations. In Norway we have seen a maturing process in the industry, a movement from high technology optimism concerning e-operations around the turn of the millennium, to a situation today where we are more realistic about what can be implemented. Some of the recent realism can be ascribed to what has been portrayed as the perceived conservatism of oil workers-, unions- and managers working in the business. However, much is also related to the reliability of sensors, poor standardization of hardware and software, technical systems and ICT-infrastructure that is to pave the way for the development of integrated operations. Sensors, systems, standards, infrastructure and broadband wired operation centres and collaboration rooms are still struggling to live up to the ambitious targets. As a consequence, many operational activities remain unchanged in today's high oil price regime and integrated operation initiatives compete with other business initiatives that are regarded as just as important. For many protagonists of integrated operations in the industry this is of course problematic. They see that the original focus on tools and technologies has had major shortages but lack a framework to think of integrated operations in a different manner. Describing the need to focus on work processes, management commitment and change management they still fall back on technological "fixes" to pave the way for a future operational practice. However, we see an increasing acknowledgement of the importance of work processes and change management in e-field initiatives[1].

Several studies show the challenges of realizing global concepts, standardized work processes and seamless integration of data[2-3]. Not everybody in the SPE-community will welcome the initiative to open up the black boxes of technological fixes. However, those of us that work with designing and implementing new socio-technical practices within integrated collaborative environments will argue that there is a need to address the details of the work practices of the business, or the fundamental ways people collaborate, coordinate, communicate and develop trust in such environments. The role ICT has in enabling or constraining action within integrated operations must be given more thoughtful consideration. We need applicable concepts and an understanding that moves beyond technological fixes and the treatment of new collaborative practices enabled by information and communication technology as something more than a residual factor. By doing so we must also go into the nitty-gritty details to approach integrated work and collaboration on a micro level. It is the practices on these levels that create organizational robustness, which according to our perspective is the core of integrated operations.

The objective of this paper is to provide some examples about why we ought to address collaboration using information and communication technology in integrated operations in the light of empirical studies about how professionals use ICT in such settings. I will present seven propositions that hopefully will help us to go beyond treating work and collaboration as a residual factor. These propositions should be given a more thorough consideration within integrated operations initiatives: to develop new collaborative practices enabled by information and communication technologies. The propositions presented here are by no means finite, but I will focus on what I regard as most important based on Statoil and Norwegian experience. The author is working with the integrated operations initiative in Statoil ASA, and has worked with research, facilitation and project management related to new collaborative practices enabled by new information and communication technologies since the early 1990s [4-5-6-7].

Examples from the subsurface community and production optimization in Statoil will be used as examples of integrated collaborative practices. In what follows I start with the seven propositions that are built around what I soon define as articulation work. Embodied in each proposition is also the understanding of integrated collaborative environments as information ecologies. After having presented the propositions I will in the conclusion address what this input will mean if we are to address these propositions in development work within integrated operations more in general.

Proposition 1: Intelligent energy and integrated operations must rely on an ecological understanding of collaboration and work practices

To understand the practices that are developing within integrated collaborative environments that will deliver hydrocarbon resources in the 21st century we must approach the dynamics of work and how work fit into the work ecology of the participants that work in such a setting. Potential new approaches to development and production of new gas and oil fields must address a situation where people in the industry try to adapt to changing work demands, try to sustain and control scarce resources and live with continually evolving information and communication. Using 'ecology' as a metaphor acknowledges that there is a limit to how far we can go to understand organizations and the development of practices that are evolving within integrated collaborative environments in the oil and gas industry as hierarchies and markets. "Intelligent energy" heralds a change towards integrated collaborative environments. Since many of these collaborative environments are virtual, increasingly global and network based, an ecology metaphor will be used to depict the evolving situation. An information ecology is a system of people, practices, and technologies in a particular "local" environment[8]. Local here means both virtual and real presence in a collaborative environment and "local" will as a consequence of this increasingly have a more global meaning, since people can be globally distributed but virtually and locally present. The virtual, local and global are key features of an information ecology and it is not just a traditional ecology bound in a particular space. Even though an information ecology has complex dynamics with diverse species and contain opportunistic niches for growth, it can as a virtual space be scaled down to individuals. It allows each professional to find her perspective, set up possible paths into a larger system and shows ways to intervene in this larger system.

Nardi and O'Day describe the key properties of an information ecology[8]. First, it is a complex system of elements and relationships. This means that there are interdependent and complementary relations among the different parts, even though the elements can be very different. Changes in one element will have consequences for another part of the information ecology. But local changes in one part of the ecology might have no effects if they are incompatible with the larger information ecology. Second, an ecology inhabits diversity and is dynamic in the sense that it experiences continual evolution. Different species in the ecology will develop different niches, in the meaning of roles and functions, which will give natural opportunities for these particular species. In our integrated collaborative ecology we see that production engineers fill a niche where they are doing well tests, report to management, discuss with colleagues and perform daily allocation of the producing wells. The set of tools that a production engineer uses in this process is also diverse; mail, spreadsheets, software for the analysis of wells and systems of well performance, telephone conferencing with the central control room, analysis procedures and best practice documentation just to name a few. These are resources in the ecology that production engineers will use in their work.

Let us dwell for a moment on the conception of knowledge that accompanies this ecological perspective. Most theories about knowledge tend to view knowledge as something organizations and individuals *have.* This brings forward efforts to make knowledge explicit[9] via attempting to locate, transfer and store knowledge. An ecological perspective will address practice, the focus will increasingly move towards understanding practices: analysis, methods of judgment, interpretations and problem solving in dynamic environments. Knowledge in this perspective focuses on what professionals *do* and not have.

Third, Nardi and O'Day argue that diversity, in terms of different species is necessary for the growth of the ecology to be sustained under the treat of chaos and change. Diversity captures different roles, education, experience and organizational identity. Fourth, different parts of the information ecology co-evolve and migrate to fill available niches and by doing so they also change the composition of the system. Information ecologies evolve when new ideas, technologies, activities and forms of expertise arise in them. Nardi and O'Day[8] argue that people participate in the ongoing development of their information ecologies, they learn, adapt and create, so will their relations to their tools and technologies: "Even when tools remain fixed for a time, the craft of using tools with expertise and creativity continues to evolve. The social and technical aspects of an environment *coevolve*. People's activities and tools adjust and are adjusted in relation to each other, always attempting and never quite achieving a perfect fit".

Never quite achieving a perfect fit is an important statement here. In this lies a notion that the perfect ICT-infrastructure is a vision that is not sustainable, cost efficient or possible to achieve with available resources. Consequently there will always be tensions between the ICT-infrastructure and the work practices; they will never be perfectly aligned[2]. This is part of the dynamic balance achieved in healthy ecologies - a balance found in motion, not stillness[8]. Such a co-evolution becomes possible because the information ecology has an ongoing structure over time and develops its own history. Depicted in this history is the stable participation of an interconnecting group of people, their tools and practices. Nardi and O'Day show that this history captures the activities, materials, and tools of the trade that have an ongoing history of development and change. Fifth, a number of keystone species necessary to the survival of the ecology will inhabit it[8]: "When we add new technologies to our information ecologies, we sometimes try to work in the absence of essential keystone species. Often such species are skilled people whose presence is necessary to support the effective use of technology". Finally, Nardi and O'Day argue that ecologies have a sense of locality. This brings attention to what role technology fills in the information ecology. A computer in an operation centre or collaboration room is a communication device. Even though the computer can have more or less the same hardware and software configuration it can mean different things for different people in the ecology. This means that the identity of the technology is different in parts of the ecology because the perceived role, availability, utility and other properties of the machines are different[8].

To sum up the first proposition: integrated collaborative environments as an information ecology will have niches of which production optimization is a part. There will be other niches that are wired up by an ICT backbone infrastructure. Each niche has its keystone species like production engineers. They share much of the resources of the environments and must collaborate with the species outside their niche, whether these are offshore 'species' like control room operators, onshore species like topside process engineers and reservoir engineers. An integrated collaborative environment will have keystone species that collaborate and develop strong links to the niches of these species. How will the species that inhabit different niches collaborate in an information ecology that evolves around production optimization?

<u>Proposition 2:</u> Collaboration and communication must be understood as both primary work and articulation work

Both formal and informal work practices characterize the work conducted by species in creating robust information ecologies. *Robustness related to information ecologies is in this paper defined as practices that integrate a division of labour based on primary work activities enmeshed with collaboration and coordination practices described as articulation work.* I will now describe these two types of work. In what follows I will use the framework developed by Les Gasser[10] to build basic elements of work to address integrated operations informed by the metaphor of information ecologies. Let us start with the keystone species in this niche; the production engineer. She uses several computer mediated systems to acquire status, predict output and follow-up wells. Specialist systems like GAP and PROSPER are resources for the engineer to use. The job of the production engineer is to follow up the performance of the wells and challenge the operating limits of the wells in a short- and long- term perspective. This is her *primary work*.

Primary work is the activities that directly address the specific agendas and goals of the work situation. This description of work tends to exist in a formal job description and is tied up into a larger formal structure via an espoused division of labour. She uses numerous computer systems to support her primary role. Information and communication technologies are *resources* at her disposal in this work. Integrated operations in production optimization is created when many people do concurrent activities, but we can organize our view of a particular axis in this complex picture of numerous tasks if we define a sequential *task chain*. A task chain is the production sequence for a object or event, like the tasks that must be undertaken by production engineers and the central control room (CCR) offshore during a well test. It has a start and a stop. This task chain crosses niches in the information ecology, but many of the tasks are undertaken within just one of the niches of the information ecology. The task chain is a formal representation of things most of us are familiar with, whether they are company procedures, “best practices” or flow charts. The well test as a task chain is unproblematic for most production engineers and it represents no great problem for them to repeat the test a number of times. However, each real well test as a task chain tends to be slightly different from the ideal description or “best practice”. Why is this the case?

Gasser argues that in any particular instance the precise structure of the task chain is unpredictable because it will depend upon the contingencies of the work process, including intersecting task chains. In our language here, it crosses the niches to other species. The central control room (CCR) operator’s task chains can have other priorities and may reschedule the task to be able to undertake the well test. In this sense task chains interact and must be coordinated across species and niches for the production of work. The well test task chain must be coordinated with the running oil production task chain, two niches with keystone species that can have different priorities. A complex and coordinated structure of intersecting task chains that in this case involved production engineers and the CCR is a *production lattice*. An integrated collaborative environment can handle concurrent task chains but its major function is to coordinate and integrate the work undertaken by different species in their niches in situations when contingencies develop and bring the niches and their species closer through collaboration.

If we go back to one of the production engineers, the contingencies for her primary work in following up wells in a particular task chain change as a consequence of input from a topside process facility optimization engineer in another task chain. Pressure is exerted upon the production lattice of which their work task is a part. Some of the traditional commitments on which she had based her work have changed and it necessitates a reorganization of work that meets the new principal agendas of the work situation: topside process optimization engineers and subsurface production personnel must collaborate for full asset optimization. The reorganization of the commitments that stabilize production is an important type of work for the production engineer. Work related to re-organization and maintenance of the production lattice is defined as *articulation work*. This work establishes, maintain or break the coordinated intersection of task chains.

Let me present an example here that shows how the task chain of the topside process engineer is integrated with the task chain of the production engineer. After the start-up of well X pressure support from water injector well Y was increased by the CCR. This led to a higher water cut in well Y. The tail producer well Z was already producing at a high water cut, and the well had no gas lift. At the next turn around on the installation a few weeks ahead, all wells would be shut down for several days. It was anticipated that well Z would not be able to get back on production after the production stop due to severe lift problems. Well X would not be able to drain all the remaining oil from its current position. Well Z was producing at a minimum wellhead pressure (14.6 bar a) and by putting the well on low pressure on the test separator, it was possible to increase the drawdown and thereby accelerate the oil production before the turn around. Normally this would not have been possible without flaring the gas produced from Z. The idea being put forward by the topside process engineer in collaboration with the production engineer was therefore to route the production from the test separator directly to the 2nd. stage separator. The process engineer had earlier discussed this possibility with the CCR operators, and actions were taken immediately after the idea was raised. The inlet pressure on the 2nd. stage separator was 7 bar a and wellhead pressure could therefore be reduced by approximately 7 bar. These possibilities between intersecting task chains were available only for a short window in time and had to be exploited in that period.

Wright[11] argues that standard operating procedures seldom adequately represent the complexities of work as practiced, and what is required by humans to fill the primary role in everyday practice. Neither do they grasp the fact that both technology and work practice form a dynamic space that change over time. When we want to address articulation work in the light of integrated operation we want to look at the practice subsurface professionals live by (i.e. knowledge as something professionals do) when they decide which information to use and share, put together often incompatible elements of goals, information, software and knowledge in everyday work situations. It is not the case that individuals only work according to procedures or that such procedures are irrelevant. The main point is that these procedures lead to problem solving activities among colleagues.

Gerson and Star[12] have described the essence of articulation work and these problem-solving practices: “Reconciling in-commensurate assumptions and procedures in the absence of enforceable standards is the essence of articulation. Articulation consists of all the tasks involved in assembling, scheduling, monitoring, and coordinating all of the steps necessary to complete a production task. This means carrying through a course of action despite local contingencies, unanticipated glitches, in-commensurate opinions and beliefs, or inadequate knowledge of local circumstances. Every real world system is an open system: It is impossible, both in practice and in theory, to anticipate and provide for every contingency which might arise in carrying out a series for tasks. No formal description of a system (or plan for its work) can thus be complete…Every real world system thus requires articulation to deal with the unanticipated contingencies that arise. Articulation resolves these inconsistencies by packaging a compromise that ‘gets the job done’, that is closes the system locally and temporally so that work can go on”.

Consequently Gerson and Star[12] argue that without an understanding of articulation, the gap between formal requirements and the actual work process will remain inaccessible to analysis. When the articulation of work is deleted from representations of that work, the resulting task descriptions can only be uneasily superimposed on the flow of work. In real life integrated collaborative environments are dynamic production lattices that consist of both primary and articulation work. It is a collection of interlocked and coordinated tasks.

To sum up the second proposition: an understanding of professionals’ joint construction of primary and articulation work must be undertaken if we are to develop new work practices enabled by new information and communication technologies. We cannot reduce our understanding and approach to work and information ecologies by only looking at primary work. While most integrated operations initiatives focus on primary work, the next propositions will go deeper into the articulation work that is necessary to make the primary work function among the species and niches in the information ecology.

Proposition 3: Shared objects must be developed in order to create collaboration and a shared understanding of practices

Different niches in the ecology must develop their own perspectives to deal with their primary work tasks. At the same time they must collaborate with other niches in analysing and taking decisions in an integrated collaborative environment. Perspective making and perspective taking are two important concepts here[13]. Perspective making addresses the communication that strengthens the unique qualities of production engineers. The tools, models and language developed to handle the contingencies in their part of the ecology. These elements are further developed through reflection and practice and tend to lay the foundation for what is perceived as valid knowledge. Communication that increases the niche's ability to understand the perspectives of other niches is called *perspective taking*. The niche of production engineers must learn to visualize their own understanding and knowledge and make it available for discussions, analysis and communication with other niches. Each niche must also understand how they differ, if not the niches will have problems communicating and coordinating their tasks.

Since the term *boundary object* was defined by Star and Griesemer[14], we see that the concept has gained a large usage within traditions that want to understand the development of bridges between communities, the creation of working orders and coherence, or communication with material objects within and across such niches. Boundary objects make it possible to translate different meanings among keystone species and help these meanings to become more coherent. They are concepts and objects that inhabit several intersecting niches and satisfy the construction of meaning in all of them[14]. The importance of boundary objects in relation to integrated collaborative environments is large since diverse niches whether real or virtually co-located need ICT-based boundary objects. Examples are videoconferencing systems, project databases, email and MSN, or databases that enable a shared collaboration between niches in the ecology.

Boundary objects need not be ICT-systems but various types of material objects that bring the niches together. In the example I presented in the previous proposition a P&ID-drawing played an important part in a discussion between the production engineer, the topside process engineer and the offshore control room. This P&ID was used in a perspective making and taking process between the three niches in the ecology. The drawing was a systemic flow chart representation of the process facility with the test separator, the first and second stage separation, the piping and valves to name some elements. The idea to route the production from the test separator directly to the 2nd. stage separator was discussed with the production engineer using the P&ID as the shared object that enabled perspective taking. The lesson from this example is that close communication between topside process engineering and subsurface production engineers using the P&ID drawing as a boundary object led to both accelerated production and increased IOR volumes.

To sum up proposition three; successful interaction and communication require perspective making and perspective taking in order to make communication and coordination flow between the niches boundary objects develop like the P&ID in this example. In the next proposition we address how data and information must have similar elements to those found in boundary objects.

Proposition 4: Information and data are resources for integrated operation

Schmidt and Bannon[15] have described what articulation work means in relation to information and communication technology and therefore also integrated collaborative environments or information ecologies: "Cooperative work is not facilitated by the provision of a shared database, but requires the active construction by the participants of a common information space where the meanings of the shared objects are debated and resolved, at least locally and temporarily…Thus, a common information space encompasses the artefacts that are accessible to a cooperative ensemble *as well as* the meaning attributed to these artefacts by the actors". In this understanding production data, for example digital code collected by well and process facility sensors and conveyed via a fibre optic infrastructure cannot be ascribed any meaning in itself. Production data becomes information when it is placed in some meaningful context by those who use it. This common information space where production engineers work along with other species and niches consist of numerous knowledge representations, ranging from specialised analysis and simulation software, collaboration tools like Net meeting, videoconferencing and mail, MSN, written and oral information.

However, if we are to understand the practices and knowledge of the production engineers we cannot just reduce their work to these knowledge representations[16-17]. If we bring these representations together it will not just be a question of collecting and retrieving documents and well data sets, make data available in a shared workspace, have discussions with colleagues or give shared access to a model. Important articulation activities to understand the production engineers' work will involve activities like validation of information and data, comparing-contrasting and double checking this information. Subsurface professionals like these engineers will use different representations to develop a useful understanding of data and information before it is applied in their real settings. Drawing a parallel to Ellingsen and Monteiro's[3-16] work, professionals need to know the methods and models employed in information generation. Information credibility, meaning if a chunk of information is approved and trusted is a function of the knowledge the user has of the methods and models that were used in the development of the information. In this sense chunks of information coming from an unreliable source are less likely to be used without closer scrutiny. Ellingsen and Monteiro[3-16] show how information is not only assessed in relation to technical systems, models, calculations and models, but that *who* generates them becomes of the utmost importance. The literature tends to support that knowledge workers spend considerable time identifying the originator of the information[15.] Schmidt and Bannon[15] show how information tend to be evaluated with respect to personal qualities of the originator, personal style of over-under statements, the problem solving style of the originator and her role or place in the hierarchy[16]. This means that different tools and software cannot be used blindly in any situation since they have risk elements or uncertainties that must be made explicit in analysis, discussions with colleagues and when taking decisions.

Let me present an example that shows the essence of these practices. It deals with undertaking a pressure build-up (PBU) analysis. A PBU analysis is important to get a deeper understanding of particular reservoirs and can thereby be a key enabler to increase production. One of our assets has a reservoir driven by bubble point pressure; meaning that the reservoir pressure should not go below the bubble point level pressure. The reason for this is that the gas will come out of solution below bubble point pressure which will lead to a reduction in the oil mobility and thereby reducing the long-term recovery from the reservoir. When conducting a PBU analysis, a production engineer expert typically evaluates the well history and creates a trend development. She can gather input data from well history data, well PLT-data, well completion data, well production history data, reservoir parameters and other data sets. These various types of data are used to identify a model where segments and faults are found by stratigraphy. The permeability of the formation is assessed and other factors like: storage, skin and number of layers are evaluated. Such input is used to develop a general model selection of the well. This model is then used to interpret other pressure build-up data sets from other well tests and evaluate if the well tests match the general well model. If this model matches a determination of Pr and PI from the well test results further analysis is undertaken, using methods like MBH and Vogel. A thorough investigation is undertaken before it is assumed that the MBH and Vogel method is appropriate in this setting. A discussion with other production and reservoir personnel is undertaken at various points in time. Together the subsurface personnel scrutinize the PBU test and interpret results. What is the average permeability? Is there so much consistency in transient data that one model can be applied to all PBUs in the test wells? What action can be taken based on the results; do we increase the pressure support in the well? All along a mixture of various tools and models is used, and all along the appropriateness of the models and tools is evaluated in relation to the properties of the well and the reservoir. It is a process with much calculation but little can be automated from start to stop.

Another important element in understanding the communication between professionals here is that a high degree of empathy or subtleness must exist in situations where there are other people present. This becomes of utmost importance when we cross species and niches and especially when we deal with virtual collaboration and communication. In many situations it is difficult to know how much of the context and how much awareness is in place; how much of the information is already shared, what do we need to say and can leave tacit?

To sum up proposition four: collaboration in such an integrated collaborative environment requires a shared information space. However, the work that professionals do cannot be reduced to the information and knowledge representations on which such a space is built. Collecting retrieving and making data and information available in shared models and datasets will not suffice. Articulation work is needed to validate, compare, contrast and double-check as the PBU example shows. Subtle issues like validating the originator of information, empathy in understanding particular situations, personal styles of professionals and having an awareness of what is going on is vital [15-16-17].

<u>Proposition 5:</u> People will develop mechanisms to handle inconsistent ICT-systems and infrastructures

Given that we have a shared information space among the species in our information ecology and have a flexible structure that secures a proper balance between primary and articulation work, will we then have the flexible integrated collaborative environment that we want to develop? Ideally yes, but in a real-life setting we will always have to maximize the limited resources at our disposal. The orderly flow of work depends upon the consistent *alignment* of resources and commitments in the workplace[10]. The resources that we have in each situation can be misaligned with the demands of work.

We deal with one example related to production optimization here, a situation of *resource slip*. Such a slip is the under supply or misalignment of resources needed or expected to carry out a work task. In the light of production optimization such a slip may occur in several resource dimensions. In the organizational dimension there can be too little time to follow up all the wells, small budgets for long-term optimization work in relation to daily optimization and “fire-fighting”, inappropriate quality of personnel due to lack of training and lack of management attention. In the technological dimension we can experience inaccurate data because of poor reliability of sensors, technical inadequacies in quality of ICT services and incompatibility in the software and hardware. Inadequate computing resources or too low transfer bandwidth are other issues that can create low system output/feedback.

These slips are socio-technical in nature but they lead to contingencies because the work is developing in a dynamic and open manner where all potential action alternatives cannot possibly be written in our procedures or embedded in the work flows of our systems. There will always be a need for smaller or bigger negotiations over resource commitments under conflicting demands. This will happen frequently when existing resource allocation mechanisms do not fit emerging contingencies.

When using ICT in integrated collaborative environments people must handle the misfit or contingencies they encounter in their everyday primary work situations and still do their work. Let us take a closer look into the variety of general strategies people use to handle such resource slips. There are at least three strategies for accommodating such slips in dealing with computing: fitting, augmenting and working around[10]. If we begin with *fitting*, this work is the activity of changing computing or changing the structure of work to accommodate for the computing misfit. Fitting work tend to be a function of complex negotiations between those who control resources and the others that must live with the misfit. This work can involve making changes to computing arrangements so that a misfit between organizational practice and use lead to a patching, upgrade or new version of the ICT system that removes the misfit. Further, by adjusting work routines and commitments when a slip is made to compensate for the misfit.

Augmenting work is to execute additional work to make up for the misfit. Gasser argues that augmentation is adding additional tasks to a task chain. It thereby complicates the production lattice and increases the need for articulation work. Typical examples are practices related to verifying and revising data in production optimization. When errors are expected in existing systems additional work of verifying and revising data is important adaptation work. Under the influence of important errors people track down the causes and mitigate the consequences. Further, by consolidating data sources through combining data from different sources they are able to understand the conditions.

Working around is the third strategy for handling a misfit situation. It is often an ad hoc strategy to solve immediate and urgent problems: "It means intentionally using computing in ways for which it was not designed or avoiding its use and relying on an alternative means for accomplishing work". First is data adjustment, entering wrong data, dummy data to get ahead and use less time. This is a kind of procedural adjustment in the sense of working around formal computing to reverse organizational procedures for getting service or making changes. Gasser[10] argues that the ability to work around established procedures depends upon having the power to create and exploit flexibility in work routines, a close working knowledge of the procedures and the particular division of labour in the organization (one must know whom to trust and whom to ask for favours and speedups) and having the access to key actors who can do the work one needs in the way one needs it done: "Working around the formal system depends upon great skill with the formal system". Finally, backup systems that use alternative ways whether manual or automated to keep duplicate records, i.e., data not kept in the proper computer system instead kept in engineers' favourite tool of tools: spreadsheets. It is these three types of articulation work: fitting, augmenting and working around that make up the nitty-gritty details that enable integrated operation in everyday situations and create the necessary dynamic to make collaboration and coordination flow. The particular accommodation strategy that people in such environments employ depends on how they are able to coordinate and balance the demands of their work with the available resources. Can it provide greater leverage in undertaking the primary work? Gasser[10] asserts that without these three types of articulation work computing services and performance would degrade very rapidly at significant organizational cost: "Fitting, Augmenting, and Working Around are central to integrating computing into work…Computing remains useful and intelligible to staff through constant informal interaction and communication, and through continual work of maintaining accurate data and integrating computing by adjusting work routines".

However, each of these three types of adaptations require work and can be conceptualized in terms of production chains and production lattices: "Each time an actor works around a particular inappropriate computing arrangement or problem, he or she is creating and executing tasks in a task chain, and most likely these tasks intersect with the work of others, embedding his or her work in a production lattice. The ease or difficulty of fitting, augmenting, or working around computing is linked to the execution of the task chains comprising that work…When the pressure of primary work is great enough and people do not have the option of performing "legitimate" adaptations (e.g., software maintenance), they rely on locally effective alternatives -other types of Fitting, Augmenting, and Working Around – to keep computing integrated into their work, and to keep computing marginally usable"[10]. The significance of these lessons is that it is the highly variable details of action and practice that are vital. They are vital because it is here computing is integrated into work through complex, coordinated action of people and groups in different work situations accommodating misfits and contingencies. It is not necessarily the formal structure and technical design that provide the glue that integrates information and communication technology into work.

To sum up proposition five, ICT resources tend to be misaligned with the demands of work and a situation of resource slip develops in the use of ICT in integrated collaborative environments. Professionals develop several strategies to handle this misalignment between work and resources, via fitting, augmenting and working around. These strategies are also articulation work and may not always support the objectives and demands of primary work. However, they form the necessary dynamics to make collaboration and coordination flow in an integrated collaborative environment. Primary work would soon degrade without these types of articulation work.

Proposition 6: There is no easy way to automate and aggregate data acquisition from sensors and manual input to make better decisions

The subsurface domain today represents numerous proprietary software and hardware platforms, much because of the functional silo thinking in the past. With the growth of increased cross-disciplinary collaboration there is a trend towards increased integration of seamless applications that make use of central data repositories. Integration is important and this paper is not a manifest against integration and standardization. However, we must be aware that integration into seamless applications can lead to a perspective where work is only understood as information flow.

Let me be more explicit on this. If we integrate seamless information between specialist applications using for instance middleware we tend to lose the articulation work the professionals undertake when they check data and information before using it in their settings. Let us assume that this data is automatically collected by sensors and aggregated in the assets' IMS real-time data system or aggregated from manually entered data related to the history of a well. For instance, the reliability of the data about how much a particular well produces and the composition of the hydrocarbon liquids requires input from a monthly well test. In the first days after the test the production engineer can rely on the data. However, the older the well-test data the less a production engineer can rely on the well test data source as reliable input to understand the performance of the well. The more this kind of well test data is aggregated through networks of wells without knowing the changing performance of wells in-between well tests she will end up with aggregations that have large uncertainties. The production engineer knows her wells and finds other ways of dealing with the data when the well test is no longer reliable. These types of data are evaluated and checked by the production engineer and put in the proper context because of her detailed understanding of the assets wells. In this case the production engineer might experience that seamless information flow between applications leads to loss of the ability to conduct this important articulation work. Both poor IMS-input and non-calibrated multi-flow meters can make it harder to discover errors in the initial data and information chain, errors that can accumulate at the other end of the chain. When non-asset experts are to evaluate the seamless data they will have problems finding the errors because they do not know the context well enough and do not know how to combine context dependent data elements.

I have worked in a project (VISOK) to develop web-based front-ends from subsurface legacy systems[6] that showed examples where subsurface personnel are reluctant about entering data in systems that aggregate data for decisions. They describe a situation where they are "caught in the process", without having the ability to describe or fill in the argumentation that support their conclusions. The categories available in the ICT system that were aggregated and presented via the VISOK front-end did not enable them to express what they knew and consequently provided too little bandwidth to convey the essence of their calculations. It was not system critique that established this practice but the subsurface professionals sense of pride in doing a good job and an urge to maintain their professional integrity. They knew that there was large uncertainty in the data at the time of entry, and because they knew that there will always be a number of ways of interpreting and evaluating this kind of input. Consequently they would have no control of their data developed in their specialist systems and employed in another context by a middleware solution. When the data were compared and aggregated by personnel and managers using the middleware front-end application they could not possibly grasp the elements that were at risk. In this case the mere use of formal information transfer did not provide the necessary information, contexts and uncertainties to make the information applicable. The practices that moulded the aggregated information were also invisible, and as a consequence also the trustworthiness of the information.

To sum up proposition six; which is not an argument against automation and development of seamless ICT infrastructures. It is plea to make us consider the importance of articulation work throughout the chain of data from sensor/manual input to decision processes. These practices are more than primary work, data management and QA/QC procedures. Even if we will have functional sensors in one part of the chain, there will be a need for good articulation work practices all along the chain to apply the data and information in its proper context. If we just automate and create front-end solutions enabled by middleware we will do very little with the work practices of the professionals except making them invisible. We will also have problems with the mechanisms of trust- and trustworthiness that tend to lie behind the use of the data.

Proposition 7: Articulation work and trust is the foundation for all good data and information management practices

In the VISOK example[6] in the last proposition I showed how subsurface personnel put pride into making their data trustworthy. What role does trust and trustworthiness play in good data and information management practices? Gasser[10] argues that when people are expected to do the same work tasks in a similar manner, coordination of activities requires the *commitment* to a certain character and organization of work: “work organizations can be seen as a complex structure of organized commitments, which serve to coordinate tasks. Thus the degree of certainty of commitments or degree of trust influences how smoothly the entire task structure functions”. Work tasks also tend to be dynamic because they are interconnected with other tasks.

How people handle others in different situations is an interesting feature of articulation work. Let us draw some parallels to the ecology within our integrated collaborative environments and the actions undertaken by our keystone species the production engineers. When she cannot find the information she is looking for she will know who work together and approach these to fill in the holes that information systems, analysis and data sets cannot provide. She will to a large extent know who knows what in the asset environment and which persons to trust when acquiring technical domain input. Knowing the players in the game facilitates collaboration via help, advice or ideas[18]. She will know to approach the reservoir engineer to check out details related to the characteristics of the particular segment of the reservoir. This person might help her understand the sudden increase in the water-cut of the well: have the segment water breakthrough from a previous unknown fault? She will discuss the re-routing of a low pressure producer from the test separator directly to the second stage separator together with the topside process engineer. Together they will find out that they are able to keep this low pressure well producing for a few more weeks. In this much more than primary work activities are involved. Detailed knowledge of members’ personalities and skills will be employed to deal with the contingencies. She will know how to approach and discuss things virtually with an offshore control room operator that is afraid of accelerating or tuning the production of the well. Even though she knows that her primary work is to question and challenge the operating limits of wells and networks in order to be able to do her job in virtual collaboration with others offshore they must behave in a trustful manner. Because she knows from previous experience with this operator that he is afraid of sand production and that people offshore wants to have a stable production regime she must behave in way that acknowledges this. If not she will have problems next time she needs the CCR’s collaborative input. The CCR-room operator must be confident that the proposed changes in choke settings on the well will not create sand production and subsequent hick-ups on the topside production process on the platform. She must argue that sand production at this particular choke setting will not occur anymore because they have had a well intervention in that well recently that has changed the operating conditions of the well. It will not produce sand at this choke setting level anymore.

This is just one example where a potential lack of trust between offshore and onshore nodes can influence information assessments in integrated collaborative environments. Trust is a vital mechanism to understand collaboration and is a mechanism that reduces transaction costs. Much of the work that is spent monitoring and controlling others becomes of less importance: ”…trust is the willingness to accept vulnerability based on positive expectations about another’s intention or behaviors…trust represents a positive assumption about the motives and intentions of another party, it allows people to economize on information processing and safeguarding behaviors” [19].

I will not go into details on research that shows that information receivers and senders trust the informal information they get via meetings, visits and each other via collaboration more than formal information[15-16-18-20]. However, what is important is how subsurface personnel as originators of information render themselves and the information they produce trustworthy. This is important articulation work because the output-data do not always show whether particular methods, applications, models and simulations are more trustworthy than others. To be more specific here; the models and methods used for instance in a well test or a pressure build-up test have uncertainties. How much certainty can we ascribe a particular mathematical model based on SAPHIR to calculate pressure build-up in the wells and network of wells? How can these calculations be compared with other calculations?

Many small measurements create the case via numerous independent measurements. Close interaction between production engineers, and reservoir engineers was necessary to establish the correct model for the analysis of reservoir pressure. The MBH-method (Mathew-Brons-Hazebroeks) was found to be suitable for calculating the average reservoir pressure from the parameters obtained from the pressure build-up (PBU) interpretation as presented in the previous example. It is important to acknowledge that it is not the tools in themselves that are evaluated, but their use in each situation. The mathematical model used to calculate pressure build-up was not questioned, but it was important to determine whether the calculations were compared with other calculations, which pressure they represented and the scope of the pressure. Objects in the PBU analysis will be situational and are not static objects that can be easily captured in a repository and transferred across contexts without losing much or their contextual content[17].

A perspective of integrated collaborative environments that stresses the trust element is very different from much state- of-the-art thinking concerning organizing principles and coordination mechanism in organizations. Williamson[21] has argued that rational economic actors should not rely on trust when managing interdependencies and allocating shared resources. Trust in this perspective is looked upon with suspicion, as a pre-modern concept that will not fit the challenges of modern organization when it comes to organizing and coordinating economic and collaborative activities. Personal acquaintances are believed to reduce the likelihood of economic changes between strangers, thereby limiting economic progress, since trust blinds and binds. Excessive reliance on trust principles also blur the allocation of accountability and decision rights at the heart of both hierarchy and market forms. Mainstream thinking concerning integrated collaborative environments tends to have the same shortcomings. Considerable scepticism exists in using trust as an organizing principle within and across organizations. Groups or niches develop coordination mechanisms to manage interdependence among individuals, units and activities when confronted by behavioural uncertainty. They are ways of working with the problem of interdependence and uncertainty, and such approaches represent a logic in which work can be coordinated and information handled.

In the literature we increasingly see that there is a move from market/hierarchy coordination mechanisms[21] towards using community and trust as a third coordination mechanism or organizing principle [19-22]. As McEvily[19] argues, and here I agree, a too narrow focus on market and hierarchy mechanisms is based on a flawed understanding of how organizations and trust in particular works, since trust tends to be a basic necessity for virtually all forms of exchange, hierarchies and markets included. Whenever actors are simultaneously dependent upon and vulnerable to the actions and decisions of others as they are in integrated collaborative environments, trust is a decisive organizing principle. In addition, the coming of more knowledge intensive corporations increases the importance of trust as a coordination mechanism. Trust becomes an increasingly attractive mechanism to economic agents[22]. Neither market or hierarchy, nor a combination of the two is proper to handle knowledge creation in the integrated collaborative environments that is developing in the business.

To sum up the seventh and final proposition: the degree of certainty of commitments or degree of trust influence how smoothly the entire task structure functions in an integrated collaborative environment. Trust is a vital mechanism to understand collaboration and it can be combined in varying degrees with market and hierarchy since it is a mechanism that reduces transaction costs. Data and information management practices build on knowing the players in the game and evaluating the trustworthiness of the data.

Conclusions

Will not human-factor engineering and functional allocation methodologies handle the challenges addressed in this paper? Most function allocation methods have the primary objective to address primary work and describe functions[11-24] and will not go into the details of what here is described as articulation work. In many cases articulation work would be regarded as dysfunctional or taken for granted. Articulation work becomes increasingly important when work becomes knowledge intensive (i.e. in the subsurface domain) and primary work seem to lose more of its procedural qualities. The importance of contextual factors in interactive system design has grown over the years where the complex dependencies between work activities are stressed[11-15-24-25]. Organizational robustness in integrated collaborative environments will be created if we stop looking at it as a residual factor that is addressed after the implementation of new real-time technologies. This does not mean that technology is unimportant here. Tools are important resources in action. However, if we address the creation of organizational robustness as a socio-technical challenge[25] we approach integrated collaborative environments as development of new practices. These new practices will consist of a division of labour based on both primary work activities enmeshed with collaboration and coordination practices described as articulation work. Several of the propositions here represent a break with mainstream thinking concerning integrated collaborative environments in the business. Statoil has started addressing the propositions via developing a program for collaborative training in integrated collaborative environments. This training has two aspects. One part addresses perspective making and improves the skills of subsurface professionals in internal collaboration and develops increased efficiency in using the tools of their professions. The second part of the training is based on perspective taking, developing the competence to make the professionals more skilled in communication with colleagues outside their own profession. Training in virtual collaboration, communication, defining rules of the game in collaboration are some elements included in this part of the training. The training tries to be systematic in cultivating the articulation work activities that create a robust integrated collaborative environment. Taking information ecologies seriously means that both Statoil personnel and suppliers will eventually take part in this collaborative training. We have previously had substantial success in integrating third-party participants in training sessions[7-23]. In the end perspective making and perspective taking is about changing practice.

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