Center for Integrated Operations in the Petroleum Industry

SHORT REPORT

The role of models in operative decision making processes in the subsurface domain – A pragmatic perspective

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SUMMARY

This report discusses the roles that model based representations of an oil reservoir play and may play in operative interdisciplinary work processes. Based on a selection of expert-interviews, we discuss how models are used in an operational context, and specifically try to understand the limitations of (existing) model based tools in supporting interdisciplinary decisions during drilling.

The report is based on a pragmatic understanding of scientific representation, and draws from different theoretic perspectives within science studies that focus on the *usage* of representation in actual work settings. Models are discussed as knowledge objects with close relationships to cognition, expertise and communication.

The report maintains that in the context of interdisciplinary operations like drilling, there is a great reliance on human interpretation, articulation work, and contextualization of data to make optimal decisions. The goal is not simply increased model accuracy, but rather modeling tools that support these processes in a fluid and ever changing context.

Keywords	Reservoir management, geology, drilling, modelling, science and technology studies, integrated operations, pragmatics, distributed cognition, articulation work.

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1 Introduction

This report discusses the roles that model based representations of an oil reservoir play and may play in operative interdisciplinary work processes. While the models represent something, and their representational qualities *per se* may be interesting to look at, the angle here is a pragmatic[1] one: We focus on the *activity* of representation and the *use* of the models in actual operations. We will demonstrate that understanding the contexts in which the models are employed and the knowledge work with which they are intertwined is critical to obtain innovative uses and implement new technology. The geomodel and reservoir model play important roles in long term and large area decisions on most modern oil fields. While these models are central in strategic development of most oil fields, we are addressing their role in interdisciplinary operative decisions in the subsurface domain, where their usage is much more varying. Put concretely: we look at how the geomodel and the reservoir model play a part of the decision basis in decisions during operations, particularly drilling, and how it is aligned with real-time information obtained in such operations. By doing so, we try to provide an understanding of the pragmatic qualities of models in general.

2 Background

2.1 *Integrated operations and the geology / reservoir domain*

In Norway, an information revolution in the oil industry has received the label "Integrated Operations".[2] Generally IO is about using the increased opportunities in terms of communication and of information acquisition, handling and aggregation, to create new ways of working. A pillar of Integrated Operations is increased utilization of model based control mechanisms.[3] Within the reservoir domain research efforts have been directed towards "real-time"[4] and "closed loop" reservoir management. A general idea behind this research is to increase and improve the use of model based tools to support decisions, if possible including predictive components where real time data is fed into models to simulate future development. Control by means of model based forecasts (simulation) can possibly support or even replace some human decisions in some cases.[5]

The loop can be said to be "closed" when new real time data are automatically fed into models to make predictions, and when these form the basis for make adjustments of input parameters, for

[1] "Pragmatic" here refers to a study of the effects of an artifacts or symbols in a given context, rather than their representational content. This will be elaborated later.

[2] No paramount definition of the term is generally adopted and the concept is approaching a catch-all phrase for innovation within the Norwegian Oil Industry. Key references for most of the discussions of the concept are the studies by Norwegian Oil Industry Association (OLF, 2005). See also Vinge (2009) for an analysis of the concept as a discourse.

[3] E.g. within process control (Qin and Badgewell, 2003), production optimization (Bieker et al, 2006; Kosmidis et al, 2005; Foss et al, 2009; Wartmann et al, 2008) and drilling (Rommetveit et al, 2004; 2008).

[4] The time horizon of "real time" is understood at the IO center to depend on context. Since reservoir management has many work flows with long time horizons, the concept of "real time" within these is often in the magnitude of months.

[5] See http://en.wikipedia.org/wiki/Model_predictive_control . Such methods has for example been used successfully in the process industry. See for example Qin and Badgewell (2003).

example of drainage strategy. Closed-loop reservoir management is a vision, a principle to be strived for, more than a concrete goal. Also, much IO related research is directed towards improving the “tuning” of the reservoir model by improved and faster methods for history matching. Closed loop reservoir management strategies in the near future will probably not mean a loop without human judgment involved, but more likely that predictive simulations and model based visualization may be an even more important part of the composite basis of information for decisions taken by humans. (Carlile and Hepsø, manuscript) With a development towards more updated models and faster and more precise simulations, opportunities for model based support for more types of decisions may present themselves.
This report is written within the Real-Time Reservoir Management program of the IO center of the Norwegian University of Science and Technology (NTNU).[6] However, rather than working on technical modeling issues which forms the bulk of this program, our research is aimed at obtaining a better understanding of work processes within the reservoir domain. Also we try to pursue fundamental understandings of how the models and human capacities (knowledge, perception, communication, thought etc) interact in practical work.
In the subsurface domain there are two key models representing the reservoir as a whole, and these are thus natural resources to draw upon in one way or another when exploring the possibilities for model based control of the reservoir management. The **geomodel** outlines the geological structures and properties, and the **reservoir model** models the flow of fluids in these structures based on production data. The purpose of the geomodel is generally to represent the the reservoir structures and properties in a unified way, for example enabling one to calculate volumes of reservoir rock and also enabling communication about the same volumes.[7] The purpose of the reservoir model is typically to calculate the volumes of fluids in the rock and to simulate their movement, by using (mainly) production data from existing wells as inputs into a rather simplified model of the rock structures and their flow-relevant characteristics. The structures and properties are usually based on the geomodel.
This report builds on the realization that for many important discussions and discussions based on information from the geo and reservoir domains, models and forecasts made by modeling are not very central. This is especially true in the case of operative decisions with when speed is essential and when the decision basis is interdisciplinary. It is our experience from operative organizations that the geo and reservoir model are most important in decisions and evaluations for large areas, when the scale of the problem to be solved is big, when time horizons are long and when the context of the decision is predictable. (Almklov, 2008a; 2008b; see also Almklov, 2006) To implement model based control methods in the reservoir domain one must first understand why the models of the reservoir are used only in some situations.

This report will provide an exploration into the use of model-based decision support in operative, interdisciplinary phases of the work of reservoir engineers, geo- and petrophysicists and geologists. In particular we will discuss the role of models in connection with drilling, since this is one of the most crucial operations in terms of risks, economic gains and also since it is a major source for new real time information about the reservoir.

[6] Reservoir management is organized under Program 2.1 at the IO center. See http://www.ntnu.no/iocenter/research/program2/p1
[7] See also Almklov (2006) for a discussion of the geomodel as a tool for interdisciplinary communication.

2.2 About the interviews, the authors and this report.

The authors are both social scientists each with an additional master's degree in geological engineering. Our engineering backgrounds make it easier for us to navigate within the oil disciplines than it probably is for most social scientists, but we are not trained or experienced in the specific topics that we are investigating here. This is challenging, both in terms of understanding our informants correctly and of asking the right questions, but also it is a problem when writing on these issues. Many examples and observations, interesting to us and to other social scientists, may seem to many engineers and geologists like over-interpretations of trivialities from the oil business. On the other hand even simplified accounts of the subsurface decisions and tools we discuss here will be hard to grasp for outsiders, even within the industry.[8]

A problem in doing work process research in such settings is that the work processes are linked inextricably with technical, practical and theoretical issues that are accessible and understandable almost exclusively for people with experience from the field. Our research in one sense seeks to convey some of the practical and operational experiences of the experts we interview. We do, however, try to do this through a theoretical framework that we believe will help us obtain a more generic and fundamental understanding of the challenges they face, hopefully inspiring reflection also beyond our own disciplines.

Our research is based on the conviction that there is a research gap in terms of the understanding of the social and human aspects of the work processes in the oil industries. (Hepsø, 2006) Work processes are often discussed as stereotyped flow charts representing the movement of objectified tasks, not addressing the articulation work and adjustments necessary to execute the tasks in practice.[9] In drilling operations, where workflows from several domains converge, there might not even exist such stereotyped representations either, and how work is actually carried out is an issue where details and peculiarities remains obscure for most but a group of initiated practitioners.

This report is primarily based on an interview series with a small selection of experienced personnel in the reservoir and "geo" disciplines (geophysics, petrophysics and geology). The interviews were loosely structured around a set of topics concerning the use of models in operational settings. It was an explicit ambition of the interviewers to allow the interviewees to reflect on their own work through addressing generic issues and what we in the recruitment process labeled as "philosophical" themes in their practical experience. Besides these core interviews, the report is also based on one of the authors' previous research of work processes in subsurface departments (Almklov), and also we draw on the other author's ongoing PhD - research on model supported collaboration in drilling. (Haavik)

In the following we will quote some of the interviews. It should be noted that these quotes are *illustrations* of our interpretation and not presented as "evidence" of the arguments in the text.

[8] Much of the technical terminology can be looked up at Schlumberger's dictionary: http://www.glossary.oilfield.slb.com/

[9] See Hepsø (2006), Almklov (2008a; 2008b) and Haavik (manuscript) for different discussions of articulation work in the oil industry. For the concept in more general terms confer Gerson and Star (1986) or Strauss (1985), a similar discussion is also found in Suchman (1987).

3 Theory

Our analysis is based on a selection of ideas and concepts from different theoretical schools, but all within what one can call some kind of *pragmatic* understanding of representation. The essence of this view is that we look for what the signs, symbols, representations **do** within a certain context, the task they serve and the effect they have. It implies here that we study the effects of the models in a given context, what they do and what is done to them, and not only their abstract meaning. This implies that we study the ”activity of representing” rather than representations as such. (Giere, 2004:743) Within such an understanding the effect rather than the “content” of the sign is the object of attention. One can even say that absence of content has a meaning, depending on the context, if it has an effect, like the letter your sweetheart never sent you.[10] Rather than a full fledged framework, we will here briefly introduce some ideas that provide some of the means to interpret the interviews.

First we discuss the models as scientific representations, and provide a few characteristics of their representational structure and how they relate to the reality they represent. We then discuss the generic dilemma of transparency and black-boxing in the construction and use of models, how the chosen representational structure will always *hide* some complexity and alterative meanings. Then we go on propose a theoretical basis for addressing the relationship between such representations and the knowledge of people trying to understand the reservoir by using them, arguing for a view of knowledge as “distributed” between individuals and technology. Related to that discussion we also briefly introduce a theory that may explain some of the roles that models may serve as a means of communication between individuals and disciplinary groups. Though the quotes and empirical findings will mostly be presented in the next section, a few of the statements from our informants are so to the point that we have chosen to use them as illustrations for the theoretical issues as well.

3.1 Models as representations

> The only thing we know for sure is that the model is wrong. And we always say to ourselves - the only thing we know for sure is that we are wrong but we try to be as little wrong as possible. - Geologist[11]

Quite understandably information about the subsurface properties of an offshore oil field is quite scarce. It is extremely inaccessible and information gathering depends on multi-million dollar ventures: seismic surveys, exploration wells, well logging, tracer injection etc. Still, such ventures are often worth the cost and on most fields there are a multitude of sources available that all yield some kind of information about the reservoir, however with varying accuracy and characteristics. We will provide a highly simplified and generalized account of these types.

By way of existing wells one has measurements and registrations that are results of or physical contact or close interaction with the reservoir and its fluids, like logs based on electrical and radioactive measurements in the borehole, samples and as the well is tested and put into production they have different kinds of production data. These data types are mostly relatively[12] detailed and accurate; however they basically only provide robust information about the immediate vicinity of the well. A more indirect, but very important, source is seismic data, which

[10] This example of how non-communication carries meaning is borrowed from Bateson (1972).
[11] Quoted in Almklov and Hepsø (manuscript).
[12] Compared to seismics for example. However, there is a wide variety of accuracy and resolution of these data types as well.

presents "images" of the structures made by highly processed recordings of acoustic reflections. In addition, highly indirect forms of information like documented, personal or informally conveyed experience from similar fields, observations from analogical fields on dry land and even geological theory, are important sources of knowledge, forming for example the background of interpretations and extrapolation of more concrete data.[13]

This multitude of information can be combined in many ways. The diversity of information from the reservoir is a resource, both in terms of quality checking by independent sources, but also by the fact that they complement each other when interpreted in concert. Maybe the most typical example of this is how detailed point observations from the logging of a well path can, when extrapolated, "fill inn" the innards of a coarser data type representing large volumes, typically the seismics. (See Almklov, 2008a)

Whereas the data diversity allows for a multitude of combinations, the models we discuss here are accumulated and integrated representations of a selection of information. They cover the whole volume and they are integrated in a consistent manner. It is one realization of an overall interpretation, represented as a coherent symbolic structure. They represent a whole, built from the fragmented and diverse data sets and information. Modeling is a way of dealing with large subsurface volumes from a rather small office on shore. The models are attempts to systematically adjoin data so as to make the data points speak also of the unknown areas between them. They are interpreted constellations of data, made to exhibit formal similarities with the reservoir itself.

From a pragmatic perspective, the relationship between models and the world can be expressed following Giere (2004:743) as *S uses M to represent W for purpose P*. Here S is the scientist (or in our case, the subsurface group), M is the model, W is a piece of the material world and P is the purpose.

Whereas it may be possible, in instances when one is modeling very well defined or abstract entities to evaluate the representation of W in the M in terms of truthfulness, the reference value in models of the material world below the bottom of the sea is one of degrees of abstract *similarity*. In the words of the geologist quoted above, they are at best "as little wrong as possible". Given the highly inaccessible nature of an oil field, these models are simplifications of the structures, their grid sizes are large and the accuracy is in many cases low, at least compared to the data from wells. However, they serve many purposes, and are invaluable assets on most offshore oil fields. Carlile and Hepsø (manuscript) note that there is a distinct difference between the production and process control domains and the reservoir domain to be found in the level of *confirmation* of the models: Whereas adjustments made based on model prediction in process control quickly will lead to identifiable changes that confirm or disprove the model, such feedback will be slow and often intangible when making decisions based on the reservoir model. Much IO-research can be understood to be directed towards increasing the frequency of confirmation of the reservoir model (typically history matching).

The uncertainty is explicitly underscored and recognized as a key feature of the reservoir and geomodel by many in the business, including our informants. To quote one of them, "[t]he geomodel is one thing, but the uncertainties around it are maybe what is more important than the model in itself."

The simplification, and the representational compromises involved in building a model, allowing for and learning to live with uncertainties and compromises, should be understood not only as a

[13] See Almklov (2008b) and Carlile and Hepsø (manuscript).

shortcoming in terms of representing the world accurately, but also as a consequence of its purpose. Michael Lynch (1990:181) writes on visual representation in science that.

> "[S]cientific representation is more than a matter of reducing information to manageable dimensions. Representation also includes methods for adding visual features which clarify, complete, extend, and identify conformations latent in the incomplete state of the original specimen."

Though Lynch writes about scientific representation more generally, this clearly holds value for models also. They are simplifications and selections, but also amplifications of characteristics that are relevant and manageable within the subsurface disciplines.[14] In Lynch's (Lynch, 1990:162) words they are more *eidetic*, closer to theory, than the raw data. Hence, each model is a certain kind of aggregations and simplifications, made not only with a keen eye on the world it represents, but also directed towards a certain purpose.

3.2 Transparency and black-boxing

A good model leaves irrelevant information in obscurity, or out of the model, and displays what is regarded as relevant information. This simplification and selection can be compared to the principle of "black-boxing".[15] Black-boxing means that you are "hiding" unnecessary complexity to focus attention to what is relevant for the rest of the system.

For example a model must be built around a chosen seismic realization, from many alternatives. Also, in the typical geo-model geological heterogeneities below a certain scale will not be mapped, but rather be described by some average properties. Although such selection and simplification may be necessary, it also poses a dilemma, since the simplified version might hinder the access to important details, because "irrelevant" information in one situation may be critically relevant in the other. Sometimes one may need the unnecessary: more detail, different information types or knowledge of how the simplified version was constructed from raw data. Haavik (manuscript) discusses situations during drilling where transparency into the black boxed complexity (of drilling data) is necessary and argues that the safe handling of such operations are dependent on the an ability to switch between closure and openness.

One informant talked about how data needed to be sorted away when constructing a model, and how that could get you in trouble.

> So when the complexity is high, then you kind of sort away some of the data. And if you are unlucky and sort away the wrong data, those that tells you that here you should have done something differently, then you get into trouble [ut og kjøre].

Safety issues is not our main concern here, but lessons can be learned from the discussions within safety literature on this issue, since considerable attention has been given to transparency of sociotechnical systems in some important works (e.g. Hollnagel et al 2006; Perrow, 1987). The importance of this property as a precondition for safe functioning of sociotechnical systems is

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[14] See Almklov (2006) for a discussion of how observations of variation of geological properties are conveyed as boundaries. This can be regarded as a typical example of amplification of selected data, in this case into a geometrical shape.

[15] 'Black box' originally was a phrase used in cybernetics (see for example, Ashby, 1957) to describe a conventional device in circuit diagrams that outlines the inputs and outputs of a certain component, and not its inner workings. The term has later been used in a variety of different ways within science and technology studies (see, for example, Latour, 1987). This topic has also been addressed in Almklov (2008a). The issue of black-boxing vs. transparency is generic design-dilemma, for example seen in programming (see Turkle and Papert, 1990).

linked to how well the internal functioning of a system can be understood and thus how easy deviances can be discovered. Whereas black-boxing is a very strong design philosophy, the lack of transparency into the inner workings of the box may have negative consequences if the design is faulty or if the context changes. Work process based considerations the balances between transparency and black-boxing should therefore also be of relevance to model-supported operations. When an ambition of integrated operations is to implement control loops based on forecasts made by modelling,[16] it is obvious that the success of these controls will hinge on the choices and strategies in terms of black-boxing and transparency. Into which information is transparency necessary and which information can safely be black boxed and represented by simplified or aggregated representations and simulations?

3.3 Models as tools for cognition and collaboration.

> There is reason to suspect that what we call cognition is in fact a complex social phenomenon. The point is not so much that arrangements of knowledge in the head correspond in some complicated way to the social world outside the head, but that they are socially organized in such a fashion as to be indivisible. (Lave, 1988:1)

> The emphasis on finding and describing 'knowledge structures' that are somewhere 'inside' the individual encourages us to overlook the fact that human cognition is always situated in a complex sociocultural world and cannot be unaffected by it. (Hutchins, 1995:xii)

In this section we will discuss two relevant views of how models rather than being static representations of knowledge, serve as tools in cognitive and communicative processes, thus highlighting the pragmatic aspects of them. The two quotes above both stress the role that semantic signs play in cognition, and vice versa, that many semantic representations must be understood as tools for cognition.

A fundamental role of scientific representation is that it interacts with human cognition in what some authors refer to as distributed cognition. [17] A simple example of distributed cognition is when a human solves a mathematical problem by manipulating numbers on a piece of paper. The *representations* of the numbers are also *tools* for the human mind externalizing a complex problem too hard to solve without symbolic tools. According to this perspective on human reasoning we must address the *interaction* between "external" representations, like the numbers on paper, and "internal" cognitive processes, and view this as one system of cognition. (Hutchins, 1995) We will return to this discussion later, and only note that the relevance of this theoretical concept here is that it fits well with how many of our interviewees describe their use of models and simulations. They are cognitive tools in their work of trying to explore and understand the reservoir, and not only representations of what they know. Models are tools for thought.

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[16] E.g. within production optimization (Foss et al, 2009; Wartmann et al, 2008) and drilling (Rommetveit et al, 2004; 2008).

[17] The concept of 'distributed cognition' has several sources. Hutchins (1995) is one of the most commonly cited (though the term is not used in the book). See also Giere (2002) for a discussion of the concept in relation to models. He traces its origins to the works of McClelland et al (1986). See also Hutchins and Klausen (1996) for the airplane cockpit as an example of a distributed cognitive system. See Sinding-Larsen (1991) for a related and interesting account of the intimate relationship between knowledge and systems of explication. Almklov (2008a) follows a somewhat similar argument as the one presented here, however not explicitly linked to models.

In terms of *purposes*, in Giere's "equation", the models obviously play an important role as a means of communication. As communication tools, the geomodel (in particular) and the reservoir model bear some resemblance to what Star and Griesmer (1989) have characterised as "boundary objects".[18] Such objects play the role as a common representation on the boundary between intersecting disciplines or social worlds, and where there is a need to ensure integrity of information without being able to (or interested in) reaching full consensus. Such objects are both "adaptable to different viewpoints and robust enough to maintain identity across them". Especially the geomodel could be seen as a type of boundary object since it serves as a coordinating artefact between disciplines (ibid). In our interviews, the informants described the models along such lines, and how they to some extent are results of negotiations and as compromises between different experts of the subsurface domain.

> Then it is one person that has this idea and another person that has a different idea about this and it has to be combined/coordinated [Norwegian: "samkjørt"] to get into a communal model, and that one can of course have some uncertainties associated with it, but in any case you need a communal model. When you talk to drilling people, it is far between the drilling people that want to know about uncertainties. Drilling people only wants a yes or no.

This quote by a geologist on a rather new field, describes the role of the model as a tool for coordinating different views on the reservoir, and of facilitating communication by providing a communal version around which uncertainties can be discussed. Also, since it can be used on a very aggregated level, displaying formation boundaries and faults as solid lines, it serves as a informative visualization to answer to those outside the geological community, for example the drilling personnel, rather than discussions of uncertainties and alternatives of their data sources and interpretations. Henderson (1991) stresses how certain types of boundary objects are employed as visual tools in the coordination of work, and refers to these as conscription devices. The archetypical example of such representations is engineering drawings, where interdisciplinary group participation is centred on simplified, convention bound drawings, ordering the collective work.

Whether or not one chooses to focus on these aspects of the models specificly, they do serve some communicative purposes both as simplifications for "outsiders" and in being points of reference internally in smaller groups or even for the individual geologist or reservoir engineer orienting himself.[19] Models are tools for communication and for coordination of work.

[18] The geomodel is more obviously a representational object in the intersection of different disciplines compared to the reservoir model. Since the reservoir model is dynamic, the *outcomes* of simulations are the more important than the model itself, to people that are not reservoir engineers.

[19] For an interesting view of how extremely simplified representations serve as points of orientation, see Vertesi (2008). Her article shows how the subway maps of London are internalized by Londoners to the extent that they some times say that it is the terrain that is wrong, not the map.

4 Models in operational decisions.

> But when we begin to drill, the only thing we know from all our experiences is that when we drill we find out things are not the way we think they are.

In this report we focus on the use of models in operational settings. While the more general discussion of the models as representational objects is indeed interesting in itself, our main concern here is their usage to support decisions in operations. The geo and reservoir model are not primarily designed for a real time support of operations, and we will see a few consequences of this in our findings. In the operations, where expensive equipment and man-hours are put into action, *time* is an inescapable constraint of all decisions. Also, the subsurface models must be aligned with even more disciplines, as the technicalities of drilling and well operations must be considered. The context hence is even more *interdisciplinary*.

In this section we will discuss the findings from our interviews that mainly focused on the use of the geo- and reservoir model in operational context, and specifically in drilling operations. The geo- and reservoir model are important tools on a larger scale, supporting field strategy decisions, and the placement of new wells and so on. They are rather seldom used in an automatic (closed loop) fashion and also they seldom play a role in the decision making processes of operative phases, as when wells are drilled, for example. In our interviews we tried to explore the reasons for this and try to better understand if and how the information contained in the geo and reservoir models can support operational decisions. We have grouped our findings rather loosely as a series of topics with relevance for this exploration. First, we discuss the different role of models in large, old fields and in newer, smaller fields. Secondly, the issue of different data resolution in the models and the log data and the difficulties this makes for data integration is addressed. Thirdly, we elaborate on how the conceptual and practical gap between using models as representations and tools might be overcome by new models whose properties are better aligned with the requirements for them to be applicable in operational settings.

4.1 Different practices on different fields[20]

We discussed the informants' use of models in general, but we focussed particularly on the operational context, mostly on the possible role of the geo and reservoir model (or derivates of these) in supporting decisions during drilling operations. Most of our interviewees had experience from or knowledge the practices of several different oil fields. Whereas in some fields many work processes where almost built around the models, they were more secondary tools on some other fields. Interestingly, in one of the largest oil fields on the Norwegian Continental Shelf with a long production history and vast amounts of production and well data, both the reservoir and geomodel were normally of little importance, save a few full field studies for example related to the overall drainage strategy. For example the planning of new wells was not based on simulations, but rather on comparison with existing ones, and other kinds of interpretation. This was partly explained as partly a consequence of the large amounts of data available, which means that much "raw" information is at hand for direct interpretation and which also means that data integration requires more work. It was also explained as a consequence of the fact that new wells in old fields were usually placed in more complex "left-over" areas.

[20] Note that older fields on the NCS are normally larger than most new fields. Thus most observations of differences between big and small could also been attributed to age and vice versa.

On a newer field, with less than a handful of wells, relatively poor seismic quality and no production experience, the geomodel and reservoir model were the pivotal elements of the planning of new wells. Generally it seems (if one should dare a rather simplistic generalization) that the less actual data there is to extrapolate, the models (which are based on systematic extrapolation) are a more important part of the general body of knowledge of the field. So even though more data would probably enhance the accuracy of the models, the models will not necessarily be more important, even though the *R* may approach *W* in Gieres (2004) "equation".
When we ventured into the topic of the use of models in operations, putting the plans into action so to speak, diversity between the model uses on the different fields persisted, but the tendency was clear on all fields: Raw data from the well being drilled took the center stage in operational decisions, most often aligned with seismics. The role of the models were clearly subordinate in almost every decision making process. Hence the ambitions of integrated operations, with model based decision support, is a distant goal in terms of utilizing information from the geological and reservoir domain in operations. The reasons for this must be understood by inspecting the qualities of the modeling tools in relation to the specifics of the contexts of operations. We discussed a few such topics in the interviews, mainly using drilling as an example.[21]

4.2 Real time updating to support operative decisions?

On the fields from which our interviewees had their main experience, the reservoir and geomodel are tools that are employed, to a varying degree, in the planning of new wells, typically to predict the volumes of porous rock to be accessed and the expected fluid contents and productivity of this. What is interesting then is whether these models are *updated* during operations, whether such updated versions are an important element in decisions during drilling operations, and ultimately if this process can be supported by automated methods. One could for example envision the possibility that well observations obtained during drilling could be fed into simulations that generate forecasts of the production given different alternatives, to choose the optimal positioning of the production segment of the well in terms of productivity. This ideal of model based predictive control of the reservoir, seems to be far away, at least when it comes to real time support of operations. As soon as operations start, there seems to be a radical discontinuity in the work process. Not only are the models not updated, but they are in many cases not consulted when decisions are made.

> I think in most cases that I've been involved in, […] we've generally had a set of geosteering criteria based on real-time data and that's what we based our decisions on, rather than feeding the data back into the model, reinterpreting the model and then making decisions based on what the model says.

The models do, however, form a static background or a kind of a "base line" to their interpretation of raw data. He continues:

> We've *checked* it against the model to see whether the new information significantly changes the model, whether it just falls within the uncertainty we've defined in the model or whether it's completely outside our understanding of the model.

Our other interviews also pointed in the same general direction. Why, then is it so that the models are bypassed and not included in the real time decision loop during operations? There are several reasons for this. Some are quite obvious, as habit and work load, whereas others are more

[21] We introduced some of these topics ourselves, but some are our subsequent interpretations of topics raised by our informants.

intricate. We believe that much of the answer can be found in the integration of data sources, a task whose complexity should not be underestimated.

4.3 Integration. Properties of real time data vs. models

There is a quite fundamental and straight forward problem of different resolutions when aligning drilling or logging data with the reservoir and geomodel. The resolution of the latter two is in a magnitude of more than 10 lower than the former. Discussing the dilemma of whether to put more trust in *on the fly* interpretation of raw data or on the model, one informant discusses their complementarity.

> That is why I always go back to the model and check it, because the model is very much seismically driven and you're looking at two resolutions of data. So you get your logs and they are in certain resolutions and it tells you certain things and then you have your seismic which is at a different resolution and generally a scale different, your whole model is a scale different. So you're always looking at different resolutions data and you're trying to make the best decisions. So at least in my experience, we always go back and check the model under the operations while we're doing; we hope that it's matching pretty well or it's not so radically different that we can't live with that, there's always some uncertainties anyway [..].

The two different scales and the difference between the data types gave him the opportunity to use the model and seismic to contextualize and check the raw data. Regarding the data types as tools, the different perspectives or "double description"[22] provided by the data sets has a value of its own.

Though it has poor resolution, the model data is "connected" to the whole of the reservoir, whereas the data from the borehole is local. Coupling these radically different data sets without loosing the accuracy and resolution of the local data and the "connectedness" of the model is a challenge that must be solved in each case. How far outwards can the well data be stretched. How high in resolution can the seismic be trusted? And when they meet, giving questionable information about small scale features far from the well and below the seismic resolution, which is really closest to truth?

Typically the geomodel, if accurate, will help the workers orient themselves in the structural neighborhood of the well, but the detailed information from a new well path will not be filled into it as a well is drilled but rather be evaluated independently. The informal "checking" described by the informant here, is a typical ad hoc solution where the data (or rather meaning drawn from different data sets) is integrated by means of human judgment. To couple the detailed well data with the geomodel, for example to obtain a fine gridded model around the well, would require great effort, since it is a matter of interpretation to find out how far away from the well one can extrapolate the well observations.

There are a lot of tough decisions to be made as to how to fit new raw data from one point, into a global model. The new data must be aligned with the global data, and the choices to be made in this process are issues of complex interpretation. An informant that works on a very large field with reservoir and geomodels that where basically only updated in campaigns explained:

[22] Bateson's (1972; 1979 and most specifically 1982) discuss how descriptions of a phenomenon from two or more viewpoints may generate knowledge beyond what is in each data source itself. Like 3D vision is obtained by the combination of the 2D images on our retinas. Also Almklov (2008a) argues that additional information is gained by experts interpreting diverse data types in concert.

> And then we must figure out, “how the heck are we going to update this monster?” Because if you start fiddling with two wells, then you do something with the rest as well.

A fundamental dilemma is how to align the detailed and highly reliable data along the well path, with the low resolution and less accurate data from the reservoir. The models are one realization of these combinations, based on the pre-existing information, but along the path of new wells their accuracy and resolution will be on the low side, closer to the seismic resolution at best. To integrate the new data with the models, one have to make choices as to how far to trust the real time data, how far into the “monster” it reaches and how much of the monster should be changed. Should one go for fit for purpose models for small sections of the reservoir, or maybe temporary versions? And then a key question is, how to quality insure the update process, to make sure that hastened real time updates doesn’t hurt the integrity of the model as a whole?

There are many possible solutions available, all with certain pros and cons. One is to create proxy models for certain areas, another is to make a temporary version or a locally updated version, and then merge this with the official version with time when one has time to do proper quality insurance, and one could use geostatistical methods. It is beyond our capacity to evaluate these solutions, but we will rather stress the underlying generic problem of which they are solutions, that of robustly and quickly tying detailed and accurate real time data to a global geo- or reservoir model.

To sum up, we asked about the extent to which the real time data were implemented in models to support decisions. To all the informants the geo and reservoir model formed a part of the background knowledge base that they consulted to contextualize real time data. The only example from our interviews that real time data was fed into the models during drilling was that some of the informants had some experience with doing a near real time manual updates of the structures (i.e. the boundaries between the structures not their content) in the geomodel, and that this updated version was used in discussions and decisions during operations. This was, however usually subordinate to their attention towards real time data. Real time updating of the reservoir model or automatic updating did not occur. So except the update of structures in the geomodel on one of the fields[23], interestingly the field where one with few existing wells, one can basically assume that the models would not be up to date to support decisions during drilling.

There are many reasons for this, but we believe that one essential one is that the adjoining of different information types requires interpretation, and that knowledge of the uncertainties within the models, and the limitation of the data types in each context is critical. This is work demanding, and it is also dependent of contextual knowledge, for example of the uncertainties in the model, so it is probably not easily transformed to a computer routine.

4.4 Transient decision making context

A problem with employing models in operational phases is that the goals to be optimized for are often moving targets, and that the decision making context is changing as new data comes in and as operational risks vary. Moreover the contexts are not always easily defined. A typical example is that the considerations between obtaining an optimal well to produce while in the operational phase will always be made also with an eye on the technical possibilities and risks presented by the drilling. Hence, the linking of the modeling work with the decision making process will need

[23] It was not entirely clear whether they were speaking about their previous experience or their plans for the upcoming wells. Probably it was both: that they had some experience with structural updates and were planning to use it later on.

to be a continuous process of calibration, demanding a lot of attention and a continuous redefinition of the problem to be solved. In operations the price depends on time, and the contexts of decision making is transient. This doesn't only mean that decisions must be made fast, but it also means that new information and new constraints for the problem to be solved can show up all the time. Hence accuracy is not the only prerequisite for the information basis to be included in decisions. It must also be in time and adjustable to the changing context of the decision. While blackboxing implies hiding part of the context to focus the attention on the important "text", the transient context of operative decisions probably poses a critical challenge to the relevance of many modeling tools. For example, the simplification of the heterogeneity of a geological structure that works all right in most situations, may hide critically important information, for example if one is geosteering in that formation.

Also, a couple of the interviewees expresses concerns that focus on feeding data through models to keep them updated, would direct efforts away from "listening to the well" as one put is.

> [D]o you focus on going back to and always looking at the geo-model, using a geo-model to make decisions for you or you are listening to the well as breathing, as living? It's telling you stuff along the whole drilling progress. Are you listening to that, are you paying attention to [pause] are you using that to make your decisions?

4.5 How translate model uncertainty into operational context?

Being built to a large extent by extrapolations of incomplete data sets, great uncertainties are the norm for most models of the reservoir. To the extent one recognizes the lack of information one has, this is possible to handle by quantifying and describing the uncertainties. One may view risk as the traditional product of the (known or expected) likelihood of an undesired event and its consequence, and uncertainty as the likelihood of being wrong, of not seeing the risks or miscalculating the likelihoods.[24] What the operational setting introduces is a *consequence* of faults in the model. This will vary with every decision one takes. In some situation there is even a possible hazard involved in spending too much time and effort evaluating the uncertainties and risks. Since they have possible consequence the uncertainties in the model will in the operational phase be known or unknown risks, and since knowledge of the uncertainties of the models as we will see in the next section to a great extent is a matter of undocumented experience based knowledge, it is not straight forward to translate it into what risks it implies for each decision. Many of our informants' concerns about relying to heavily on the geo and reservoir models in "quick" decisions and of updating them on the fly was centered around the importance of taking uncertainties of the models into consideration. Inspired by (among other things) safety research, we tried to spell out what uncertainty could mean in relation to models, and how knowledge about it is maintained.

[24] Within safety literature this has for instance been discussed, in much more detail and with more rigour, by Aven (2009). See also Möller et al (2006).

0.	No uncertainty	In model
1.	Known and codified. E.g. Assumed variation within a range, E.g. of permeability.	
2.	Known and not codified. E.g. We know there's a possibility of faults in the area, but can't really say exactly where and how many.[25]	Epistemic uncertainty
3.	Known unknowns: We know that the model is inaccurate in this area.	
4.	Unknown unknowns: We think our model is correct here (but it isn't)	

Table 1 Different types of uncertainties related to model data.

Without going into the details of discussions within safety literature, it suffices to argue that in addition to the codified knowledge and the codified uncertainties that may be put into a model, there is a range of different "epistemic uncertainties" (Möller et al, 2006:421), spanning from what one knows, but which may be hard to express through the codes in the scientific domain, through known unknowns all the way to the things one doesn't know that one doesn't know. Arguably much of this grey area of knowledge is "stored" more in the brains of people than in models.

The types of uncertainty that are not in the model, will pose risks that will need to be evaluated in operative phases using the contextual knowledge of the model that reservoir engineers and geologists have gained from working with it. Since the geo and reservoir model contains comparably greater uncertainties and have a lower possibility of confirmation[26] than for instance models of the process plant, the need for contextual knowledge will be greater to evaluate such risks.

4.6 Distributed cognition, human knowledge and models

As mentioned several of the interviewees talked about the understanding of uncertainties before the drilling phase, and the importance of really understanding and being familiar with uncertainties in the model (and how they may affect the well). This clearly illustrates the connectedness of the model to the minds of those using it to plan a well, but also some also suggest that updates of a model during drilling may introduce new uncertainties and risks that they do not understand.

A model as a tool must be seen in relationship with the knowledge of the people that construct and use it, for example during well planning. Usually, wells are planned through intense studies of the models and other data, and it forms a part of a general body of knowledge located in the interaction of the minds of the people in the group and the tools they use. Most notably this relationship is visible in the way all of our informants stresses the importance of being familiar

[25] The boundaries of this category are not straight forward. One can say that type 2 is epistemic uncertainty in the sense that it is not possible to express within the epistemic system of explication (in this case the model). But still it is known by the epistemic community, and may be written down as text or *other* forms of explication. It may also, in the form of tacit knowledge, inform interpretation, for example.

[26] If the model is wrong and make a decision based on it, you will not receive as quick and clear a response telling you that as you normally will on models with higher accuracy and with quicker response time. (Carlile and Hepsø, manuscript)

the uncertainties in the model. This includes both knowing the documented and calculated uncertainties, as well as the ”epistemological” uncertainties, the possibility of being wrong (3 and 4 in Table 1). The latter is of course particularly dependent on experience. One interviewee thinks models could be used more in operations, but cautions us that it could (amongst other things) introduce new uncertainties that must be studied and understood.

> I could see models being used a lot more in operational; let’s say improving operational results. There’s a risk as well [..], do you have the time to feed it back into the model and if you come up with a rightly different model, you’ve perhaps introduced a whole new uncertainty range that you need to study and understand. Do you have the time to do that within your operational phase […] or not? So, there’s probably a lot of cases where it could really help you, and there’s a lot of cases where it may actually hurt you because you loose your focus from maybe using your experience on the real time data and making operational decisions based on what you know rather than on what your model says.

If one, by automatic adjustments of the geomodel with real time data for example, could obtain an improved model during drilling, one should presume that that is all right. But a couple of our informants suggested that that isn’t all unproblematic. Much of the knowledge “in” the model, actually sits in the relationship between the group of subsurface personnel that is familiar with it, and the model *per se*. Hence even a change for the better can possibly reduce the understanding of the reservoir, if the group working with it looses familiarity with its weaknesses, uncertainties and how it has come into being.

> I think modeling is very important to understand how this reservoir operates, how the communication between wells is and so on. So it is an incredibly important task. But in a pure operational setting I believe that a good reservoir engineer who knows his reservoir back and forth, when he gets receives [new] data… he could almost draw in three dimensions how the oil-, gas and water contacts are when you have had these changes [geometrical deviances seen from raw data].
>
> It is the understanding that is important, and that you can obtain without running a stochastic modeling and the whole package.
>
> I mean … a person that has worked on a field year after year, knows this field relatively good. And I don’t believe that these people have the need for a reservoir simulation to get to know how a change in the reservoir will occur.

These observations are both relevant for our discussion of the black-boxing versus transparency dilemma and are good examples of how the models may be a part of a distributed cognitive system. The building of a model and the calibration and “playing around with it”, is a crucial part of the knowledge of many workers. They are skilled at understanding the reservoir *through* the model (as a tool of exploration). Hence, their knowledge is more than what is explicitly foregrounded and presented by the model. We believe that when many of the informants talked about the importance of “knowing the uncertainties of the model”, this is a related, if not the same kind of experience based personal knowledge. Thus, an automated, black boxed update is a problem if it means that the workers’ understanding of the inner workings of the model, its weaknesses and limitations, isn’t able to keep up.

There is an interesting, though subtle difference in the ways models in general, and also the geomodel and reservoir-model, can be perceived. On the one hand one can view it as a *representation of the knowledge* about the reservoir, and it certainly is. On the other hand, it is also *part of* the knowledge of the workers, indivisible from cognition as it is their tool for understanding it. In line with theory on distributed cognition, for example, knowledge includes signs (for example those in models) and the minds that use them. The model is integrated in the knowledge of the workers, and a part of their way of understanding, as much as a result of their understanding. In line with this, several of our informants tie the effective use of the reservoir simulation to knowledge gained by an intimate relationship with the model. In the discussion of how to integrate new data types in reservoir modeling[27] one informant notes:

> [I]f we can do history matching that is the best. Because then you learn something about the flooding processes in the reservoir, in the process. But that doesn't mean that you should use the model afterwards. [laughs] It is the understanding, the understanding of the reservoir, which is important to gain from it. And if you have that, then a good engineer will be able to work intuitively with the model he has in his head and be able to do much of his work.
> Q: So what you are really doing here is highlighting the reservoir model as a tool for learning to understand the reservoir, more than the predictive value of it.
> A: Yes.

5 Conclusion

The crux of this report is that effective use of modeling tools within IO must rest on an understanding of the work processes in which they are developed and employed. We have specifically inspected the setting of drilling operations and the possibility of drawing the models types in the geo/reservoir domain more into the decision making processes there.

The previous sections have illustrated the embeddedness of the models in communities of practitioners that know their quirks, uncertainties, historicity and limitations. This familiarity has implications for how models can be used as knowledge objects, especially as they have relatively "weak" relationships to the nature they represent. This means that one should proceed with caution when treating them as mere *representations*, and for example exporting them or merging them with other data sets, thus "loosing" the contextual knowledge with which they are integrated.

What we see is that improvements along the lines of the IO visions in this domain must rely heavily on the ability not only of generating more accurate models or of connecting real-time streams to the geo- or reservoir model, but probably just as much on the development of tools specifically adjusted to the operational setting. The interdisciplinary nature, complexity, raw data availability and transience of the operational decisions seem to place these models in a secondary, supportive role as information sources among many. And in this role, flexibility to changing contexts, that you don't have to do much work to fit your tool to the problem you are about to solve, will be important. Whereas some problems can be solved directly by improved simulation and forecasting techniques, many gains may also be achieved by improving the "boundary object" function of models in these situations, for example by providing simple tools that facilitate interactive communication across disciplines and that improve situation awareness in a fluid situation.

[27] We were discussing whether data from 4D seismic should be integrated into the reservoir model by history matching or if it should be used as a separate data source.

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