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CODIO—Collaborative Decisionmaking in Integrated Operations

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Abstract
We describe CODIO, an Integrated Operations (IO) development project currently underway in the North Sea region. The aim of the project is to optimize the drilling process by ensuring that drilling teams generate a continuous stream of right decisions made at the right time. Current IO projects do not fully address the challenges posed by decision making in the new IO environment with abundant real-time data, operation centers, virtual multidisciplinary teams, mobile workforce, etc. The CODIO project develops and evaluates a new model for decision support in IO. The model is based on advanced decision theory, combined with real-time situation assessment, collaborative ICT-supported work processes, and a semantic model for sharing data and knowledge. Decision support in CODIO exploits recent advances in Bayesian techniques, adapted to dynamic and (near) real-time decision situations. Constructing decision models "on the fly" is enabled by collaboration technology including visualization. Previous work on applying Semantic Web standards (OWL, RDF) in IO is used to support proactive information gathering and sharing. CODIO is being verified by systematic laboratory testing, followed by gradual introduction in the ODC (Onshore Drilling Center) facility operated by ConocoPhillips in Tananger, Norway.

Introduction
Over a remarkably short time of 3-4 years, the concept of Integrated Operations (IO) has been firmly established in the NCS (Norwegian Continental Shelf) region, and is being implemented by all major operators and service companies (Fig. 1). The promised benefits are immense: 3-4% increased oil recovery, 5-10% accelerated production, and 20-30% lower operational cost. According to a study by the Cambridge Energy Research Associates in 2003, the increased use of new and emerging digital technologies could potentially boost world oil reserves by 125 billion barrels over the next 5 years. Petoro A.S. of Norway has estimated the added value of applying *e*Field and IO on the Norwegian Continental Shelf to be USD 25 billion. A more recent report by the OLF (Norwegian Oil Industry Association) indicates that the value of IO to Norway could be 250 billion Norwegian kroner (USD 35 billion). OLF (2005) identifies the progression of Integrated Work Processes through gradually more advanced generations (G1 – G2). The current implementations of IO are based on "Traditional approaches" with limited integration, and mark the transition to more integrated G1 processes (2005-2010), to be followed by G2 processes (2010-2015) with radically new operational concepts and business models. Elements of G2 processes are already being seen, particularly around the integration of Companies.

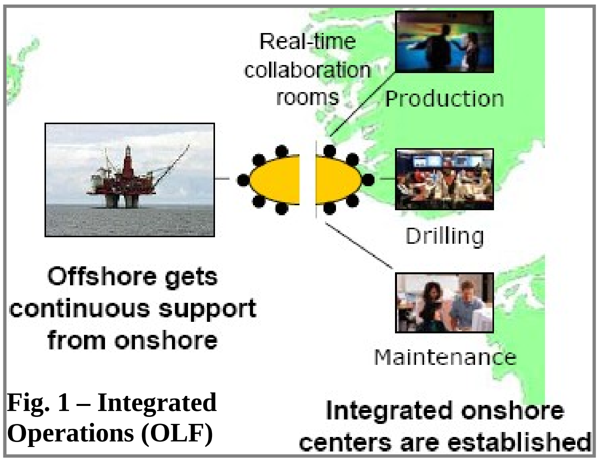

Fig. 1 – Integrated Operations (OLF)

The nature of well planning and well execution is changing dramatically as a result of new IO processes and technology. Onshore drilling centers will be used actively in the well planning and execution process. Contractors and service providers will be involved through participation in the operator's onshore drilling centers or usage of their own drilling and expert support centers in combination with real-time collaboration solutions. Decision making will move more and more onshore, though safety critical decision makers will still be located offshore, but onshore drilling centers will have more responsibility in optimization and decision-making. The drilling process will increasingly be automated, using AI (Artificial Intelligence) and other techniques for automated reasoning and decision making.

In this paper we first analyze challenges to and opportunities for improved decision making in IO, and then outline an approach to decision making based on *decision science* and Bayesian decision networks. In IO, collaboration and information sharing are essential activities, and we introduce the notion of group decision support enabled by formal domain *ontologies*. We use an example from drilling operations to illustrate the concepts that we have introduced, and propose a conceptual architecture for a new generation decision making support tools for IO. Finally, we summarize our work and offer conclusions and prospects for future work.

Decision making in Integrated Operations

Implementing IO requires fundamental change in several dimensions, including introduction of new technology, new ways of organizing work, and new processes for decisionmaking. We can classify complexity of decision processes along two dimensions: *Decision complexity* and *coordination complexit*y. The first dimension addresses the difficulty of the decision in terms of number of options, degree of uncertainty and outcome, etc. The second dimension addresses issues such as number of decision makers and stakeholders, communication requirements, organizational and physical distribution, etc. We believe decisionmaking in IO can range from routine to highly complex in the first dimension, while the coordination complexity is generally high in most IO cases.

There is a widespread hypothesis that the abundance of real-time data enabled by new technology automatically will lead people to make "faster and better" decisions. We question this hypothesis, because more available real-time data does not by itself address the hard issues of decisionmaking in IO, which include:

- *Multiple objectives or criteria*: Different measures for each criteria and competing or conflicting criteria, or trade-offs
- *Complexity* – timing/sequencing, number of factors: Difficult to keep all the issues in mind at one time
- *Uncertainty*: Decisions must be made without being able to eliminate uncertainty
- *A large number of alternatives* are possible: Trade offs are difficult to assess
- *Information overload:* An avalanche of information available, but much is conflicting and of uncertain reliability
- *Anxiety about consequences*: Subjective biases may influence the decision

Decision science (Howard 1966), (Raiffa 1968), (Clemen and Reilly 2001) approaches these problems in a normative and consistent manner. An important principle of rational decisionmaking is that decision outcome and decision quality are not synonymous. A good outcome is a future state of the world that we prize relative to other possibilities. A good decision is an action we take that is logically consistent with the alternatives we perceive, the information we have, and the goals and objectives we have. The quality of a decision should be judged by the knowledge and information available at the time the decision was made.

A central promise in the IO paradigm is that we will have an avalanche of information literally at our fingertips. The thinking is that if a little information is good, more information will be even better. This, however, is not necessarily right. In our desire to reduce uncertainty, we often ask for too much information. We believe – mistakenly – that more information will give us a clearer picture of the future. However, more information helps only to the extent that we can use it intelligently. In fact, vast amounts of data may only confuse matters. Researchers across various disciplines have found that the performance; i.e., the quality of decisions or reasoning in general, of an individual correlates positively with the amount of information he or she receives – up to a certain point. If further information is provided beyond this point, the performance of the individual rapidly decline (Chewning and Harrell 1990). The information provided beyond this point will no longer be integrated into the decision making process and information overload will be the result (O'Reilly 1980). The burden of a heavy information load will confuse the individual, affect his ability to set priorities, or makes prior information harder to recall (Schick et al. 1990).

Figure 2 provides a schematic version of this discovery. More information will make us increasingly confident about the accuracy of our predictions. However, as shown in Fig 2., information is ony useful up to a certain point. As discussed by Bratvold et al (2007), the information must be *relevant* and change your beliefs about some uncertainty. It must be *material* and have the ability to change decisions you would otherwise make. Finally, it must be *economic*: The cost of the information must be less than its value.

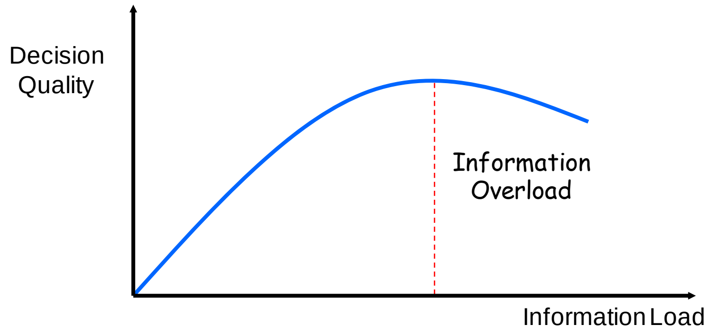

Fig. 2 - Information Overload

Bayesian networks and decision support

The main goal of decision analysis is to create insight and transparency to a decision situation. This clarity of thought provides clarity of action in selecting the optimal decision alternative given the many possible choices. In many real-world situations, the decision process is non-trivial due to factors such as unknown or unlimited sets of alternatives, uncertain costs and success rates of actions, risks for adverse side effects, uncertain value of the outcomes, etc. In practice, decision makers use reliance on intuition and informal weighing of alternatives, via more rigorous analysis based on factual information, to highly formal decision theories prescribing how to make consistent and normative decisions with uncertain information.

A unifying paradigm for normative decision making is the principle of Maximum Expected Utility (MEU): Choose the alternative that maximizes the expected utility of the action, given probabilistic information and utilities of the possible outcomes. MEU is the basis for a comprehensive field of decision analysis techniques (Clemen and Reilly 2001), starting with simple decision trees.

A powerful and common approach is *Bayesian Decision Networks* (BDN), also known as *influence diagrams*, which subsume decision trees. A decision network is a probabilistic graph that links events, actions, outcomes, and utilities (Fig. 3). The model encodes dependencies among all variables, and readily handles situations where some data is missing. A Bayesian network can be used to learn causal relationships, and hence can be used to gain understanding about a problem domain and to predict the consequences of intervention. Because the model has both a causal and probabilistic semantics, it is an ideal representation for combining prior knowledge and data.

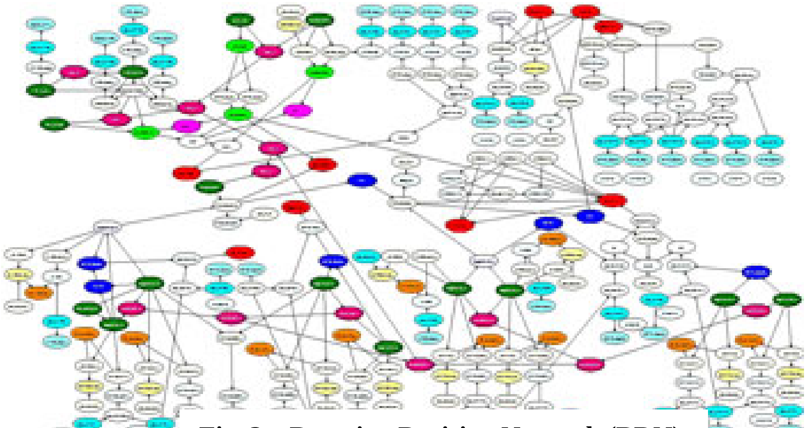

Fig. 3 – Bayesian Decision Network (BDN)

Algorithms have been devised that “solve” the decision network and compute the MEU recommendation for a given situation. Likewise, Bayesian algorithms exist for updating the probabilistic information embedded in the networks as new (possibly real-time) data arrives. Decision networks can also help decision makers identify where new information is valuable (value-of-information reasoning, Bratvold et al. 2007).

In practice, real-world decision problems are rarely described in purely formal decision theoretic terms. The requirements of precision and clarity in defining all relevant alternatives and preferences (with utilities), and the identification and quantification of all relevant uncertainties is a major hurdle for many individuals and organizations. It is challenging and sometimes time consuming to establish a model (e.g. a BDN) that sufficiently accurately captures the collective understanding of the problem amongst decision “stakeholders” (decision analysts, those making the decision, those implementing it, those directly affected by it, etc.). Still, there is no better alternative. There is ample literature illustrating how limited the human reasoning ability is when facing complex decision situations with significant uncertainties; i.e., the typical decision situation in the oil & gas world. Although we may believe that intuition and experience will lead us through and help us identify the optimal decision, we far more often end up with lack of clarity, poor understanding of the ley value drivers and, ultimately, mediocre choices.

Group decision and ontologies

Decision analysis in IO must address communication, collaboration and shared decision making in virtual and mobile teams. *Group DSS* is a hybrid type of DSS (Decision Support System) that allows multiple users to work collaboratively using various tools, often categorized according to a time/location matrix: synchronous vs. asynchronous, and face-to-face vs. distributed interaction. Research issues for Group DSS include impacts on group processes and group awareness, multi-user interfaces, concurrency control, communication and coordination within the group, shared information space and the support of a heterogeneous, open environment that integrate existing applications. Such issues have been studied in several domains, including Air Traffic Control, emergency management, military command, etc.

Team-based decision making presupposes that team members “speak the same language”. The Semantic Web and its RDF/OWL languages support shared concept models or *ontologies*, and the AKSIO (Fjellheim and Norheim 2007, Fjellheim and Norheim 2008) and IIP (Rylandsholm 2005) projects show how ontologies for the petroleum industry can be

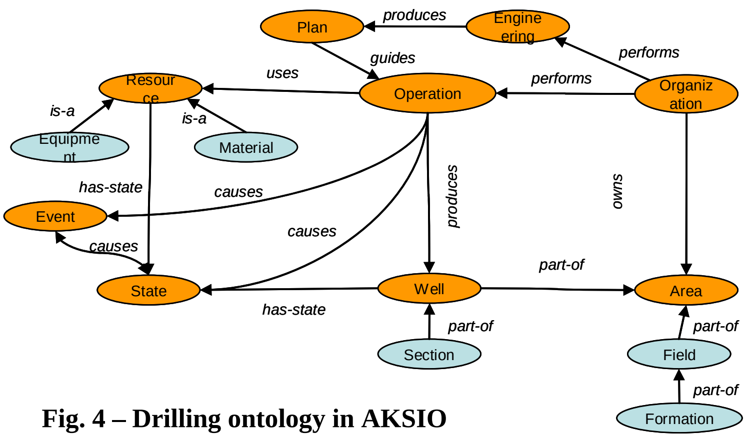

Fig. 4 – Drilling ontology in AKSIO

developed and applied. AKSIO focuses on knowledge management in IO (Fig. 4)[1]. The illustration shows the upper level of a concept graph for terms and relations used in the drilling domain (Well, Section, Operation, Resource, State, etc.). In the AKSIO system, the ontology is used to annotate and structure drilling experience reports, such that they subsequently can be retrieved in a timely and context-relevant manner to support improved well planning and execution.

Based on concept sharing, a Group DSS can help teams to converge on consensual decision models. An interesting stream of work in this respect dates back to IBIS (Rittel and Kunz 1970) - a systematic group process for exploring complex problem domains. Graphical and web-based tools have been built to support IBIS, incl. Semantic Web-based approaches (Shadbolt 2004).

R&D challenges

The ultimate goal of IO is to maximize value created from petroleum resources, which can only be ensured by a continuous stream of right decisions made at the right time. High-quality decision making is a requirement for optimal value creation and IO promises to be an essential methodology for ensuring this optimization. Still, currently most IO projects do not fully address the challenges posed by decision making in the new environment characterized by abundant real-time data, operation centers, virtual multidisciplinary teams, mobile workforce, etc.

The CODIO project addresses these issues. Its aim is to develop and evaluate a comprehensive model for decision support in integrated operations. Some of the R&D challenges are:

- To our knowledge, no projects have explicitly addressed the “IO will lead to quicker and better decisions” hypothesis. In this project, we will evaluate the value of more data in “real time” for a set of relevant, real-world decisions.
- It is well known that too much data can stifle, rather than help, human decision making. How can the “overabundance” of data in integrated operations be turned into an advantage?
- Formal models for decision making in IO must explicitly take passage of time into consideration, and be continuously updated by real-time data. What modifications of e.g. Bayesian methods are required?
- Group processes in decision making have been studied extensively. How can we avoid adverse group effects, especially in data rich and time constrained decision situations?
- Visualization and collaboration tools, enhanced by common semantic models, may provide a link between formal and intuitive (“human”) decision making. What is an appropriate architecture for this?
- From the system point of view: what are the appropriate software and hardware architectures for distributed, mulit-user decision support systems of the kind envisaged in this project?

Case – Managed Pressure Drilling

As an illustration of how CODIO may assist in critical decision making in drilling operations, we present a simplified case from Managed Pressure Drilling (MPD) in a depleted HP/HT (High Pressure/High Temperature) reservoir, a complex operation that may require fast decision making and extensive teamwork. Depleted HP/HT reservoirs are characterized by narrow pressure margins, uncertainty in fracture and reservoir pressure due to depletion, and challenging HP/HT conditions (Fig. 5).

The MPD drilling technique involves a rotating BOP (Blow Out Preventer) on the surface and an automatic choke manifold for annular pressure control.

Let us assume that the drilling is approaching a high permeable zone when a critical situation occurs: A small gas kick is detected automatically and alarmed to the driller through a graphical interface in the drilling room. The kick is immediately reported from the driller to the toolpusher, drilling supervisor and onshore personnel.

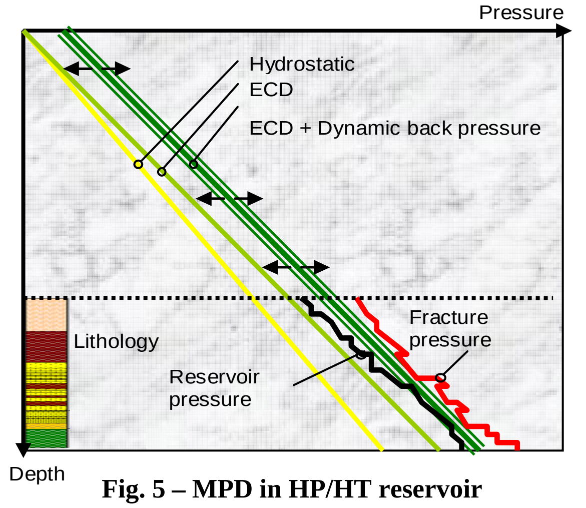

Fig. 5 – MPD in HP/HT reservoir

Faced with this situation, the involved decision makers must consider the options that are available and the problems they may have to face as a result of selecting one of them. There is a chance of malfunction in the choke control system when gas reaches surface, which may lead to bad pressure control with chances of either a large kick or reservoir fracture. Continual wear and tear on equipment may be critical, and finally maximum pressure at the choke manifold may be exceeded. In the last case, the choke will be disabled and high the pressure BOP will be utilized.

[1] Based on a cursory glance, there is not much of a difference between an ontology map and a BDN. However, the uses of the two representations are quite different and symbols (ovals and arrows) have very different meanings. Hence it is important not to confuse the two structures.

A summary of the available decision alternatives is shown in Table 1.

No.	Action	Consequence(s)
1	Stop drilling and circulation. Closed BOP and high pressure choke. Initiate well control procedure	Standard procedure. Time consuming: ~12 hours. Cost: 0.3-0.5 mill. USD/24 hours
2	Increase back pressure from choke. Continue circulation and drilling. Circulate kick out through choke manifold	May solve the problem but with chance of repetition. Need advise from chief engineer from choke manifold supplier and specialists on hydraulic simulations
3	Increase back pressure from choke. Continue circulation and drilling. Increase mud weight and circulate kick out through choke manifold	May solve the problem and reduce chance of repetition. Need advise from chief engineer from choke manifold supplier and specialists on hydraulic simulations

Table 1 – Decision alternatives in the MPD case

Using the Bayesian decision network (BDN) approach, a model of the decision situation may be created. Fig. 6 is a simplified BDN diagram for the MPD case. The first step is to agree on the significant (chance) "events" (blue ovals) that are relevant, and how they are causally dependent on each other. Thereafter, we need to define the action alternatives (green boxes) and analyze which event(s) the decisions will affect most directly. Finally and most importantly, we need to agree on the "payoff" structure (yellow diamond): How do we value the potential gains and losses of each possible outcome?

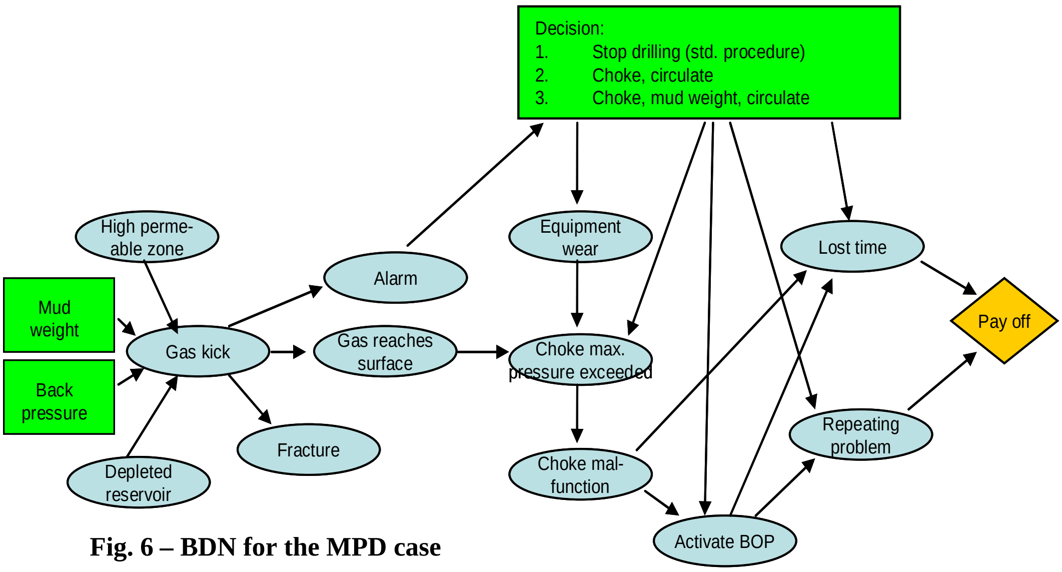

Fig. 6 – BDN for the MPD case

Several comments about the diagram are in order. First, the decision network is greatly simplified – it is just an illustration of the complex real situation. Second, the network is not a flow diagram, but an *influence* diagram. It shows how events depend on or influence each other in a causal directed sense. Each dependance is defined in terms of a condition probability table (CPT), not shown here. The statistical numerical information is an essential part of the model and the key to its use for effective decision support. Real-time data will be used to calibrate and update the model with regards to the actual situation. Effective algorithms calculate the optimal decision based on the information provided by the BDN graph structure and the probability information in the CPTs.

Coordination complexity

Several personnel categories are involved as actors in the MPD decision process, as shown in Table 2.

No.	Actor	Role	Location
1	Drilling supervisor	Representing operator	Offshore or onshore
2	Toolpusher	Location supervisor for the drilling contractor	Offshore
3	Driller	Operation performed by driller from drilling room	Offshore
4	Mud engineer		Offshore
5	Engineer on rig	Monitors choke manifold control panel continuously	Offshore
6	Personnel at operator's office		Onshore
7	Experts monitoring from operation center(s)	Chief engineer from choke manifold supplier and specialists on hydraulic simulations	Onshore

Table 2 – Decision actors in the MPD case

In CODIO, we focus carefully on the individual *tasks* and coordination *workflows* that the relevant actors are engaged in. A general decision process model like in Fig. 7 includes general tasks. They are not all always performed, the roles are not alaways the same, nor the timing and synchronization. It is dynamically instantiated in different ways, depending on the type of problem. For example, the driller continuously checks the drilling parameters and takes decisions to keep them in a secure range. He continuously performs tasks 1, 2, 4, 5, 6, 7, 8, 11, 12, in a very short time. The driller is the only person involved. In other cases the diagnosis tasks can be very complex, and may possibly be structured in a workflow. The overall coordination problem is how the individual actors' decision tasks/workflow interact and converge to an effective stream of real-time decisions.

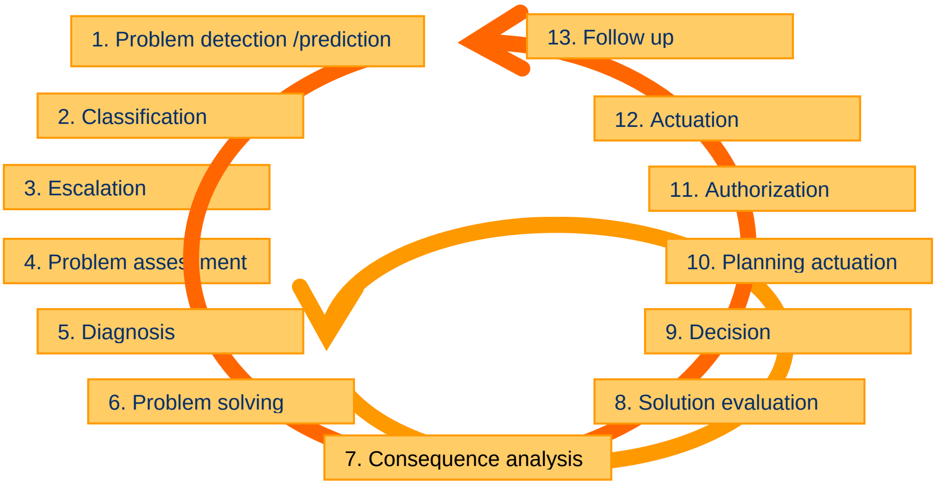

Fig. 7 – General decision process model

CODIO - Conceptual architecture

The CODIO project proposes to create a new synthesis of previous work in integrated operations, decision support, and semantic technology in order to improve decision making processes in future well planning and execution. The ultimate goal is to contribute to dramatic performance improvements in NCS operations.

Fig. 8 indicates the main components of the CODIO architecture. The central component is a Dynamic decision model, an explicit model of the evolving decision space available to the operation. The decision model will be based on Bayesian decision network concepts as explained above, properly adjusted to take IO constraints into consideration.

Two work processes interact with the decision model. A Collaborative decision making process is responsible for creating and updating the model. Actors include personnel from operator companies, from service providers, and other experts. The process may borrow from IBIS-like methodologies for collaborative problem resolution. A Decision implementation work process is responsible for translating the agreed-upon decisions back to the actual well operation. This process is largely outside, but interfaces to CODIO. Both processes are amenable to gradual automation as they become better understood (Iversen et al. 2006).

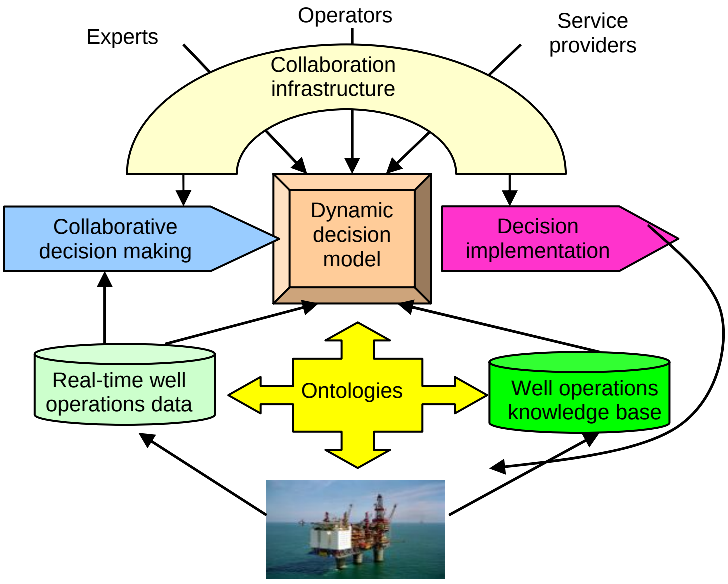

Fig. 8 – CODIO conceptual architecture

The decision making and implementation processes are collaborative processes supported by a Collaboration infrastructure. This includes prominently IO onshore centers with large-screen displays, two-way multimedia communications, etc. The CODIO project does not propose to develop any new technology in this area, but will adjust to existing/planned infrastructure and point to how to best exploit it for effective decision making.

The decision processes can rely on updated Real-time well operations data, fed by a continuous stream of field data. Likewise, an accumulative store of experience in a Well operations knowledge base may be invoked to support decision making (Fjellheim and Norheim 2008). Both stores can rely on centrally maintained Ontologies for data integration and smart retrieval of data/knowledge.

Summary and conclusions

We have reported on the research challenges in the initial phases of the CODIO project, a research project that aims at developing a new model and support system for decision making in Integrated Operations. In CODIO, we apply a holistic view of decision making that considers both decision complexity and coordination complexity aspects in parallel. For the first aspect, we study the use of decision science methodology, in particular Bayesian Decision Networks adapted for real-time use. With regards to the second aspect, we rely on coordination and workflow technology, as well as ontological support for information sharing. The enginnering domona for CODIO will be the drilling process, and cases will be selected from challenging HP/HT wells in the North Sea region. We propose a comprehensive system architecture that will be the basis for real-world pilot applications.

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