Engineering Applications of Artificial Intelligence 26 (2013) 2206–2214

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

journal homepage: www.elsevier.com/locate/engappai

Experience transfer for process improvement

Pål Skalle [a,*], Agnar Aamodt [b], Odd Erik Gundersen [c]

[a] Department of Petroleum Engineering and Applied Geophysics, Norwegian University of Science and Technology, S.P. Andersensveg 15a, NO-7491 Trondheim, Norway
[b] Department of Computer and Information Science, Sem Saelandsvei 7-9, NO-7491 Trondheim, Norway
[c] Verdande Technology AS, Stiklestadveien 1, NO-7041 Trondheim, Norway

ARTICLE INFO

Article history:
Received 27 November 2012
Received in revised form
2 May 2013
Accepted 23 June 2013
Available online 6 August 2013

Keywords:
Oil well drilling
Ontology
Case-based reasoning
Symptoms

ABSTRACT

The oil well drilling process is the selected representative of a challenging industrial process. The drilling process is becoming more complex as oil fields mature and technology evolves. At the same time, the amount of information is increasing in volume and frequency. Although technology is advancing, failures occur at almost the same rate as before, leading to loss of valuable time. Whenever the process is failing, or running smoothly, valuable experience is gained. To take advantage of established and continually growing new experience a formalized methodology, knowledge intensive case-based reasoning, was applied for capturing of drilling process experience and for reusing it. Experience was collected from different information sources. Structured cases were used to describe failure episodes; its circumstances and how the failure was repaired. A general domain knowledge model supports the case-based reasoning process. It was demonstrated how the system was able to recommend how to solve problems when they arise, while at the same time bridging the gap between new and experienced personnel. Method performance was tested on 62 selected field cases. The system also identified the failure causes of problems and could thereby suggest more effective repair actions.

1. Introduction

A majority of the remaining oil and gas reserves are located inside the continental shelves. Offshore drilling operations are very expensive, and numbers of wells are kept as low as possible. For this reason offshore wells tend to be long and complex. This is also the explanation of why the number of process failures does not diminish much over time. In spite of technology evolution, complexity also increases.

A failure during drilling operations is defined as the state of a process when non-productive time (NPT) is occurring. NPT is typically in the range of 15% of total rig time, but can become much higher during drilling of difficult wells (Halliburton Solving Challenge, 2012). The motivation behind the work presented here is to advance computerized methods for helping the petroleum industry in reducing unwanted downtime.

Another worry in the industry which supports our motivation is the knowledge gap created by “The Great Crew Change” that exists in most companies (e.g. (McCormack, 2010)). The problem is not one of just filling the gaps. There are sufficient numbers of people entering the workforce to do that. The problem is one of “experience attrition”. The immediate challenge is therefore how to transmit the soft and hard skills necessary to quickly bridge the gaps between new and existing personnel. Companies want a measurable return on investment. They want to achieve a reduction in accidents, an improvement in oil and gas measurement yield, and fewer lost days of production.

The ultimate goal of our research is to improve process quality and efficiency by systematically capturing useful human experience during a drilling process and make relevant past experience available on-line when needed.

This calls for skills to be transportable between companies and among different industries. Case-based Reasoning (CBR) is a methodology that enables computer systems to assist in achieving these tasks. The goal of the work described in this paper is to investigate how knowledge transfer in the drilling process can effectively be realized by combining the re-use of situation-specific experiences (cases) with justifications and explanations generated by a general domain model (ontology). The combined approach is referred to as knowledge-intensive CBR. We have developed an experimental system that is able to read data from a drilling process and capture interesting parts of it (Aamodt et al., 2012). After having captured and stored human experience accompanied by technical information, we demonstrate different ways of re-using the experience, and point out especially two applications in larger detail:

- Determine the optimal repair of a problem
- Determine the failure cause of a problem

* Corresponding author. Tel.: +47 91 897 303; fax: +47 73 94472.
E-mail address: pal.skalle@ntnu.no (P. Skalle).

0952-1976/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engappai.2013.06.012

We have studied a novel combination of two technologies that have proved to work well in other industries: Case-based reasoning (Cheetham and Watson, 2005) and Ontologies (Obrst et al., 2003). This combination has also been applied to other problems in the oil and gas domain (Kravis and Irrgang, 2005).

Case-based reasoning is a method and a technology for solving new problems in complex processes by comparing a new problem to previous situations, and reusing the experience from the most similar situations in solving the new problem (Aamodt and Plaza, 1994). CBR can be described as adoption of common human problem-solving behavior for computer use (Popa et al., 2008). In practical systems, the technology incorporates different types of information, which empower the system to learn and adapt from an ever-growing case base of new experiences. In order to set our method in a wider perspective, in Section 2 we discuss existing approaches to experience transfer.

In Section 3 follows a description of how the case knowledge and general knowledge are represented, and the various sources of information and knowledge are described. The quality of the CBR systems, in terms of finding relevant past cases, has been tested on field data in a small scale, and the results are presented in Section 4, including two applications. A discussion of the results and future plans concludes the paper.

2. Related research

Technology itself is advancing at an impressive rate, introducing methods to solve new and old problems more efficiently. To learn from mistakes while applying new or old technology brings technology faster forward. To take advantage of this proven fact the industry has turned to AI-engineers, realizing that experience transfer is an AI challenge.

The transfer of knowledge according to the CBR paradigm involves three main processes: observing and interpreting a situation, identifying and capturing interesting information in the situation for integration into the knowledge base (i.e. the case base), and finally searching for and re-using past cases as knowledge in new situations. In general, episodic experience from drilling operations is either stored in writing, e.g. as different types of drilling reports, or as human experience in the heads of the people involved in the operations. Experiences typically contain the drilling operators' understanding of the process; how they handled the situation; their ability to point at root causes, etc.

In-depth studies to identify and share successful drilling practices across companies (Brett et al., 1998) have shown measured benefits in the order of 10%. Thorsvoll and Grotmol (1999) reported a similar approach; joint business development between operator and service companies' added value to both parties after a systematic approach to improve quality and communication (experience transfer). Integrated operations represent a recent method of experience transfer (Milter et al., 2006). Real-time data transferred from offshore to land enable support of drilling operations in an efficient manner. Support from onshore results in a much better utilization of engineering resources and experience.

A more recent example is the blow out in the Gulf of Mexico from Deepwater Horizon (BP, 2010). A thorough investigation made it rather clear that both the cement operation and cementing equipment failed due to poor design and risk assessment.

A particular challenge in computerized experience transfer systems is the knowledge representation issue, i.e. how to represent the symbol structures that stand for human experience in formal data structures in a computer. CBR applications are still at its beginning in the oil industry, although CBR itself is a well-established technology. Previous work within the oil industry related to how experience is organized and represented to make it fit for reuse can be divided into (1) situation-specific approaches, and (2) generalized approaches.

In situation-specific approaches case-based reasoning is the dominating technology. Experience is represented as a collection of parameters and other information that together describe an episode, i.e. an interesting situation worth remembering. Typically, cases are clustered into classes with the same solution. The CBR task is to match a new case with historical cases and assign the class of the best matched case(s) as the correct class of the new case. Previous work on applying case-based and model-based (ontology-based) reasoning to oil and gas-related problems includes Mendes et al. (2003), Abdollahi et al. (2008), Popa et al. (2008). Earlier work by the authors includes initial investigations of the technology's potential (Nordbø et al., 1992), results from the EU project Noemie on combined decision-support and data mining (Skalle et al., 2000) decision support by first finding the root cause of the problem (Shokouhi and Skalle, 2009; Shokouhi et al., 2009), earlier report on experience transfer (Skalle et al., 2010), a survey of CBR applications in drilling engineering (Shokouhi et al., 2012), and a description of Verdande Technology's DrillEdge system (Gundersen et al., 2013). While most of this research focus on the CBR methods, the work presented here has a stronger emphasis on the role of the general domain model, i.e. the ontology.

Research at the Australian Research institute (SCIRO) documented one of the first applications of CBR in the petroleum engineering domain (Kravis and Irrgang, 2005). Alternate drilling plans were derived from comparison with previously drilled wells. Each well represented one case. Bhushan and Hopkinson (2002) applied CBR to globally search for reservoir analogues as an important step in planning and development of oil fields. Such information would be useful when appraisal information is limited. The key lies in characterizing each reservoir by a set of attributes which describes the reservoir and can be used to differentiate it from other reservoirs.

Khajotia and colleagues (2007) took a non-typical approach in applying CBR within a predictive mathematical model. The method was designed to mimic the approach to the problem taken by experienced field personnel, by taking knowledge of corrosion rates from existing cases and apply them in new fields having somewhat similar parameters.

In generalized approaches to experience transfer, *rule-based reasoning* is the typical method. A rule, whether a final decision rule or an intermediate inference step, can be viewed as a generalization over a set of cases that share many of the same properties. Rules are empirical and may be based on sound, if not well understood, physical, economic, social, or other principles (Brown et al., 2005). They allow us to shortcut some thinking processes and, in doing so, can also cause us to make costly mistakes. As we grow more and more experienced, we personally develop and adopt new rules of thumb. But rules often have exceptions. In a rule-based setting, cases can be viewed as exceptions to the rules, opening up for combined systems.

In *model-based reasoning* knowledge is represented as multi-relational dependencies between parameters and other concepts, as opposed to the single relation (i.e. the "if-then" implication) of rule-based methods. In the knowledge-intensive CBR approach taken in our research, model-based reasoning – based on an ontology model – constitutes the generalization-based method.

3. Our approach to experience transfer in the drilling process

In our approach to knowledge-intensive CBR the case base and the general domain knowledge play together in helping the user identify possible problems of an ongoing drilling operation. The structure and contents of these knowledge types are as follows.