

Improved Efficiency of Oil Well Drilling through Case Based Reasoning

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Abstract

A system that applies a method of knowledge-intensive case-based reasoning, for repair and prevention of unwanted events in the domain of offshore oil well drilling, has been developed in cooperation with an oil company. From several reoccurring problems during oil well drilling the problem of "lost circulation", i.e. loss of circulating drilling fluid into the geological formation, was picked out as a pilot problem. An extensive general knowledge model was developed for the domain of oil well drilling. About fifty different cases were created on the basis of information from one North Sea operator. When the completed CBR-system was tested against a new case, five cases with descending similarity were selected by the tool. In an informal evaluation, the two best fitting cases proved to give the operator valuable advise on how to go about solving the new case.

Introduction

Drilling of oil wells is an expensive operation, costing around 150 000 US \$ pr. day, and any loss of time caused by unwanted events is costly. Some unwanted events are repeatedly occurring but still so complex that they are not easily solved. The necessary experience obtained by individuals or by the organization is difficult to transfer efficiently to those that need it. Lost circulation during oil well drilling is an unwanted event characterized by not obtaining any or part of the drilling fluid (also called mud) back to the rig in spite of a running mud pump.

The failure type may be sub-divided into four categories, related to possible fractures or other undesired properties of the geological formation: Induced fractures; natural fractures, cavernous formation and permeable formation. The strength of the sedimentary formation is surpassed due to an unfortunate combination of operational events. The problem occurs on an average base once every well drilled, and may last for less than an hour, but sometimes it takes 14 days to solve it. It is too complex a problem to predict or solve by means of a mathematical simulator. The many necessary simplifying constraints would make the simulator unrealistic.

The necessary experience to deal with the problem may not be available at the time of occurrence; the "expert" may not be available, written experience is usually partial or scattered, or the problem is too delicate to select the optimal procedure based on on-site available experience. A promising approach in such situations is case based

reasoning, an approach which is designed to mime a human being's typical way of reasoning when solving a new problem; searching through a "bank" of previous experience. A similar, previous experiences is a good initial approach to solving the problem.

The trend in case-based reasoning methods for complex decision support is currently towards data-centered approaches, in which a case often is viewed as a data base record (or data table). Case matching is based on a rather simple, syntax-based similarity metric – typically combining the number of common attributes with attribute weights. In contrast, we advocate a more knowledge-intensive and user-centered CBR approach, in which a case is a user experience, and where case matching is based on semantic criteria by using a body of general domain knowledge as explanatory support in the matching process. Different attributes may then match by being related in the general model.

State of the art

CBR-applications on diagnosis and repair.

Case-based approaches to problem solving and learning have been taken in a variety of diagnosis and repair applications. Along with help desk applications, successful fielded applications of this kind have been extensively reported over the last years (e.g. Allen-94, Manago-98, Auriol-99). However, the CBR approach has still to be seriously applied in the petroleum engineering field. A first approach has been observed in the field of drilling (Skalle-98), but only at the conceptual and design levels. The current system is a continuation of that research into an implemented experimental system.

Data support methods during oil well drilling

Several oil companies (Milheim-99) recognize the need to retain and centralize the knowledge and experience of the organization, often as a reaction against outsourcing and spreading of knowledge during the early 1990's. Milheim-99 presents a heuristic simulation approach to the domain Drilling of Oil Wells, developed around data sets of 22 actual wells. The accumulated data are treated statistically and fitted to a model based on combining human thought, artificial intelligence and heuristic problem solving. The model will adopt to a specific geological area, and capture experience, reuse it and gradually improve and learn. They encompass and model the complete process, not primarily repetitive cases. Their approach is more ambitious but less focused than ours.

The Well Learning System (WLS) (Minton-98) is a simple, yet very efficient mechanism for organizational learning. A multi-disciplined team involved in planning or execution of the drilling plan is lead through a process including exposure to 30 templates, a process which manage company policies, standards, up-to-date engineering software finally ending up with all the necessary final reports. This system has been successfully tested by several oil companies. We are now discussing an extension of WLS by including CBR capabilities to provide more active advice and guidance.

The GeoFrame database built in a POSC standard data format or data model allows information to be shared between applications from many disciplines. Drilling engineers and geologists can share critical information while planning and monitoring

a well. A data browser filters the information so that only data relevant to the e.g. drilling engineer is presented by default, and made suitable for different applications. The work of McCann-98 is thus limited to databases and logistics of data.

Engineering solution to lost circulation

Different types of formation fractures are treated differently. A recent advancement (Rojas et al., 1998) involves utilization of the combined knowledge of fracture size (obtained through downhole pressure recorder) and maintenance of the desired sealing material particle-size-distribution (special equipment is necessary).

Other advancements include fracture width determination on the basis of mud loss history, (Lietard-99), liner drilling through different zones (Sinor-98), new mud and cement technology for drilling through salt domes (Sweatman-99).

New engineering technology will gradually expand and improve methods of solving the problem. This is implicitly taken into account in our system, described below, through retaining new cases as they are (attempted to) being solved.

Knowledge-intensive case based reasoning

The objective of this paper is to describe the two important aspects our knowledge-intensive CBR process, and described how they are combined in our system for drilling operations assistance. The CBR-method applied is properly documented elsewhere (Aamodt-94a and Aamodt-94b) and summarized below through the following steps;

- b) Gather data
- c) Detect a possibly approaching problem
- d) Decide if gathered data are sufficient to define the situation as a new problem.
If not;
 - e) Perform additional examinations (i.e. check loss rate, check circulating pressure etc.).
- f) Search the case base for similar past cases.
- g) Generate a set of the most likely hypothesis and present a set of possible solutions in descending order to the current problem.
- h) Use general domain knowledge to provide explanatory support for each plausible hypothesis, and refine the hypothesis list.
- i) Interact with user to select the best hypothesis. Generate a detailed “to-do” list.
- j) After the case has been solved, the case base can be updated based on the situation just experienced.

The two aspects we will focus on in the following are the two core components of knowledge-intensive CBR:

- *The general domain knowledge model*
- *The case model*

General domain knowledge

The role of the general domain knowledge is to provide explanations for supporting the CBR process. The support is threefold: First, it enables the searching for past cases to be based on semantic rather than pure syntactic criteria, by using general knowledge to explain the similarity of two apparently different parameters. Second, its

can explain how a past solution can be adapted to solve a new problem, and third, it can be used to explain what to retain in the case base from a case just solved (i.e. the machine learning part of the CBR process).

The domain knowledge describing the oil well drilling domain is organized in a general model containing concepts interrelated by a set of different relations, and situation-specific case knowledge. Below, the four main components knowledge of the general knowledge are summarized: Domain objects, Relations, Tasks, and Cases.

Domain objects

All domain concepts are defined in a frame-based representation formalism. Each domain term is defined in its own frame. The representation may equally well be viewed as a densely linked semantic network, where a node represents a frame and the links represents slots. One of the relations is the “has-subclass” relation, and the upper level of the subclass hierarchy is shown in Figure 1.

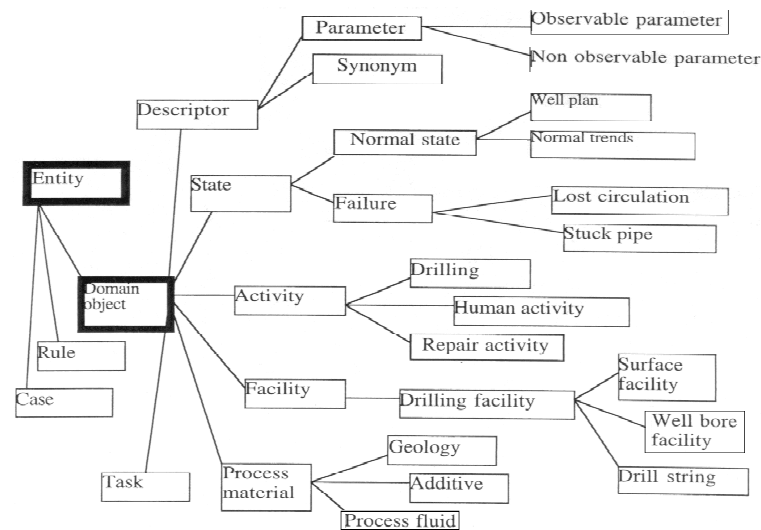


Figure 1. *Upper level structural model of the drilling domain. Cases and the drilling domain object are subclasses of Entity:*

As seen in the figure, a domain object can be described by one or more of six object types;

- Descriptor (recordable and non observable variables)
- State (the state at time of failure)
- Activity (within the drilling domain)
- Facility (equipment necessary to perform activity)
- Process material (involved in activity)
- Tasks (of operational problem solving and human learning)

In Figure 2 “Operation parameter”, a subclass of “Observable parameter” is selected to exemplify further sub-classification. The knowledge base contain about 1500 concepts interlinked by app. 40 different relation types.

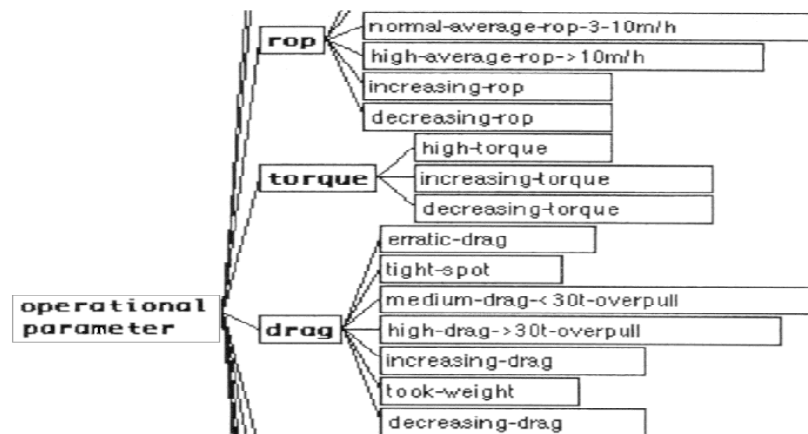


Figure 2. *Sub classification of operational parameter. Transformation from qualitative (high-drag) to quantitative value (>30t-overpull) is shown.*

Relations

Attributes or parameters in the knowledge model are interconnected through structural relationships (has subclass, has part, has instance, has value), causal and other kinds of influence relations. Properties are inherited along the relation lines. The parameters, i.e. the outmost “leaves” in all “branches” in the class hierarchy, are inter-linked through the following relationships (where a relation’s explanatory strength is shown in parenthesis):

Structural	(1.00)
Causes	(0.90)
Leads to	(0.85)
Enables	(0.80)
Influences	(0.75)
Implies	(0.70)
Involves	(0.65)
Indicate	(0.60)
Describes	(0.55)
Occurs-in	(0.50)

Relations always have an inverse relation, e.g. “caused-by”. In addition to numerical values a quantifier/modifier can be introduced to each relation (multiplication weight shown in parenthesis): always/strongly (1.1), typically (0.95=default), sometimes/moderately (0.7), or seldom/weakly (0.3).

A few examples from the Relationship list are:

HIGH-MUD-FILTER-LOSS *INSTANCE-OF* MUD-FILTER-LOSS
 HIGH-MUD-FILTER-LOSS *ENABLES* CLOGGED-BHA
 HIGH-MUD-GAS-CONTENT *CAUSES* LOW-DOWNHOLE-MUD-VISCOSITY
 HIGH-PIMP-RATE *CAUSES* HIGH-PUMPT-PRESSURE

An important notion in identifying a failure mode is the notion of a non-observable parameter state, i.e. a system condition that is not directly describable by measured parameters (or findings) at the surface, but usually related to other conditions in the open hole. The model links non-observable parameters (like “clogged-bha”, “sagging-tendency”, and “turbulent-flow-regime”) to observable ones.

Tasks

In order to reach a goal the task has to be specified. Such tasks may be:

- Solve problem (stuck pipe, lost circulation, tool failure etc.)
- Plan drilling operation (in such a way that problems are avoided or minimized)
- Learn (learn from previous mistakes, learn about the knowledge model etc.)

The challenge is first of all to solve the problem. To enable solving by means of Case Based Reasoning the following task breakdown for lost circulation has been defined, partly based on Darley & Gray & Roger (Darley-88).

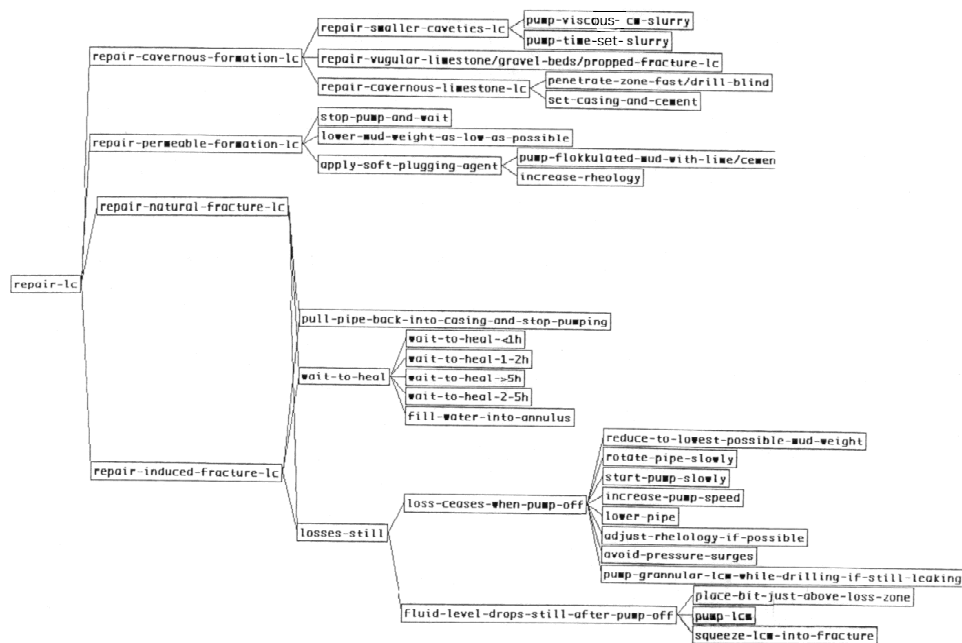


Figure 3. The task “Repair Lost Circulation”

Cases

The case base contains all the problems of “lost circulation” experienced by a chief North Sea drilling operator in the Norwegian oil company Saga, a total of 43 cases. In Table 1 the structure of a completed case is presented (a new, unsolved case is of course, incomplete).

Case structure	Case example
1. Characteristics: Owner Place/date Depth/formation	Saga Petroleum 34/07-P22/11.07.1994, 2203 3342 m/Lista 07
2. Observed parameters: Activity Drilling fluid Mud yield point Mud density Still-standing time Leak-off/mud weight margin Initial loss	drilling Novaplus very high (> 35 lb/100 ft ²) high (1.4 – 1.7 kg/l) very long (> lh) small (0.02 – 0.05 kg/l) complete
3. Solution path: Pooh some stands waited < lh ran pump at low rate small losses ----- pooh-to-casing-shoe waited>2h increases-pump-rate-stepwise established-full-return drilled ahead	
4. Outcome: Success ration	New lost circa incident after 500 m drilling 0.5
5. Explanation	Since induced fracture may be caused by ECD which is enabled by narrow ann. and very high YP which is influenced by very long still stand time
6. Operators experience and lessons learned:	Upper section was drilled with average effective ROP of 35.9 m/h. Lots of solids bed accumulating. In WBM losses are cured fast and we know intuitively we will succeed rather quickly.

Case matching routine

Within a completed case an expert will evaluate the importance of each attribute, and designate a proper level of relevance. Four level were chosen;

- b) Sufficiently indicative (1)
- Strongly indicative (2)
- c) Indicative (3)
- d) Spurious (4)

Results and example run

As a part of the evaluation of the system it was decided to enter a new case (case 50), a lost circulation incident which occurred on April 1999 in well 34/7-P-20. Hence, this case had been solved before and was used as a test case against the system. The result

of this test was analyzed and discussed with the user. By showing this example only, we also indicate that our evaluation regime has been of a qualitative rather than quantitative nature. In this domain a correct/false distinction is not realistic, since the utility of a case will often be partial.

We entered a set of attributes describing the new lost circulation situation of case 50. Parts of the input window are shown in Figure 4.

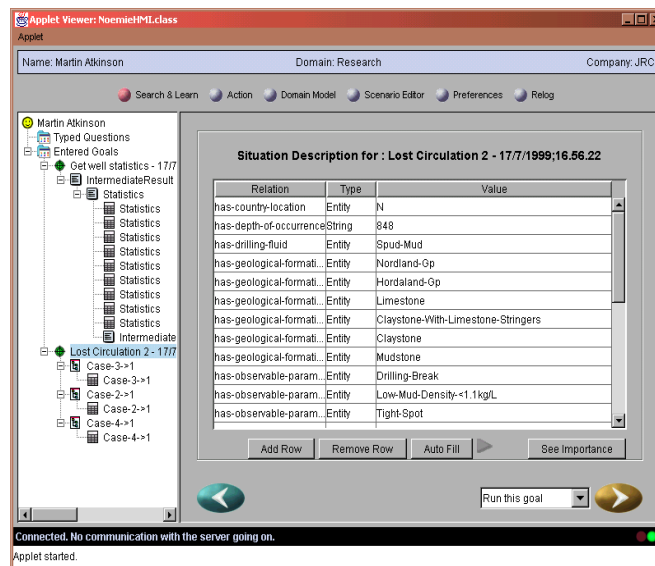


Figure 4. Entering lost circulation attributes of well 34/7-P-20, case 50

Entering the attributes of case 50 was straight forward since acceptable attribute values are obtainable from drop down menus in the user interface for every new relation. After entering case 50 and pressing the “Return Cases” button, the CBR-tool returned the following list of similar cases, provided with matching degree as shown in Table 3.

Table 2. Matching cases to case 50

Case number	Matching degree
16.	0.70
21.	0.43
12.	0.38
06.	0.27
02.	0.22

The content of the two matching case is presented in Table 3.

The analysis showed that the suggestions presented in Table 3 on why the problem occurred and what solution were applied in those two previous cases are highly

relevant and indicative of how the new case 50 could actually was treated. In reality the operator treated case 50 as follows:

- Numerous-lcm-pills-pumped and squeezed

Resulting in:

- long-lc-repair-time 15 h
- very-large-final-pit-loss 100 m³

case-16	
has-task	value solve-lc-problem
has-activity	value tripping-in circulating
has-depth-of-occurrence	value 5318
has-time-of-occurrence	value 02.10.1996
has-platform-name	value snorre-tp
has-operator-name	value suga
has-country-location	value n
has-well-name	value 34/7-p22
has-well-section	value 8.5-inch-hole
has-well-section-position	value in-reservoir-section
has-drilling-fluid	value novaplus
has-geological-formation	value shetland-gp cromer-knoll-gp hegre-gp claystone-with-dolomite-stringers claystone-with-limestone-stringers sandstone mudstone
has-observable-parameter	value high-pump-pressure high-mud-density-1.41-1.7kg/l high-viscosity-30-40cp normal-yield-point-10-30-lb/100ft2 highly-inclined-well->60dg short-open-hole-<500m large-final-pit-volume-loss->100m3 long-lc-repair-time->15h low-pump-rate low-running-in-speed-<2m/s complete-initial-loss tight-spot decreasing-loss-when-pump-off very-depleted-reservoir->0.3kg/l high-mud-solids-content->20% small-annular-hydraulic-diameter-2-4in small-leak-off/mm-margin-0.021-0.050kg/l very-long-stands-still-time->2h
has-repair-activity	value pack-to-casing-shoe waited-<1h increased-pump-rate-stepwise lost-circulation-again pumped-numerous-lcm-pills no-return-obtained set-and-squeezed-balanced-cement-plug
has-outcome	value squeeze-job-acceptable
has-operators-explanation	value we tripped in and lost circulation while breaking circulation. the mud seemed unstable and barite settled probly out and tended to pack around bha. we also know that depletion lowers the fracture resistance and this combined is sufficient to explain the losses. we also probably crossed faults
has-lesson-learned	value when 138 kg/m3 course nut plug lcm was pumped to apprx. 90 m above mwd tool, a check for backflow was performed. lcm may have settled out, contributing to plugging mwd-tool. don't stop circulating when lcm plug is close to mwd-tool

Table 3. The best matching case(case 16) of a new case (case 50)

This is what happened in case 16 also. We will however never know for sure if case 50 would have been handled better if given access to this CBR-tool and the findings in case 16, 21 and 12. In all three cases pseudo oil based mud were applied and the repair time was extensively long (> 15 h). In case 16 it was finally decided to set and squeeze a balanced cement plug. In case 21 it was learned that Venfyber cure losses in POBM. Both these experiences could have been applied to solve the losses in case 50 more efficiently.

Discussion

In this first version of a CBR-tool for support in the drilling operation, it is room for many improvements;

The domain model and the cases are only as good as the data allow. An important improvement is to expand the basis for data input to the model and the cases by adding time-based mud logging data (today the tool only supports depth-based mud logging data). Time-based mud logging data is an integral part when trying to diagnose a lost circulation case.

Three-parameter relationships are not included in the tool, an approach that will enhance the explanatory capability.

Retrieved cases are lacking several qualities;

- Specify in detail type of fault (from sub class tree)
- Specify the strongest relationships applied in the matching process

The present tool has the ability to suggest optimal solutions to occurred problems. The ability to predict and thus suggest preventive measures is more challenging and potentially more prosperous. It will require a “dynamic” CBR tool, where time dependent data and trend analysis must be combined with experience on dynamic changes.

Although the case base contains 43 cases, this is relatively small amount. Few successful cases are yet available. As more cases are stored, improved matching will be achieved, the tool’s capability will improve with time.

Conclusion

1. Lost circulation is an example of a repetitive problem during oil well drilling. The time loss in handling such problems are costly (offshore operation costs are around 150 000 US\$ pr. day).
2. A CBR-tool has been developed with the aim of incorporating the ability to evaluate complex and ever repeating problems. As an integrated part of the tool a comprehensive model of the drilling domain has been designed and all attributes have been inter-related with relations of varying strength.
3. A pilot version of the tool has been tested on a new problem (a problem not shored in the case base) and provided useful knowledge such as cause factors and remedial actions.
4. The CBR-tool is in its “childhood”, and its potential as a supporting tool is large.

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