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Real Time Application of Bearing Wear Prediction Model Using Intelligent Drilling Advisory System

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Abstract: The real-time prediction of bearing wear for roller cone bits using the Intelligent Drilling Advisory system (IDAs) may result in better performance in oil and gas drilling operations and reduce total drilling cost. IDAs is a real time engineering software and being developed for the oil and gas industry to enhance the performance of complex drilling processes providing meaningful analysis of drilling operational data. The prediction of bearing wear for roller cone bits is one of the most important engineering modules included into IDAs to analyze the drilling data in real time environment. The Bearing Wear Prediction module in IDAs uses a newly developed wear model considering drilling parameters such as weight on bit (WOB), revolution per minute (RPM), diameter of bit and hours drilled as a function of International Association of Drilling Contractors (IADC) bit bearing wear. The drilling engineers can evaluate bearing wear status including cumulative wear of roller cone bit in real time while drilling, using this intelligent system and make a decision on when to pull out the bit in time to avoid bearing failure. The wear prediction module as well as the intelligent system has been successfully tested and verified with field data from different wells drilled in Western Canada. The estimated cumulative wears from the analysis match close with the corresponding field values.

Key words: IDAs (intelligent drilling advisory system), real-time analysis, drilling data, bearing wear prediction, WITSML, oil and gas industry.

Nomenclature

b = fractional bearing life
t = time, hours
τ_B = bearing wear constant, hours
v = rotary speed
w = weight on bit
b_1 = bearing wear constant
b_2 = bearing wear constant
V = volume of seal/bearing
K = coefficients obtained by regression analysis
WOB = weight on bit
RPM = bit rotary speed, rpm
$Hours$ = time
l_b = bearing life parameter
T = hours drilled
Bw = bearing dull grade
D_b = bit diameter
a = coefficient
b = coefficient
c = coefficient
d = coefficient
Bw_i = instantaneous bearing wear
H_i = well depth at step i
ROP = rate of penetration
ROP_i = instantaneous ROP corresponding to drilled depth H_i
WOB_i = instantaneous WOB corresponding to drilled depth H_i
RPM_i = instantaneous RPM corresponding to drilled depth H_i
Bw_{acc} = accumulated bearing wear (0-8)
n = total number of steps measured
$T_{maxlife}$ = maximum lifespan according to all used life (8), hours
T_{ins} = instantaneous drilled hour, hours

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1. Introduction

The increasing complexity of oil and gas drilling operations as well as increasing drilling costs has increased the demand on research and development of real-time analysis of drilling data which can provide safer, efficient and cost-saving drilling operations. For many years, the drilling engineers and researchers have been coordinating extensive research works to develop efficient real-time engineering software for the oil and gas industry. The engineering analysis tools or software have been developed by many oil and gas companies and some software providers to fulfill the growing demand of a more digital oilfield. The existing oil and gas softwares usually deliver some engineering analysis tools and help in performing drilling operations, but can not provide all required information for better optimization in real-time environment. The Well site Information Transfer Standard Markup Language (WITSML) is a web-based oil and gas industry standard [1] used to conduct transfer of drilling data between onsite or remote WITSML servers and engineering software. A WITSML server is a source of both static and real-time (dynamic) drilling data. The Intelligent Drilling Advisory system (IDAs) is being developed [2] as a stand alone engineering system which is able to retrieve oil drilling data from onsite or remote servers for visualization as well as, do the analysis using different engineering modules in a real-time environment. WITSML standard drilling data can be both depth and/or time based and may be updated every 1 to 10 seconds by the server. This information makes the server a much more trusted data source in terms of reporting and benchmarking. WITSML Application Programming Interfaces (API) [3] have been being tested in the oil and gas industry to automate reporting and drilling for the next generation drilling rigs that will be fully automated in the next decades to come. The use of WITSML is enabling asset teams and business units amongst operators to identify and reduce the invisible lost time and to improve drilling performances [4]. The potential scenario between rig site and our system IDAs is shown in Fig. 1.

The drilling data is transferred from the rig site to a WITSML server by a wellsite service company as shown in Fig. 1. The application software needs proper server authentication to retrieve drilling data from a

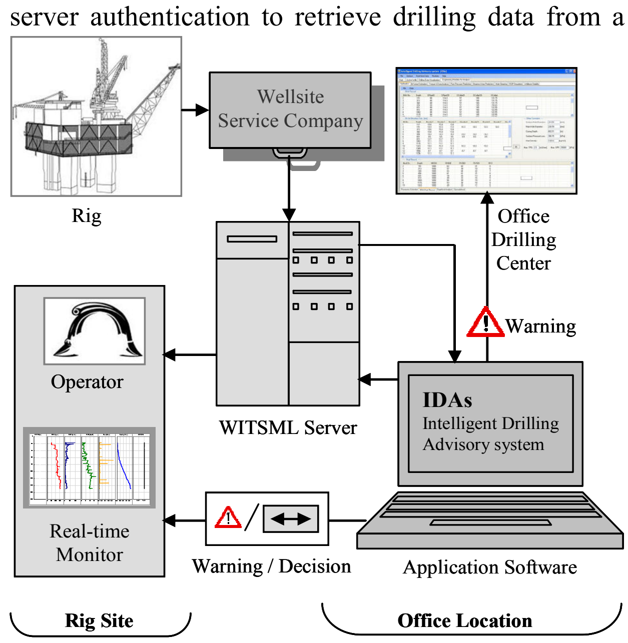

Fig. 1 Potential scenario between Rig site and IDAs.

WITSML server using web service protocol. After successful server authentication, IDAs retrieves drilling operational data from the WITSML server to the office location for visualization, collaboration and analysis of the drilling operational data. The drilling data retrieved from the server, the corresponding analytical results and warning/alarm can be visualized in the office drilling center for better decision making by the drilling engineers. The results, warning or alarm and/or analysis made by the engineers can be sent back to rig site and displayed on a real-time monitor for the rig operators to optimize the drilling operations.

The Intelligent Drilling Advisory system (IDAs) provides meaningful analysis of both static and dynamic drilling operational data using different engineering modules. Five engineering modules are currently included into the system to provide meaningful drilling data analysis. The bearing wear prediction module for roller cone drill bits is one of the most important modules and it predicts drill bit bearing wear using drilling data in real time for better decision-making and to be able to increase overall drilling efficiency. The drilling operation is very rich with mechanical parts and products and therefore, equipment and tool wear is very common during drilling operations. There exist two main reported types of bit wear of roller cone bits during a typical drilling operation: cutting structure wear and bearing wear. Bearing wear may in some cases produce catastrophic events which interrupts the well progress and can lead to significant remedial operations and costs [5]. The real-time bearing wear model and its implementation into IDAs are briefly discussed in the following sections. The paper is organized as follows: Section 2 discusses the bearing wear prediction model. Section 3 presents the real-time application of bearing wear model. Section 4 introduces the system requirements for IDAs. Section 5 discusses testing of bearing wear prediction module and the results. Section 6 gives conclusions.

2. Bearing Wear Prediction Model

2.1 Literature Review

The bearing wear prediction model helps the drilling engineers evaluate bearing wear status including cumulative wear of roller cone bits while drilling, and to make the decision on when to pull out the bit in time to avoid bearing failure. The failure of a bearing is not necessarily the catastrophic event sometimes described. It takes typically several hours after the damage to the bearing for the cone to fall off [5]. With the use of normalized down-hole mechanical parameters and simple logic, the torque created by the excess friction in the bearing and the torque caused by the locked cone dragging on the bottom of the hole can be differentiated from changes in lithology or drilling parameters [6]. Neural network has been successfully used in different fields due to their capability to identify complex relationship when sufficient data exist. A new model was successful developed to predict the condition of the bit. Inputs were lithology, torque, ROP, WOB and RPM and outputs were bit wear, including bearing wear and tooth wear [7-8].

Some researchers have put forward empirical formulae about bearing wear of roller cone bits since more than half century. The prediction of bearing wear is much more difficult than prediction of tooth wear. A bearing wear equation used to estimate bearing life is as follows [9]:

$$\frac{db}{dt} = \frac{1}{\tau_B}\left(\frac{v}{100}\right)^{b_1}\left(\frac{w}{4d}\right)^{b_2} \quad (1)$$

Insert breakage rather than tooth wear is the primary cutting structure concern at high mechanical horsepower 1evels. Field experimentation yields data on allowable WOB and RPM to avoid insert breakage. Below these WOB and RPM restrictions, insert wear is negligible, so the remaining unknown in WOB and RPM optimization is bearing life [10]. Journal bearing insert bit runs without excessive insert breakage or gauge wear typically fail due to seal/bearing wear. The factors affecting seal and bearing surface wear are numerous and complex. A well known wear equation was selected to characterize generalized wear in a journal bearing as [10]

$$V = K \cdot WOB \cdot RPM \cdot Hours \quad (2)$$

When a critical volume of material has been removed, the bearing failure will occur.

The bearing wear is proportional to the frictional work, which mainly depends on the travelled distance and contact pressure between the two surfaces of the cone and the journal. The travel distance and contact pressure are related to the rotary speed of the bit (RPM) and the weight on bit (WOB). The bearing life parameter can be expressed as follows [11]:

$$l_b = 60 \cdot RPM \cdot T \cdot (WOB)^{0.5} \quad (3)$$

2.2 Real-Time Bearing Wear Prediction Model

From the above explanation, it can be seen that the bearing wear of a roller cone bit is mainly related to the two important drilling parameters, weight on bit (WOB) and rotary speed (RPM). In fact bearing wear is a complex process, including many factors, such as bit type, formation being drilled, Bottom Hole Assembly (BHA) and down hole conditions. The wear is also related to bit diameter D_b, as well as time, which should be in the model. In order to make the model more flexible, each variable is assigned a power. A synthetic coefficient K is introduced and the final bearing wear prediction model is assumed as follows [5]:

$$Bw = K \cdot (D_b)^a \cdot T^b \cdot (WOB)^c \cdot (RPM)^d \quad (4)$$

If the depth drilled ($H_{i+1} - H_i$) and the instantaneous rate of penetration ROP_i at each step i are known, the instantaneous bearing wear is

$$Bw_i = K \cdot (D_b)^a \cdot \left(\frac{H_{i+1} - H_i}{ROP_i}\right)^b \cdot (WOB_i)^c \cdot (RPM_i)^d \quad (5)$$

The real-time accumulated bearing dull grade is

$$Bw_{acc} = \sum_{i=1}^{n} Bw_i \quad (6)$$

In addition, the real-time model can be used to predict maximum lifespan, as well as the bit life hours left, if run with other parameters. IADC provides a linear scale estimating bearing wear dull grade for the oil and gas industry and it ranges from 0 to 8. The value 0 means no life used and 8 means all life used, i.e., no bearing life remaining. For example, assume that the current bit will continue to be used until all bit bearing life is used, then the maximum lifespan can be predicted using the following equation:

$$T_{\max Life} = \left(\frac{8}{K \cdot (D_b)^a \cdot (WOB)^c \cdot (RPM)^d}\right)^{\frac{1}{b}} \quad (7)$$

The instantaneous drilled hours can be predicted in real-time using the instantaneous bearing wear of Eq. (5):

$$T_{ins} = \left(\frac{Bw_i}{K \cdot (D_b)^a \cdot (WOB)^c \cdot (RPM)^d}\right)^{\frac{1}{b}} \quad (8)$$

Then the bit life hours left can be predicted using Eqs. (7)-(8). The predicted hours left can help drilling engineers to make the decision on when to pull out the drill bit in time to avoid bearing failure.

2.3 Coefficients of Bearing Wear Model

The coefficients of the bearing wear model are determined by performing regression analysis on field data. The data are obtained from a database of drilling parameters recorded and a total number of 500 bit runs are extracted. These drilling data were measured in hundreds in western Canada wells. From the 500 bit runs analyzed only selective runs were used to do the multiple variables nonlinear regression analysis. The resultant coefficients for the authors' model [5] are shown in Table 1.

2.4 Verification of Real-Time Bearing Wear Model

After the coefficients in the model are obtained, it can be used to predict the bearing wear under certain conditions. The different models reported in the literature review to predict the bearing wear were compared to the results from the new model with field data. Two groups of field data are used to verify the bearing wear prediction models. First group of data were used to obtain coefficients of wear models as shown in Table 1. These coefficients are used to predict bearing wear from the first group as well as, the other data groups. The comparison of the relative error of the wear models is shown in Table 2 [5].

Through comparison of different models, the bearing wear prediction model obtained by the authors has a better prediction than other models as shown in Table 2. However, it could be improved by using more and better quality drilling data. If possible, the bearing model can be modified for roller cone bits with different IADC code, which means each IADC class has its own set of coefficients.

Table 1 Coefficients of real-time bearing wear model.

K	a	b	c	d
0.00073151	-0.20000	1.0000	0.15000	1.1158

Table 2 Comparison of relative error of the bearing wear models.

Field Data	Relative Error		
	Author's Model	Kelly's Model	Doiron's Model
First Group	12.11 %	18.89 %	25.71 %
Second Group	28.36 %	34.37 %	42.73 %

3. Real-Time Application of Wear Model

The new real-time bearing wear prediction model is implemented as the Bearing Wear Prediction module in IDAs, to predict bearing wear status including cumulative wear of roller cone bit in real time while drilling and the hours left of bit life until the drill bit is completely worn out or all life is used. The overall program flow chart of the calculation process is shown in Fig. 2.

IDAs retrieves drilling operational data such as WOB, ROP and surface RPM from the WITSML server as input parameters after the successful server authentication process. The WITSML server, usually, stores drilling data in three different index types: measured depth, date time and 1 or 10 second data. The depth- and time-indexed data can be static or dynamic drilling data, whereas, 1 or 10 second index type includes real-time or dynamic drilling data. For dynamic analysis, the system checks the availability of new sets of data to be used in the analysis. Sometimes

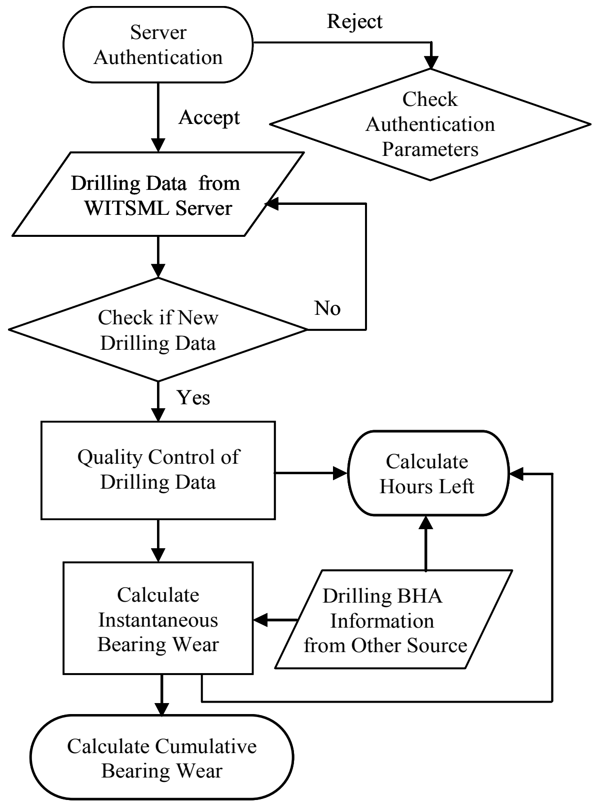

Fig. 2 Program flow chart of calculation process.

some drilling data may contain impractical null values such as -999.25 or an empty string or very high value above the acceptable limits of the parameter, caused by the vibration of the measurement tools or other surrounding disturbances. This disturbance may for example be caused by the result of loss of data transmission mechanism due to noisy rotating equipments. This impractical and unacceptable data should be controlled or filtered properly to get meaningful and valid results from the analysis. The system automatically performs filtration or quality control on the drilling data by filtering these data points based on set boundaries consisting from practical ranges of the drilling parameters. For an example, Fig. 3 shows the filtration or smoothing results of rate of penetration (ROP) within a set of boundaries.

The drilling Bottom Hole Assembly (BHA) information of a particular well can be obtained from the Electronic Tour Sheet (ETS) provided by the server. The instantaneous bearing wear is estimated by Eq. (5) using the retrieved drilling data and BHA information of the corresponding well. The cumulative bearing wear is then predicted using Eq. (6). In addition, the estimated bit life hours left can be predicted using the instantaneous bearing wear, retrieved WITSML drilling data and corresponding bit information as mentioned in the program flow chart, Fig. 2.

4. System Requirements for IDAs

The web service protocol, Simple Object Access Protocol (SOAP) is used for drilling data transmission between the WITSML server and the user-friendly software, IDAs. Therefore, the wired or wireless internet connection is an important requirement for the client's computer.

The basic hardware and software requirements for IDAs are as follows:

- Supported operating systems

(1) Windows XP Home edition, Professional edition or later version;

(2) Windows XP Service Pack 2 or above;

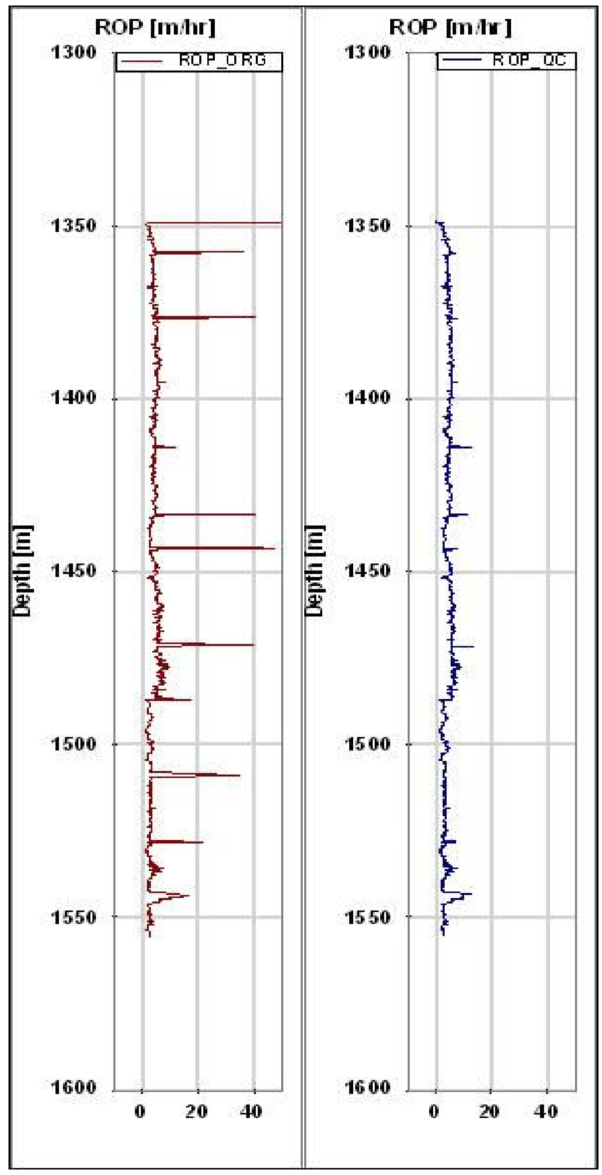

Fig. 3 Filtration or smoothing of drilling parameter, ROP.

(3) Windows Vista;

(4) Windows Server 2008 or later version.

- Software requirements

(1) Microsoft Visual Studio 2008 or later version;

(2) Microsoft .NET Framework version 2.0 or later. The recommended requirement is version 3.5.

The Microsoft .NET Framework is a software technology that is available in several Microsoft Windows such as Windows XP, and as a built-in technology in Microsoft Visual Studio. It includes a large library of pre-coded solutions to common programming problems.

- Hardware requirements

The minimum requirement is 1.6 GHz Central Processing Unit (CPU), 384 MB Random-Access Memory (RAM) and a 1024X768 display. The recommended requirement is 2.2 GHz or higher CPU and 1024 MB or more RAM. On Windows Vista, the recommended requirement is 2.4 GHz CPU and 768 MB RAM.

5. Testing Bearing Wear Prediction Module

The Bearing Wear Prediction module of the system is successfully tested with a remote WITSML server compatible with the WITSML version 1.3.1.1. Usually the WITSML server provides static or real-time data of different drilling parameters of a particular well. The user of the system can choose the required parameters for data visualization, collaboration and analysis. A remote WITSML server, storing drilling data of some wells in Western Canada, was chosen to test the Bearing Wear Prediction module of the IDAs. The required drilling data from different bit run sections of the completed Western Canada well "A" is retrieved and tested by IDAs to estimate instantaneous and cumulative bearing wear using the Bearing Wear Prediction module of the system.

As a first step to work with this module, the user needs to choose the required drilling parameters and the corresponding units of the parameters from the "Parameter Selection" page of this module. Fig. 4 represents the parameter selection procedure of the "measured depth" index type drilling data and the corresponding unit selection process to perform the bearing wear analysis. The client can select the required parameters and units by taking reference from the "Curve Information" table in Fig. 4 for a particular well.

The drilling bit information of that particular well includes bit diameter, bit type and jet nozzle sizes and can be obtained from the ETS provided by the server. The bit information is then included into the system to perform a successful analysis. The drilling parameter

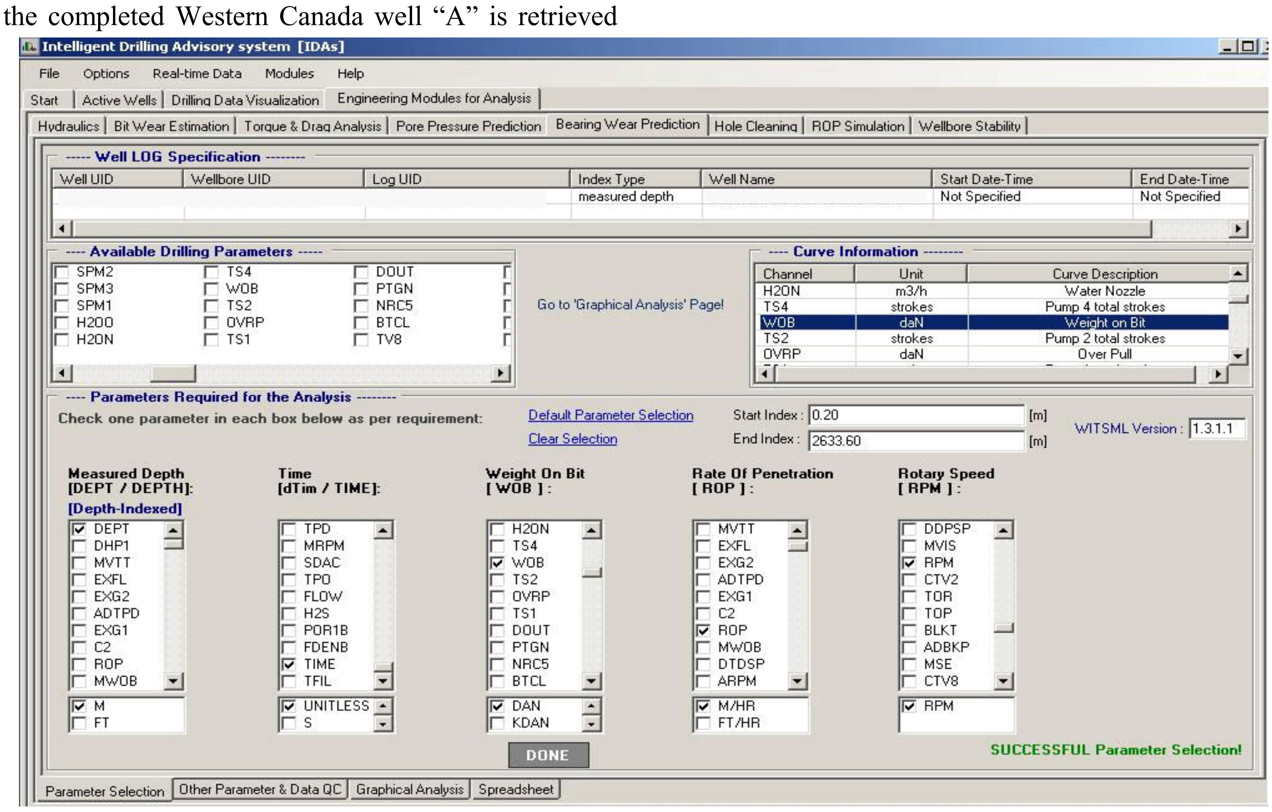

Fig. 4 Representations of parameter and unit selection process.

selection including units and bit information is important and a mandatory step for efficient and accurate analysis. The name of the drilling parameters and the corresponding units may vary for different servers. For example, mud weight/density is usually stored as "*MDEN*" in one server whereas it may be named as "*MWIN*" in another server. Similarly, the unit of weight on bit is usually "daN (DekaNewton)", but can in some cases be in "kdaN (KilodekaNewton)" for some other servers. Therefore, the options for selecting parameter, units and bit information are included in the intelligent system to perform accurate analysis in the real-time environment.

Table 3 summarizes the information for the drilling bits including the reported wear grades provided by the ETS on the data server and the estimated cumulative bearing wear analyzed by the system, for different bit run sections of the Western Canada well. The bit section 1 represents the drilled depth range from 17 m to 151 m, where as the range for sections 2 and 3 are from 313 m to 360 m and 360 m to 454 m, respectively.

Table 3 Summary of bearing wear analysis.

Bit Section	Drill Bit Manufac-turer	Bit Diameter [mm]	Jet Size [mm]	Reported Wear	Estimated Wear
1	J and L	311.0	3 X 15.8	3.0	2.2
2	J and L	311.0	3 X 15.8	5.0	4.0
3	Hughes	311.0	3 X 15.8	2.0	1.8

The 2D graphical representations of depth based drilling data retrieved from the WITSML server and the corresponding bearing wear of roller cone bits predicted by IDAs for bit sections 1-3, are shown in Figs. 5-7, respectively.

In these figures, the first three charts, including the measured depth represent the retrieved drilling data whereas the last three charts represent the results of data analysis using the Bearing Wear Prediction module. The fourth charts of Figs. 5-7 show the instantaneous bearing wear predicted by the system using Eq. (5). The corresponding fifth charts show the

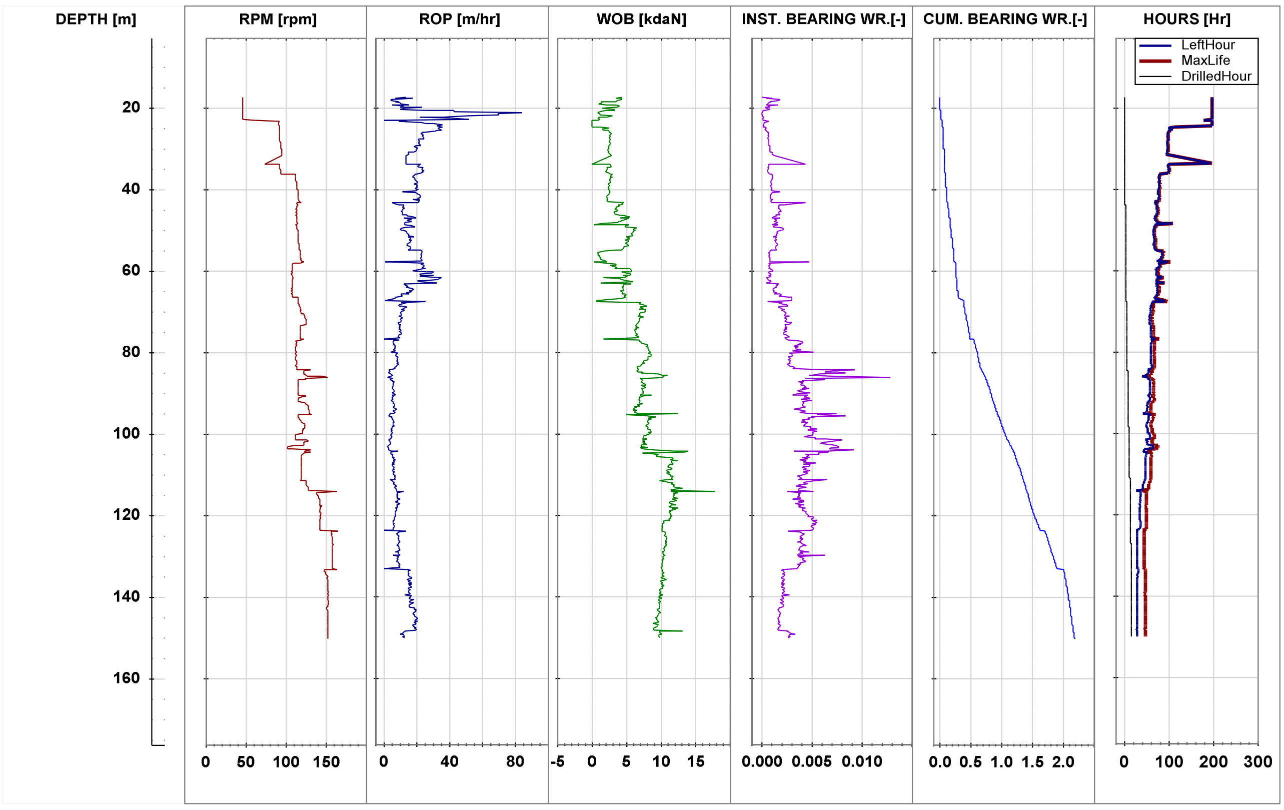

Fig. 5 Graphical representation of drilling data and corresponding results for bit section 1 of the Western Canada well.

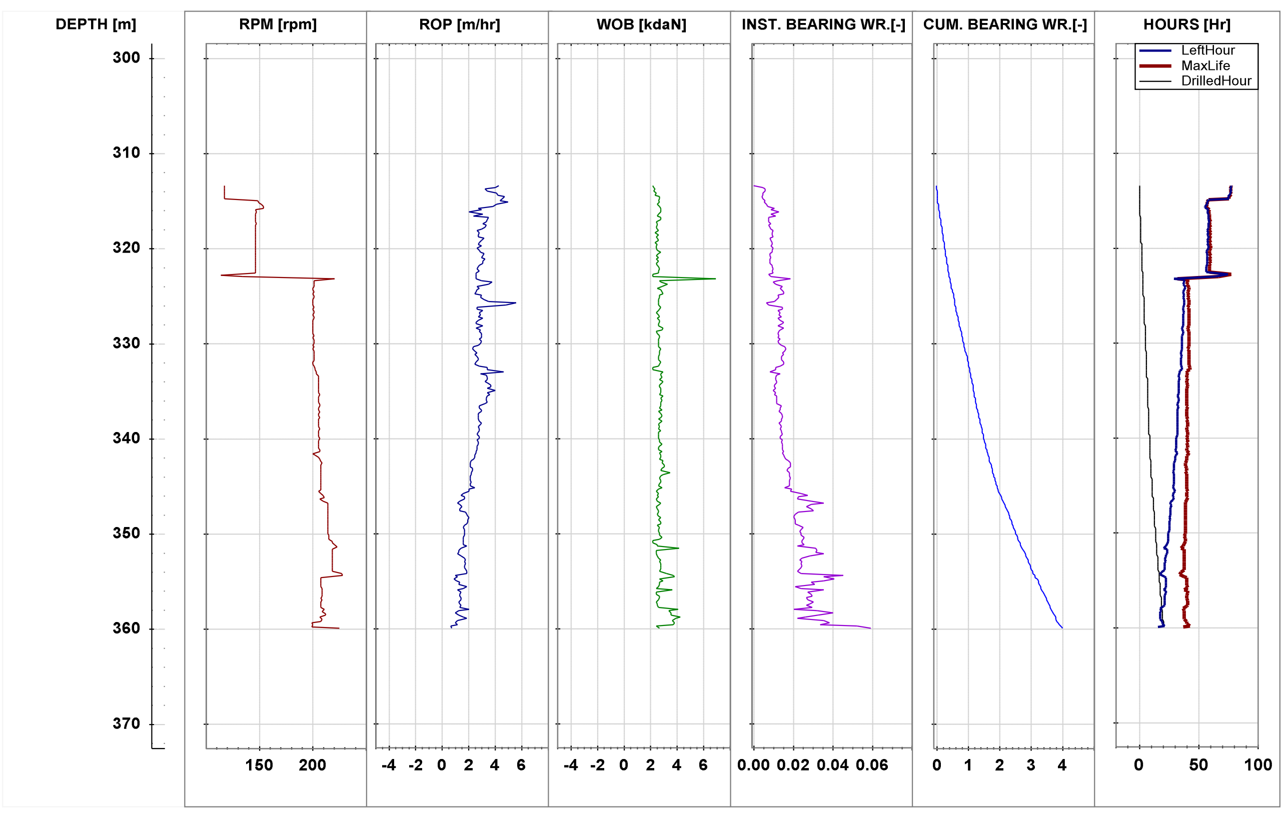

Fig. 6 Graphical representation of drilling data and corresponding results for bit section 2 of the Western Canada well.

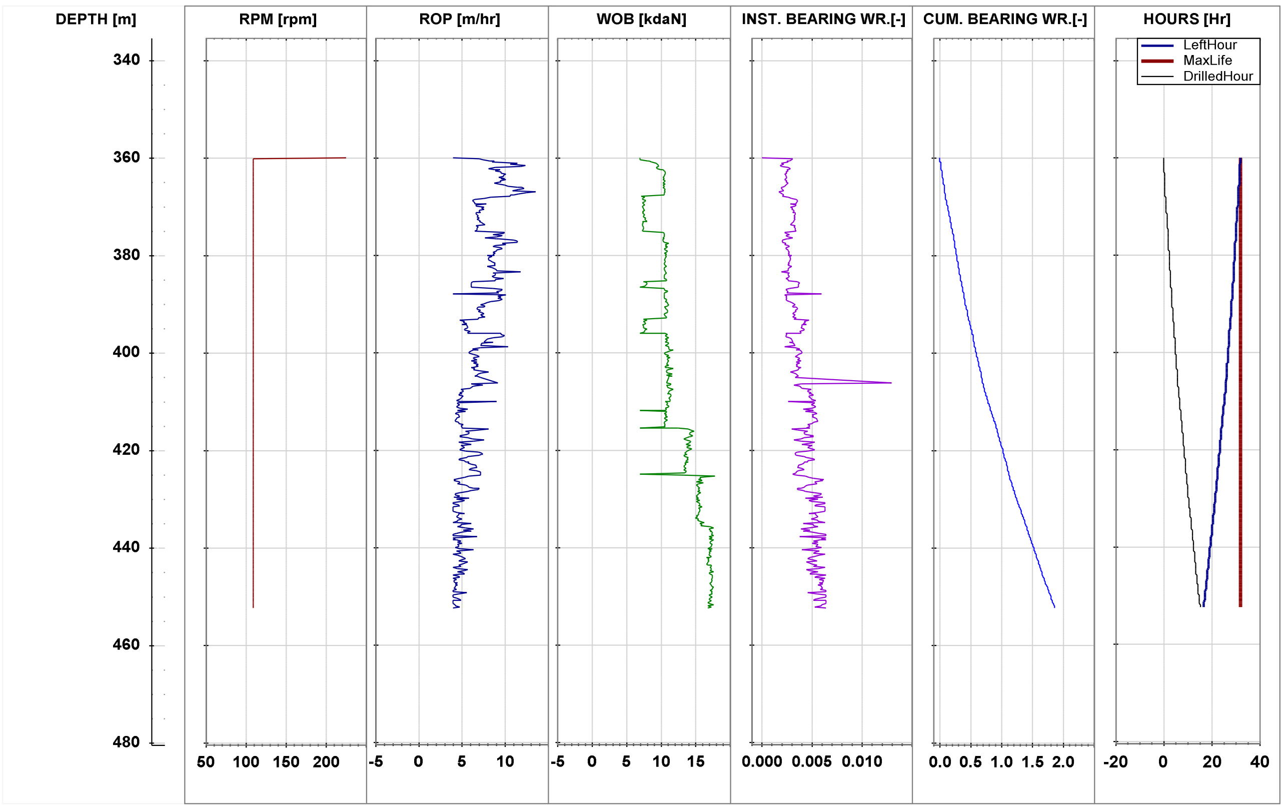

Fig. 7 Graphical representation of drilling data and corresponding results for bit section 3 of Western Canada well "A".

results of the predicted cumulative bearing wear in Eq. (6). The predicted cumulative wears are compared with the reported field wear to verify the real-time application of Bearing Wear Prediction module in IDAs.

The estimated bearing wear for the roller cone bit is 2.2 for section 1 as shown in Fig. 5, whereas the reported is 3.0 as shown in Table 3. The estimated bearing wear for section 2 and section 3 are 4.0 and 1.88 as shown in Figs. 6-7, respectively. The reported wear value is 5.0 for bit section 2 and 2.0 for bit section 3 as shown in Table 3. Although the analysis gives around 20% error in some cases, the bearing wears obtained by the authors model has a better prediction than other models and could be improved by using more and better drilling data and sets of bearing wear coefficients, as mentioned in the previous section of this paper. The real-time analysis of oil and gas drilling data is very complex task and it is hard for drilling engineers to predict the wear status while drilling. Therefore, the percentage of error, obtained by this analysis is acceptable to give at least, a better prediction of real-time bearing wear status to drilling engineers in oil and gas industry.

The last charts of Figs. 5-7 show the predicted drilled hours and the corresponding left hours, if the bits are assumed to be used as full life (bearing wear, 8). The maximum life hours shown in the last charts of the above mentioned figures, is predicted using Eq. (7) assuming all bearing life used.

6. Conclusions

This article presents the real time application of a bearing wear model for roller cone bit using a newly developed and user-friendly real-time drilling engineering tool, the Intelligent Drilling Advisory system (IDAs). The Web-based oil and gas industry standard WITSML (Wellsite Information Transfer Standard Markup Language) is used to transfer drilling data from a remote WITSML server to the client system. The system uses different engineering modules for drilling data analysis in real-time environment.

A bearing wear model has been implemented into the system to predict the cumulative wear status while drilling. The wear model can help drilling engineers to evaluate bearing wear status during real time drilling operations including the estimated hours left of bearing life through simulation, and to make a decision on when to pull out the bit in time to avoid bearing failures. The system is successfully tested and verified with a WITSML server in Canada. Better agreement between the estimated and reported bearing wear reveals IDAs to possibly play an important role in the oil industry to increase overall drilling efficiency and safety of real-time drilling operations as well as reduce the overall drilling cost.

Acknowledgment

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