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Reducing Consumed Energy while Drilling an Oil Well through a Deep Rig Time Analysis

Moazzeni Alireza[1,*]; Nabaei Mohammad[1]; Azari Ahmad[1]

[1] Department of petroleum engineering, Omidieh branch, Islamic Azad University, Omidieh, Iran

* Corresponding author. Email: moazzzeni@yahoo.com

Abstract: As time goes by, increase in world energy demand forces oil and gas companies to drill deeper in order to produce more oil and gas for balancing world's offer and demand. This requires drilling layers with various characteristics and dealing with more drilling problems as drilling progresses. Reduction of drilling problems can help drillers to reduce their cost effectively.

Rig time break down of more than 300 wells in one south west Iranian oil field has been analysed to determine effective parameters on non-productive time amount. Results show that the most common drilling problems always have been experienced by drilling engineers are Equipment failure, stuck pipe and lost circulation which expose huge expenses to the oil companies.

Several factors while drilling will govern how severe mud loss and stuck pipe would occur. These actually make analytical modelling of lost circulation or pipe sticking to somehow complicated. Hereby, employing artificial intelligence can be a leeway with proven capability and accuracy. In this research, operational parameters in Maroun oilfields are introduced to artificial neural networks to predict lost circulation severity, stuck pipe position and stuck pipe severity before happening. Results are well-matched with reality.

Key words: Energy; Drilling problems; Lost circulation; Stuck pipe; Rig time analysis

1. INTRODUCTION

Over several years oil industry is facing troubles associated with the stuck pipe and lost circulation. Differential pipe sticking is one of the stuck pipe mechanisms that have had a major impact on drilling efficiency and well costs (Adams, 1977; Weakley, 1990; Wisnie et al., 1994). These occurrences are common everywhere in the world and are estimated to cost the industry hundreds of millions of dollars annually (Siruvuri et al., 2006). In some areas, events related to differentially stuck pipe can be responsible for as much as 40% of the total well cost. Differential pipe sticking problems generally result in the well cost overruns and time overruns as a non-productive time in terms of loss of rig days either due to stopping of drilling operations or an attempt to free

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the stuck pipe. This huge loss is always accounted in the well budget cost as a contingency factor for the risks associated with the stuck pipe problems in the well planning and drilling performance approach.

The problem of lost circulation was apparent in the early history of the drilling industry and was magnified considerably when operator began drilling deeper and/or depleted formation(Moazzeni et al., 2010). The industry spends millions of dollars a year to combat lost circulation and the detrimental effects its propagates, such as lost of rig time, stuck pipe, blow-outs, and frequently, the abandonment of expensive wells, excessive cost due to mud losses, formation damage because of looses to the producing zone, or incomplete zonal isolation due to low top-of-well cement(Pilehvari et al., 2002). Major losses most often occur through fracture propagation. Although other forms of loss such as vugular, matrix seepage, and filter loss may also be of concern, fracture propagation losses account for over 90% of the operator lost returns expenditures(Dupriest, 2005).

Several parameters such as formation pressure gradient, formation fracture pressure gradient, drilling fluid properties, petrophysical properties of the formation, existence of fractures and caves in the formation, some drilling parameters (such as pump pressure and pump flow rate) and lots of other known and unknown parameters might affect severity of lost of circulation and stuck pipe probability. So it is if not impossible very difficult to predict existence of lost of circulation and stuck pipe in a certain formation. Despite of this concern, high curing costs of these problems and other previous mentioned lateral troubles usually forces drilling engineer to do research on these issues. For these reasons in this article we would attempt to obtain a way for predicting existence and intensity of lost of circulation and stuck pipe having existence data before and during drilling, in a (certain) formation using artificial neural networks which is one of virtual intelligence methods.

2. DRILLING COST

A key to succeed in any drilling well job is to minimize costs along with safety, environmental issues and without drilling problems. Major part of expenses in development of oil and gas fields is related to the drilling phase of the project. To minimize the cost of the drilling, appropriate drilling parameters should be taken during drilling operation. Each well according to the geology of the region, top of the target formation, technical waiting and other non associated waiting may have a drilling duration from 4 months to years (Moazzeni et al. 2010). Sometimes, due to some drilling problems, program may be suspended even for 2 to 4 years (Runtuwene et al., 2009). Drilling cost can be broken down to two distinguishable parts, fixed and variable costs. Formula 1 describes drilling cost:

$$\frac{cost}{ft} = \frac{C_b + C_r(t_b + t_c + t_r)}{\Delta D} \tag{1}$$

In this formuls, Cb is bit cost ($), Cr is rig operation cost ($/hr), tb is bit running time (hr), tc is connection time (hr), tr is drilling trip time (hr) and ΔD is drilled interval (ft). Drilling trip time can be roughly estimated by:

$$t_r = 1 + \frac{3D_{in}}{1000} \tag{2}$$

Where D_{in} is the length of the drillstring is in the hole(Paes et al, 2005).

Drilling cost is a critical factor in determining the financial returns from an oil and gas investment. Its critical nature is particularly true when operating costs are high and when drilling problems may be likely to occur. Drilling optimization is the key to reduce Non-Productive-Time (NPT) when drilling is ceased(Paes et al, 2005). Drilling optimization also will increase drilling efficiency, safety and helps to protect environment with precise planning of mud weight and required materials. In order to reduce the total cost, drilling rate should be increased which is attainable with paying attention to how interrelated operational parameters can affect each other in order to increase rate of penetration.

According to the formula, three different acronyms illustrate role of time in the cost equation. Connection time depends on the drilling crew efficiency and tripping time also depends on depth and efficiency of the crew on the floor. Bit type controls bit running time and tripping time. Inappropriate type of bit will cause a decrease in penetration rate and also unripe tripping which forces drilling operator to pull the bit out of hole. This will waste the time and impose extra expenses to the operator company.

3. NPT ANALYSIS

Non-productive time is defined as time which drilling is ceased or penetration rate is very low and the followings can be categorized as main features of NPT:

a. Lost circulation (severe and complete losses)

b. Pipe stuck (differential, mechanical and wellbore geometry related stucks)

c. Dealing with kicks and sometimes subsequent complete loss due to narrow mud weight window

d. Wellbore instability issues

e. Formation breakdown (generation of induced fractures) due to high ECD or pressure surges

f. Slow ROP in hard formations

g. Tripping for changing the bit

h. Fishing operation

i. Remedial cementing for increment of primary cementing

Qualitative NPT impact can be classified as follows:

a. Loss of or damage to equipments

b. Financial loss (behind budjet operation)

c. Health, safety and environmental (HSE) issues

d. Waiting for equipment arrival and new technique set up

Dodson in 2004 found that about 40% of non-productive drilling time was caused by both wellbore instability and pore pressure issues (e.g. kicks, gas flow, shallow water flow, lost circulation, wellbore instability, sloughing, and stuck pipe). therefore, in order to optimize drilling operation and reducing total cost, more focus should be spent on reducing these nonefficient times.

4. REDUCING NPT

Wellbore instability problems in exploration and development drilling operation cost the drilling industry more than $100 million per month worldwide and possibly as much as one billion dollars annually. The most commonly encountered wellbore instability is borehole enlargement or collapse due to brittle rock failure of the wall (Al-Ajmi et al, 2006). When the borehole wall starts to break out, small and large pieces of rock may settle down around the drill string and pack the annulus off, while larger particles may go around the bottomhole assembly (BHA) and jam the drill string which can stick string and prevent its movement. When drill string can not be pulled out, freeing operation should be started and spending time for freeing may bring drilling program behind the schedule. Sometimes many days should be spent by the drilling crew to solve the problem which imposes heavy expenses to drilling company. Most often pipes will be freed by working on them, but if drill string can not be freed, it should undergo back off operation. In this operation after determination of free point along the drill string, drill pipes will be unscrewed across the nearest tool joint above snag point. Upper section will be pulled out of the hole and operation will be resumed by running fishing tools to retrieve the stuck part. Fishing operation may last few hours up to many weeks. In Iranian oilfield due to complicated lithology, stressed zone (under Zagros catena mountain), enormous transverse faults and extreme over pressure formations in southwest of Iran, frequent kick, loss and pipe sticking scenarios are observed. Major part of drilling operation in Iranian oilfields is done by National Iranian Drilling Company (NIDC). This company has more than 50 rigs (working onshore and offshore), which increase probability of facing drilling problems. Thus freeing may impose enormous costs to this big company.

Time break down structure of drilling a well is presented in Table 1. Drilling period as is shown can be divided to different parts namely perfect well time, invisible lost time, time spent to deal with drilling problems, technical waitings and drilling hazards. Perfect well time is actually the time which well is expected to be finished normally, invisible lost time strongly is controlled by drilling crew efficiency, occurrence of drilling problems is likely to increase drilling time which can be classified as lost circulation time, kick removing time and time spent for freeing the pipe. Technical waiting will come true when operational parameters like pressure exceeds tool capacity and stronger tool should be transited to the location and employed.

Tab. 1: Time Break Down Structure of Drilling an Oil or Gas Well

Perfect Well-Time	**Invisible Lost Time**	**Drilling Problems**			**Technical Waiting/other**			**Drilling Hazards**
		Lost Circulation Curing Time	Kick Removing Time	Work on Stuck Pipe	Limited Tool Capacity	Tools Transportation	Weather Condition	
Conventional Normal Well Time		NPT Can be reduced using artificial neural networks						

Another unpredictable factor influencing NPT is weather condition, big thunders in southwest of Iran sometimes reach to the earth surface, if one on them strikes to the rig, it can cause inexpiable harm to the assets (human and equipments). Drilling hazards include issues related to health, safety and environment; it actually can contain facing with well blowout, firing and leaking H_2S from formation to the drilling fluid.

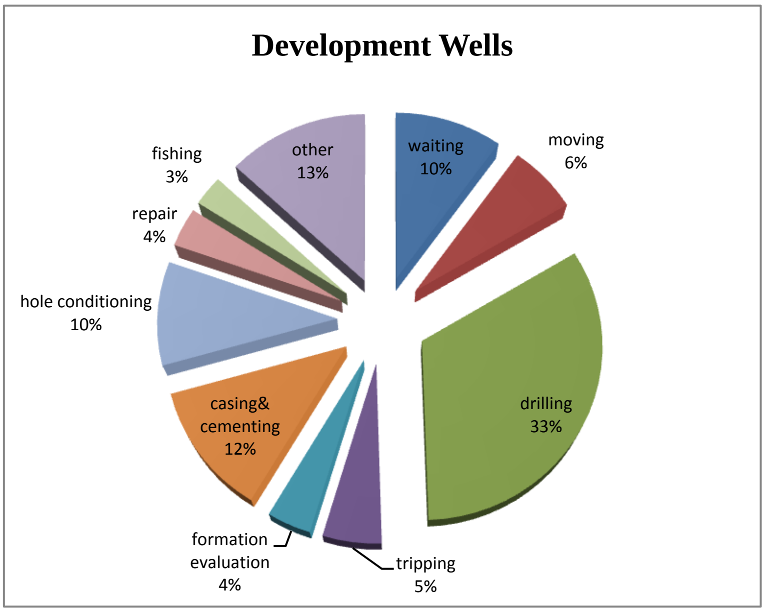

Fig. 1: Time Break down Diagram of Drilled Development Wells in Maroun Oil Field

Figure 1 shows time break down analysis of more than 200 development wells which are drilled recent years in Maroun oil field. As it can be seen, 10% of rig time was spent on hole conditioning almost caused by well bore instability and lost of circulation. Also 3% of rig time was used up for fishing which usually is due to stuck pipe. Equipment failure (repair) is one of other important factors which could waste 4% of rig time while drilling in this oil field. So if it be considered that millions of dollars should be spent for drilling a well, one can find importance of even 1 percent reduction in non productive time. Artificial intelligence is a powerful method which can help us to approach to our aim, reduction of non productive time.

5. METHODOLOGY

Traditionally, stuck pipe situations were solved using standard tools and techniques developed in oil field practice. There have also been recommendations to study the causes of drill pipe sticking and thereafter to suggest changes in operating practices to minimize stuck pipe incidents. In early 1980's and 1990's, various researchers (Howard , 1994; Biegler at al., 1994; Siruvuri et al, 2006;) believed that the real key to savings and success in a well planning was in the avoidance of the risks associated with the stuck pipe incidences. Some studies (Boomer, 1995) in the past have been performed to identify important parameters associated with the occurrence of differentially stuck pipe. Among them are multivariate statistical analysis techniques and simulated sticking tests using different drilling fluids. Both kinds of studies have been used to identify and modify variables that lead to stuck pipe in order to minimize or prevent sticking. Same studies had been done for modeling lost circulation and getting an analytical solution for this problem and again there was no an acceptable solution because of complicacy of the phenomena.

This paper introduces a more powerful and an efficient application called neural network modeling, a technique that can provide better and more accurate solutions for the problems associated with pipe sticking and lost circulation events.

Neural networks, with their remarkable ability to derive meaning from complicated or imprecise data, can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques. A trained neural network can be thought of as an "expert" in the category of information it has been given to analyze. This expert can then be used to provide projections given new situations of interest and answer "what if" questions.

At the proceeding sections of this article we will describe how it can be used ANN to predict lost circulation and also stuck pipe in one of Iranian really troubleshooting oil fields that is Maroun oil field.

6. PREDICTING LOST CIRCULATION

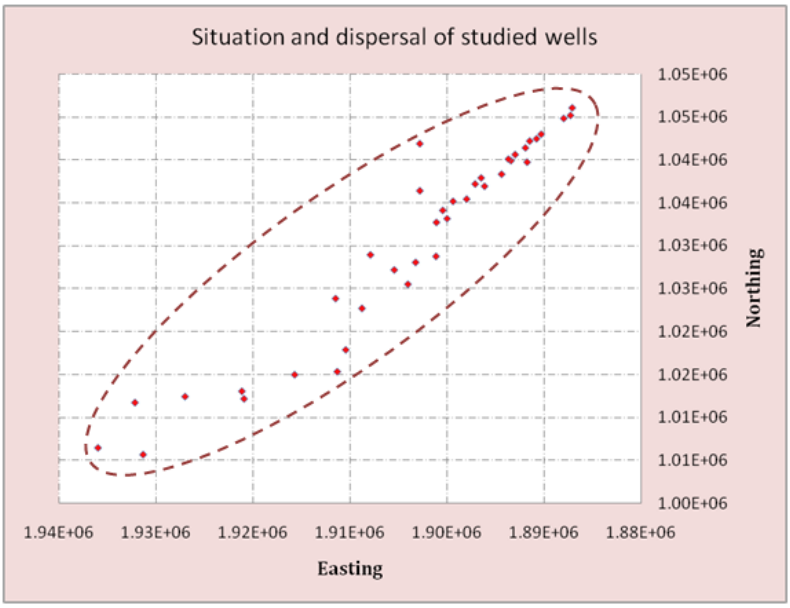

Fig. 2: Distribution of Wells under Study in Maroun Oilfield

Used data in this work are composed of some recorded drilling daily report data for 32 recently drilled wells in Maroun oil field. Situation and dispersal of selected wells for this work are shown in Figure 2. Major attempt would be estimating quantity and quality of lost of circulation in each day using recorded data in that day or previous days. Whereas lost of circulation takes place in Asmary formation more severely and seriously than other sections of drilled wells in this field, this research was restricted only to this section of wells. Using data-mining process some of more effective parameters on lost of circulation was selected. These data are:

a. Present depth of well from ground surface in the considered day in meter

b. Present depth of well from sea level in the considered day in meter

c. Drilled depth of well in the considered day in meter

d. Drilling time in the considered day in hours

e. Length of open hole section at the end of considered day in meter

f. Asmary formation top from ground surface in meter

g. Northing of the considered well

h. Easting of considered well

i. Bit size in inch (open hole diameter)

j. Average output of pump in considered day in gallon per minutes

k. Average pump pressure in considered day in Psi

l. Mud weight in Pcf

m. Solid percent of drilling fluid obtained from retort solid equipment

n. θ_{300} achieved from rotational viscometer

o. θ_{600} achieved from rotational viscometer

p. Drilling mud fluid loss gained from API filter press device

q. Amount of lost of circulation in day pervious of considered day in barrel

r. Amount of lost of circulation in two days pervious of considered day in barrel

After selecting and gathering required date, these data has been normalized between 0 and 1 but before that work all representative data of lost of circulation were squared (for intensive dispersal). Since the last goal was amount of lost of circulation in a certain day, certainly output of network just would be lost of circulation which would be introduced to network after normalizing between 0 and 1 and squaring.

There for a three layer, feed forward-back propagation network was selected. used activation functions in this work are LOGSIG for input and hidden layers and PURELIN type for output layer. As mentioned before using input data, they should be normalized in a distinct range (usually between 0 and 1) using following equation:

$$\tilde{x}_i = \frac{x_i - x_{i_{\min}}}{x_{i_{\max}} - x_{i_{\min}}} \tag{3}$$

In this equation i vary from 1 to m. Also $x_{i\ min}$ represent minimum amount of x_i and $x_{i\ max}$ shows maximum amount of x_i in the data set. On the other hand, target of the network will be amount of mud loss during one day and also must undergo normalization. Because of target data scattering, square of mud loss is used instead of mud loss value itself. So normalized value of target data would be obtained as follow:

$$\tilde{y}_i = \frac{\sqrt{y_i} - \sqrt{y_{i_{\min}}}}{\sqrt{y_{i_{\max}}} - \sqrt{y_{i_{\min}}}} \tag{4}$$

Also the only hidden layer in this network had 30 neuron. For performing this research, after numerous trial and errors, a feed forward back propagation network was utilized with LEARNGDM adaptation learning function and TRAINLM training function.

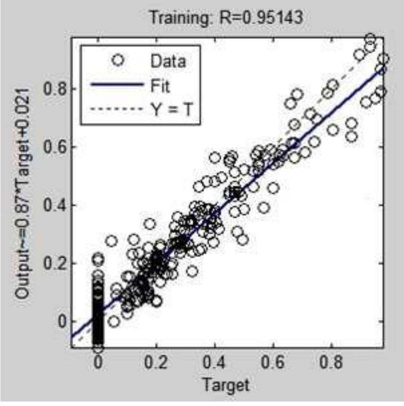

Fig. 3: Training Results of the Used Network for Predicting Lost of Circulation

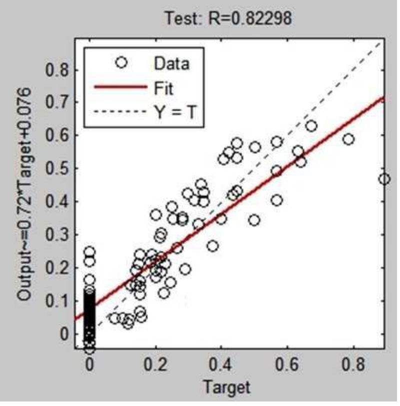

Fig. 4: Testing Results of the Used Network for Predicting Lost of Circulation

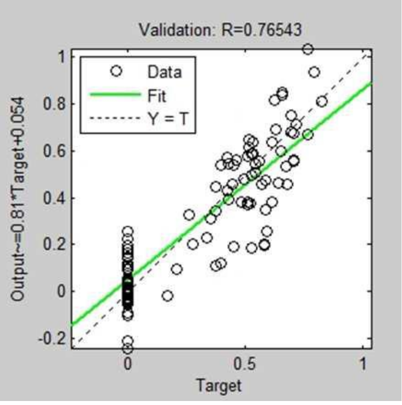

Fig. 5: Validation Results of the Used Network for Predicting Lost of Circulation

About 70% of input data were taken for network training, 15% for network testing and the rest for validation of the network. Figure 3, 4 and 5 show network results for training, testing and validation respectively. R value for training is 0.95, for testing is 0.76 and for validation it is 0.82 which demonstrate that network results will show good compatibility with real data from field. Figure 6 expresses a comparison between network predictions and real data. As it is obvious, network precision in low mud loss is adorable but it is not good in very severe losses. This can be because of data inconsistency or off scale input parameters. Meanwhile, lots of parameters affect lost circulation which may not be considered along input data and this may make some deviation from reality. One of the effective factors on mud loss stopping is selected technique to treat lost circulation after occurrence like type and concentration of LCM used to stop mud loss which is not intelligible for network.

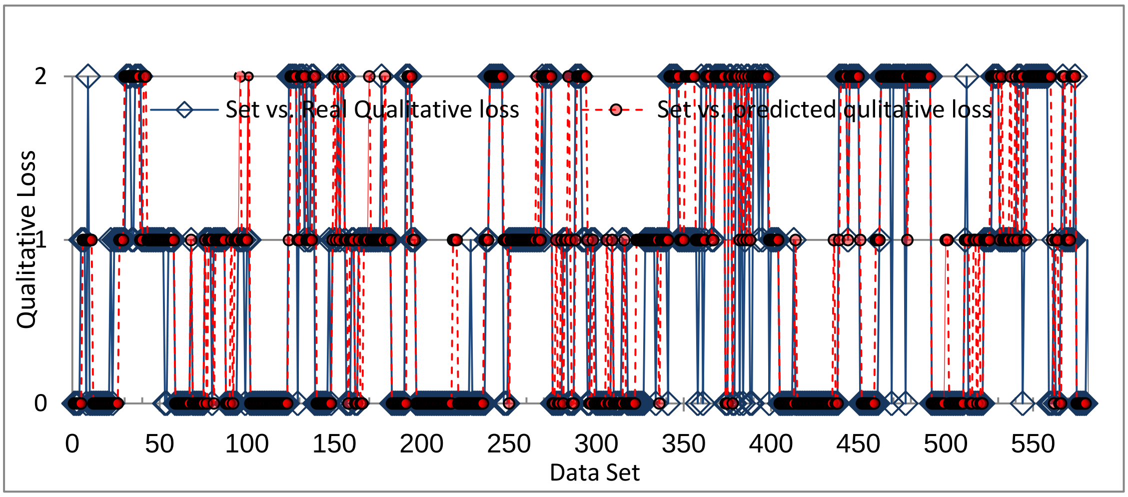

Fig. 6: Qualitative Lost Circulation Prediction

In order illustrate severity of lost circulation in drilling engineering fashion, it should be reported qualitatively, by means seepage, partial (severe) or complete loss. For this conversion, below classification can be employed:

a. Seepage (negligible) loss when loss is lower than 10 bbls/day and is represented by 0,

b. Severe loss when it is between 10 to 100 bbls/day and is represented by 1,

c. Complete loss when it is more than 100 bbls/day and is represented by 2.

Using these rules, network would be able to report the results qualitatively rather than quantitatively. This is shown in the Figure 5. As it can be seen from Figure 6 the generated network can almost precisely predict type of lost circulation before occurring.

7. PREDICTING PIPE STUCK

Next step for reducing non productive time is recognizing zones which might lead to stuck pipe. As it was mentioned before predicting this problem is really difficult. But artificial neural network as a powerful tool for predicting complex phenomena can help us for solving this problem too. At the first it was attempted to build a network for predicting stuck pipe in all wells drilled in Iran but no meaningful result was obtained. At the next step work was limited to the Maroun oil field. For this purpose data of 166 point which stuck pipe was happened on them was collected. To complete the input data 100 more point which there were no problem while drilling them was added to previous data. So 266 set data was introduced to ANN as input data. Each input set data was consisted of 13 effective parameter on stuck pipe as follow:

a. Type of formation: while drilling in Maroun oil field it might be countered with 1- Aghajari, 2- Mishan, 3-Gachsaran (7-4 membrane), 4- gachsaran (3-2 membrane) 5- gachsaran (first memberane or cap rock), 6-Asmari and 7-under Asmari formations. For introducing desired point to the network, a seven digit code (from 0 and 1) was produced. If the desired point was belonged to a certain formation, representative digit of this formation was 1 and other digits were 0. For example the code 0000010 indicates that considered point is belonged to Asmari formation.

b. Top of the formation in meter.

c. Dip of the well at the desired point

d. Depth which well was deviated in meter. So at top of this point well is vertical and below it the well is deviated.

e. Size of last casing or liner run in well in inch.

f. Depth of last casing or liner in the well in meter.

g. Bit size in inch.

h. Mud weight in pound per cubic feet.

i. Marsh funnel viscosity

j. Plastic viscosity

k. Yield point

l. Initial gel strength

m. 10 min. gel strength

After normalizing input data between 0 and 1, they were introduced to the network. Since the aim of this section of work is forecasting probability of stuck pipe, output of the network would be 0 or 1 which 0 shows that pipes would not stuck in this hole and 1 shows that pipes would stick.

For predicting stuck pipe with the selected input data, a feed forward back propagation network with five layer has been selected. As it can be seen in figure 7, activation functions in layer 1 to 4 are TANSIG and in layer 5 is PURELIN. In this network first layer has 30 neuron, second layer has 25 neuron, third layer 15, forth layer 10 and last layer has 5 neuron.

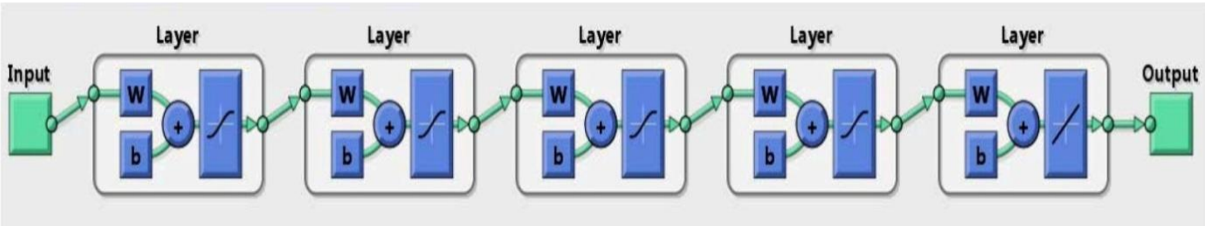

Fig. 7: A Schematic View of Selected Network for Predicting Stuck Pipe

It should be emphasized that probability of stuck in a hole with this network can be predicted not probability of stuck in a certain point. So before starting drilling of a certain hole, network by considering drilling conditions can forecast probability of stuck in this hole.

Also it seems bottom hole assembly configuration has an important effect on stuck pipe which is missed in this work and can be considered in supplementary works.

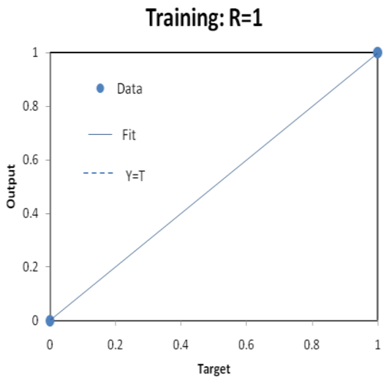

Fig. 8: Training Results of the Used Network for Predicting Stuck Pipe

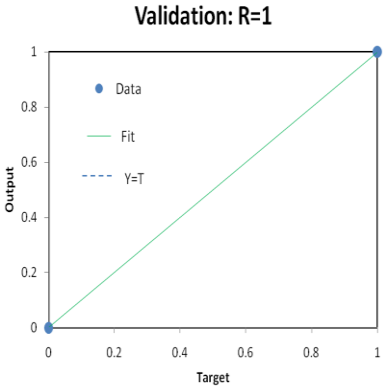

Fig. 9: Validation Results of the Used Network for Predicting Stuck Pipe

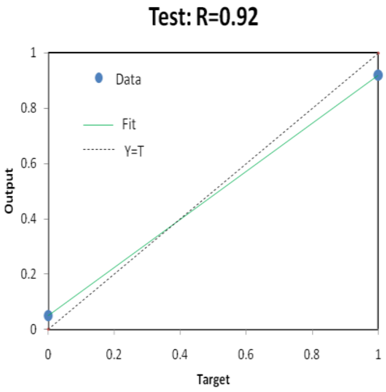

Fig. 10: Testing Results of the Used Network for Predicting Stuck Pipe

About 70% of input data were taken for network training, 15% for network testing and the rest for validation of the network. Figure 8, 9 and 10 show network results for training, validation and testing respectively. R value for training is 1, for testing is 0.92 and for validation it is 1 which demonstrate that network results will show good compatibility with real data from field. Figure 11 expresses a comparison between network predictions and real data.

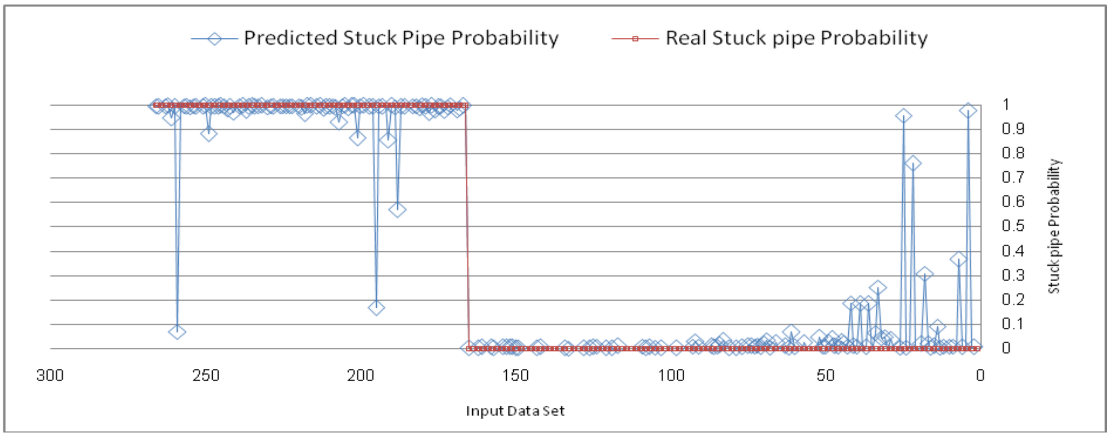

Fig. 11: Comparison between Network Predictions and Real Stuck Pipe Data

8. CONCLUSIONS

Reduction of non productive time can strongly reduce drilling cost, specially while drilling development wells.

Stuck pipe and lost of circulation can incredibly increase non productive time while drilling in Maroun oil field

A methodology was proposed for prediction of lost circulation and stuck pipe probability in any coordinates of field using operational data.

Proposed methodology is based on artificial neural networks which its ability to solve complicated problems is proven.

Lost circulation and stuck pipe are governed by numerous factors that make finding analytical solution with acceptable accuracy very difficult or impossible.

Neural network helps to have accurate prediction of lost circulation in Asmari formation of Maroun oilfield.

Neural network helps to predict stuck pipe in a special hole before drilling this hole with a high degree of accuracy.

Utilizing artificial neural network is recommended while dealing with different interrelated parameters (like lost circulation).

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REFERENCES

[1] Adams, N. (1977). A field case study of differential-pressure pipe sticking: SPE 6716.

[2] Al-Ajmi, A.M., & Zimmerman, R.W. (2006). Stability analysis of deviated boreholes using the mogi-coulomb failure criterion, With Applications to Some Oil and Gas Reservoirs: IADC/SPE 104035.

[3] Biegler M.W., & Kuhn G.R. (1994). Advances in prediction of stuck pipe using multivariate statistical analysis: SPE 27529.

[4] Dupriest, F.E (2005). Fracture closure stress (FCS) and lost returns practices: SPE 92192.

[5] Howard, J.A., & Glover, S.B. (1994). Tracking stuck pipe probability while drilling: SPE 27528.

[6] Moazzeni, A.R., Nabaei, M., Shahbazi, K. & Shadravan, A. (2010). Mechanical earth modeling improves drilling efficiency and reduces non-productive time (NPT): SPE 131718.

[7] Moazzeni, A.R., Nabaei, M. & Ghadami, S. (2011). Decision making for reduction of non-productive time through an integrated lost circulation prediction. *Journal of Petroleum Science and Technology*, to be published.

[8] Paes, P., Aragao, A., & Chen D.C. (2005). Cost effective drilling optimization technologies in Campos Basin: SPE 94785.

[9] Pilehvari, A., and Nyshadham, V.R. (2002). Effect of material type and size distribution on performance of loss/seepage control material: SPE 73791.

[10] Robert, J. B. (1995). Predicting production using a neural network: SPE 30202.

[11] Runtuwene, M., Suprihono, S., Rizka, D., Prasetia, A. E., Toralde, J. S., & Nas S. (2009). Pressurized mud cap drilling drastically reduces non-productive time in soka field, south sumatera: SPE/IADC 125311.

[12] Siruvuri. C., Nagarakanti. S. & Samuel R. (2006). Stuck pipe prediction and avoidance: a convolutional neural network approach: IADC/SPE 98378.

[13] Weakley, R.R. (1990). Use of stuck pipe statistics to reduce the occurrence of stuck pipe: SPE 20410.

[14] Wisnie, A.P., & Zheiwei, Z. (1994). Quantifying stuck pipe risk in gulf of mexico oil and gas drilling: SPE 28298.