Drill bit selection in a formation with different sedimentary facies using the Markov chain: A case study at one of the oil fields in the south of Iran

Afsaneh Ghaffari Rad¹; Sajjad Negahban²; Behzad Tokhmechi³; Hossein Mostafavi⁴

¹ *Faculty of Mining, Petroleum and Geophysics Engineering, Shahrood University of Technology, Shahrood, Iran.*
  Afsaneh.ghaffarirad@gmail.com, ORCID: 0000-0003-3579-0295

² *Faculty of Mining, Petroleum and Geophysics Engineering, Shahrood University of Technology, Shahrood, Iran.*
  s.negahban@shahroodut.ac.ir, ORCID: 0000-0002-8548-2357

³ *Faculty of Mining, Petroleum and Geophysics Engineering, Shahrood University of Technology, Shahrood, Iran.*
  tokhmechi@ut.ac.ir, ORCID: 0000-0003-1516-0624

⁴ *Exploration Directorate of National Iranian Oil Company, Tehran, Iran. Mostafavi.hossein@gmail.com*

Abstract

The selection of a drill bit is an essential issue in well planning. Furthermore, identification and evaluation of sedimentary rocks before well drilling plays a crucial role in choosing the drill bit. Moreover, the Markov chain as a stochastic model is one of the powerful methods for identifying lithological units, which is based on the calculation of the transition probability matrix or transition matrix. The Markov chain experiences transitions from one state (a situation or set of values) to another according to specified probabilistic rules. In this paper, the Markov chain was implemented for bit selection in a formation with different sedimentary facies (such as the Dashtak Formation). Therefore, the proper drill bit was proposed by utilizing the transition matrix of rock facies and the available bits. This process was carried out in two wells where the thicknesses of the Dashtak Formation are 960 meters and 1410 meters. Consequently, the results indicate that the Markov chain is a practical method for selecting bits in a sequence of rock facies based on an acceptable matching between the reality mode (the used bits in the well) and the Markov chain results. Besides, in the case of using an improper bit in a well, and using a bit in a washing and reaming operation, there were differences between the used bits and the Markov chain outputs.

Keywords:
Dashtak Formation; drill bit optimization; lithology; transition matrix; sedimentary facies

1. Introduction

Drilling oil and gas wells has encountered various challenges from the beginning. New technologies are being discovered to solve critical technical problems in smart and cost-effective ways. Bit selection is one of the important parameters for planning and designing new wells. Choosing a wrong bit or damaging a bit in a well leads to rising drilling costs. Bit selection is a crucial task to perform. There are many aspects that need to be considered and evaluated before the decision is made. There are a lot of parameters in drilling operations that must be evaluated and designed to improve the efficiency of the drilling process (**Edalatkhah et al., 2010; Karadzhova, 2014**). One of these challenges is selecting the proper bit for different formations (**Abbas et al., 2019**). The process of drilling a well on the ground requires a drill bit. Indeed, the bit is the fundamental tool used by the drilling engineer and is located at the end of

the drill string (**Baniya, 2018**). Choosing the best bit according to the current conditions is one of the most important aspects of drilling engineering. The type of bit and its life determine the cost of drilling and ensure its proper operation (**Boryczko, 2012**). The Dashtak Formation is a formation with a sequence of different layers. This feature of the Dashtak Formation causes difficulties in bit selection and, likewise, the loss of money and time (**Azizi et al., 2008**). Therefore, the purpose of this study is to utilize a probabilistic method to select a suitable drill bit in this formation, given that the Markov chain has been introduced as a powerful method for modelling rock facies. Modelling in the Markov chain is performed using the transition matrix (the transfers number from each facies to the other facies or itself is displayed) and the transfer probability matrix (**Krumbein and Dacey, 1969**).

In recent years, various methods have been proposed for the optimal selection of a drill bit. In the last decade, the application of the Markov chain in the oil industry has attracted significant attention from research teams. **Jun et al.** in **2012** solved the problem of a three-dimen-

Corresponding author: Sajjad Negahban
s.negahban@shahroodut.ac.ir

sional simulation of oil and gas reservoirs using the Markov chain. The results show that this new approach can depict the spatial distribution characteristics of sandstone formations. Subsequently**,** in 2013, **Nikoogoftar et al.** proposed the Markov chain model to model lithology units for reservoir management. Validation of the results has shown that the rock facies are modelled with acceptable accuracy. In 2017, **Ove Strand** used the Markov chain to model the well blowout preventer (BOP) system accurately. This research represented a simple numerical method for solving many experiments for a BOP installation. The present study, the application of the Markov chain probabilistic method in simulating rock facies and selecting a drill bit in one of the Iranian formations was proposed.

1.1. Geology of the region

The Lower–Middle Triassic Dashtak Formation is a formation in the Kazerun Group with lithologies of do-

lomite, shale, anhydrite, Argilaceuos dolomite, etc. The lithologies of this formation consist of 6 sequences alternately, such as the section of shale Agar evaporative part A, evaporative part B, evaporative part C, the Sefidar dolomite part, and evaporative part D. Due to the presence of thick anhydrite layers, this formation is considered as an important cap rock in the Zagros Basin for gas reservoirs of the Dahrom Group (Dalan and Kangan) in the south of Iran (**Khoshnoodkia et al., 2010; Hajian-Barzi et al., 2015; Rahmani et al., 2018; Habibnia et al., 2016**). In this study, petrophysical and geological information of two wells has been used for modelling. The thickness of the Dashtak Formation in well #1 and well #2 is 960 meters and 1410 meters, respectively. **Tables 1** and **2** depict the type of used bits and the intervals which were drilled by each bit in wells #1 and #2.

2. Markov chain theory

The Markov chain is a particular type of Markov process in which the system state selects only discrete values, and it is based on the probability matrix. The future of this process does not depend on the way it was taken in the past, but only on its current position (**Awiszus and Rosenhahn, 2018; Kratochv´ıl, 2018**). Accordingly, an accidental string of variables $\{X_t, t \geq 0\}$ is called a Markov chain if for all state values $i_0, i_1, i_2, ..., i_t \in I$, then

$$P\{X_{t+1} = j | X_0 = i_0, X_{t+1} = i_{t-1}, ..., X_t = i\} = $$
$$= P\{X_{t+1} = j | X_t = i\} \quad (1)$$

Where the values $i_0, i_1, i_2, ..., i_t$ are different states in the space of state i (**Brooks et al., 2011; Zhi-zhong et al., 2018; Zakaria et al., 2019**).

A one-dimensional series of sequential events by the Markov chain is shown in **Figure 1**. In this Figure, the

Table 1: The Intervals drilled by used bits in well #1

Bit Type (IADC[1]) \ Lithology (m)	Dolomite	Argilaceuos Dolomite	Anhydrite	Argillaceuos Limestone	Shale	Cherty Limestone	Anhydrite Dolomite	Dolomite Limestone
537	168	70	81	20	10	20	0	19
527	48	55	53	24	48	0	22	0
214	10	18	26	0	0	25	0	0
215	0	102	0	0	58	0	0	0
135	0	0	0	35	0	0	0	0
517X	25	0	0	0	0	26	0	0

Table 2: The Intervals drilled by used bits in well #2

Bit Type (IADC) \ Lithology (m)	Dolomite	Argilaceuos Dolomite	Anhydrite	Argillaceuos Limestone	Shale	Cherty Limestone	Anhydrite Dolomite	Dolomite Limestone	Anhydrite Limestone	Dolomite Oolite	Marl	Unknown
537	97	39	49	37	13	17	0	31	28	0	5	132
527	102	118	54	4	4	8	4	29	14	4	18	269
214	4	2	20	0	0	0	0	0	0	0	0	24
215	22	9	16	5	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0	4
517X	73	0	14	0	0	13	13	0	0	0	11	0
M223	36	12	12	0	32	8	0	0	0	0	0	0

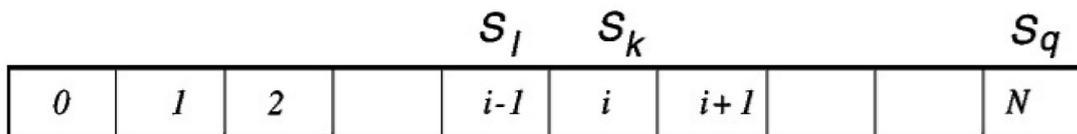[1] International Association of Drilling Contractors (IADC)

Figure 1: Sequential events for a one-dimensional the Markov chain (Elfeki and Dekking, 2001)

probability of cell i to be in state S_k, cell i-1 is in state S_l, and cell N is in state Sq, and the S_k event occurs when Sq and S_l occur. The transition probability from state i-1 to i is expressed by **Equation 2** (in this relation, Z represents the cell state).

$$P (Z_i = S_K | Z_{i-1} = S_l, Z_N = S_q) \qquad (2)$$

This probability can be written using **Equation 3** (**Elfeki and Dekking, 2001**):

$$P (Z_i = S_K | Z_{i-1} = S_l, Z_N = S_q) = \frac{P_{kq}^{(N-i)} P_{lk}}{P_{lq}^{(N-i+1)}} \qquad (3)$$

Where:

$P_{kq}^{(N-i)}$ – the transition probability of state k to q with (N −i) cell interval,

$P_{lq}^{(N-i+1)}$ – the transition probability of state l to q with (N −i+1) cell interval.

In this study, the Markov chain with discrete state and continuous time was used in one-dimension.

2.1. Algorithm for rock facies modeling and drill bit selection

Walter's law states, there is a natural relation between sedimentary environments in which different facies are formed. Thereby, the sequence facies of sedimentary formation are not random and independent of each other (**Rink and Thompson, 2015; Blevec et al., 2016**). The modelling algorithm of the facies of the Dashtak Formation by the Markov chain is shown in **Figure 2**. According to this Figure, six steps were defined to go through this algorithm, which are as follows:

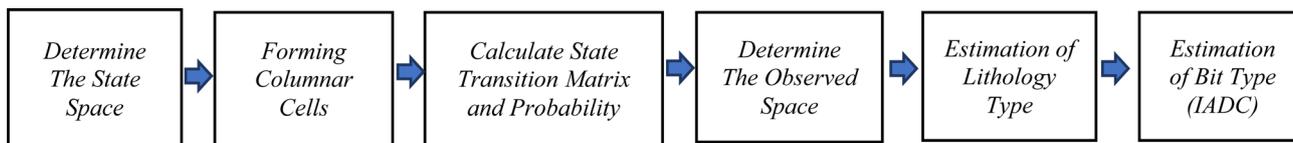*Step 1:* The state space was determined, according to the variable under study (sedimentary facies of the

Figure 2: Schematic steps of the proposed model

Table 3: Transfer Matrix or Transition Matrix in well #1

state	1	2	3	4	5	6	7	8
1	230	2	3	0	1	4	1	0
2	1	205	1	0	3	0	0	0
3	6	2	159	1	0	2	0	1
4	0	1	1	105	0	1	0	0
5	1	2	1	0	119	0	0	0
6	2	0	2	2	0	53	0	0
7	0	0	1	0	0	0	14	0
8	0	0	1	0	0	0	0	19

Dashtak Formation) and as a result, state space is equal to the number of existing facies in any sedimentary sequence (**Nikoogoftar et al., 2013**). According to the lithologies listed in **Tables 1** and **2** for well #1 and well #2 respectively, the state space was 8 and 12 members.

Step 2: The data which have been used in this paper, belong to the facies recognized through well log data. According to the resolution of well logs at the wells (the resolution of lithology was 1 meter), according to the thicknesses of the Dashtak Formation at these wells, wells #1 and #2 were divided into 960 and 1410 cells, respectively, similar to those represented in **Figure 1**.

Table 4: Transfer Probability Matrix in well #1

state	1	2	3	4	5	6	7	8
1	0.96	0.01	0.02	0	0.004	0.002	0.004	0
2	0.005	0.98	0.005	0	0.010	0	0	0
3	0.035	0.0115	0.93	0.006	0	0.0115	0	0.006
4	0	0.00926	0.00926	0.97222	0	0.00926	0	0
5	0.01	0.02	0.01	0	0.96	0	0	0
6	0.038	0	0.038	0.038	0	0.886	0	0
7	0	0	0.07	0	0	0	0.93	0
8	0	0	0.05	0	0	0	0	0.95

Step 3: In this step, the transfer of states from i-1 to i was calculated (i-1 and i were the facies type here, and i-1 may be equal to i) then divided on each row's sum. The transition probability matrix, which shows the probability of transition from state i-1 to state i, was illustrated by **Equation 4**:

$$P_{i\text{-}1\,i} = \frac{E_{i\text{-}1\,i}}{T_i} \qquad (4)$$

Where:

$E_{i\text{-}1\,i}$ – the transitions from i-1 to i,

T_i – the sum of rows i,

$P_{i\text{-}1\,i}$ – the probability of transfer from facies i-1 to facies i.

Tables 3 and **4** show the number of transfers from each lithology to other lithologies and the probability transfer matrix in well #1 (**Nikoogoftar et al., 2013**).

Step 4: In the current step, the location of the observed space (sedimentary facies) was determined. The study field contained geological sections with 960 meters in depth (960, 1-meter cells) and 1410 meters (1410, 1-meter cells). For modelling this section, the information of two wells (similar to **Figure 1**) was used as the observed space. To estimate the condition of each cell, the vertical transfer matrix of two wells was used.

Step 5: the condition of each cell was estimated using the transfer probability matrix and the observed space. As shown in **Equation 3** and **Figure 1**, each unknown cell Z_i, using the known states of cells (i -1), (N) and applying the conditional distribution P ($Z_i = S_K \mid Z_{i\text{-}1} = S_l$, $Z_N = S_q$) can be estimated. Cell (i -1) in the previous neighboring Z_i has the state S_l, and cell (N) in the boundary of the formation with the next formation has the state Sq. Regarding these two parameters, the S_K state in the cell (i) was estimated; In relation 3 of the expressions $P_{kq}^{(N-i)} P_{lk}$ the probability of transition from was state k to state q, which was the power of the difference between the estimated cell distance and the boundary of the next formation (N-i).

Step 6: In the last step, drill bit selection in the next stage (cell i) was developed by modelling rock facies by the Markov chain (using the transfer probability matrix of two wells) in MATLAB software.

3. Analysis of Predictions

Figures 3 to **14** compare the proposed bit by the Markov chain to the bit actually used in wells #1 and #2. Every figure illustrates the used and simulated bits in one well. The red lines represent the interval drilled by the used bit and the blue lines indicate the proposed bit by the Markov chain in an interval. In this research, seven types of drill bits (6 types of Roller-Cone Bits and 1 type of Fixed Cutter (PDC[2]) Bit) have been used. The IADC codes for categorizing roller cone bits based on a 4-character designation which represents the bit's cutting structure, formation compatibility and any special features (**Oteri, 2010**). The IADC codes for classifying fixed cutter bits comprises both rock properties and structural peculiarities. The designation of each bit includes 4 characters. The first character is the type of cutting structure and matrix material. The second describes the profile of the drill. The third character is characterized by hydraulic solutions. The fourth and final character defines the size and density of the blades (**Boryczko, 2012**).

There were hard and Chert layers in some depths in well #2. In these layers, low revolutions per minute (RPM) and high weight on bit (WOB) should be applied to reduce bit erosion. Furthermore, the proper rock-breaking mechanism in such a formation is crushing and scraping (**Sherbeny et al., 2016; Akisanmi, 2016; Strasburger et al., 2019**). Thereby, the implementation of a PDC bit (M223) in these cases causes severe erosion
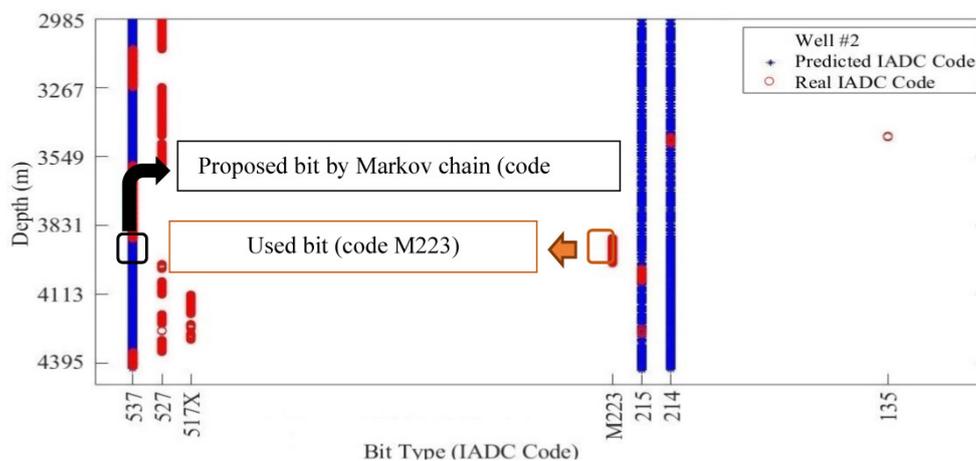

Figure 3: The mismatching of the improper used PDC bit (code M223) with the simulated bit by the Markov (code 537) in well #2
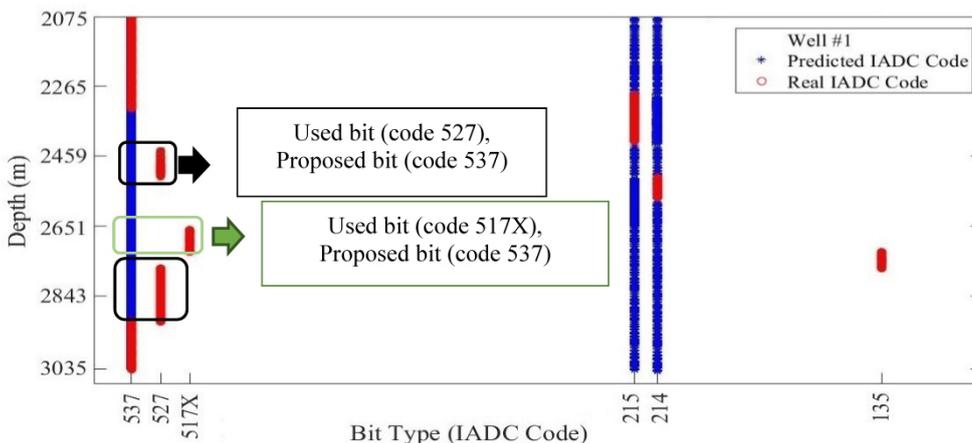
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[2] Polycrystalline Diamond Compact

Figure 4: The mismatching between the proposed bit by the Markov chain (code 537) and the improper used bit (codes 527 and 517X) in well #1
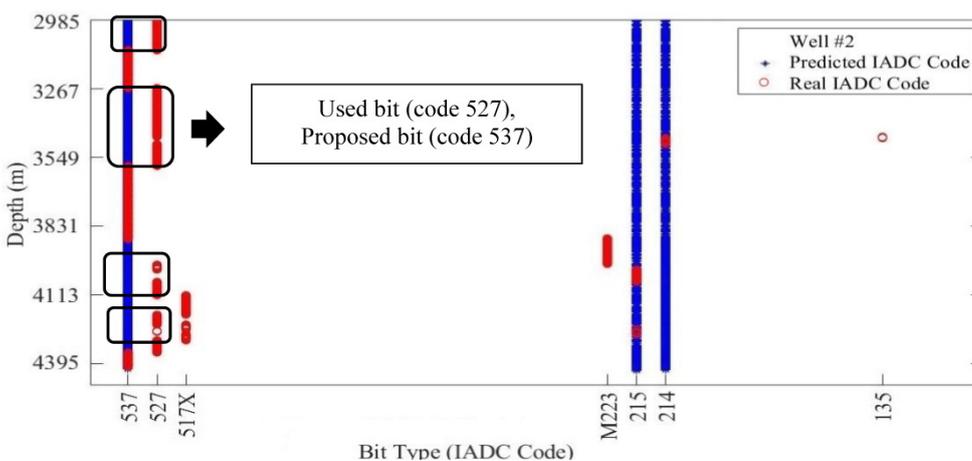

Figure 5: The mismatching between the proposed bit by the Markov chain (code 537) and the improper used bit (codes 527) in well #2
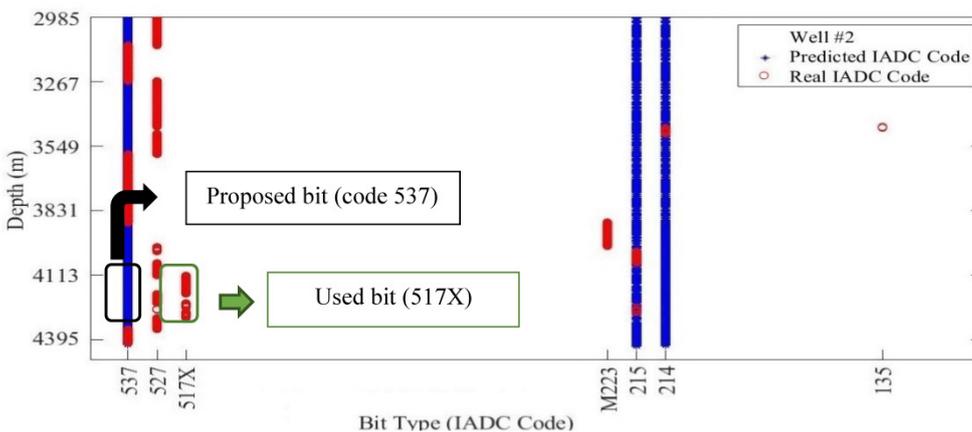

Figure 6: The mismatching between the proposed bit by the Markov chain (code 537) and the improper used bit (codes 517X) in well #2

of the bit and low drilling speed and consequently, leads the bit to be stuck or lost. According to the above, IADC bit code M223 was not suitable for drilling at this depth in well #2. As shown in **Figure 3**, there is mismatching between the improper PDC bit (code M223), which was used in the indicated section and, the simulated bit by the Markov (code 537) in well #2.

In most cases, the bit with the IADC code 527 was pulled out of the hole, due to high torque, changes in bottom hole assembly, and breaking and damaging of
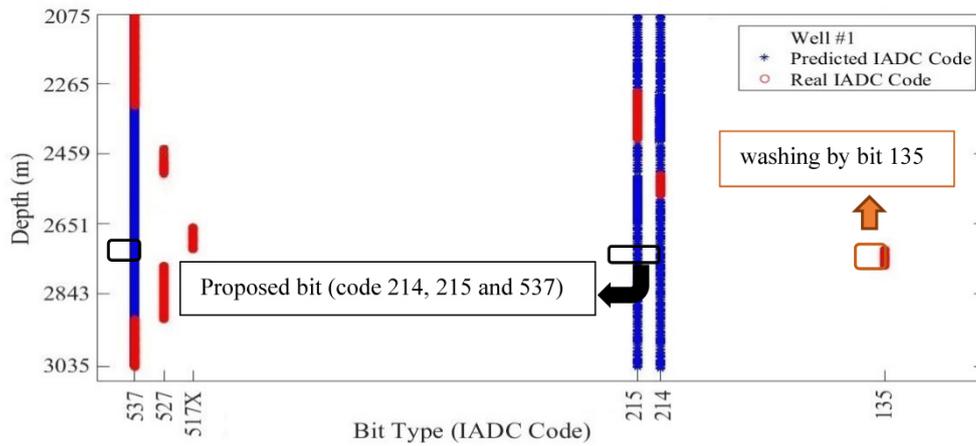
Figure 7: The mismatching between the proposed bits by the Markov chain (code 214, 215, and 537) and the used bit (codes 135) for washing in well #1
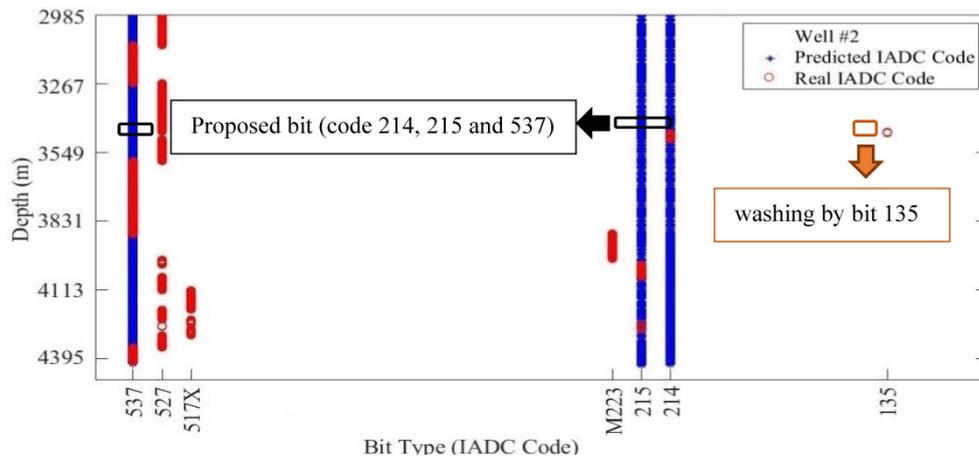

Figure 8: The mismatching between the proposed bits by the Markov chain (code 214, 215, and 537) and the used bit (codes 135) for washing in well #2
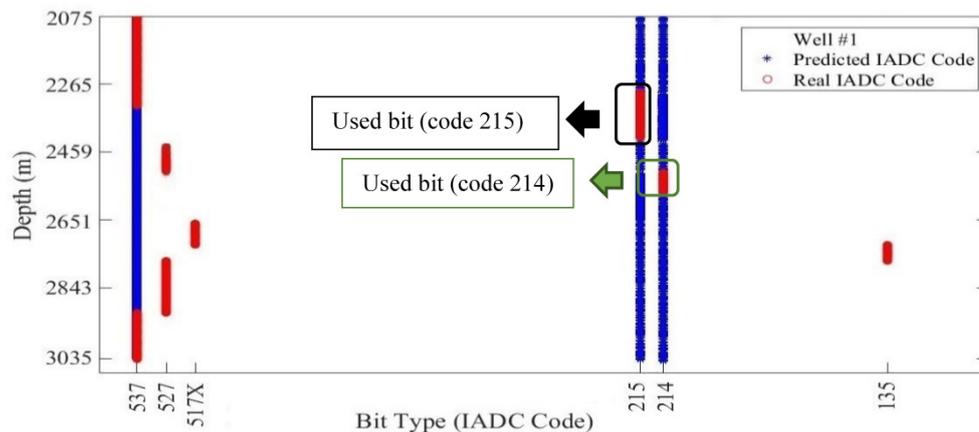

Figure 9: The matching between the proposed bits by the Markov chain (code214, 215) and the used bits (code214, 215) in well #1

the bit tooth. The drilled lithologies were mostly dolomite, anhydrite, and limestone with moderate and almost similar hardness. **Figures 4** and **5** depict the Markov chain which advised the bit with IADC code 537 according to the wellbore conditions and the available bits, be-

cause the drill bit 537 has harder cutters than drill bit 527 and also, the possibility of damaging its tooth is low.

The bit with the IADC code 517X could not be used in some depths due to the cones having been dropped in the well. The excavated lithology was dolomite, anhy-
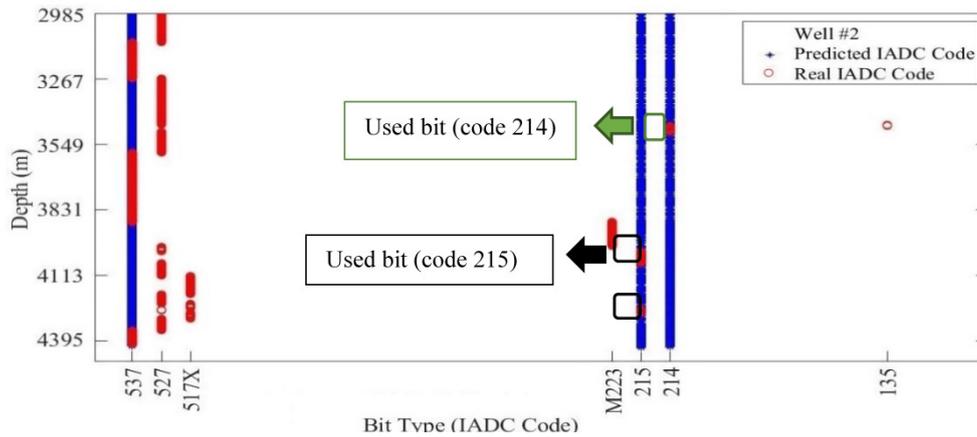
Figure 10: The matching between the proposed bits by the Markov chain (code214, 215)
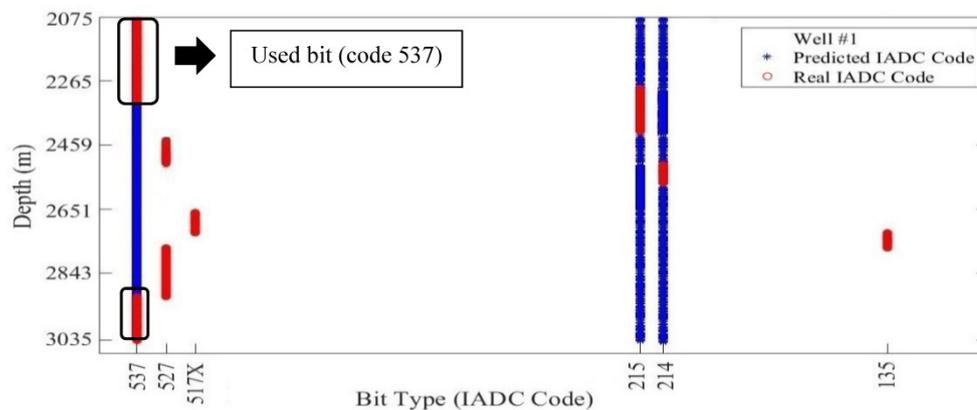and the used bits (code214, 215) in well #2

Figure 11: The matching between the proposed bit by the Markov chain
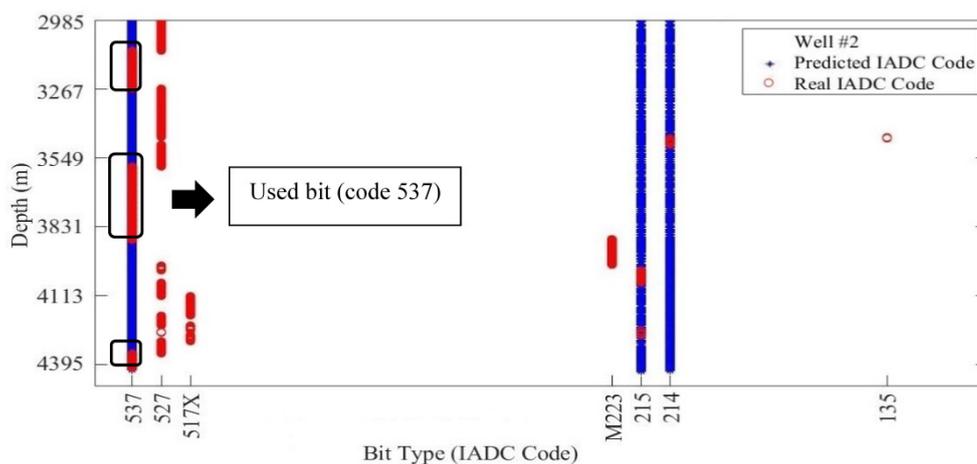(code537) and the used bit (537) in well #1

Figure 12: The matching between the proposed bit by the Markov chain
(code537) and the used bit (537) in well #2

drite, and limestone, thus due to the moderate hardness of the formation in this area, the bit was worn out and lost its cone. According to the excavated lithology, the bit with the IADC code 537 was proposed by the Markov chain (see **Figures 4** and **6**).

The drill bit IADC code 135 has been used in wellbore washing due to the casing operation. Therefore, in the pointed section in **Figures 7** and **8**, only the washing and reaming operations were performed. Consequently,
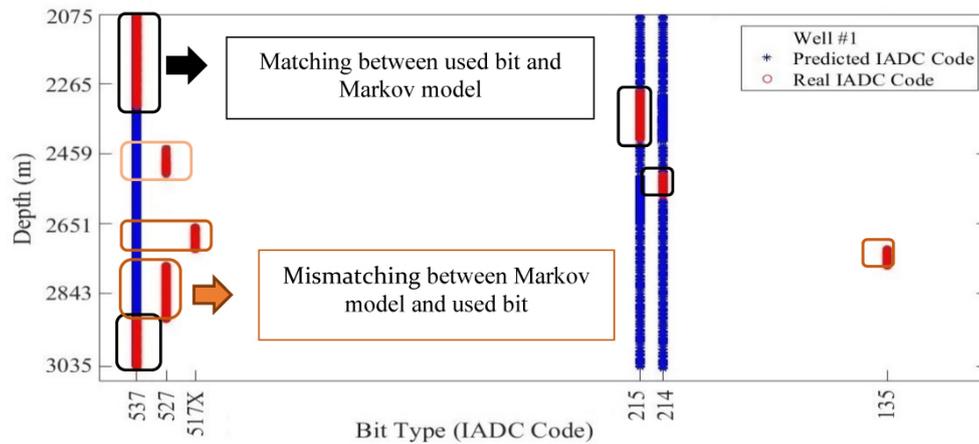
Figure 13: The matching and mismatching
between the proposed bit by the Markov chain and the used bit in well #1
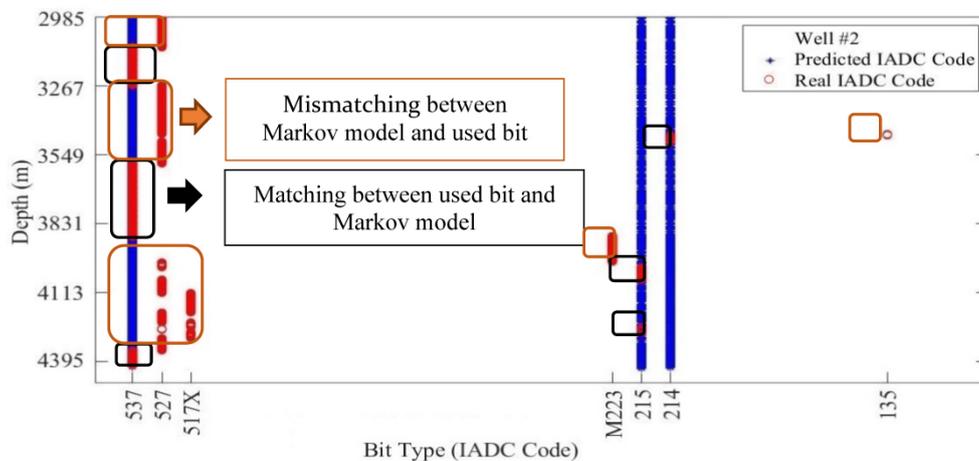

Figure 14: The matching and mismatching
between the proposed bit by the Markov chain and the used bit in well #2

there was a mismatch between the actual bit and the Markov chain prediction.

Drill bit IADC code 215 was used to wash the well after fishing operations in some sections. According to the Markov chain prediction, the application of this bit (drill bit IADC code 215) seems to be a suitable choice due to the lithology and well conditions (as illustrated in **Figures 9** and **10**).

Drill bit IADC code 214 was utilized to drill the lower and upper cement plugs, in the casing operation. As a result of the well conditions and the Markov chain prediction, which was presented in **Figures 9** and **10,** the application of drill bit IADC code 214 was appropriate to choose at the indicated part of the wells. However, due to the low ROP[3] of these bits, the lithologies of the drilled section, and the weakness of these bits, the application of drill bits IADC code 214 and 215 were proposed for the drilling of cement plugs and were not proposed for drilling a thick formation.

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[3] Rate Of Penetration

The drill bit 537 drilled the borehole without any specific drilling problems, and the operation was done only for drilling and not to solve drilling problems. As mentioned, most of the lithologies of these two wells were drilled with this bit. According to **Figures 11** and **12**, the Markov chain proposed this type of bit at most depths. The only difference between this type of bit and the two types of drill bits IADC codes 527 and 517X is its cutter hardness, which indicates it was qualified for drilling medium to hard formations such as the Dashtak Formation.

Eventually, in well #1, as shown in **Figure 13**, in 580 meters (60.41%) of the Dashtak Formation, there was a significant positive correlation between the used bit and the proposed bit. However, in 380 meters, no similarities were found between the used bit and the Markov chain results. Besides, 110 meters of the formation were drilled by drill bit 527, and 160 meters of it were drilled by bit 517X, which according to the available bits and the usable bits in these wells and the given description, bit 517X could be replaced by bit 537. Consequently, it can

be suggested that the bit could adequately be modelled by the Markov chain in 88.54% of the formation.

In well #2 (see **Figure 14)**, 58.68% of the formation (757 m), which were drilled by the proper bit, were correctly proposed by the Markov chain. On the contrary, 46.31% of the formation (667m) was not precisely modelled by the Markov chain. As mentioned before, this mismatching was due to the use of improper bits or the use of some bit for non-drilling operations, such as washing and reaming. Therefore, in regard to replacing unsuitable bits (527, 517X) with the proper ones (bit 537) the amount of error could be reduced significantly. In the case of utilizing replaced bits, 75.46% of similarities could be found between the used bits and the proposed bits.

4. Conclusion

The appropriate drill bit selection requires the consideration of various parameters, such as geological and operational factors. In this paper, the facies sequence as a lithology parameter was used to propose the drill bit in drilling engineering. The following conclusions can be drawn from the present study:

- The Markov chain model proposed applying a combination of three types of Roller-Cone Bits IADC code 214, 573, and 215 in wells #1 and #2 in the Dashtak Formation.
- The use of a milled tooth bit, such as drill bits IADC code 214, for well washing, after operations such as fishing and cementing, was proposed by the Markov chain model. Moreover, the Markov chain proposed an insert tooth bit with stronger cutters (such as bit 537) where the hardness of the formation was medium to high. Also, Markov chain proposed this bit type (bit 537) to reduce the cost and time of tripping operations.
- In well #1, where drilling problems are less frequent than in well #2, there is 88.54% similarity between the used bits and the Markov chain results. The existence of 11.46% error between the used bits and the proposed bits could be due to utilizing bit 135 for non-drilling operations, such as washing and reaming.
- In well #2, according to the Markov chain results, 75.46% of the sections of this well were correctly predicted. In addition to the reasons, which were explained for the inaccuracy of the model in well #1, there were about 24.54% differences between the proposed bits by the Markov chain and the used bits, due to the lack of sufficient knowledge about the lithology of some sections in well #2.

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SAŽETAK

Odabir dlijeta za bušenje stijena s različitim taložnim facijesima uporabom metode Markovljeva lanca: primjer studije naftnoga polja u južnome Iranu

Odabir dlijeta iznimno je važan korak u izradi projekta bušotine, a prepoznavanje i procjena taložnih stijena prije početka bušenja ima presudnu ulogu u odabiru dlijeta. Markovljev lanac, kao primjer stohastičkoga modela, jedna je od važnijih metoda za razlikovanje litoloških jedinica. Temelji se na računu matrice vjerojatnosti prijelaza ili matrice prijelaza. Markovljev lanac opisuje prijelaze iz jednoga stanja (situacije ili skupa vrijednosti) u drugo prema određenim vjerojatnosnim pravilima. U ovome je radu prvi put opisana uporaba Markovljeva lanca kod odabira dlijeta za bušenje kroz interval s različitim taložnim facijesima (formacija Dashtak). Stoga su u odabiru odgovarajućega dlijeta korišteni prijelazna matrica stijenskih facijesa i podatci o dostupnim dlijetima. Ovaj postupak proveden je u dvjema bušotinama gdje su debljine formacije Dashtak 960 i 1410 m. Dobiveni rezultati pokazuju da je Markovovljev lanac praktična metoda za odabir dlijeta kod bušenja niza litofacijesa. Zaključak je donesen na temelju stupnja podudaranja između stvarnih podataka (dlijeta korištenih u bušotini) i rezultata dobivenih modelom (Markovljevim lancem). Također, u slučaju uporabe neodgovarajućega dlijeta u bušotini za operacije pročišćavanja i proširenja kanala bušotine pojavile su se razlike između korištenih dlijeta i rezultata dobivenih Markovljevim lancem.

Ključne riječi:
formacija Dashtak; optimizacija dlijeta; litologija; prijelazna matrica; taložni facijes

Authors contribution

Afsaneh Ghaffari Rad (Petroleum Engineer): Analysed the data, managed the whole process and supervised it from the beginning to the end. **Sajjad Negahban** (Assistant Professor): Initialized the idea, collaborated in literature review and participated in the interpretation of the results. **Behzad Tokhmechi** (Associate Professor): Collaborated in the initiation of the idea, data processing and the interpretation of the results. **Hossein Mostafavi** (Petroleum Engineer): Collaborated in the initiation of the idea, data gathering and the interpretation of the results.