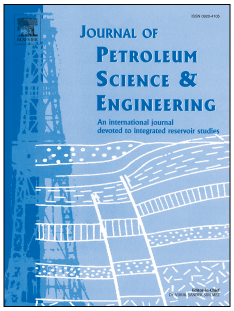

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Rasool Khosravanian, Bernt Sigve Aadnøy

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Closed-Loop Well Construction Optimization (CLWCO) Using Stochastic Approach Under Time Uncertainty

Rasool Khosravanian, Bernt Sigve Aadnøy
Department of Energy and Petroleum Engineering, University of Stavanger, Stavanger, Norway

Abstract:

There is a digital step change taking place in well construction today. More and better data will become available for a vast number of analyses. The well construction process is complicated and includes several hundred parameters. There are many inhouse drilling analytics tools used by service and consulting companies . The objective of this paper is to aim at a complete time optimization and to improve Health, safety and the environment (HSE) in a time-effective way. In this paper we establish and apply a full approach methodology for closed Loop well construction optimization (CLWCO) under time uncertainty.

CLWCO involves six major steps: data gathering ,a work-breakdown structure (WBS) in drilling scenarios , time estimation (budget time &technical time) ,time simulation (MCS&PERT), scenario analysis & optimization and finally updating time model.

CLWCO involves three major steps: optimizing the time plan based on current time knowledge, drilling new wells and collecting time data, finally updating multiple time models based on all of the available data. In the CLWCO step, work breakdown structure (W.B.S), time and controls for new wells are optimized by Monte-Carlo Simulation and program evaluation review technique (PERT) .

This paper goals are to identify and in best case quantify “the value of Mont Carlo simulation and Program Evaluation Review Technique (PERT) in batch & conventional time drilling optimization” in offshore wells for clients or operating company. Batch drilling does not combine professionally with modern techniques yet .we fill this gap by using modern techniques to optimize and enhance drilling work. We evaluate and analysis above-mentioned approach for batch drilling which has become increasingly prevalent in the petroleum industry as large and small investors alike seek to increase their profit margin. The insight of many of these oil and gas companies was to drill and complete wells using new techniques with the desire of considerable reduction in drilling time and cost for the field. when similar hole sections such as 32”,24”,16”,12 ¼” and 8 ½” of different wells were drilled one after the other efficiency and profits would be greatly increased. According to obtained results in closed loop well construction optimization (CLWCO), these methods are successful as it needs less time and cost to drill a lot of wells using the same platform. we simulated a drilling program for the case study of SP field by Monte-Carlo Simulation and program evaluation review technique (PERT) ,at the end we propose the optimum probable time to do future drilling program in SP field .

The time versus depth graph of drilling project show that the improved drilling efficiency for drilling project designed as 11 wells would reduce the total drilling time around 15 % in compare of previous drilling projects in phase SP6,SP7 and SP8 ,totally average drilling time have been improved between 2.5 to 8 days in MCS and PERT simulation technique for each well by using CLWCO.We presented the optimal plan coupling with batch drilling could be implemented in the future phases of SP field, which has resulted in decreasing drilling time to 30 days by using casing-drilling and liner-drilling technology.

Key words: Closed-Loop Well Construction Optimization (CLWCO) , Monte-Carlo Simulation , Program Evaluation Review Technique (PERT) , Casing While Drilling System , Uncertainty

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1.Introduction

Modern drilling and well technology are needed to find time-cost efficient manner in projects. Time has the least amount of flexibility .Managers often cite delivering projects on time as one of their biggest challenges; therefore, Schedule issues are the main reason for conflicts on projects, especially during the second half of projects. Today, drilling company can use the suitable improvements introduced to the batch drilling operation . Real time drilling technologies and equipment utilized to present the success so far, such as new hybrid PDC bit technology in combination with real time drilling techniques ,There has been a major progress in use of advanced hybrid bits, resource optimization through Batch Drilling in offshore drilling. Statoil examined this before at Drilling on SP in 2004 year and has used with batch drilling approach and implement a time-based drilling solution. In this paper, we have plan to improve and optimize drilling time in compare of previous drilling time in SP field .This process is complicated and has a lot of complexities, finally we try to improve ability to develop better drilling plans. It needs closer collaboration between the rig manager, petroleum and drilling engineers working on rig.

A drilling project life cycle is the different of main phases that a project passes through from mobilization to in demobilization . These phases are sequential, and their names and numbers are determined by the drilling management and control needs of the organization or organizations involved in the drilling team project. Drilling Phases are commonly time bounded, with a start and ending or control point. A life cycle can be shown in the below figure within five phases. Drilling project lifecycle can be determined or shaped by the unique aspects of the organization, industry, or technology employed. While every project has a definite start and a definite end, the specific deliverables and activities that take place in between will vary widely with the project. The life cycle provides the basic framework for managing the project, regardless of the specific work involved.

Any EPD contractor companies need to manage drilling operations professionally; therefore, we should develop better procedures and methods for optimizing drilling time of complex wells. The different elements of the workflow are divided into well design, operation planning, mobilization, and operation execution and demobilization phases. Each element targets work breakdown structure too.

Batch drilling approach consist of simultaneous hole drilling of several wells and target to speed up drilling operations and avoid early wear and tear of rig equipment, at first all 26-inch casing of wells were installed. Then the next hole section or phase of the drilling started and so on. batch drilling at the offshore sector including significant decrease in transport operations, an advantage of this method is that materials used for drilling sludge related to each stage of drilling are made simultaneously and will be used in next well. Other advantages of this method are more ease for drilling effective planning and equipment control, reduced transportation and logistics of personnel of drilling service companies because offshore drilling projects have limited logistics capabilities and finally better use of manpower and equipment.

Project Management (PM) is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements (PMBOK, 2013). It is accomplished through the appropriate application and integration of logically grouped project management processes categorized into process groups called Project Life Cycle. A project life cycle is the series of phases that a project passes through from its initiation to closure. These phases are initiating, planning, Executing, Monitoring and Control, and Closure. Project activities within each phase involve interrelated actions characterized by input, tools and techniques, and output. This ensures effective flow of the project throughout its life cycle in an integrated manner called Project Management Processes (PMP).

The integrated project management (IPM) methodology divides the entire project into specific concepts, called Project Management Knowledge Areas, and models each knowledge area separately. PMI has identified ten (10) knowledge areas, which include: integration management, scope management, time management, cost management, quality management, human resource management, communications management, risk management, procurement management, and stakeholder management

In many areas around the world in Deepwater or shallow water, especially the GOM and North Sea daily operational cost of an offshore rig such as semi-submersible or drillship range from $1 million to $1.5 million for the entire project. This terrible cost, as well as increasing concern to exceed stakeholders expectation, has emphasized the necessity for sound project management to ensure that offshore or onshore wells are drilled at optimum possible costs and times since the main objective in all offshore drilling operations is to safely drill useable holes at minimized cost. Most often, only technical aspects of rig operations are thought to influence the number of days spent on location. In a more practical sense, however, both technical and non-technical issues control the success of rig operations; hence, the essential need for a comprehensive professional approach for effective time project delivery.

Advanced Drilling project time and cost management are a complex part of multi-domain expertise that involves drilling engineering, geology, geophysics, HSE, project management, logistics and more. Several activities are carried prior to any drilling operations covering a complete well cycle. Depending on operator's policy, organization of work should typically comprise in different tasks.

Well construction and intervention accounts for typically 40% and often as much as 70% of an oil or gas company’s capital spending. For this and other reasons, that area is widely recognized as the most critical and complex operation to “get right” in the entire oil and gas value chain. Furthermore, sometimes drilling operation are highly complicated , happening in an environment with important HSE risks and often involving an intricate web of interfaces in which ten or more suppliers are working together to deliver a single well. See figure 1.

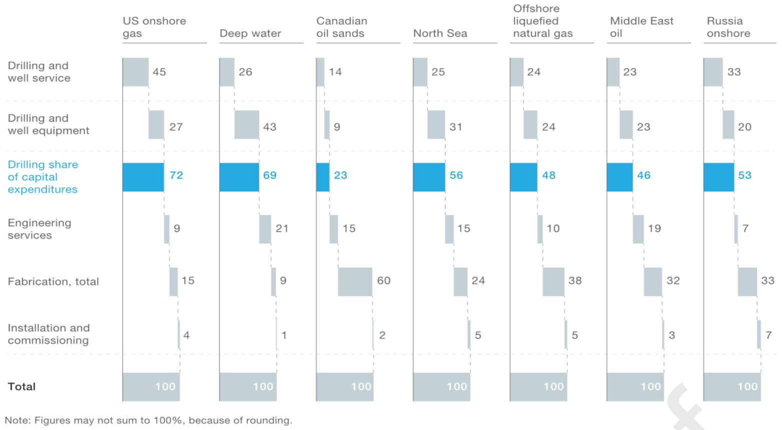


Fig.1–The cost of drilling and completion (Anders Brun and Sanzhar Zharkeshov ,2018)

2.Literature Review

PERT and MCS are broadly established as management scheduling tools in downstream projects in petroleum industry and civil project. There are some publications addressing uncertainties in data and models are established to generate the probabilistic histogram of the time and scheduling of drilling projects but in such cases, these techniques not professionally considered for batch drilling operation yet.We establish and apply a full approach methodology for closed Loop well construction optimization (CLWCO) under time uncertainty. We will use stochastic simulation method for determining total drilling time by using MCS and PERT for first time in this paper .We will use this scheduling tools in drilling operation projects in offshore fields. these techniques make more precise task duration predicates by using mathematical analysis to explain the time uncertainty in projects. The main objective of this paper is to describe the advantage and disadvantage of both the PERT and MCS so rig managers and operating company considering adopting a schedule risk analysis tool are aware of the constraints.

CPM and PERT are good examples of network scheduling techniques (Bhosale et al.,2017). These two methods target to help project managers in controlling , implementing monitoring the progress of all project phases(Chitra & Halder, 2017). The CPM technique formulae all project parameters, includes durations of task, as deterministic values. Given the changing environmental conditions, it is not fully possible to predict future events. CPM techniques used for planning and scheduling for analysis of and the construction of biogas plants. Zareei (2018).

Dolabi et al. (2014) applied the CPM to reach an appropriate schedule for projects and concluded that however the CPM can partially decreasing uncertainties for projects scheduling, but a low change in any task can lead to unrealistic of the scheduled time in the projects. Therefore, the assumption of deterministic time of task in the network is unrealistic results in scheduling the projects and this method and technique includes significant mistake to calculations and results. Approaches based on probabilities and statistics tools such as PERT have been established to solve CPM problems and capable to consider the influence of uncertainty on output realistically. In other words, tasks are stochastic with a certain behavior in the PERT. time of all task has a mean and standard deviation that describe uncertainty in the time analsysis. furthermore, the PERT stochastic networks are used to optimize the project time. In PERT networks, time minimization target to reduce the total completion time of project, if necessary, by allocating extra resources to some project tasks.

Some researchers present the first phase of a multi well in subsea project ,this phase included the setting of the conductor’s pipe for all twenty wells, pipeline bases, manifold piles and fifteen wells drilling operation to various stages of completion. Drilling operation were executed in batches approach to maximize efficiencies and economic value(John D. Hughes,Rod A. Coleman,1995).Stochastic project or PERT-networks was key techniques to explain the stochastic behavior of such networks (Clark, 1962). Monte Carlo simulation has become an attractive statistical-based tool for drilling time well predicting. The method has been used in well time and cost analysis (Williamson et al. 2006; Løberg et al. 2008; Adams et al. 2010).The method has been used for forecasting such as cost and time management in well (Hugh S. Williamson , Steven J. Sawaryn and et al 2006). Monte Carlo simulation can propagate uncertainty from evaluating variables to output realizations required for decision-making (Bratvold and Begg 2010).This paper looks at the experiences of two such batch-drilling projects in Trinidad and Tobago and explores the cost effectiveness of such drilling, in our very complex and uncertain geology. (Craig Boodoo ,Denison Dwarkah and et al 2003).In this paper authors present the drilling optimizations executed in the SP field, which has resulted in one year of saved rig time. they cover the improvements introduced to the drilling process and also the technologies and equipment utilized to achieve the success so far;

such as optimized well trajectories for performance drilling, introduction of PDC bit technology in combination with ultra-high-powered steerable motors, cementing techniques and drilling fluid optimization. This article looks at the experiences of two phases six to eight such batch-drilling projects in SP field too that implementing by Statoil Company and explores the cost effectiveness of such drilling, in very complex and uncertain geology(Brage Johannessen , Jostein Vestvik ,2005) .The cost simulation method proposed an appropriate decision tool for completing evaluating construction cost and uncertainties based on the project managers experience. This paper present platform for Monte Carlo simulation approach with assessment of stochastic simulation and input PDF selection via hypothesis testing, and specification of correlations between simulated variates (Jui-Sheng Chou 2011).This paper establishes a stochastic analysis engine, which was tested and validated by field data. paper also present graphical tool for managing our projects with probabilistic tasks. (DanTrietsch , Kenneth R.Baker 2012).This paper present a stochastic duration-cost-quality tradeoff problem using three meta heuristic algorithm includes fuzzy memetic, nondominated, sorting optimization algorithm. (David A.Wood ,2017).

In October 2003, development drilling of the ConocoPhillips Indonesia Inc.Ltd operated Belanak Field commenced when the platform rig was rigged up over a previously installed twenty-four slot platform. Drilling commenced with the objective of drilling and completing ten slant directional wells and six horizontal wells. they utilize a full batch drilling concept in order to minimize costs. (A. Septiantoro, J. Bujnoch and et al ,2005).Farhad Habibi presents a step by step strategy for exact predation of time and cost of projects using the Project Evaluation and Review Technique (PERT) and expert views as fuzzy numbers. (Farhad Habibi, Omid Taghipour Birgani and et al ,2018).

Casing While Drilling (CwD) were executed successfully at 2 exploration wells in Q3 2011 by implementing Vertical-CwD (VCwD). First trial of VCwD was run only in surface section with a simple cutters casing shoe mounted on the end of a casing string. (H.Taufiqurrachman, and E.Tanjung, and et al ,2013).Casing while Drilling (CwD) was recognized as the most cost-effective mitigation system against the risk of stuck-pipe, continuous back-reaming and unplanned casing setting depths in such highly reactive, time-dependent shale. In consequence, current portfolio of deep and ultra-deep wells in Northern Oman mandates CwD as the new conventional approach for drilling large-diameter surface sections, instead of the drill-pipe method(Sánchez, F.,; Smith, M., , and et al ,2011).On three infill wells, the intermediate 12 1/4-in. intervals were drilled and cased with casing-while-drilling (CWD) technology with a rotary-steerable system (RSS). (Kyle S. Graves,Delimar C. Herrera,2013).Retrievable Casing Drilling tools have been used to drill more than 600,000 ft of hole in over 120 wells encompassing six casing sizes ranging from 4-1/2” to 13-3/8” and reaching inclinations of 90.This drilling system is composed of downhole and surface components that provide the ability to use normal oil field casing as the drill string so that the well is simultaneously drilled and cased. The casing is rotated from the surface for all operations except slide drilling with a motor and bent housing assembly for oriented directional work. (Tommy Warren, Robert Tessari,2004).

The template of this paper is designed as follows. At first, we provide the introduction, the literature review and the innovation of paper. The second section defined the two method and all detail to its running in simulation. The third section present a giant offshore case study in order to simulate how to implement the proposed methods and analyzing its efficiency with other similar methods. The fourth Section calculated and plot results of the case study for 11 wells, and finally, presents discussion and results.

3.Problem Statement

There is a digital twin change taking place in smart well construction today. More and precise data will become generate in real time drilling for a vast number of analyses. Wellbore stability optimization in digital well construction process is complicated matters and includes several key parameters. Today the oil service company provides partial optimization of various elements. Here Six steps to closed Loop well construction optimization (CLWCO) under time uncertainty as shown in figure 2.

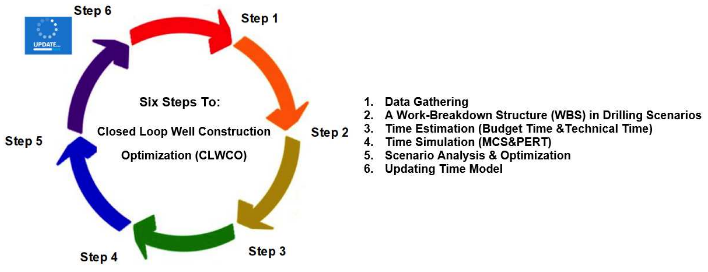


Figure 2. closed Loop well construction optimization (CLWCO) steps

3.1.What is Batch Drilling?

Batch drilling involves drilling in succession the same hole section in each well on a given platform, rather than drilling each well individually. Once the same section is drilled in every well on the platform, then the next section is drilled on each well in succession. As each section is drilled, the rig crew learns the characteristics of that section from the first well and applies this knowledge when drilling the same section on subsequent wells.

Batch drilling allows the rig to use the same mud system, bit sizes, drilling tools and casing size for all the wells at one time. This improves drilling efficiency, equipment handling and logistics, saving time and money on expensive offshore drilling operations.

stochastic input variables can be simulated with numerous kinds of probability functions such as normal, U shaped, lognormal ,uniform, Rayleigh, cosine , half cosine and so on. A real distribution can be established if there are satisfactory geomechanics data. If not drilling data available for different time in simulation , we will assume a probabilistic distribution with best fits of the data set.

The selection of a PDF graph is fundamental in simulation and may various choices , depending on data accessibility, data type and data quality . Drilling is often using the normal distribution. in the number of datasets with evidence of mode or most probable value, it is suggested that normal or triangular PDF histogram be applied. In the case of small datasets from which unrepresentative sample points of the population have been eliminated through exact analyses, generally uniforms PDF graph are the favorite choice. If type of PDF graph is recognized, then the distribution is formulated. For example, the normal distribution is simulated by two parameters, its mean (μ) and standard deviation(σ).The uniform probability density function is determined by its minimum and maximum values, while the triangular distribution is defined by its minimum value a, maximum values b , peak value c. Measures dispersion of data, variance (σ2), σ and P5 to P95 are useful parameters present the extent to which a given data set spread around the (μ) or highest probability P50 for a symmetric distribution.

3.2. Monte Carlo Simulations

The Monte Carlo simulations used in this paper is based on procedure defined by Williamson et al. (2006). it has four steps.

1-select the time model in drilling operation includes batch or conventional drilling .

2-perform data gathering and determine lower and upper limit for input variable: The time parameters (with normal and random variables) with base case uncertainties are shown in Table 1. This initial input information is gathered from a gas field in the SP.

3- Select distribution for input variables: All the inputs are assigned a stochastic distribution

4-Perform output generation and interpretation of the results

By using a range of possible values, instead of a single guess, a realistic span can be created. When a model is based on ranges of estimates, the output of the Model will also be in range of estimation. The Monte Carlo simulation steps and Workflow of batch and conventional are illustrated in Figure 3.

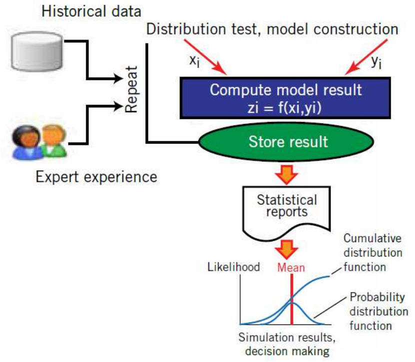


Fig.3–Phases of a typical Monte Carlo Simulation in this paper(by authors)

Normal distribution**:**Say X has a Normal distribution if

$$\phi(x)=\frac{1}{\sqrt{2\pi}*\sigma}*e^{(-1/2(\frac{x-\mu}{\sigma})^{2})} \qquad (1)$$

It is the important distribution in statistic because it fits many natural phenomena. The normal distribution is useful because of the central limit theorm.in its most general form under some conditions (which include finite variance), it states that averages of random variables independently drawn from independent distribution converge in distribution to the normal, that is, become normally distribution when the number of random variables is sufficiently large. Cumulative distribution function is:

$$\phi(x) = \frac{1}{2}[1 + erf(\frac{x-\mu}{\sigma * \sqrt{2}})] \tag{2}$$

Figure (4) shows the schematic of normal distribution and cumulative distribution.

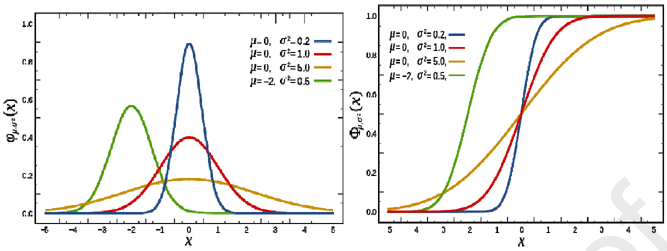


Fig.4– Left: normal distribution and right: cumulative distribution

Beta Distribution:

The Beta distribution is a continuous probability distribution defined by four parameters in figure 5: The random variable X with probability density function is a beta random variable with parameters α > 0 and β > 0.

Different parameters in Beta distribution are as follow:

Parameter	Description	Characteristics
Min	Minimum Value	Any number -∞ to ∞
Max	Maximum Value	Any number -∞ to ∞
Alpha (α)	Shape Factor	Must be > 0
Beta (β)	Shape Factor	Must be > 0

$$f(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\cdot\Gamma(\beta)} x^{\alpha-1}(1-x)^{\beta-1}, \text{ for } x \text{ in } [0, 1] \tag{3}$$

$$\mu = E(X) = \frac{\alpha}{\alpha+\beta}$$
$$\sigma^2 = V(X) = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)} \tag{4}$$

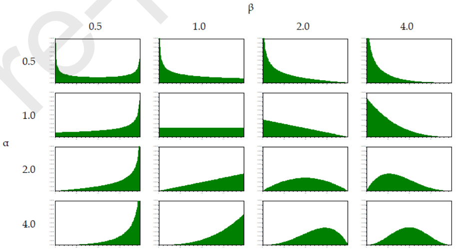


Fig.5– Different Beta Distribution

Beta distribution is popular among simulation modelers because it can take on a wide variety of shapes, as shown in the graphs above. The Beta can look similar to almost any of the important continuous distributions, including Triangular, Uniform, Exponential, Normal, Lognormal, and Gamma. For this reason, the Beta distribution is used extensively in PERT, CPM and other project planning/control systems to describe the time to completion of a task.

3.3.Closed Loop Well Construction Optimization (CLWCO) Procedure

We consider the Closed-Loop Well Construction Optimization problem where decisions such as the optimum time , drilling methods, simulation tools, and technology of new wells are to be determined. The term ‘decision variables’ is used to refer to the associated optimization variables. The drilling time plan is initially described by a budget time, and the true time model is with high uncertainty. New wells or hole section are to be drilled sequentially as is generally the case in drilling operation .

Optimization include 3 approaches :

1.Drilling Techniques: Conventional Drilling or Batch Drilling

2.Tools Includes MCS and PERT Simulation

3.Technology Includes Casing While Drilling System

The CLWCO optimization procedure determines analyzing an optimization approach to find the decision variables for new and existing wells by implementing time history matching based on all available drilling data as shown in figure 6 and 7.

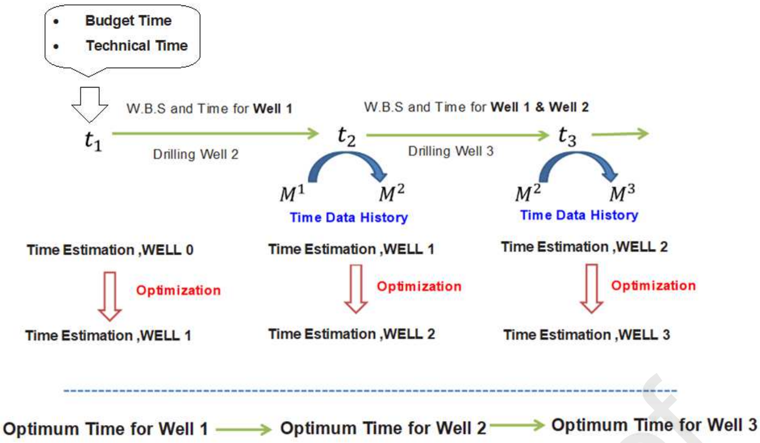


Figure 6—Time Optimization procedure

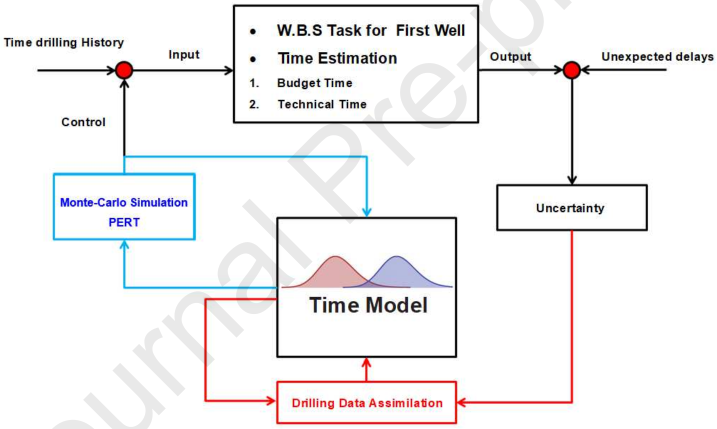


Figure 7—Schematic and notation for the Closed-Loop Well Construction Optimization (CLWCO) (by authors)

The expected time shall be determined based on statistical simulations, taking into account experience from relevant previous wells and a risk assessment of the activities. The computer excel program for CLWCO should be used for this purpose . In program you select relevant previous time data and history , and program then use these to calculate an expected time, P50. The probability distribution used is normal. See figure 8 and more datil about technical and budget time present in table 13 in the appendix.

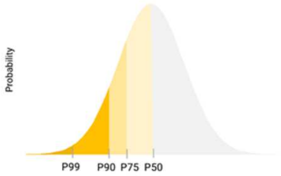


Fig.8– The expected time distributions for W.B.S tasks in drilling operation

In this part, we describe our simulation approach and the assumptions we make to implement it:

1. Well path types are the same for different wells.
2. Inclinations are the same for different wells.
3. We don't use RSS for drilling operation .
4. Total measure depths are the same for different wells.
5. Rig crews and service company are available, this can affect the time
6. An operation is not stopped or delayed because of bad weather (WOW) ,this can affect the time.

4. A Work-Breakdown Structure (WBS) in Drilling Scenarios

The followings are a summary description of the general well program for drilling and casing in any typical well. A general stratigraphic column is included as follows in figure 9. The figure 10 below gives the pore pressure predication and tops thickness and lithological description of the formations to be drilled in the typical well.

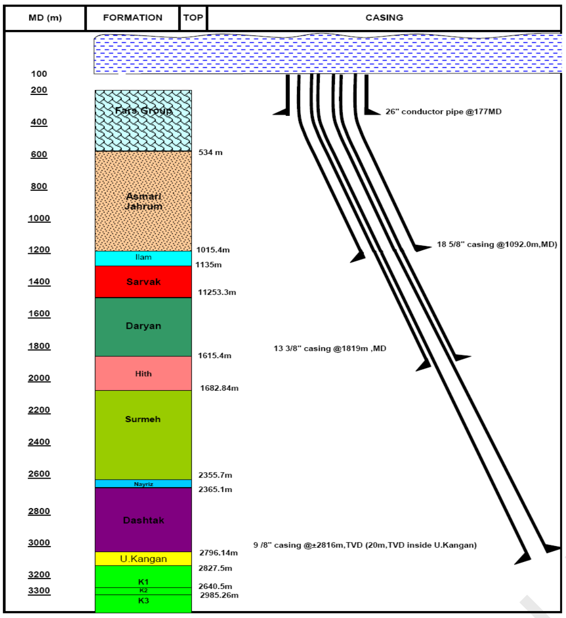


Fig.9 – Well Architecture

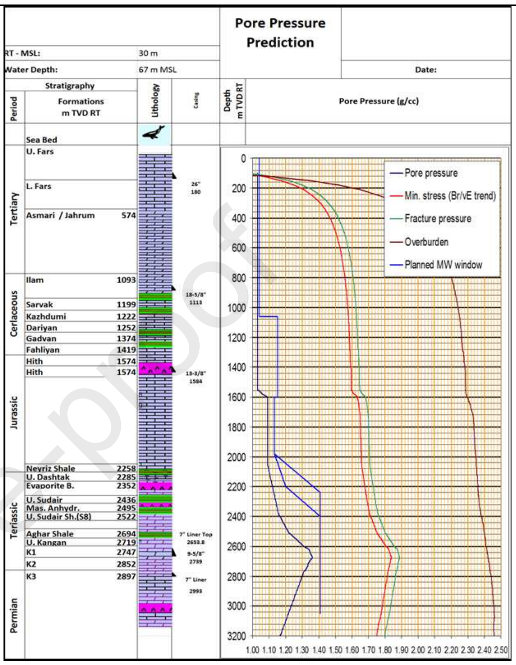


Fig.10 – Pore pressure predication

4.1.Definition of Sample Well

Drilling Operations – 24" Hole Section (Surface Casing)

Primary objective is to shutoff/seal the highly fractured dolomitic Jahrum Formation. The planned setting depth for the 18-5/8" casing will be +/-20 m TVD into the Ilam Formation. Two BHA's and MWD directional tool will be used to drill this hole section.

Drilling Hazards

Water Influx / H2S,Stuck Pipe, BHA Packed Off, Excessive Reaming ,Loss Circulation,Effect on Drilling Parameters

Bit Balling,Collapse Casing

Drilling Operations – 16" Hole Section (Intermediate Casing)

The main objective of the 13-3/8" intermediate casing section is to isolate the oil bearing Dariyah Formation and the potentially weak Fahliyan Formation. The casing shoe will be set +/-20 m TVD into the Hith anhydrite Formation.

Drilling Hazards

Tight Hole,Bit Balling and Gumbo,Drill string twist off

Sulfurous Water Flow,Loss Circulation,Low ROP,Stuck Casing

Drilling Operations – 12-1/4" Hole Section (Production Casings No. 1 and 2)

The main objective of the 10 3/4 " X 9-5/8" production casing section is to isolate/seal off the geo-pressured or unstable fractured shale sections found in the Aghar and Upper/Lower Sudair shales. Two BHA's will be used to drill this hole section with one being a slim hole assembly which will allow optimum hole cleaning while at the same time limiting loss circulation as a result of increased mud weight. The casing shoe will be set +/- 20 m TVD into the Upper Kangan Formation.

Drilling Hazards

Stuck Pipe (tight hole),Differental Pressure (Stuck Pipe)

Drillstring twist off and or Wash Outs ,Salt Water Flow (Over pressured Sudair-Dashtak Formation),Loss Circulation,Low ROP

Drilling Operations – 8-1/2" Hole Section (Production Liner)

The 8-1/2” hole will be drilled to 30 m MD after target point and target point is the lowerest perforation point which is 30 m minimum above the estimated GWC. However, the GW C varies across the field, and will be given f or each individual well. The Section will be completed using cemented 7” liner.

Drilling Hazards H2S, Well Control, Differential Sticking,Losses ,Packing off, Potential Hole Swabbing

A high-level review was conducted of the well example for A work-breakdown structure (WBS) and core areas identified where the application of advanced techniques and technology could have significant potential time saving in drilling operation .Following Table 2 in the appendix , figure 11 present more detail in drilling task summary at the designated well depths:

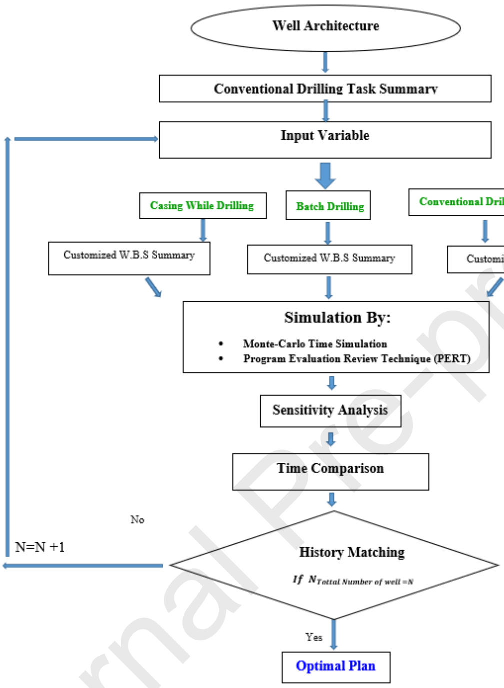


Figure 11—Main optimization loop

5. Optimization Model (MCS&PERT)

5.1.Batch and Conventional Drilling by Monte Carlo simulation

Each platform from the conductor pipe to the liner will be performed using batch operations that is to say the surface casing will be run and cemented in place before the intermediate casing sections will be started until all wells are completed. This operation will also be continued for completion program for each platform. The following figure 12 and table 2 presented the drilling project with 15 platform slots that 1 well is appraisal well and 11 wells are productions well . each well have 5 hole sections and at first all of 24” Hole Section (Surface Casing) for 11 wells drilled after that 16” Hole Section (Intermediate Casing) for all wells drilled . one appraisal wells will be drilled one well per phase and be located on slot no 8 of platform to better define the reservoir top, geometry, and petrophysical properties distribution, lateral and vertical continuity, gas water contact depth, as well as estimation of productivity and reservoir fluids characteristics thorough Logging, Coring, and Testing.

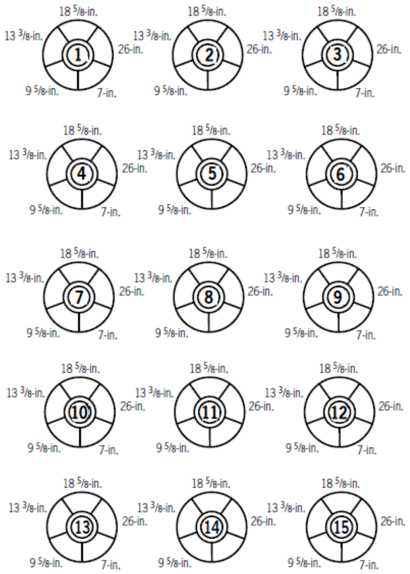
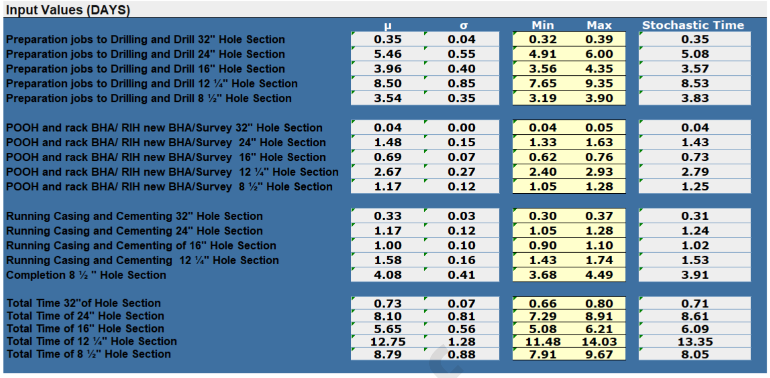
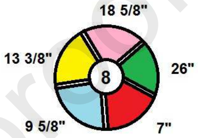


Fig.12 – Platform slot for 11 wells in this paper

Table 2–Input Variable for simulation



Input Values (DAYS)	μ	σ	Min	Max	Stochastic Time
Preparation jobs to Drilling and Drill 32" Hole Section	0.35	0.04	0.32	0.39	0.35
Preparation jobs to Drilling and Drill 24" Hole Section	5.46	0.55	4.91	6.00	5.08
Preparation jobs to Drilling and Drill 16" Hole Section	3.96	0.40	3.56	4.35	3.57
Preparation jobs to Drilling and Drill 12 ¼" Hole Section	8.50	0.85	7.65	9.35	8.53
Preparation jobs to Drilling and Drill 8 ½" Hole Section	3.54	0.35	3.19	3.90	3.83
POOH and rack BHA/ RIH new BHA/Survey 32" Hole Section	0.04	0.00	0.04	0.05	0.04
POOH and rack BHA/ RIH new BHA/Survey 24" Hole Section	1.48	0.15	1.33	1.63	1.43
POOH and rack BHA/ RIH new BHA/Survey 16" Hole Section	0.69	0.07	0.62	0.76	0.73
POOH and rack BHA/ RIH new BHA/Survey 12 ¼" Hole Section	2.67	0.27	2.40	2.93	2.79
POOH and rack BHA/ RIH new BHA/Survey 8 ½" Hole Section	1.17	0.12	1.05	1.28	1.25
Running Casing and Cementing 32" Hole Section	0.33	0.03	0.30	0.37	0.31
Running Casing and Cementing 24" Hole Section	1.17	0.12	1.05	1.28	1.24
Running Casing and Cementing of 16" Hole Section	1.00	0.10	0.90	1.10	1.02
Running Casing and Cementing 12 ¼" Hole Section	1.58	0.16	1.43	1.74	1.53
Completion 8 ½ " Hole Section	4.08	0.41	3.68	4.49	3.91
Total Time 32"of Hole Section	0.73	0.07	0.66	0.80	0.71
Total Time of 24" Hole Section	8.10	0.81	7.29	8.91	8.61
Total Time of 16" Hole Section	5.65	0.56	5.08	6.21	6.09
Total Time of 12 ¼" Hole Section	12.75	1.28	11.48	14.03	13.35
Total Time of 8 ½" Hole Section	8.79	0.88	7.91	9.67	8.05



Different hole section for each well(by authors)

we assume cantilever of jack up rig moving between different slot are in very short time and therefore it is preferring the sequence we selected for first hole section , will be the reverse sequence for next hole section too. we can consider the table 3 (in the appendix)drilling sequencing in each hole section for 11 wells. The following figure 13 show the drilling sequence for 11 well at simulation in this paper the 16-inch hole section of well 11 is under drilling

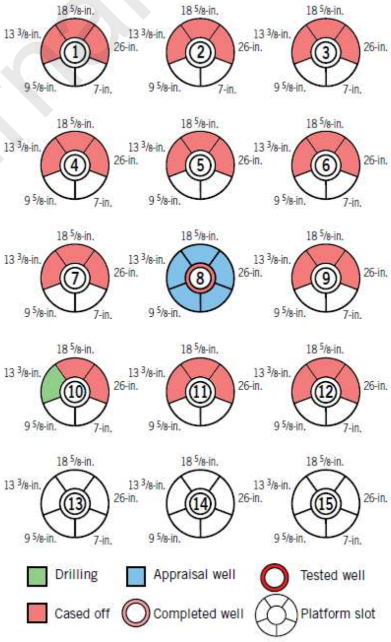


Fig.13– Monte-Carlo time simulation for five-hole section(by authors)

The drilling time of different hole sections are continuous probability densities as following table 4 :

Table 4 – Distribution of input variable

Description	Distribution	Percentage Uncertainty (± %)
Total Drilling Time of 32” section	Normal	10

Total Drilling Time of 24” section	Normal	10
Total Drilling Time of 16” section	Normal	10
Total Drilling Time of 12 ¼” section	Normal	10
Total Drilling Time of 8 ½” section	Normal	10

For 5 sections we presented time plot simulation which are shown in figures 17. Also, we can find the average time needed for drilling each section which is obtained by enormous repetition (More than 20000 times for each section) of the data in Monte Carlo algorithm. To explain the ability and capability of the MCS procedure in this paper , we provide two approaches taken from SPX field data. The simulated real data in the columns belong to SP fields, which represented the input PDF in table 4 and 5 , linked PDF data with different drilling section according to real date . The outputs and histogram from this Excel Programming now show the many possible scenario, which can be referred to the multivariate statistical analysis. The data in the output column can now be further evaluated. Some outputs analysis includes:

- planning a frequency distribution for input data such as time drilling of each section using the normal PDF function.
- Analysis the shape of the distribution base on Visual control of the frequency graph.
- Presenting of descriptive statistics such as μ ,variance, standard deviation, kurtosis and skewness by using predefined functions.
- Useful method is to copy and paste the results into another column and sort time data from smallest to largest, exclude the lowest 2.5% and highest 2.5% of values to give a 95% coverage interval of drilling time, percentile function can be applied to decide on total drilling time in figure 14.

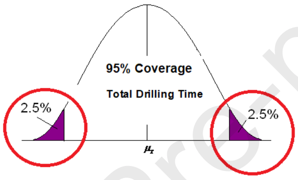
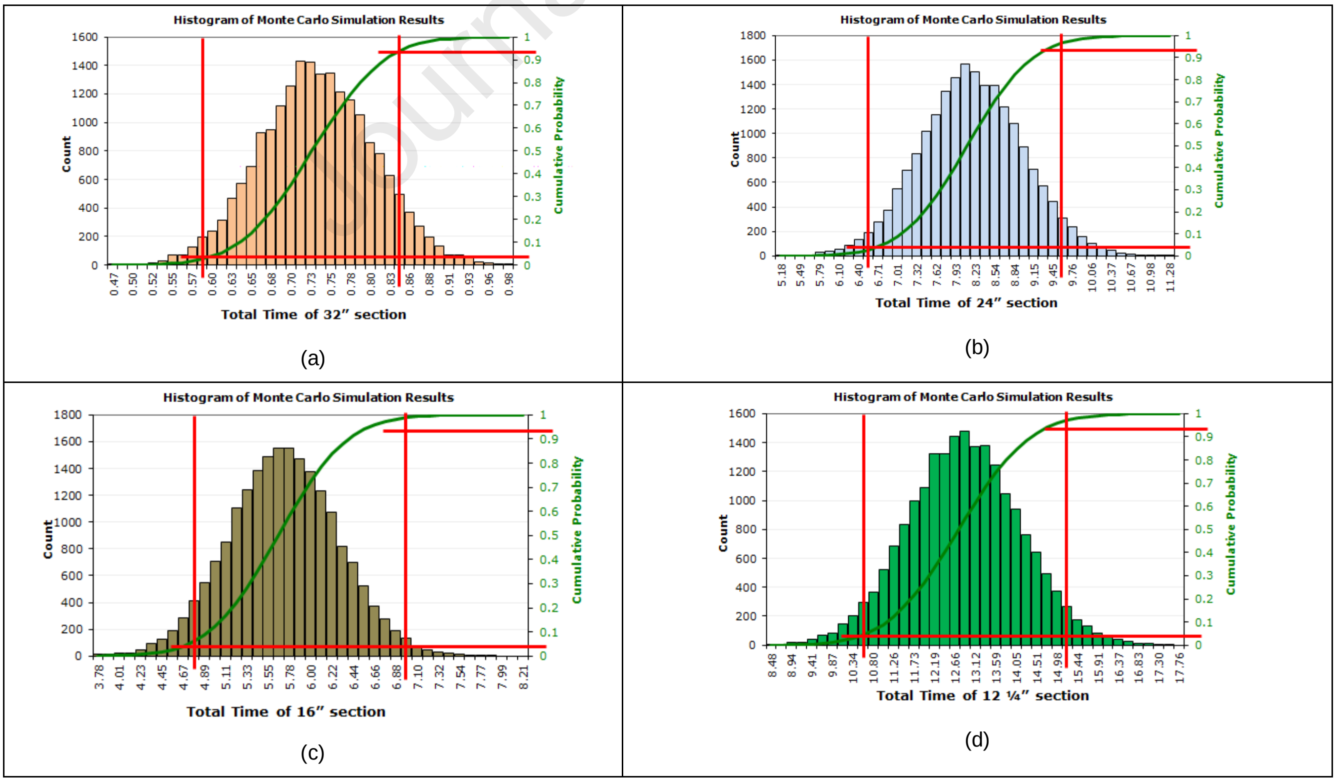


Figure14. Calculation of the total drilling time interval for batch and conventional in this paper (by authors)

- Skewness and kurtosis: these statistics could prepare additional support for total drilling time when reflecting the PDF distribution shape of the time, its closeness to normality or when determining the drilling time interval.

We will run our simulation with 20000 stochastic random data generation with uncertainty in table 4 for each section as following figure 15:

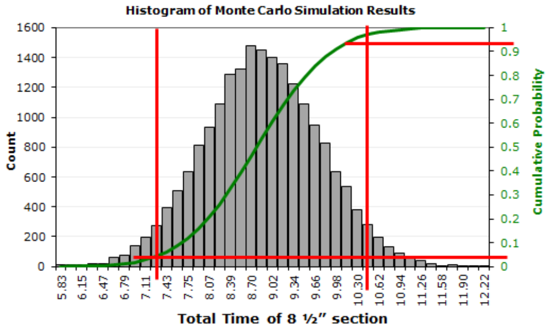


(a)

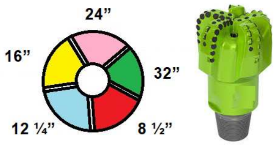
(b)

(c)

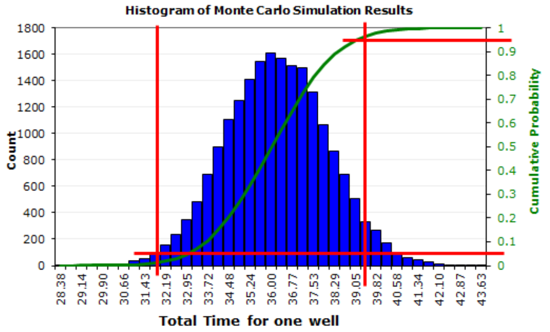
(d)

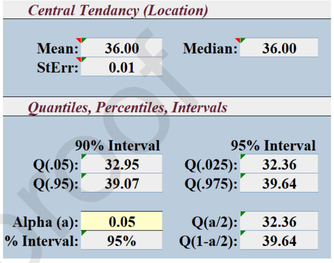


(e)



(g)





Central Tendancy (Location)

Mean:	36.00	Median:	36.00
StErr:	0.01		

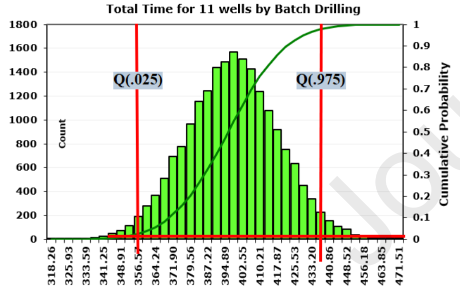
Quantiles, Percentiles, Intervals

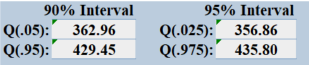
90% Interval		95% Interval	
Q(.05):	32.95	Q(.025):	32.36
Q(.95):	39.07	Q(.975):	39.64
Alpha (a):	0.05	Q(a/2):	32.36
% Interval:	95%	Q(1-a/2):	39.64

(f)

Fig.15 –Monte-Carlo time simulation for five-hole section (a) 32" Hole section .(b) 24" Hole section. (c) 16" Hole section .(d) 12 ¼" Hole section. (e) 8 ½" Hole section . (f) Total time of drilling per well with statistic summary . (g) Different hole bit size(by authors)

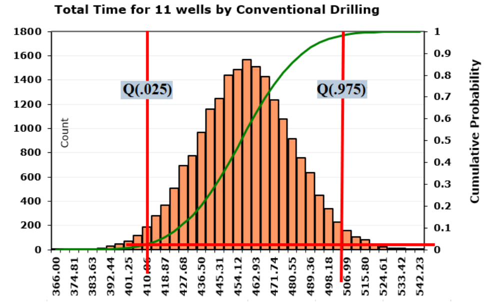
Drilling Time Comparison: In this part we present total time for 11 wells in SP drilling project with using two approaches including batch drilling and conventional drilling ,an overall time for 11 wells comparison would be the most natural approach to start, however in this case study that we calculated mean of total time 396 days for batch drilling and mean of 455 days for conventional drilling in figure 16 and 17.

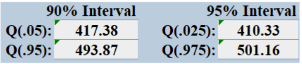




90% Interval		95% Interval	
Q(.05):	362.96	Q(.025):	356.86
Q(.95):	429.45	Q(.975):	435.80

Fig.16 –Monte-Carlo time simulation for 11 Wells in batch drilling projects(by authors)





90% Interval		95% Interval	
Q(.05):	417.38	Q(.025):	410.33
Q(.95):	493.87	Q(.975):	501.16

Fig.17 –Monte-Carlo time simulation for 11 Wells in conventional drilling projects(by authors)

Summary multivariate statistics present useful perspective of data and are particularly important for comparing total drilling time statistics in table 4.There are three main category of summary statistics present in this paper include the following concepts :

1. Central tendency including mean, standard error and the median.
2. Spread including Q5, Q10, Q50, Q75 and Q95.
3. Shape including Skewness and kurtosis.

The lowest 2.5% PDF and highest 2.5% PDF of total drilling time of 11 wells to give a 95% coverage interval of time for batch drilling case is between 356.77 days and 436.43 days in Figure.

The lowest 2.5% PDF and highest 2.5% PDF of total drilling time of 11 wells to give a 95% coverage interval of time for conventional drilling case is between 409.24 days and 501 days in Figure.

Drilling Time vs. Depth: we present the time versus depth for two approaches including batch drilling and conventional drilling. 11 wells overall time comparison would be the most natural approach to start, that will show 15 % time saving using batch drilling in figure 18 (green circle).

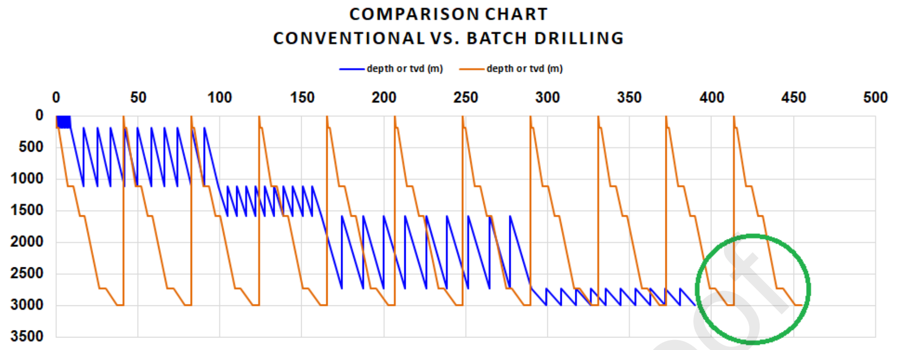


Fig.18–Comparison chart of batch drilling and conventional drilling(by authors)

The practical results of batch drilling approach imply that due to the gained comprehensive knowledge by driller team, in drilling the same operation in different wells on the same hole section repeatedly, driller team will automatically increase the efficiency and performance of the drilling operation. In this approach, the same drilling operations are implemented, and the well design is continuously optimized by driller team. The batch effect should be continuous updating information from different hole section for next hole section will be applied. The figures 18 was identified as a 15.7%-time reduction on the table 5 work breakdown structure (WBS) of batch drilling operation in the appendix.

5.2. Batch and Conventional Drilling by PERT

Using time project controlling tools play a main role in all phases of a drilling project in engineering, procurement, and drilling.This paper will prepare a comprehensive understanding of the most common project management tools used (MCS, GANTT charts, PERT analysis, etc.). using of such tools will go a long way to enabling us to manage our project successfully.

One of significant project time management technique is the PERT. This analysis technique is used when there is an upper degree of uncertainty about the individual activity duration estimates. This paper established another method of the using of the probability distribution methods. This is method of the time control of the project on the example of PERT methods . A peculiarity of PERT is the list of all or the definite activity time probability for the counting of all project time, this technique uses three experts mentioned:

1. Optimistic – activity couldn`t be completed faster than ti opt
2. Pessimistic – activity couldn`t be completed slowly than ti pes
3. Most likely (normal) – most likely time will take ti norm

After estimation three values by planner, then it is possible to calculate the expected activity time tie with below equation:

$$t_{ie} = \frac{t_{i\,opt}+4t_{i\,nor}+t_{i\,pess}}{6} \qquad (5)$$

where: ti opt – the minimum value, when it is considering that all task covering the target time or is made earlier

ti norm – the time value, when it is considering that everything is normal.

ti pess – the maximum value, when it is considering that every task does not meet target time (excluding of the huge catastrophe)

The degree of indeterminacy of activity time estimate may be shown by the dispersion:

$$\sigma_i^2 = \left(\frac{t_{pess}-t_{opt}}{6}\right)^2 \qquad (6)$$

PERT allows to get the normal dispersion of the project time planning distribution; which mode is according to the expected activity time. The SD of PDF curve should be calculated to determine the probability of completion of the drilling project in time, which is differing from the expected. It compute the stage of the indeterminacy for the whole project:

$$\sigma_{Te} = \sqrt{\sum \sigma_i^2} \quad (7)$$

This equation considers only activity dispersions, which determine the critical path method.

Base on the statistic theory, project completion probability in the interval from (Te-σTe , Te+σTe) is 68.27 %, project completion probability in the interval from (Te-3σTe , Te+3σTe) is 99.73 % (Fig.19).

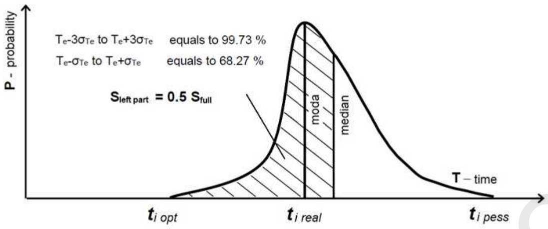


Fig.19–The frequency probability curve of the duration of each activity

5.2.1.Critical Path Algorithm

For large projects there are many paths .Need an algorithm to identify the CP efficiently .Develop information about each task in context of the overall project

1. Start time (S)
2. For each job: Earliest Start (ES)
3. Earliest start time of a job if all its predecessors start at ES
4. Job duration: t
5. Earliest Finish (EF)=(ES)+t

Finish time (F) – earliest finish time of the overall project ,Show CP algorithm using project graph as follow

1. Mark the value of S to left and right of Start
2. Consider any new unmarked job, all of whose predecessors have been marked. Mark to the left of the new job the largest number to the right of its immediate predecessors: (ES)
3. Add to ES the job time t and mark result to the right (EF)
4. Stop when Finish has been reached

Late Finish (LF) - latest time a job can be finished, without delaying the project beyond its target time (T) Late Start: LS = LF-t , Some tasks have ES=LS therefore no slack .Total Slack of a task TS=LS-ES and Maximum amount of time a task may be delayed beyond its early start without delaying project completion .Slack time is precious … managerial freedom, don't squander it unnecessarily e.g. resource, work load smoothing .When T=F then all critical tasks have TS=0 ,At least one path from Start to Finish with critical jobs only .When T>F, then all critical jobs have TS=T-F .Free Slack (FS) is the amount a job can be delayed without delaying the Early Start (ES) of any other job. always we have FS<=TS

To determine the critical path, we need to define the following quantities for each task in the project network in figure 20 .

1. ES: the earliest time an activity can begin without violation of immediate predecessor requirements.
2. EF: the earliest time at which an activity can end.
3. LS: the latest time an activity can begin without delaying the entire project.
4. LF: the latest time an activity can end without delaying the entire project.

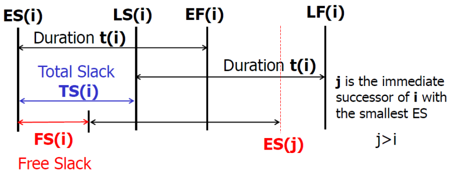


Fig.20–Task Times Detail - Task i

The following examples are concerning the drilling time comparison of batch and conventional operation drilling with PERT techniques .On the basis of beta function and critical path methods calculation , it is possible to estimate the total time drilling in batch and conventional drilling , which will be the most probable time for drilling on each hole section of 11 wells. List all drilling tasks with Identifying symbol (tag, ID number) ,Task description ,Immediate prerequisite jobs and Expected task duration were presented in a table 5 in the appendix.

Table 6 – Lower and Upper Limit for WBS and time estimation

Description	Optimistic (a)	Most likely (m)	Pessimistic (b)	Distribution type
Preparation jobs to Drilling and Drill 32" Hole Section	0.32	0.35	0.39	PERT-beta
Preparation jobs to Drilling and Drill 24" Hole Section	4.91	5.46	6.00	PERT-beta
Preparation jobs to Drilling and Drill 16" Hole Section	3.56	3.96	4.35	PERT-beta
Preparation jobs to Drilling and Drill 12 ¼" Hole Section	7.65	8.50	9.35	PERT-beta
Preparation jobs to Drilling and Drill 8 ½" Hole Section	3.19	3.54	3.90	PERT-beta
POOH and rack BHA/ RIH new BHA/Survey 32" Hole Section	0.04	0.04	0.05	PERT-beta
POOH and rack BHA/ RIH new BHA/Survey 24" Hole Section	1.33	1.48	1.63	PERT-beta
POOH and rack BHA/ RIH new BHA/Survey 16" Hole Section	0.62	0.69	0.76	PERT-beta
POOH and rack BHA/ RIH new BHA/Survey 12 ¼" Hole Section	2.40	2.67	2.93	PERT-beta
POOH and rack BHA/ RIH new BHA/Survey 8 ½" Hole Section	1.05	1.17	1.28	PERT-beta
Running Casing and Cementing 32" Hole Section	0.33	0.30	0.37	PERT-beta
Running Casing and Cementing 24" Hole Section	1.17	1.05	1.28	PERT-beta
Running Casing and Cementing of 16" Hole Section	1.00	0.90	1.10	PERT-beta
Running Casing and Cementing 12 ¼" Hole Section	1.58	1.43	1.74	PERT-beta
Completion 8 ½ " Hole Section	4.08	3.68	4.49	PERT-beta

6. Sensitivity Analysis

Comparison of the Monte Carlo simulation results with the PERT results for batch are in conventional drilling were presented in the following tables 7 , 8 and 9 .The Monte Carlo simulation and the PERT prediction is approximately the same and these two simulations have good correlation in total drilling time .

Table 7–Summary of Monte Carlo simulation for batch drilling

Monte Carlo Probability	Duration
Q(.05)	362.96
Q(.25)	382.22
Q(.75)	409.77
Q(.975)	435.86

Table 8 – Summary of Monte Carlo simulation for conventional drilling

Monte Carlo Probability	Duration
Q(.05)	417.22
Q(.25)	439.54
Q(.75)	471.24
Q(.975)	501

Table 9–Base case of PERT for batch drilling and conventional

Description	Distribution Type	EF
Base Case (Conventional drilling)	PERT-beta	445.5
Base Case (Batch drilling)	PERT-beta	385

Data generated by measurements or simulations are affected by uncertainty. Important sources of uncertainty include the measurement process, parameter selection, as well as simulations with finite precision. We consider the six case where the input data is modeled with different Uncertainty in time Estimation in the table 10 and 11 . We perform a time assessment of the sensitivity analysis on six cases, show the results of on the batch and conventional drilling case study for total time drilling by PERT simulation data.

Table 10 – Sensitivity analysis of PERT for batch drilling

Description	Optimistic (a)	Most likely (m)	Pessimistic (b)	Distribution type	EF
Base case	**a**	**m**	**b**	**PERT-beta**	358
Sensitivity Analysis (1)	a − 10%	m	b− 10%	PERT-beta	359
Sensitivity Analysis (2)	a + 10%	m	b+ 10%	PERT-beta	411
Sensitivity Analysis (3)	a − 10%	0,9 m	b− 10%	PERT-beta	346
Sensitivity Analysis (4)	a + 10%	0,9 m	b+ 10%	PERT-beta	398

Sensitivity Analysis (5)	a − 10%	1.1m	b− 10%	PERT-beta	372
Sensitivity Analysis (6)	a + 10%	1.1m	b+ 10%	PERT-beta	424

Table 11 – Sensitivity analysis of PERT for conventional drilling

Description	Optimistic (a)	Most likely (m)	Pessimistic (b)	Distribution type	EF
Base case	**a**	**m**	**b**	**PERT-beta**	445.5
Sensitivity Analysis (1)	a − 10%	m	b− 10%	PERT-beta	416
Sensitivity Analysis (2)	a + 10%	m	b+ 10%	PERT-beta	475
Sensitivity Analysis (3)	a − 10%	0,9 m	b− 10%	PERT-beta	401
Sensitivity Analysis (4)	a + 10%	0,9 m	b+ 10%	PERT-beta	460
Sensitivity Analysis (5)	a − 10%	1.1m	b− 10%	PERT-beta	431
Sensitivity Analysis (6)	a + 10%	1.1m	b+ 10%	PERT-beta	490

6.1.Casing While Drilling

Three main types of CwD in figure 21, which is determined by the configuration and operation of the drill, are as follows.

1. **Non-Retrievable System:** the system is made up of a drillable bit or drill shoe, a casing string, and a casing drive system. The drill shoe is fitted securely to the bottom of the casing string; the latter is rotated by a power swivel which is hooked up to the drive system. This system only offers a limited number of options- it can only drill in a straight hole, and to a pre-determined depth
2. **Retrievable BHA System** :The retrievable casing while drilling BHA system strikes a balance between conventional drilling tools and CwD. The main advantage of this system is that it can be steered and used with both conventional measured while drilling (MWD) and logging while drilling (LWD) tools.
3. **Drilling with Liner Systems** :Drilling with Liner (DwL) works in much the same way as the previous two systems, except it does not involve the use of a casing drive system. The liner hanger setting tool is connected to the drill pipe, and then attaches to the power swivel at surface. There are three sub-types of this system: non-retrievable, wireline retrievable and drill pipe retrievable.

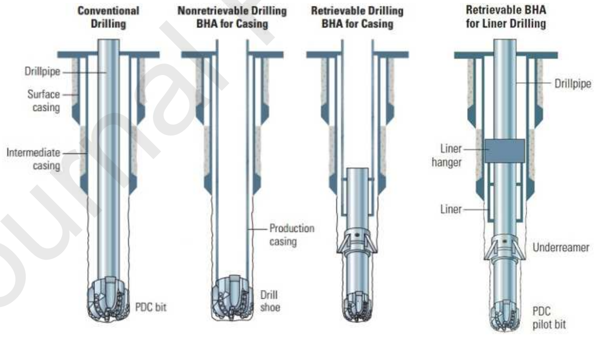


Figure 21 – Different Options for Casing While Drilling System (Kyle S. Graves ,2013)

The following scenario for batch drilling(Table 12) was considered for drilling optimization operation time in our simulation:

Table 12– Casing While Drilling Scenario

Our priority	**Method**	**The Benefits**	**Main Assumption for time Simulation**
Effective method in minimizing drilling time	Retrievable BHA Casing While Drilling System	1. Two operations including drilling and casing running combining in one operation, each meter drilled will be cased. 2. Time for tripping in and out were decreased, and all risk concerned with it. 3. Improves drilling efficiency by reducing of the non-productive time(NPT). 4. Drilling time and cementing saving	We used retrievable BHA casing while drilling system due to Maintain good directional control . ROP with retrievable BHA casing while drilling system is less than ROP with drill pipe due to Limited ls to casing RPM.

This approach allows the operator to make significant time and cost savings versus previous technology when running and cementing the casing . Further, the RIH/ POOH is a significant factor affecting the overall duration of the operations, as presented below. A WBS study was performed on a sample of the work operations, decreasing work string to RIH/ POOH for 3 operations type compared. The table 13 are a summary of time saving during the casing while drilling operations in the appendix.

Casing while Drilling makes this Scenario profitable both time and cost in SP field. We are combining two main tasks of operations in one are clear ,other benefit reduced cementing costs due to smaller annulus volume need less cement .In Optimal Scenario , we remove the need for separate casing or liner runs, simultaneously different section of all borehole is drilled and cased .when each hole section was drilled the borehole is ready for cementing service . In Optimal Scenario improves safer drilling operations by needing fewer persons on the rig and less pipe handling than routine drilling in figure 22. In addition, with casing constantly on bottom, the potential for none productive time(NPT) due to wellbore instability is decreased.

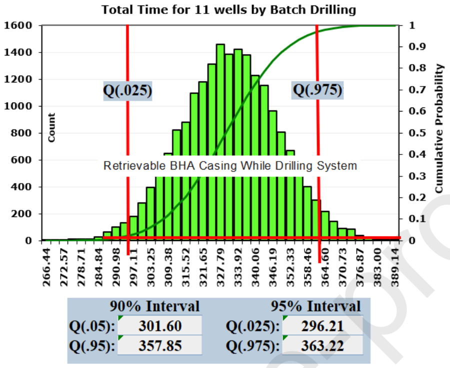


Fig.22 –Monte-Carlo time simulation for 11 Wells in batch drilling projects(by authors)

7.Discussion

There was presented Program evaluation review technique PERT concept using as the appropriate tools of the time control in drilling operation . The approach was considered on the example of the offshore drilling project, we included excel program of PERT method, and now it is usable in the time control of drilling operation with more WBS . One of the essential and key factors of the drilling projects is the date agreed for the well completion of a drilling project. It is obvious that the delays in the completion of critical task of the projects causes the different losses in engineering , procurements and drilling phases. But the drilling operation is a complex process today , main parameters such as delays in delivery the projects to client, harsh and windy weather conditions in deep drilling offshore projects, complicated formation such as high pressure and high temperature(HPHT) , the regulation of high-quality well controlling and cementing, jack up or semi-submersible class and mechanisms breakdowns influence on it. In this paper we present the batch drilling policy as appropriate strategy . it makes easier our conditions because we will gather very good information and knowledge about different formation or drilling hazards , therefore. we are capable to control and manage these main problems skillfully .This Our paper is focused on giant offshore gas fields that strongly require the time control in this drilling projects . This paper applied the best ways to control the drilling operation projects, which is recognized Program Evaluation and Review Technique (PERT). while there are exist other methods for controlling time of drilling projects include GERT, but our proposed case study match and cover by PERT network . it uses as good tool for rig manager to control the well time of the drilling project. The case study of the PERT usage is explained with the comparison between the batch drilling project and the conventional drilling project. A batch drilling approach is strongly recommended for the development of the remain phases of SP Field. This approach, planned with a proper logistics in a suitable location like Asalouyeh Island, will result in appreciable savings both on time and materials

Statoil signed Agreement with Petropars in 2002, Norwegian oil company Statoil play main role as technical operator for three phases of SP development project including 6, 7 and 8 . This development offshore projects consist of drilling and completion of the wells ,well head platforms pipelines and production topsides. ten wells in each phase , totally 30 wells were drilled in SP 6-8. drilling projects started in the January 2004 in SP6, June 2004 in phase SP7, and December 2004 in phase SP8.Statoil company was succeeded to improved drilling operation by using well trajectories ,cementing and drilling fluid optimization ,applying PDC bit technology and ultra-high-powered steerable motors.

The prior average drilling and completion times by the other company in SP field have all been exceeded included 93 days for phases 2 and 3, 87 days for phases 4 and 5 and the total operational time spent on each wellbore have been decreased to approximately half of the original budget estimate of 72 days per well (Figure 23 and 24).

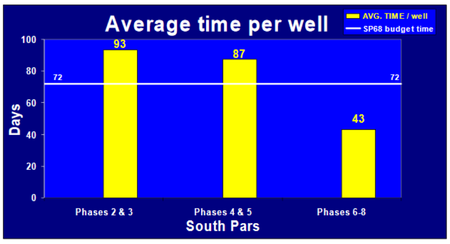


Fig.23 – Average drilling and completion times in previous drilling projects(B. Johannessen, and J. Vestvik,2005)

Fig.24 –Time versus depth plot for drilling projects in phases 6 to 8 (budget time) (by authors)

In our simulation, the estimated time per well had been calculated to 41.4 for conventional drilling by MCS , 40.5 days by batch drilling ,36 days in batch drilling by MCS and 35days in batch drilling by PERT technique . In compare of phases 6 to 8 , we used new generation hybrid drill bit to improve penetration rate in these simulations. we were designed it to lower well construction costs through faster and more durable drilling performance. Average drilling time have been improved between 8 to 2.5 days in two simulation technique for each well .

History drilling data from the previous phases 1 to 3 presented average drilling times in the variety of 90 to 93 days per wellbore, with a marginally higher average time in phases 4 and 5. All the previous best hole section drilling times in SP have been optimized by the SP 6 to 8 drilling projects for each well but in this paper, the average drilling time per well was 30 days per well, equivalent to a 30% improvement compared to the original estimate of 43 days per well by using Casing-Drilling and Liner-Drilling Technology in our simulation (Figure 25 and 26).

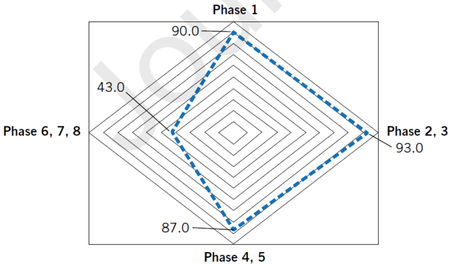


Fig.25 – Average well drilling time simulation, days(by authors)

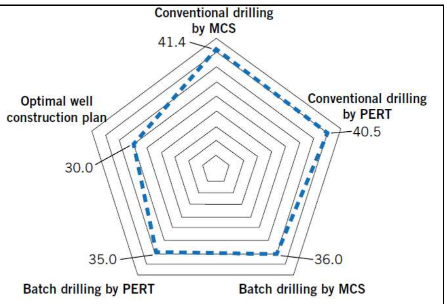


Fig.26 – Average well drilling, completion times, days(by authors)

Both the appropriate simulation techniques and the correct selection of technology and the type of drilling bits, have a significant impact on the costs and drilling duration. Following plot (Figure 27)show optimal simulations with total average drilling time 30 days.

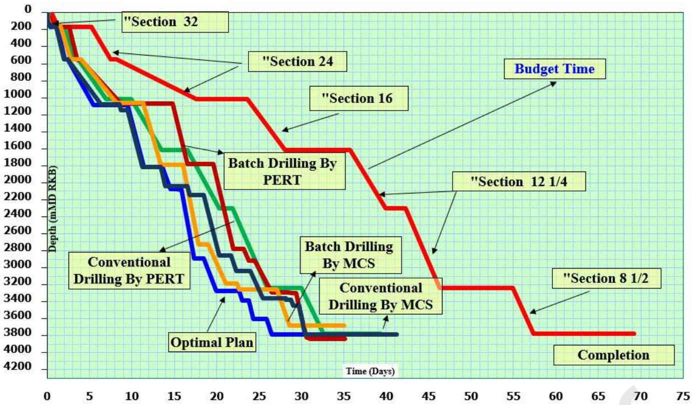


Fig.27 – Average drilling and completion times with MCS and pert techniques in this paper(by authors)

8.Conclusions

8.1.Summary of Work

Every drilling project and its resources are finite, drilling project managers should focus with (and around) project limits. One of the main project manager roles is organizing project constraints to ensure that project gets completed on time, on cost, and with the optimum allocated resources. in this regard, we established a full approaches methodology for Closed-Loop Well Construction Optimization (CLWCO) .The approach backbone includes optimization, data gathering, and time drilling history matching implemented in a repeated sequence. Uncertainty is considered by generating, and optimizing over, multiple time uncertainty by Mont Carlo and PERT approach.

Traditional methods for predicting time project such as the Critical Path Method CPM with deterministic approach do not lead to reasonable outputs due to the poor and unrealistic in their results and lack of efficiency in environment with uncertainties. Two approaches used for batch and conventional drilling are associated with conditions of uncertainties therefore ,based on Mont Carlo and PERT approach for managing uncertainty of drilling time in well construction. Applicability of CLWCO is to optimize the drilling time in onshore and offshore field in all around the world especially in the middle east region .

8.2.Practical Conclusion

The following practical conclusions are made related to case study:

1. From our case study analysis , the success of the batch drilling program has been proved and in this paper. one of these phases have been simulated in SP Field by Monte-Carlo Simulation and PERT method. According to the results with the highest amount of confidence, it can be concluded that how much it takes to drill each section of a well in this field, thereby time can be scheduled and time can be predicted in order to have the best estimation of drilling program. At least 15 % percent decrease in total drilling time is observed, comparing conventional drilling and simulated batch process(11 wells).
2. Program evaluation review technique PERT method used with calculation in this paper; results show the advantages include decreasing drilling time approximately around 15 % in practical case of the drilling operation .
3. A practical output of this paper is that instead focus on determining appropriate task duration distributions that is time-consuming and costly process, well designer and project planners should assign more attempt to accutarly determining the task durations.
4. We presented the optimal plan coupling with batch drilling could be implemented in the future phases of SP field, which has resulted in decreasing drilling time to 30 % by using casing-drilling and liner-drilling technology.

9.Future Work

Digitalization has sparked radical shifts in how we could manage and run the drilling operation remotely .Digitalization is a growing force in the offshore oil and gas drilling industry too. Its potential to optimize drilling operations time , increase safety , quality and reduce risk is a strong driver for an industry with ever-rising costs. The coronavirus (COVID-19) crisis has accelerated these beyond anything we could have imagined. Machine learning is an attractive topic in this age of Artificial Intelligence. Artificial Intelligence could be as future work for predicting machine learning models in CLWCO.

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11.Nomenclature

CLWCO: Closed-Loop Well Construction Optimization
μ: Averages
$\sigma 2$: Variance
SD: Standard deviations
PDF :Probability Distribution Function
W.B.S : Work Breakdown Structure
POOH / POH : Pull Out of Hole
RIH:Run in Hole
Q5, Q10, .. : Quantiles,
MCS: Monte-Carlo Simulation
PERT: Program Evaluation Review Technique
erf(.) : is the error function
CPM : Critical Path Method
BHA : A bottom hole assembly

11.Appendix :

Table 2 – Drilling Task Summary

Section	Task	Tools for Time Saving in this paper
32"	**Start**	

	Preparation jobs to Drilling	Advanced Techniques & Technology
	Drill 32" hole to 164 mMD	Advanced Techniques & Technology
	POOH and rack BHA	Advanced Techniques & Technology
	Running &Cementing of 26" conductor	Advanced Techniques & Technology
24"	**Start**	
	Preparation jobs to Drilling	
	Drill 24" hole to top Jahrum	Advanced Techniques & Technology
	POOH and rack BHA / RIH Rotary BHA	Advanced Techniques & Technology
	Drill 24" hole to TD	Advanced Techniques & Technology
	POOH and rack BHA	Advanced Techniques & Technology
	Running &Cementing of 18 5/8"Csg	Advanced Techniques & Technology
16"	**Start**	
	Preparation jobs to Drilling	Advanced Techniques & Technology
	Drill 16" hole to TD	Advanced Techniques & Technology
	POOH and rack BHA	Advanced Techniques & Technology
	Running &Cementing of 13 3/8"Csg	Advanced Techniques & Technology
	Start	
12 1/4"	**Preparation jobs to Drilling**	
	Drill 12 1/4" hole until bit trip required	Advanced Techniques & Technology
	POOH and rack BHA/ RIH new BHA	Advanced Techniques & Technology
	Drill 12 1/4" hole to TD	Advanced Techniques & Technology
	POOH and rack BHA/ RIH new BHA	Advanced Techniques & Technology
	Drill 12 1/4" hole to TD	Advanced Techniques & Technology
	POOH and rack BHA/Survey	Advanced Techniques & Technology
	Running &Cementing of 9 5/8"Csg	Advanced Techniques & Technology
8 1/2"	**Start**	
	Preparation jobs to Drilling	Advanced Techniques & Technology
	Drill 8 1/2" hole to TD	Advanced Techniques & Technology
	POOH and rack BHA	Advanced Techniques & Technology
Completion	**Completion**	
	Preparation and RIH 7" Pre-drilled liner	Advanced Techniques & Technology
	RIH JMZX Production packer	
	RIH 7" tubing and upper completion	
	`Install X-mass tree and flow the well and testing	

Table 3–Drilling sequencing for 11 wells in this paper

Section	**Drilling Sequence**
32"	09-07-04-01-02-03-05-06-12-11-10
24"	10-11-12-06-05-03-02-01-04-07-09
16"	09-07-04-01-02-03-05-06-12-11-10
12 1/4"	10-11-12-06-05-03-02-01-04-07-09
8 1/2"	09-07-04-01-02-03-05-06-12-11-10
7" Completion	10-11-12-06-05-03-02-01-04-07-09

Table 5 – work breakdown structure (WBS) of batch drilling operation

Section	Task	Time Saving for batch drilling
32"	**Start**	
	Preparation jobs to Drilling	Time is the same for both operation
	Drill 32" hole to 164 mMD	Time is the same for both operation
	POOH and rack BHA	Time decreasing
	Running &Cementing of 26" conductor	Time decreasing
24"	**Start**	
	Preparation jobs to Drilling	Time is the same for both operation

	Drill 24" hole to top Jahrum	Time is the same for both operation
	POOH and rack BHA / RIH Rotary BHA	Time decreasing
	Drill 24" hole to TD	Time is the same for both operation
	POOH and rack BHA	Time decreasing
	Running &Cementing of 18 5/8"Csg	Time decreasing
16"	**Start**	
	Preparation jobs to Drilling	Time is the same for both operation
	Drill 16" hole to TD	Time is the same for both operation
	POOH and rack BHA	Time decreasing
	Running &Cementing of 13 3/8"Csg	Time decreasing
	Start	
12 1/4"	Preparation jobs to Drilling	Time is the same for both operation
	Drill 12 1/4" hole until bit trip required	Time is the same for both operation
	POOH and rack BHA/ RIH new BHA	Time decreasing
	Drill 12 1/4" hole to TD	Time is the same for both operation
	POOH and rack BHA/ RIH new BHA	Time decreasing
	Drill 12 1/4" hole to TD	Time is the same for both operation
	POOH and rack BHA/Survey	Time decreasing
	Running &Cementing of 9 5/8"Csg	Time decreasing
8 1/2"	**Start**	
	Preparation jobs to Drilling	Time is the same for both operation
	Drill 8 1/2" hole to TD	Time is the same for both operation
	POOH and rack BHA	Time decreasing

Table 13– summary of time saving

Section	W.B.S	Casing While Drilling in Compare of Drill Pipe Drilling
32"	Start	
	Preparation jobs to Drilling	Time is fixed
	Drill 32" hole to 164 mMD	Time Increasing
	POOH and rack BHA	Time Decreasing
	Running &Cementing of 26" conductor	Time Decreasing
24"	Start	Start
	Preparation jobs to Drilling	Time is fixed
	Drill 24" hole to top Jahrum	Time Increasing
	POOH and rack BHA / RIH Rotary BHA	Time Decreasing
	Drill 24" hole to TD	Time Increasing
	POOH and rack BHA	Time Decreasing
	Running &Cementing of 18 5/8"Csg	Time Decreasing
16"	Start	Start
	Preparation jobs to Drilling	Time is fixed
	Drill 16" hole to TD	Time Increasing
	POOH and rack BHA	Time Decreasing
	Running &Cementing of 13 3/8"Csg	Time Decreasing
	Start	Start
12 1/4"	Preparation jobs to Drilling	Time is fixed
	Drill 12 1/4" hole until bit trip required	Time Increasing
	POOH and rack BHA/ RIH new BHA	Time Decreasing
	Drill 12 1/4" hole toTD	Time Increasing
	POOH and rack BHA/ RIH new BHA	Time Decreasing
	Drill 12 1/4" hole toTD	Time Increasing
	POOH and rack BHA/Survey	Time Decreasing
	Running &Cementing of 9 5/8"Csg	Time Decreasing
8 1/2"	Start	Start
	Preparation jobs to Drilling	Time is fixed
	Drill 8 1/2" hole to TD	Time Increasing
	POOH and rack BHA	Time Decreasing
Completion	Completion	
	Preparation and RIH 7" Pre-drilled liner	Time Increasing
	RIH JMZX Production packer	Time is fixed

	RIH 7" tubing and upper completion	Time is fixed
	Install X-mass tree and flow the well and testing	Time is fixed

Table 1 – Initial Input Information

Section	Budget (acc. Days)	Planned Depth	Technical (acc. Days)	Task
32"	0.0	0	0.0	**Start**
	0.5	0	0.1	Preparation jobs to Drilling
	1.3	164	0.4	Drill 32" hole to 164 mMD
	1.7	164	0.4	POOH and rack BHA
	3.2	164	0.7	Running &Cementing of 26" conductor
24"	3.2	164	0.7	Start
	5.3	164	2.0	Preparation jobs to Drilling
	7.5	550	3.3	Drill 24" hole to top Jahrum
	8.2	550	3.7	POOH and rack BHA / RIH Rotary BHA
	17.6	1020	7.0	Drill 24" hole to TD
	18.9	1020	8.1	POOH and rack BHA
	21.2	1020	9.2	Running &Cementing of 18 5/8"Csg
16"	21.2	1020	9.2	Start
	23.6	1020	9.9	Preparation jobs to Drilling
	28.0	1617	15.0	Drill 16" hole to TD
	29.8	1617	16.0	POOH and rack BHA
	33.2	1617	17.0	Running &Cementing of 13 3/8"Csg
12 1/4"	33.2	1617	17.0	Start
	35.8	1617	18.3	Preparation jobs to Drilling
	39.9	2300	22.1	Drill 12 1/4" hole until bit trip required
	42.3	2300	23.7	POOH and rack BHA/ RIH new BHA
	46.3	3238	29.8	Drill 12 1/4" hole toTD
	46.3	3238	29.8	POOH and rack BHA/ RIH new BHA
	46.3	3238	29.8	Drill 12 1/4" hole toTD / Dropped ROP to <5m/hr
	48.5	3238	32.0	POOH and rack BHA/Survey
	52.2	3238	33.7	Running &Cementing of 9 5/8"Csg
8 1/2"	52.2	3238	33.7	Start
	54.9	3238	34.9	Preparation jobs to Drilling
	57.4	3780	37.5	Drill 8 1/2" hole to TD
	59.3	3780	38.7	POOH and rack BHA
Completion	60.3	3780	38.7	Completion
	63.5	3780	40.2	Preparation and RIH 7" Pre-drilled liner
	64.5	3780	40.9	RIH JMZX Production packer
	65.5	3780	42.6	RIH 7" tubing and upper completion
	72	**3780**	44.2	Install X-mass tree and flow the well and testing

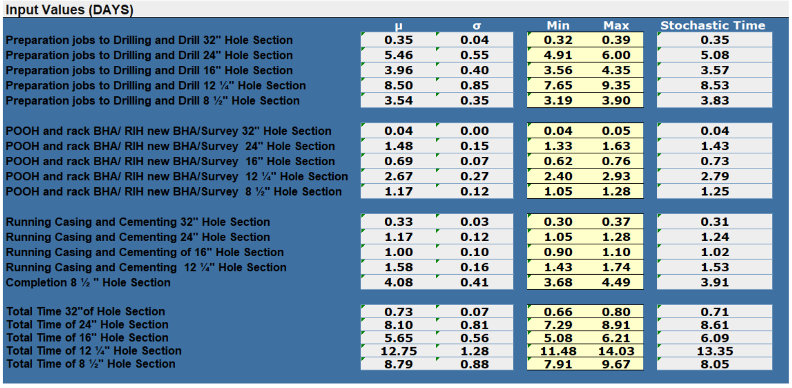
Table 3–Drilling sequencing for 11 wells in this paper

Section	**Drilling Sequence**
32"	09-07-04-01-02-03-05-06-12-11-10
24"	10-11-12-06-05-03-02-01-04-07-09
16"	09-07-04-01-02-03-05-06-12-11-10
12 1/4"	10-11-12-06-05-03-02-01-04-07-09
8 1/2"	09-07-04-01-02-03-05-06-12-11-10
7" Completion	10-11-12-06-05-03-02-01-04-07-09

Table 5 – work breakdown structure (WBS) of batch drilling operation

Section	Task	Time Saving for batch drilling
32"	**Start**	
	Preparation jobs to Drilling	Time is the same for both operation
	Drill 32" hole to 164 mMD	Time is the same for both operation
	POOH and rack BHA	Time decreasing
	Running &Cementing of 26" conductor	Time decreasing
24"	**Start**	
	Preparation jobs to Drilling	Time is the same for both operation
	Drill 24" hole to top Jahrum	Time is the same for both operation
	POOH and rack BHA / RIH Rotary BHA	Time decreasing
	Drill 24" hole to TD	Time is the same for both operation
	POOH and rack BHA	Time decreasing
	Running &Cementing of 18 5/8"Csg	Time decreasing
16"	**Start**	
	Preparation jobs to Drilling	Time is the same for both operation
	Drill 16" hole to TD	Time is the same for both operation
	POOH and rack BHA	Time decreasing
	Running &Cementing of 13 3/8"Csg	Time decreasing
	Start	
12 1/4"	Preparation jobs to Drilling	Time is the same for both operation
	Drill 12 1/4" hole until bit trip required	Time is the same for both operation
	POOH and rack BHA/ RIH new BHA	Time decreasing
	Drill 12 1/4" hole to TD	Time is the same for both operation
	POOH and rack BHA/ RIH new BHA	Time decreasing
	Drill 12 1/4" hole to TD	Time is the same for both operation
	POOH and rack BHA/Survey	Time decreasing
	Running &Cementing of 9 5/8"Csg	Time decreasing
8 1/2"	**Start**	
	Preparation jobs to Drilling	Time is the same for both operation
	Drill 8 1/2" hole to TD	Time is the same for both operation
	POOH and rack BHA	Time decreasing

Table 2–Input Variable for simulation



Input Values (DAYS)	μ	σ	Min	Max	Stochastic Time
Preparation jobs to Drilling and Drill 32" Hole Section	0.35	0.04	0.32	0.39	0.35
Preparation jobs to Drilling and Drill 24" Hole Section	5.46	0.55	4.91	6.00	5.08
Preparation jobs to Drilling and Drill 16" Hole Section	3.96	0.40	3.56	4.35	3.57
Preparation jobs to Drilling and Drill 12 ¼" Hole Section	8.50	0.85	7.65	9.35	8.53
Preparation jobs to Drilling and Drill 8 ½" Hole Section	3.54	0.35	3.19	3.90	3.83
POOH and rack BHA/ RIH new BHA/Survey 32" Hole Section	0.04	0.00	0.04	0.05	0.04
POOH and rack BHA/ RIH new BHA/Survey 24" Hole Section	1.48	0.15	1.33	1.63	1.43
POOH and rack BHA/ RIH new BHA/Survey 16" Hole Section	0.69	0.07	0.62	0.76	0.73
POOH and rack BHA/ RIH new BHA/Survey 12 ¼" Hole Section	2.67	0.27	2.40	2.93	2.79
POOH and rack BHA/ RIH new BHA/Survey 8 ½" Hole Section	1.17	0.12	1.05	1.28	1.25
Running Casing and Cementing 32" Hole Section	0.33	0.03	0.30	0.37	0.31
Running Casing and Cementing 24" Hole Section	1.17	0.12	1.05	1.28	1.24
Running Casing and Cementing of 16" Hole Section	1.00	0.10	0.90	1.10	1.02
Running Casing and Cementing 12 ¼" Hole Section	1.58	0.16	1.43	1.74	1.53
Completion 8 ½ " Hole Section	4.08	0.41	3.68	4.49	3.91
Total Time 32"of Hole Section	0.73	0.07	0.66	0.80	0.71
Total Time of 24" Hole Section	8.10	0.81	7.29	8.91	8.61
Total Time of 16" Hole Section	5.65	0.56	5.08	6.21	6.09
Total Time of 12 ¼" Hole Section	12.75	1.28	11.48	14.03	13.35
Total Time of 8 ½" Hole Section	8.79	0.88	7.91	9.67	8.05

Closed-Loop Well Construction Optimization (CLWCO) Using Stochastic Approach Under Time Uncertainty

Highlights

We propose closed-loop well construction optimization (CLWCO) workflow using Stochastic methods.

The proposed closed-loop is implemented in a complex problem based on a real drilling operation.

We use the Monte-Carlo Simulation and Program Evaluation Review Technique (PERT) for history matching and for time optimization.

The new CLWCO implementation improved average drilling time between 2.5 to 8 days.

Quantification of closed-loop well construction optimization can help improve decision-making.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

None