Integrating risk management concepts into the drilling non-productive time

Mohamed Barakat¹ · Mahmoud Abu El Ela² · Fouad Khalaf²

Received: 11 September 2020 / Accepted: 26 November 2020 / Published online: 3 January 2021
 © The Author(s) 2021

Abstract

Introducing the non-productive time (NPT) concepts in the 1960s was a necessity dictated by the ever-increasing cost and complexity of the oil and gas well drilling. The NPT definition stayed unsettled until two decades later, the definition converged toward its accepted current definition of “the time when planned or out-of-plans drilling-related activities do not add value to the operation objectives.” NPT as it is defined in drilling nowadays is a form of time waste or loss which adversely impacts the overall efficiency of the drilling operation. Since the 1980s, risk management (RM) has become a sound technique to evaluate operational losses or wastes of many resources, including time. This paper presents an attempt to couple RM techniques with NPT philosophy together with other concepts such as Systems Thinking, Synergy, Continuous Improvement, and Total Quality. These concepts and derived techniques suit well controlling the intolerable waste that shows up in the form of delay in operations and materializes into most of the undesirable costs of drilling. These concepts, adopted herein, were applied on data from 60 rigs which were used to drill 250 wells for a period of 1 year of operation. In all 19 types of NPT were considered. A Java software model was developed and used to express NPT as an undesired event with probability of happening, in order to follow with RM terminology. The probability levels (related to the NPT values) for each rig were then defined and further classified into the four familiar ranks and their colors as used in RM: Acceptable (green), Tolerable (yellow), Inadmissible (orange), and Unacceptable (red). A matrix was established for all NPT categories and for the 60 rigs and was then named Rig-NPT Risk Matrix. A maximum probability ceiling was established as a reference for unacceptable risks of all NPT categories and for all the 60 rigs. Finally, sets of risk control recommendations were proposed to minimize the NPT in order to improve rigs performance. The concept of NPT and the science of RM when integrated gave a new approach to minimize the drilling losses. Using NPT analysis coupled with risk management was used to indicate where to optimize exerted efforts in order to synergize improvement of overall drilling performance.

Keywords Non-productive time (NPT) · Rig performance · Integrating risk management and NPT concepts · NPT analysis

Abbreviation

ALARP As low as reasonably practical
 BOP NPT due to repair or lack of performance during the nipple up or down for the blow-out preventer

COMP NPT due to fail to run completion equipment
 CORE NPT due to excess time during the coring operation
 CSG NPT due to excess time during run the casing
 CT NPT due to excess time while coil tubing operation
 DCOM NPT due to excess time during well de-completion activities
 DRLG NPT due to stop drilling operation for any reason
 FISH NPT due to excess time during the fishing operation
 HSE Health safety environment
 IDE Integrated development environment for Java
 KILL NPT due to excess time during well killing activities

✉ Mahmoud Abu El Ela
 m.ella2003@gmail.com; m.ella@cu.edu.eg

Mohamed Barakat
 mohamed.barakat007@gmail.com

Fouad Khalaf
 fouad.khalafm@gmail.com

¹ Master of Science Program in Risk Engineering, Faculty of Engineering, Cairo University, Giza, Egypt

² Faculty of Engineering, Cairo University, Giza, Egypt

LOG	NPT due to excess time during the logging operations
MAIN	NPT due to excess time during the maintenance operation for the rig equipment and tools
MILL	NPT due to excess time during the milling in casing for sidetrack
NPT	Non-productive time
P	Frequency of occurrence (probability) of an NPT per year
P&A	NPT due to excess time during the plug and abandon the well operation
PPE	Personal protective equipment
R	Risk rank
RMV	NPT due to excess time during rig move operation
S	Severity of consequences
SQL	Source quicker loader
STIM	NPT due to excess time during stimulation jobs
SUSP	NPT related to the suspended operation
SWOT	Strengths, weaknesses, opportunities, and threats
TEST	NPT due to excess time during testing the well for production
TINL	NPT due to excess time during pipe trips activities
TOAD	Tool for oracle application developers
WH	NPT due to excess time while installing the wellhead

Introduction

The NPT is defined as the time in which the drilling operation ceases in an unplanned way or when the drilling penetration rate becomes excessively low (Dew and Childers 1989). Given the colossal investments in the drilling ventures of oil and gas, whether land or offshore, the drilling time has become intimately reflective of its operational costs. Therefore, reducing the NPT should improve drilling performance and reduce well cost to save money. The NPT concept started in the 1960s, and since then many studies and approaches emerged in an attempt to control lost time to acceptable values.

In Estes (1971), set standardization of bit selection to decrease the NPT using Pareto analysis technique (80/20 rule) to achieve the study objectives. The Pareto principle states that “*for many outcomes roughly 80% of consequences come from 20% of the causes*” (Pareto and Page 1971). Earlier, this principle has seen many applications in quality control where it was first created. Estes applied this technique in drilling and found that 80% of the losses in the drilling costs come from 20% of the drilling problems.

Such finding allowed him to focus on the most cost-effective drilling problems.

Later, Perez et al. (1990) described a successful application of the total quality management methodology for restructuring and improving the drilling organization, generating solutions to improve drilling efficiency, and to solve operational problems encountered in the initial development efforts of a deep onshore field in Venezuela. Then, Bradley et al. (1991) analyzed the drilling time distribution for Gulf of Mexico area from 1985 to 1990, focusing on the cost and the causes of stuck pipe incidents. However, Kadaster et al. (1992) set a systematic approach (extending over more one drilling subsystem) to analyze, evaluate, improve, and re-apply drilling mud, bits, and hydraulic techniques to reduce cost per foot during the drilling operation.

In 2004, Tibiletti et al. stressed the importance of minimizing the NPT. In this work, actual case study from Rashid Petroleum Company (Mediterranean Sea, Egypt) was presented to reduce the NPT in deep water subsea high cost wells. The study included a comparison between the normal operation time and the NPT to show how the NPT has impact on the project performance.

In addition, Gala et al. (2010) reviewed the relation between the NPT and drilling hazards. They developed engineering evaluation processes that helped use of the best drilling tools and techniques available to them to reduce the NPT from 40 to 10%.

Moreover, Everage et al. (2011) reviewed and analyzed a real case study about one of NPT incident of twist-off drill pipe. In this study, the main parameters of risk (probability and cost as a measure of severity) were considered without naming them. This work included a case study about excessive NPT due to normal weight and heavy weight fatigue failures while drilling horizontal wells compared to the vertical wells. The results of the study showed that the failures of heavy weight drill pipe were reduced by 47%, when the American Petroleum Institute standards were applied.

The key performance indicators (KPI) concept played also a major role in supporting drilling performance and evaluating the NPT (Hernandez and Torres 2011). The performance reviewing steps include an immediate action for decision-making process, a balance scorecard application for the required discussion, a periodical review time allocation, and a performance track record. The KPI reflect the performance of a process in achieving its objectives and standards. The main purpose of using KPI is to reduce the drilling costs, eliminate the drilling risks, and maintain the operational integrity (Hernandez and Torres 2011). However, these approaches dwelled on the time value of the NPT without introducing the influence of frequencies or probabilities of happening on the cost of NPT over a common period of time in order to comparatively rate rig performance as far as NPT in a selected number of major drilling operations.

The introduction of the notion of probabilities of happening tends to give weights to the happening of the respective values of losses, and when severities (represented by cost) are added, the risk is introduced in the decision which accounts for the uncertainty of happening.

Hurtado and Redlinger (2016) reviewed several NPT field applications and presented a correlation between the drilling efficiency and the successfully proven HSE techniques. They showed that repurposing proven HSE techniques for use outside safety reduces the NPT and improves the drilling efficiency.

Recently, the RM has become a management style conducive to continuous improvement, total quality, and, more generally, business excellence. The RM is an organized process of identifying, evaluating, and handling all risks in order to bring undesired events, in life or in business, to acceptable or tolerable values. In 2004, Main presented the fundamentals of the risk assessment concepts. Later, Khalaf and Abu El Ela (2008) reviewed the basics of risk management and showed that coupling likelihood of happening of an undesired event and its consequences can serve as measure for optimizing operations and is a way toward arranging, recognizing, assessing, choosing, and executing activities to control losses and wastes. As such RM has applications in drilling-NPT analysis.

The structure of the hazard administration has seven phases: (1) defining the problem and putting it in context, (2) analyzing the risks associated with the problem in context, (3) examining options for addressing the risks, (4) making decisions about which options to implement, (5) taking actions to implement the decisions, (6) conducting an evaluation of the action's results, and (7) documenting the process (Barakat 2018). It is clear that little research work has been tried to extend the concepts of hazard administration or the total quality (TQ) to the NPT on drilling operation and performance. In addition, little research work has been also tried to use the concepts of the risk management to evaluate rig performance. Therefore, the current work intends to borrow the concepts of risk in order to study and assess the NPT performance in the oil and gas drilling operations to find ways to control and reduce the NPT and to evaluate rigs performance according to the risks level of NPT.

Study objectives and methodology

The objectives of this study include the followings:

1. Develop a risk-based general methodology suitable for evaluating rig performance using NPT.
2. Recognize and classify hazards based on analysis of offset wells.

3. Identify and prioritize the hazardous situations related to NPT branches.
4. Analyze, prioritize, and address the major risk based on the existing NPT.
5. Provide recommendation to improve the rigs performance through controlling NPT values.

To achieve these objectives, the authors developed the following methodology as shown in Fig. 1:

1. *Data Collection* Drilling data of 250 wells were collected from the operation of 60 onshore rigs for 1 year.
2. *Data Classification* The collected data were classified according to either productive time or NPT.
3. *Data Analysis* The collected data were analyzed to identify the categories and types of the NPT, analysis revealed 19 NPT categories in the collected data—these were considered in this study, but the approach can be extended to cover additional NPT categories, provided that enough statistical data are made available.
4. *Development of an Analysis and Reporting Software Model* A computer program model was developed using Java programming language to get probability of the particular NPT.
5. *Model Verification* The model was verified by using random samples and test data.
6. *Results of the Field Application* The oilfield data were used to estimate the probabilities and risks of each NPT category for each rig under study.
7. *Rig-NPT Risk Matrix* Risk matrix was established for all categories of the NPT and the 60 rigs to present the distribution of the critical and unacceptable high-risk type.
8. *Risk Control (RC)* The causes of the NPT were analyzed to reduce the NPT, to decrease the probability of NPT, and to improve rig performance.

Data collection, classification, and analysis

The study was carried using data of 60 onshore rigs (Barakat 2018). The work focused on onshore rigs data; however, the model can easily be applied to workover and offshore rigs. The NPT data were collected during the drilling activities for 1 year, through which 250 wells were drilled. The selected onshore rigs have moderate capacity between 1500 and 3000 horsepower. The average daily rig rate is about US\$ 40,000/day.

The data collection and analysis were the main entry point for the model. The data source files can be of any type such as .xls, .csv, .xml, .txt, or flat files. Collected data were grouped into 19 categories of the NPT; Table 1 shows the classification of the NPT categories. All categories of NPT data are present in the 60 rigs.

Fig. 1 Sequence of steps

Model structure

It was not easy to deal with huge data without using applicable software to analyze and process the information. The extracted data in this research exceeded one million records for a whole year of rigs activities. Therefore, Java programmed software was used to handle data processing. This software calculates the risk and probability values for

the selected rigs according to predefined criteria. The Java software has structure to process data directly from daily drilling report and produces NPT probabilities as output for each one of the 60 rigs.

The program structure consists of four main sections:

1. *Source Quicker Loader (SQL)* This section loads the data from the external data source files into tables of an oracle database “Master Database.” It supports multiple types of input data files:txt, xml, and flat files.
2. *Oracle SQL Database* This part holds all loaded data including the Master Data and the Probability Data tables. The Probability Data tables were generated to estimate probability (P) and risk values (R, being the product of probability times cost of the lost time). For each one of the given 60 rigs, there were 19 records representing the majority of operations on the rig daily or monthly operation. Given the size of data available, the records represent precise calculated probability values for all data.
3. *TOAD (a Tool for Oracle Application Developers)* The database management system is used to create the Master database and the tables which hold the data. It was used to gain access and to control the created oracle database. This tool displays the tables in a well-organized form for better accessibility.
4. *Java NetBeans IDE (Integrated Development Environment)* It is used for Java development code writing and user interface creation. The developed user interface has a direct connection to the master database on the probability table to fetch probability values calculated for the 60 rigs with respect to the 19 majority operations. The developed Java code uses the probability table to select and to count the total of NPT hours of each rig for each operation and then divides it on the total number of normal operation time as presented in Eq. 1. These data are the probability of the NPT for the selected operation.

$$P = \frac{\text{NPT}}{\text{Normal Operation Time}} \quad (1)$$

where P : frequency of occurrence (probability) of an NPT per year.

Figure 2 illustrates the user interface developed by Java code to facilitate the user interaction with the data. As shown in Fig. 2, the user is able to select the rig, start, and end date, operation type, and whether NPT or not for the probability calculation. The calculated values (for each rig and NPT category) are the total lost time, the total operation duration time, and the probability value.

Table 1 Classification and codes of the NPT categories

No.	Code of the NPT category	Description
1	BOP	NPT due to repair or lack of performance during the nipple up or down for the blow-out preventer
2	WH	NPT due to excess time while installing the wellhead
3	COMP	NPT due to failing to run completion equipment
4	CORE	NPT due to excess time during the coring operation
5	CSG	NPT due to excess time during run the casing
6	CT	NPT due to excess time while coil tubing operation
7	DRLG	NPT due to stop drilling operation for any reason
8	MAIN	NPT due to excess time during the maintenance operation for the rig equipment and tools
9	P&A	NPT due to excess time during the plug and abandon the well operation
10	RMV	NPT due to excess time during rig move operation
11	TEST	NPT due to excess time during testing the well for production
12	DCOM	NPT due to excess time during well de-completion activities
13	FISH	NPT due to excess time during the fishing operation
14	LOG	NPT due to excess time during the logging operations
15	MILL	NPT due to excess time during the milling in casing for sidetrack
16	STIM	NPT due to excess time during stimulation jobs
17	SUSP	NPT related to “suspended operation”
18	TINL	NPT due to excess time during pipe trips activities
19	KILL	NPT due to excess time during well killing activities

Model validation

The authors used data from five rigs for different types of operations to validate the model, as shown in Table 2. The selection of the validation data was carried out randomly. Then, the probability of the occurrence of each NPT type for each rig was counted manually according to the concept of Eq. 1, and compared with the results of the Java software analysis. It was found that the manually calculated values are consistent with the results of the model. Accordingly, the model was applied to treat the entire data analysis of the current study.

Table 2 Data used for verifying the Java model

1	2	3	4	5
Rig name	NPT category	Annual NPT (h)	Annual operation time (h)	Probability (3/4)
R1	BOP	8.5	342.5	0.0248
R2	TINL	93	96	0.9688
R3	RMV	7	1348.5	0.0052
R4	WH	2	111.25	0.0180
R5	FISH	0	21.5	0.0000

Fig. 2 User interface of the Java reporting module

Model integration with the risk management approach

RM approach was used to analyze and assess the NPT data. Figure 3 shows the steps of the risk management approach. The risk is two-dimensional occasion. Therefore, each hazard or NPT category is distinguished by two parameters of assessment: likelihood (probability) of event of particular undesired occasion, and seriousness of results of such occasion (represents severity) as presented in Eq. 2.

$$R = P * S \quad (2)$$

where R : risk value, P : frequency of occurrence (probability) of an NPT per year, S : severity of consequences.

The probability of the occurrence of each NPT type (19 NPT category) in each rig (60 rigs) was obtained from Java software analysis. The unit cost of US\$ 1667 per hour was taken constant in all cases. The severity value (hourly rate of the rig) was calculated based on that the daily rig rate (US\$40,000/day). After that the risk was estimated for each NPT. The risk was classified into four categories according to the criteria presented in Table 3. The calculated risk included four colored areas to differentiate between risks according to their level. The critical and unacceptable type “red” is extreme the highest risk and should be reduced first.

The second type of risk is “orange” which is the risk, and it has the second priority to be decreased. The third one is moderate which is the lowest type of risk “yellow,” and it has the least priority to be eliminated. The fourth one “green” is acceptable. After the risk of each NPT category is identified and classified for each rig, Rig-NPT Risk Matrix was developed for the 19 NPT categories and the 60 wells to present the distribution of the critical and unacceptable high-risk type.

Results of the field applications

NPT analysis

In order to determine the most effective NPT type on rigs which should be controlled, Table 4 was prepared for all NPT categories. The table shows the distribution of the annual operating and NPT of the 60 rigs in 19 operations. The total annual operating time of the 60 rigs is 327,668.65 h. However, the total NPT is 37,051.85 h. Accordingly, the annual cost of all NPT in the 60 rigs is \$61,765,434 considering that the hourly rate of the rigs is US\$ 1,667.

As shown in Table 4, the probability of the occurrence of the NPT in the 60 rigs at each operation is estimated. Then, the probability is sorted from the highest to the lowest (from

Fig. 3 Risk management approach

Table 3 Risk matrix categories

Level of risk	Title	Index	Description
R1	Acceptable	1	Acceptable risk, for the time being
R2	Tolerable	2	Monitoring measures are required
R3	Inadmissible	3	Need control measure for mitigation
R4	Unacceptable	4	The situation is refused and measures of reducing risk should be taken

Table 4 Probability of the NPT in all operations

1		2	3	4	5	6
NPT category	Description	Annual NPT (h)	Sever- ity* (US\$/h)	Cost of NPT (2×3) (US \$/ year)	Annual operating time (h)	Probability (2/5)
DCOMP	NPT due to excess time during well de-comple- tion activities	82.5	1667	\$137,528	86	0.959
SUSP	NPT related to the suspended operation	385.5	1667	\$642,629	509.25	0.757
FISH	NPT due to excess time during the fishing opera- tion	4266.5	1667	\$7,112,256	5766.25	0.740
KILL	NPT due to excess time during well killing activities	167	1667	\$278,389	229.75	0.727
Main	NPT due to excess time during the maintenance operation for the rig equipment and tools	1264.5	1667	\$2,107,922	2423	0.522
P&A	NPT due to excess time during the plug and abandon the well operation	475.25	1667	\$792,242	1517	0.313
Mill	NPT due to excess time during the milling in casing for sidetrack	585.85	1667	\$976,612	2383.5	0.246
TINL	NPT due to excess time during pipe trips activi- ties	402	1667	\$670,134	1958	0.205
STIM	NPT due to excess time during stimulation jobs	273.5	1667	\$455,925	1408	0.194
COMP	NPT due to failing to run completion equipment	4326.25	1667	\$7,211,859	23,797.3	0.182
LOG	NPT due to excess time during the logging operations	1052.25	1667	\$1,754,101	8750	0.120
DRLG	NPT due to stop drilling operation for any reason	17,198.75	1667	\$28,670,316	164,644	0.104
CT	NPT due to excess time while coil tubing opera- tion	2439.5	1667	\$4,066,647	23,868	0.102
BOP	NPT due to repair or lack of performance dur- ing the nipple up or down for the blow-out preventer	1513.75	1667	\$2,523,421	14,996.25	0.101
CSG	NPT due to excess time during run the casing	2055.5	1667	\$3,426,519	27,644.3	0.074
TEST	NPT due to excess time during testing the well for production	41.5	1667	\$69,181	749.75	0.055
WH	NPT due to excess time while installing the wellhead	220.25	1667	\$367,157	4731	0.047
CORE	NPT due to excess time during the coring opera- tion	36	1667	\$60,012	1994.5	0.018
RMV	NPT due to excess time during rig move opera- tion	265.5	1667	\$442,589	40,212.8	0.007
Total		37,051.85	1667	\$61,765,434	327,668.65	0.113

*Daily rig rate is USD 40,000. Therefore, the hourly rate is 1,667 US\$/h

0.959 to 0.007). The probability values are divided into three levels. The probabilities from 0.727 to 0.959 is considered the maximum NPT probability that occurred during the de-completion, suspended, fishing, and killing operations. The moderate level is around the probability of 0.5 (maintenance operation). However, the low level of probability is from 0.313 to 0.007. Table 4 indicates that the highest NPT probability comes from the unplanned operations. The unplanned operations are considered sudden orders or problems that happen during the operation time without any planning

ahead for it. Also, the probability of maintenance is considered moderate and needs focus to decrease it.

Rig-NPT Risk Matrix

The performance of the rigs was evaluated on the basis of quantitative risk assessment. The principle of risk assessment is used to present the results of probability, severity, and risk. A comparison among 60 rigs was prepared for each kind of NPT (19 types of NPT). The results of the comparisons between all NPT categories in all rigs are presented in

Table 5 Risk of the NPT during the drilling operation (DRLG) for the 60 rigs

1	2	3	4	5	6	7
Rig name	Annual NPT (h)	Annual drilling time (h)	Probability (2/3)	Severity* (US\$/h)	Cost of NPT (2×5) (US\$/year)	Risk (4×5) (US \$/h)
R1	500.25	4054	0.1234	1667	833,750	\$205.66
R2	1.5	1267.5	0.0012	1667	2500	\$1.97
R3	124	4506.5	0.0275	1667	206,667	\$45.86
R4	205.5	4053	0.0507	1667	342,500	\$84.51
R5	486.5	4090.75	0.1189	1667	810,833	\$198.21
R6	0	378	0.0000	1667	0	\$0.00
R7	510.25	3904.25	0.1307	1667	850,417	\$217.82
R8	0	0	0.0000	1667	0	\$0.00
R9	0	0	0.0000	1667	0	\$0.00
R10	0	0	0.0000	1667	0	\$0.00
R11	0	0	0.0000	1667	0	\$0.00
R12	116.5	3219.25	0.0362	1667	194,167	\$60.31
R13	50	1203.5	0.0415	1667	83,333	\$69.24
R14	383.25	3534.5	0.1084	1667	638,750	\$180.72
R15	0	0	0.0000	1667	0	\$0.00
R16	544.5	5235	0.1040	1667	907,500	\$173.35
R17	297.75	3890	0.0765	1667	496,250	\$127.57
R18	296.75	3281.25	0.0904	1667	494,583	\$150.73
R19	702.25	3956.5	0.1775	1667	1,170,417	\$295.82
R20	511	4508.75	0.1133	1667	851,667	\$188.89
R21	235	3836.5	0.0613	1667	391,667	\$102.09
R22	499.25	4269.25	0.1169	1667	832,083	\$194.90
R23	144.25	4613.75	0.0313	1667	240,417	\$52.11
R24	568.75	4729.25	0.1203	1667	947,917	\$200.44
R25	384.25	4348.75	0.0884	1667	640,417	\$147.26
R26	88.25	2038.5	0.0433	1667	147,083	\$72.15
R27	257	4060	0.0633	1667	428,333	\$105.50
R28	0	0	0.0000	1667	0	\$0.00
R29	0	0	0.0000	1667	0	\$0.00
R30	988.5	5024.75	0.1967	1667	1,647,500	\$327.88
R31	0	0	0.0000	1667	0	\$0.00
R32	538.75	4469.5	0.1205	1667	897,917	\$200.90
R33	0	0	0.0000	1667	0	\$0.00
R34	253.5	3131.75	0.0809	1667	422,500	\$134.91
R35	220	3630.25	0.0606	1667	366,667	\$101.00
R36	807.5	3400	0.2375	1667	1,345,833	\$395.83
R37	0	0	0.0000	1667	0	\$0.00
R38	254.5	4084.5	0.0623	1667	424,167	\$103.85
R39	0	0	0.0000	1667	0	\$0.00
R40	620.25	4503.25	0.1377	1667	1,033,750	\$229.56
R41	372.25	4664.5	0.0798	1667	620,417	\$133.01
R42	474	3973.5	0.1193	1667	790,000	\$198.82
R43	202	4360.5	0.0463	1667	336,667	\$77.21
R44	315.75	4991	0.0633	1667	526,250	\$105.44
R45	272.25	4016.75	0.0678	1667	453,750	\$112.96
R46	839.75	3537	0.2374	1667	1,399,583	\$395.70
R47	505.75	4264.25	0.1186	1667	842,917	\$197.67
R48	44.5	691.25	0.0644	1667	74,167	\$107.29

Table 5 (continued)

1	2	3	4	5	6	7
Rig name	Annual NPT (h)	Annual drilling time (h)	Probability (2/3)	Severity* (US\$/h)	Cost of NPT (2×5) (US\$/year)	Risk (4×5) (US \$/h)
R49	64	3113	0.0206	1667	106,667	\$34.26
R50	1319.75	4899.25	0.2694	1667	2,199,583	\$448.96
R51	469.5	4289	0.1095	1667	782,500	\$182.44
R52	0	63	0.0000	1667	0	\$0.00
R53	0	0	0.0000	1667	0	\$0.00
R54	676.75	4075.75	0.1660	1667	1,127,917	\$276.74
R55	0	0	0.0000	1667	0	\$0.00
R56	60	1622.75	0.0370	1667	100,000	\$61.62
R57	100.75	1028.5	0.0980	1667	167,917	\$163.26
R58	190.5	3104.5	0.0614	1667	317,500	\$102.27
R59	701.5	4727	0.1484	1667	1,169,167	\$247.34
R60	0	0	0.0000	1667	0	\$0.00
	17,198.75	164,644.25	0.1045	1667	\$28,670,316	

*Daily rig rate is USD 40,000. Therefore, the hourly rate is 1667 US\$/h

Rig-NPT Risk Matrix to show the critical and unacceptable risks.

Due to space limitation, the details of only one category of the NPT in the 60 rigs are presented and discussed. The selected NPT is that during the drilling operation (DRLG). This type was the most common type between rigs in the collected data. As shown in Table 4, the annual cost of this NPT category in the 60 rigs is \$28,670,316 out of the total costs of all NPT categories (\$61,765,434).

All NPT of drilling mainly happened during rotating time. Table 5 presents the risk values of the NPT during the drilling operation in the 60 rigs obtained from the Java software analysis. Similar tables were extracted for the other 18 NPT categories. Table 5 shows the distribution of the annual NPT of the 60 rigs in the drilling operation. The total NPT in the drilling operations of the 60 rigs is 17,198.75 h. However, the total annual operating time during the drilling operation of the 60 rigs is 164,644.25 h. Accordingly, the estimated annual cost of the NPT in the 60 rigs during the drilling operation is \$28,670,316.

As shown in Table 5, the lowest and highest probabilities values for the NPT during the drilling operation are zeros and 0.27, respectively. The probability of the occurrence is zero in 16 rigs out of the selected 60 rigs (27% of the rigs). Accordingly, 44 rigs out of the 60 rigs (73% of the selected

rigs) reported of NPT-related problems. Figure 4 presents the histogram of the risk values between all rigs. The results of Table 5 and Fig. 4 can guide the selection of the characteristics of the other rigs (the 16 rigs) without NPT problems. Therefore, since the severity expressed by the constant hourly rate, the calculated risk (qualified as the cost of the NPT) is influenced by the probability value.

In Fig. 4, four risk levels were considered:

1. The histogram shows the unacceptable area of risk for rigs which have risk values higher than US\$ 345/h. These rigs (3 rigs) are considered the worst of the fleet and need improvement in order to decrease the NPT of the drilling. They represent 5% of total number of rigs. They have severity cost ranging between \$345 and \$460 cost \$/h.
2. Those in the orange zone are 7% of the total (4 rigs). The severity cost of the drilling operation using these rigs ranges between 230 and 345 US\$/h.
3. The rigs in the yellow zone (19 rigs) represent 32% of the fleet. The severity cost of the drilling operation using these rigs ranges between 115 and 230 US\$/h.
4. The percentage of rigs in green zone is 30% of total rigs (18 rigs out of 60). The severity cost of the drilling

Level of risk	Title	Description
R1	Acceptable	Acceptable risk for time being
R2	Tolerable	Monitoring measures are required
R3	Inadmissible	Need control measure for mitigation
R4	Unacceptable	The situation is refused and measures of reducing risk should be taken

Fig. 4 NPT risk values during drilling operation for the 60 rigs

operation using these rigs ranges between 0 and 115 U\$/h.

Similar to the above-mentioned risk analysis which was performed for the NPT of the drilling operation, risk assessment for all other NPT categories in all rigs was carried out to prepare Rig-NPT Risk Matrix as shown in Table 6.

The risk matrix can be used as a benchmark to select the rigs which will continue or not when the oil is devalued. Any horizontal row in the Rig-NPT Risk Matrix reflects the quality of the performance for each rig. More red boxes in the horizontal row reflect bad performance for this rig. However, the vertical column reflects the number of occurrences of the same problem for all rigs. From this table, it can be recognized that fishing and milling operations are the common problems in the rigs under study. Higher NPT in these operations occurs more than in the other operations in all rigs, which is expected as these operations are unplanned.

For which, further planning is required in order to reduce fishing and milling NPT.

Recommendations and mitigation actions

Strengths, weaknesses, opportunities, and threats (SWOT) Analysis was performed to specify the SWOT for the NPT through verbal interviews of rig crews and other drilling personnel. Table 7 illustrates the results of this SWOT analysis for all categories of the NPT which contributed to the identifying factors involved in the surveyed categories of NPT, a total of 19. It was found that NPT values increase when the negative impact of the following factors (components of the general risk matrix) is high: equipment, personnel/people, environment, and work processes. These factors affected the final system output and determined the final impact on business.

A set of risk control recommendation were developed for all critical and unacceptable risks in all NPT categories.

Table 6 Rig-NPT Risk Matrix

Rig name	NPT category																		
	BOP	WH	COMP	CORE	CSG	CT	DRLG	MAIN	P&A	RMV	TEST	DCOM	FISH	LOG	MILL	STIM	SUSP	TINL	KILL
R1																			
R2																			
R3																			
R4																			
R5																			
R6																			
R7																			
R8																			
R9																			
R10																			
R11																			
R12																			
R13																			
R14																			
R15																			
R16																			
R17																			
R18																			
R19																			
R20																			
R21																			
R22																			
R23																			
R24																			
R25																			
R26																			
R27																			
R28																			
R29																			
R30																			
R31																			
R32																			
R33																			
R34																			
R35																			
R36																			
R37																			
R38																			
R39																			
R40																			
R41																			
R42																			
R43																			
R44																			
R45																			
R46																			
R47																			
R48																			
R49																			
R50																			
R51																			
R52																			
R53																			
R54																			
R55																			
R56																			
R57																			
R58																			
R59																			
R60																			

NPT=0	R1 Acceptable Risk	R3 Inadmissible Risk	R2 Tolerable Risk	R4 Unacceptable Risk
-------	--------------------	----------------------	-------------------	----------------------

Table 7 SWOT analysis for NPT

<p><i>Strengths</i></p> <ul style="list-style-type: none"> -Presence of written NPT report -Ability to change and improve -Availability of multiple communication channels -Presence of preventive plans -Good supportive team -Ability to work hard 	<p><i>Weaknesses</i></p> <ul style="list-style-type: none"> -Stop operation -Omitting investigation reports -Excessive lost time -Bad communications -Reactive culture -Low commitment -Shortage of money and cash -Improper data handling -Poor personnel behavior -Poor work environment -Risk of losing reputation
<p><i>Opportunities</i></p> <ul style="list-style-type: none"> -Possibilities of changing drilling program -Evaluating service companies -Possibility of changing tools and equipment -Good client relationship -Chance for improving rig performance -Chance of improving safety behavior 	<p><i>Threats</i></p> <ul style="list-style-type: none"> -Repeated downtime -Risk of losing contract -Delay in paying bills -Fluctuating oil market

However, in this paper, the recommendations for the critical and unacceptable risks are only presented for the drilling operation, shown in Table 8, which gives the main reasons of the NPT and the proposed mitigation action for risk control.

The implementation of the risk control measures depends on the cost of mitigation which should be ALARP (as low as reasonably practical): lower than the benefit resulting for the risk reduction.

Conclusions

1. The approach of risk assessment helped evaluates rig performance, a necessary step prior to know what and where to improve.
2. Java software model was developed to estimate the probability of the undesired events for the NPT during 1 year

of operation for 60 onshore rigs. The model was used to define the highest and lowest probability of the NPT per each NPT category in the drilling operations of all 60 rigs. Such calculation would have been otherwise tedious.

3. The results after applying the model made possible the integration of risk management concepts into the NPT analysis process; such treatment of data has facilitated the development of Rig-NPT Risk Matrix.
4. The inclusion SOWT analysis was helpful for generating sets of case-by-case recommendations that can be extended to NPT incidents in order to improve the rig performance.

Finally, integrating risk management concepts in the NPT analysis introduces uncertainty, represented by the probability parameter, which defines priorities for NPT control.

Table 8 Mitigation actions and risk control recommendations for the NPT of the drilling operation

No.	Activity	Reasons of the NPT	Recommendations/mitigations actions
1	Picking up and laying down drill pipe using the lay down machine	<ul style="list-style-type: none"> -In some cases, workers were standing between pickup machine and fixing arm. That caused few accidents which led to NPT -Stuck of the lifting wire with roller, caused stop movement for the wire and leaded to NPT -Fall of drill pipe from lifting machine (high speed movement or imbalance) -In some cases, workers were standing in the disconnecting- drill- pipe area. That caused few accidents which led to NPT 	<ul style="list-style-type: none"> -Job safety analysis should be reviewed before commencement of task -Proper Personal Protective Equipment (PPE) to be worn -Impact gloves must be worn -The workers should not stand between the tubulars rolling on the pipe racks -Proper lifting equipment should be used when lifting tubing/drill pipe -Unnecessary or unauthorized personnel should not be standing in the work area -Allow buffer zone to be in place. The personnel (owner, contractor, third party, etc.) have to follow the instruction -Follow rig safety procedures -Distribute safety alerts between the workers -Keep safe distance from the drill pipe during the unlatching operation -Use proper tools -Check the tools (power tong, power unit) before the job -Review job safety analysis procedures -Use correct PPE -Have a good communication between the workers to avoid any accident -Shale shaker operator to wear H2S personal monitor -Notify the driller immediately If any abnormal high returns come over shale shakers -The area around the shale shaker should be kept clean and clear -Test H2S alarm and make H2S drill -Do not stand on the catwalk when objects are being picked up and laid down -Stand behind the barrier area -Keep fingers clear of pinch point -Wear correct PPE (impact gloves) -Have good communication system in place between workers -Set barrier tape around the area of operation to isolate it -Follow the buffer zone procedures -Ensure that correct mud properties and treatment are used as programmed -Ensure good mud properties while testing and analyzing the returned mud from the shale shaker -Review the drilling plans before spudding -Conduct pre-job safety meeting and Job Safety Analysis before starting the job -Wear proper PPE prior starting the job -Stay away of the line of the swing hammer -Maintain good communication between crew members at all time
2	Making up or lay down bottom hole assembly	<ul style="list-style-type: none"> -Lack of concentration caused few accidents for the workers: finger and hand injury due to miss use of equipment -Over torquing equipment caused stuck pipe -Drill pipes fall down from the V-door 	
3	Changing tong dies	<ul style="list-style-type: none"> -Miss use of the tong dies caused personnel injuries, led to NPT -The dies of the tong were not properly fixed, caused falling of objects from tongs -The presence of over torque in the tongs caused flying of objects or pieces 	
4	Shale shaker operations	<ul style="list-style-type: none"> -Chemical burns -Hands injury due to mechanical movement of the shale shaker -Inhalation of H2S (in mud or cuttings) 	
5	Catwalk and pick up operations	<ul style="list-style-type: none"> -Miss use of the lifting equipment caused personnel injuries. That led to NPT -Cases of workers standing between two moving parts -Miscommunications between workers caused a delay or accident which led to NPT 	
6	Drilling operations- plan	<ul style="list-style-type: none"> -Borehole instability due to hole collapse, caving-in, stuck pipe, down time 	
7	Using sledge hammer and hammer wrench	<ul style="list-style-type: none"> -Miss use of the hammer caused finger and hand injury -Broken hammer handle caused hand injury 	

Funding The authors received no specific funding for this work. The study was unfunded.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Barakat MB (2018) Contribution of risk management to rig performance improvement: application to the analysis of drilling non-productive time (NPT). M.Sc. Thesis, Cairo University, Giza, Egypt
- Bradley WB, Jarmen D, Plott RS et al (1991) A task force approach to reducing stuck pipe costs. In: Presented at the SPE/IADC drilling conference, Amsterdam, Netherlands, 11–14 March. SPE-21999-MS. <https://doi.org/10.2118/21999-MS>
- Dew LL, Childers MA (1989) MODU drilling rig downtime: an objective analytical approach. In: Presented at the SPE/IADC drilling conference, New Orleans, Louisiana, USA, 28 February–3 March. SPE-18665-MS. <https://doi.org/10.2118/18665-MS>
- Estes JC (1971) Selecting the proper rotary rock bit. JPT 23(11):1359–1367. <https://doi.org/10.2118/3717-PA>
- Everage JM, Altizer S, Veloz J et al (2011) An aggressive approach to reducing failure-driven non-productive time in onshore drilling operations: expanding the quality program. In: Presented at the SPE/IADC drilling conference and exhibition, Amsterdam, The Netherlands, 1–3 March. SPE-140305-MS. <https://doi.org/10.2118/140305-MS>
- Gala DM, York P, Pritchard DM et al (2010) Drilling hazard mitigation technologies key in eliminating non-productive time in challenging wells. In: Presented at the SPE oil and gas india conference and exhibition, Mumbai, India, 20–22 January. SPE-129030-MS. <https://doi.org/10.2118/129030-MS>
- Hernandez CI, Torres R (2011) KPI drilling database. drilling process synergy achieved through a systematic & analytic approach. In: Presented at the 2011 AADE national technical conference and exhibition, American Association of Drilling Engineers, Houston, Texas, 12–14 April. AADE-11-NTCE-77. <https://pdfs.semanticscholar.org/ab10/399f3fb98954514d33d2bbde968a1bb85737.pdf>
- Hurtado M, Redlinger T (2016) Repurposing proven HSE techniques for use outside safety reduces non-productive time (NPT) and improves drilling efficiency—a case study on application of “chronic unease” to improve drilling quality. In: Presented at the IADC/SPE drilling conference and exhibition, Fort Worth, Texas, USA, 1–3 March. SPE-178836-MS. <https://doi.org/10.2118/178836-MS>
- Kadaster AG, Townsend CW, Albaugh EK (1992) Drilling time analysis: a total quality management tool for drilling in the 1990's. In: Presented at the SPE annual technical conference and exhibition, Washington, USA, 4–7 October. SPE-24559-MS. <https://doi.org/10.2118/24559-MS>
- Khalaf F, Abu El Ela M (2008) The risk management process—an overview. In: Presented at the SPE international conference on health, safety, and environment in oil and gas exploration and production, Nice, France, 15–17 April. SPE-111580-MS. <https://doi.org/10.2118/111580-MS>
- Main B (2006) The basics of risk assessment. In: Presented at the ASSE professional development conference and exposition, Seattle, Washington, 11–14 June. ASSE-06-544E
- Pareto V, Page A (1971) Translation of manuale di economia politica “manual of political economy”, A.M. Kelley. ISBN 978-0-678-00881-2
- Perez FE, Sanguino JE, Cumana J (1990) The development of the furial field with innovative drilling framed within the philosophy of improvement of quality of work. In: Presented at the SPE/IADC drilling conference, Houston, Texas, 27 February–2 March. SPE-19932-MS. <https://doi.org/10.2118/19932-MS>
- Tibiletti M, Mohamed O, Toubar E (2004) Reducing NPT (non-productive time) in deepwater subsea high rate wells—a field case history. In: Presented at the offshore technology conference, Houston, Texas, 3–6 May. OTC-16625-MS. <https://doi.org/10.4043/16625-MS>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations