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Development of Guidelines for Improving Well Logging Operations Based on Technical Risk Assessment

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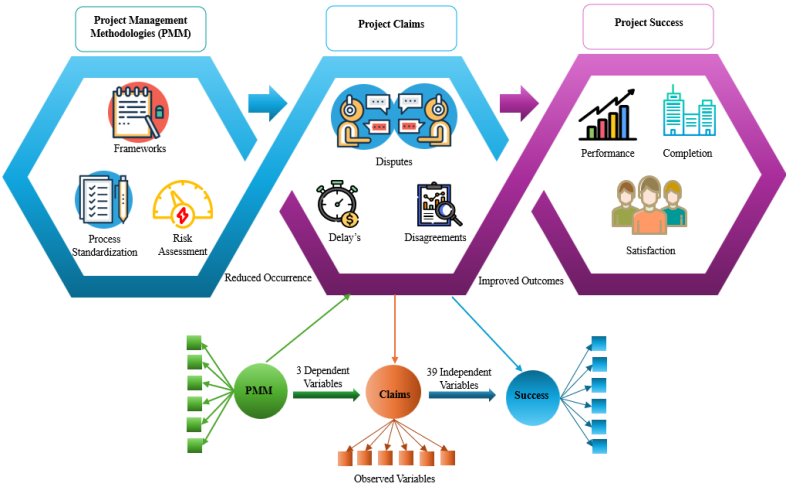
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A B S T R A C T

Well logging operations are among the most critical activities in the oil and gas industry, providing essential subsurface data for estimating and evaluating reservoir rock and fluid properties. These operations are inherently exposed to a wide range of technical and non-technical risks that may adversely affect operational safety, environmental protection, and overall efficiency. Systematic assessment of technical risks, combined with appropriate operational guidelines, can improve the performance of well logging activities, mitigate associated risks, and reduce potential operational costs. The primary objective of this study is to identify and assess risks associated with well logging operations and propose appropriate risk response and management strategies. Using the group Brainstorming technique, a panel of experts from the Central Iranian Oil Fields Company, Pars Oil and Gas Company, and Khazar Exploration and Production Company identified, evaluated, and classified the major risks associated with well logging operations. Based on expert consensus, practical mitigation measures were developed. The key recommendations include establishing standardized well logging contracts within the National Iranian Oil Company under the supervision of representatives from its subsidiaries, facilitating the participation of internationally recognized oilfield service companies in competitive bidding processes, allocating annual well logging operations among multiple qualified service providers, and developing an integrated guideline for well logging data acquisition and quality assurance. The proposed framework provides practical guidance for improving operational reliability, reducing technical risks, and enhancing the effectiveness of well logging operations in the oil and gas industry.



1. Introduction

Well logging, also referred to as wireline logging, is a continuous process of acquiring and recording detailed information about subsurface geological formations through drilled wells. These operations are conducted throughout the entire life cycle of a well, including the drilling, cementing, production, and abandonment stages. Well logging provides continuous measurements of reservoir characteristics, enabling comprehensive evaluation of hydrocarbon-bearing formations. By employing a variety of logging techniques, valuable information regarding the physical properties of the reservoir including

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lithological characteristics, petrophysical properties, and the distribution of formation fluids is obtained. The resulting datasets, commonly referred to as well logs, constitute essential inputs for reservoir engineering and production engineering analyses. A typical well logging system consists of one or more logging tools (logging sondes) deployed into the wellbore via a specialized wireline cable, together with a logging unit, which may be installed in a mobile logging truck or a permanent surface cabin. The logging sondes contain transmitters and, depending on the measurement principle, receivers for detecting physical responses from the surrounding formations [1]. The measured signals are transmitted to the surface through the wireline cable and processed by electronic acquisition and control systems housed within the logging unit. The significance of well logging lies in its ability to complement information obtained from drilling samples and conventional core analysis. Well logs represent one of the most important formation evaluation technologies and provide continuous subsurface data that are indispensable for integrated reservoir characterization. Without reliable well logging data, comprehensive reservoir studies and numerical reservoir simulation cannot achieve an acceptable level of accuracy or confidence [2] .Unlike conventional coring, which provides physical samples only from selected intervals of the wellbore, well logging offers continuous measurements throughout the entire logged section. Furthermore, well log data can be directly imported into petrophysical interpretation and formation evaluation software, whereas core samples require extensive laboratory testing before meaningful reservoir parameters can be derived and subsequently integrated into reservoir models [3]. Consequently, relying solely on core analysis while disregarding well logging data is neither economically efficient nor scientifically justified. Moreover, technical limitations associated with coring such as core breakage, poor core recovery, or collapse of the core into the wellbore often prevent successful retrieval of representative core samples, further highlighting the indispensable role of well logging in reservoir evaluation [4-6].

Sam et al. [7], in their study entitled "Stochastic Risk Analysis of Well Logging Operations," presented a comprehensive framework for evaluating operational risks associated with wireline logging activities. The authors analyzed stochastic operational risks and their corresponding control measures through a four-stage approach. First, they identified wireline logging operations as a source of three major categories of operational risk arising from hot spark generation by the prime mover, rotating mechanical components, and highly stressed equipment, and proposed new control methods to mitigate these hazards. Second, the complex logging tool system was analyzed based on seven distinct forms of energy to identify potential risk sources. Third, occupational safety risks affecting operational personnel were evaluated by considering workers' awareness and technical competence, as well as workplace conditions, including structural integrity, stability, slip hazards, available working space, noise levels, lighting, and environmental conditions. Finally, logistical aspects of the operation, including transportation, personnel deployment, and equipment handling, were briefly examined to provide a comprehensive assessment of operational risks. Moore et al. [8], in their study entitled “Uncertainty Analysis in Well Log and Petrophysical Interpretations,” investigated uncertainties associated with well logging data and petrophysical interpretation. The authors emphasized that petrophysical analysis plays a critical role in reservoir studies because it provides the primary input data required for formation identification and resource evaluation. Typical petrophysical input parameters used in reservoir studies are not directly measured by well logging tools; rather, they are generally derived through a series of processes, including data acquisition, processing, interpretation, and calibration. Since each of these stages involves inherent uncertainties, the resulting petrophysical data are subject to various sources of uncertainty and limitations. The study examined common uncertainties associated with the interpretation of key petrophysical variables derived from well log data. The authors emphasized that uncertainties arising from well log acquisition and petrophysical interpretation should be systematically analyzed, quantified, and explicitly communicated to the integrated reservoir study team so that they can be appropriately considered in reservoir characterization and modeling.

Ali Jirjis and Abdulaziz [9], in their study entitled "The Impact of Uncertainty in Petrophysical Data and Fluid Properties on Well Test Interpretation: An Application to the West Qurna Oil Field, Southern Iraq," investigated the influence of uncertainties in well log interpretation on well test analysis. Well log and well test data from three wells were comprehensively analyzed using petrophysical interpretation software and KAPPA 2016 to evaluate reservoir properties and quantify the impact of uncertainties in petrophysical parameters on well test interpretation. The findings demonstrated that the accuracy of reservoir petrophysical characterization plays a critical role in well test analysis, as uncertainties in petrophysical properties can significantly alter the estimated reservoir parameters and consequently affect the predicted well performance.

2. Materials and Methods

The present study is classified as an applied-developmental research in terms of its objective, as its findings can support managers and decision-makers in the oil and gas industry. Regarding the data collection method and research implementation approach, this study follows a descriptive-survey methodology. It is descriptive because the researcher collects data to examine research assumptions and describe the investigated phenomena. It is considered a survey study because a specific group of experts is requested to respond to structured questions designed for data collection [10,11].

The research methodology consists of the following stages:

2.1. Library Research and Data Collection

In this study, documentary and library-based research methods were employed to develop the theoretical foundations and review previous related studies. Accordingly, relevant books, theses, and scientific articles available in libraries, as well as academic resources published on online databases, were examined. Furthermore, available well logging records, operational reports of logging activities, and petrophysical evaluation reports were analyzed to investigate operational events and assess the impact of incidents occurring during well logging operations on the obtained results. Based on these investigations, the theoretical framework and research structure were developed, and related studies in this field were systematically reviewed.

2.2. Expert Interviews

In addition, data were collected through interviews with two target groups. The first group consisted of well logging operation specialists, who were interviewed to identify and evaluate the risks associated with well logging operations. The second group included petrophysicists, who were consulted to investigate potential risks related to the analysis and interpretation of well logging data. These expert interviews provided complementary information for identifying, categorizing, and assessing operational risks.

2.3. Data Analysis

In this stage, the collected data were analyzed using two risk assessment methods: Failure Mode and Effects Analysis (FMEA) and the Probability–Impact Matrix.

In the FMEA approach, risks were evaluated based on three main criteria: the probability of occurrence, the severity of consequences, and the detectability of failure. Through the development and distribution of questionnaires among experts, numerical values were assigned to each criterion based on predefined evaluation scales. Subsequently, the Risk Priority Number (RPN) was calculated by multiplying these factors, allowing risks to be ranked and prioritized.

In the Probability Impact Matrix approach, a guideline table was developed to assess the likelihood and consequences of each identified risk. Based on expert evaluations, risks were categorized into three levels: low, medium, and high risk. The results obtained from this stage were subsequently used for further risk analysis and response planning.

2.4. Analysis of Model Results

In the FMEA method, after calculating the RPN values, risks were ranked in descending order from the highest to the lowest priority, and appropriate response strategies were developed accordingly. Similarly, in the Probability Impact Matrix method, each risk was classified into a specific category to determine the appropriate management approach.

For high-priority risks, Fault Tree Analysis (FTA) was conducted to identify the root causes and contributing factors. Subsequently, risk response strategies were developed through expert consultations and questionnaire-based evaluations. Depending on the risk level and characteristics, appropriate responses including risk elimination, substitution, control, or acceptance were proposed.

Finally, based on the outcomes of the risk assessment process, operational guidelines were developed to optimize well logging operations. The proposed guidelines can be validated through expert evaluations and feedback from industry professionals to ensure their effectiveness, practicality, and applicability in real operational environments.

One of the most common approaches for risk ranking is the use of the risk probability–impact matrix. In this method, various characteristics of a risk factor are identified, and by establishing relationships among these characteristics, a value is assigned to each risk. For instance, the probability of occurrence, severity of impact, detectability, controllability, and other risk-related attributes can be considered for ranking and comparing identified risks.

These factors, after being assigned appropriate scores, are evaluated using a risk matrix to determine the relative significance and priority of each risk. In the present study, a risk matrix was developed by considering two main characteristics for each identified risk: probability of occurrence and impact severity. By multiplying the probability index by the impact index (in the event of risk occurrence), a new indicator can be calculated, which is used for comparison and prioritization of different risks.

For qualitative risk analysis, the identified risks obtained during the risk identification phase were listed, structured, and evaluated. In this stage, risks were prioritized using a qualitative approach rather than numerical values, and descriptive categories such as low, medium, and high were employed to represent risk levels.

In this method, the risk level can be expressed as a function of probability and

impact:

$$R = f(P, I)$$

The rating scale presented in the following table was developed based on expert judgment and consultation with specialists in the field.

Table 1. Qualitative Risk Rating Scale

Risk Impact	Risk Probability	Scale
0.05	0.05	Extremely Low
0.10	0.10	Very Low
0.1 5	0.20	Low
0.20	0.30	Low to Medium
0.30	0.40	Medium
0.40	0.50	Medium to High
0.50	0.60	High
0.60	0.70	Recurrent
0.70	0.80	Very High
0.80	0.90	Extremely High

Source: Research Findings

3. Results and Discussion

Table Risk Register presents the qualitative risk analysis. As shown, 35% of the identified risks fall within the red zone, 38% are located in the yellow zone, and 27% are within the green zone. Based on the results presented in the following table, several risks, including prioritizing economic evaluation over technical assessment in contractor selection, failure to utilize advanced and up-to-date equipment, non-participation of all qualified companies in the tender process, poor quality of acquired well logs, lack of an integrated guideline for well logging data acquisition, inappropriate project financial estimation (in local currency/foreign exchange), and human errors, were identified as high-priority risks. These risks are considered critical due to their direct impact on the final outcomes of well logging operations and the quality and reliability of acquired data. Therefore, they require particular attention and further detailed investigations to develop effective mitigation strategies and improve the overall performance of well logging operations [12,13].

Table 2. Risk Register

Risk Description	Risk Probability	Risk Impact	Risk Score	Risk Priority Level
Prioritizing economic evaluation over technical assessment of companies	0.8	0.7	0.56	High Priority
Failure to use advanced and up-to-date equipment	0.6	0.5	0.3	High Priority
Non-participation of all qualified companies in the tender process	0.6	0.5	0.3	High Priority
Poor quality of well logs	0.5	0.6	0.3	High Priority
Lack of an integrated guideline for well logging data acquisition	0.7	0.4	0.27	High Priority
Inappropriate project financial estimation	0.5	0.5	0.25	High Priority
Human error	0.4	0.6	0.24	High Priority
Lack of core samples or poor quality of obtained cores	0.7	0.3	0.21	High Priority
Failure to provide financial resources on time	0.7	0.3	0.21	High Priority
Lack of expertise in data interpretation	0.7	0.5	0.2	Medium Priority
Lack of knowledge regarding optimal contract development methods	0.4	0.4	0.2	Medium Priority
Currency fluctuations	0.4	0.4	0.16	Medium Priority
Lack of experience among logging team members	0.3	0.5	0.15	Medium Priority
Project withdrawal due to sanctions	0.3	0.5	0.15	Medium Priority
Failure to calibrate logging tools	0.3	0.5	0.15	Medium Priority
Incorrect data entry	0.2	0.7	0.14	Medium Priority
Incomplete acquired data	0.3	0.4	0.12	Medium Priority
Insufficient training of operation supervisors	0.4	0.4	0.12	Medium Priority
Incompatibility of available software with Iranian reservoirs	0.3	0.3	0.09	Medium Priority
Loss of well due to stuck logging tools	0.1	0.7	0.07	Low Priority
Logging tool sticking in the wellbore	0.2	0.3	0.06	Low Priority
Personnel accidents	0.1	0.4	0.04	Low Priority
Delay in delivery of equipment/relevant personnel to the well site	0.1	0/4	0.04	Low Priority
Lack of coordination with the contractor company	0.1	0.3	0.03	Low Priority
Incorrect and inaccurate reference depth setting	0.1	0.3	0.03	Low Priority
Ineffective communication between operation supervisors and contractor personnel	0.1	0.3	0.03	Low Priority
Prioritizing economic evaluation over technical assessment of companies	0.8	0.7	0.56	High Priority
Failure to use advanced and up-to-date equipment	0.6	0.5	0.3	High Priority
Non-participation of all qualified companies in the tender process	0.6	0.5	0.3	High Priority
Poor quality of well logs	0.5	0.6	0.3	High Priority
Lack of an integrated guideline for well logging data acquisition	0.7	0.4	0.27	High Priority
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Human error	0.4	0.6	0.24	High Priority
Lack of core samples or poor quality of obtained cores	0.7	0.3	0.21	High Priority
Failure to provide financial resources on time	0.7	0.3	0.21	High Priority

Source: Research Finding

4. Conclusion

Considering the high sensitivity and critical nature of well logging operations, the associated risks were identified based on expert judgment, and a risk breakdown structure was developed and categorized into four main groups: operational risks, economic risks, contractual risks, and project management risks. Given the potential consequences of these risks, appropriate mitigation measures should be implemented to improve the reliability and quality of well logging operations. Ultimately, more accurate estimation of in-place hydrocarbon volumes can facilitate more effective planning for hydrocarbon recovery.

Accordingly, the identified risks were evaluated using several risk assessment techniques, including the Risk Register, FMEA, and Fault Tree Analysis (FTA). The results indicated that the following factors were identified as high-priority risks:

- Prioritizing economic evaluation over technical assessment in contractor selection processes;
- Failure to utilize advanced and up-to-date logging technologies;
- Lack of core samples or poor quality of obtained cores;
- Failure to provide financial resources within the required timeframe;
- Inappropriate project cost estimation in both local currency and foreign exchange terms.

In general, appropriate control measures were developed for each identified risk. Risk response strategies can be classified into proactive and reactive approaches. In well logging operations, proactive responses play a significant role in reducing or even eliminating potential risks. Proposed proactive measures include:

- Developing an integrated guideline for well logging data acquisition;
- Conducting pre-operation briefing sessions in the presence of the company representative (Company Man) to explain well conditions and operational requirements;
- Organizing training courses before contract execution;
- Holding coordination meetings prior to the commencement of operations;
- Utilizing advanced international logging tools to prevent inaccurate data acquisition and improve interpretation quality;
- Giving priority to technical criteria rather than purely economic factors in contractor evaluation;
- Establishing a database of similar projects and previous operational experiences;
- Allocating well logging operations among multiple qualified logging companies based on a percentage of annual workload.

Reactive risk responses were also proposed for situations where operational problems occur. These measures include:

- Comparing well logging data with drilling cuttings and core data in cases of poor-quality logging results;
- Conducting meetings with the contractor's financial team to resolve discrepancies in submitted invoices;
- Holding joint meetings with contractors to review and approve progress payment statements;

- Using data from adjacent wells when the quality of acquired logging data is insufficient.

Overall, a significant proportion of improvement initiatives should focus on management-related aspects. The following recommendations are proposed to enhance the effectiveness and reliability of well logging operations:

1. Developing and standardizing well logging operation contracts within the National Iranian Oil Company (NIOC) under the supervision of representatives from each subsidiary company.
2. Creating appropriate conditions to enable participation of internationally recognized oilfield service companies in tendering processes.
3. Allocating well logging operations among several qualified service companies based on a percentage of annual operational activities.
4. Developing an integrated guideline for well logging data acquisition, quality control, and operational procedures.

Author Contributions

All authors contributed equally to the conception, preparation, and writing of this manuscript.

Conflict of Interest

M.A. Hatefi, in the capacity of Editor-in-Chief, had no involvement in the selection of reviewers or the management of the peer-review process, and the other authors, while observing publication ethics in referencing, declare the absence of any conflict of interest.

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AI Used Statment

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