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Implementation of Leading Indicators on K3 Performance in Offshore Oil and Gas Drilling Jack-Up Rig XYZ

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ABSTRACT

The offshore oil and gas drilling industry is a high-risk sector where effective Occupational Health and Safety (OHS) management is critical. This study examines the implementation of leading and lagging safety indicators and their impact on safety and drilling performance aboard Jack-Up Rig XYZ, operating under Saudi Aramco. Using a quantitative approach, the study analyzed 12 months of operational data through Pearson correlation and multiple linear regression. Findings revealed a significant negative correlation between leading indicators (e.g., Safe Observation Cards, audit compliance) and Non-Productive Time (NPT), with higher proactive safety measures corresponding to reduced downtime. However, lagging indicators (e.g., incident rates) showed no significant impact on drilling performance. The regression model explained 91.4% of NPT variation, underscoring the value of leading indicators in predictive safety management. Implications suggest that rig operators should prioritize leading indicators to enhance operational safety and efficiency, though technical drilling metrics like Rate of Penetration (ROP) remain influenced more by geological and engineering factors. This research provides empirical support for integrating proactive OHS measures into daily rig management practices.

Keywords: K3 Performance, Offshore Oil and Gas Drilling

INTRODUCTION

The offshore oil and gas drilling industry is a strategic yet high-risk sector that requires an effective, efficient, and sustainable OHS management system (Asad et al., 2021; Chen & Martens, 2021; Koh & Teh, 2021; Wanasinghe et al., 2024; Yang et al., 2023). The International Association of Drilling Contractors (IADC) is a global organization focused on the oil and gas drilling industry, both offshore and onshore. Founded in 1940, this organization plays a key role in establishing standards and guidelines for safety and operational efficiency in the oil and gas drilling industry worldwide (Cąliş & Buÿükakinci, 2019; Fitrijaningsih et al., 2023; Karanikas et al., 2022; Marhavilas et al., 2022; Mohammadfam et al., 2017; Uhrenholdt Madsen et al., 2022).

As one of the largest crude oil producers in the Middle East, Saudi Aramco, in its 2024 annual Upstream Overview report, specifically focusing on the performance of the oil and gas drilling sector, recorded crude oil and condensate production with an average daily production of 12.4 mmboed (2023: 12.8 mmboed). For upstream activities, the average upstream lifting cost in 2024 was 13.24 SAR, equivalent to 3.53 USD per boe produced. This efficiency is achieved through the implementation of fiscal discipline, and the use of state-of-the-art technology, especially for reservoirs located in shallow waters, is also a key advantage.

The implementation of leading and lagging indicators in the OHS management system in the upstream oil and gas industry aims to identify potential hazards, prevent accidents, and evaluate workplace accidents that have already occurred. Leading indicators, such as Toolbox

Talks, Safe Observation Cards, and Emergency Drills, play a crucial role in preventing potential risks through more proactive measures.

On the other hand, lagging indicators are used as benchmarks for past performance. Examples of lagging indicators include TRI, FAC, MTC, LTI, Fatality, and Near Miss. According to IADC data on the 4th Quarter 2024 Rig Incident Statistics Program published on January 21, 2025, there were 4 cases of Fatality in the Middle East Region (3 cases from onshore drilling activities and 1 case from offshore drilling activities). This report also found that the number of workplace incidents (Medical Treatment Case, Restricted Work Case, Lost Time Incident, Fatality) that occurred in the Middle East region was the third highest after America and Africa, as presented in the table below:

Tabel 1. 4th Quarter 2024 of Rig Incident Statistic Program

IADC

International Association of Drilling Contractors
Rotary Rig Incident Statistics Program
2024 Summary Report By Category - YTD
4th Quarter Numbers

Category	Total Manhours	Total MTOs	Total RWTCs	Total LTIs	Total FTLs	Total RCRD	LTI INCD. Rate	LTI FREQ. Rate	DART INCD. Rate	DART FREQ. Rate	RCRD INCD. Rate	RCRD FREQ. Rate
Middle East - Land	120,382,438	23	24	25	3	75	0.05	0.23	0.09	0.43	0.12	0.62
Middle East - Water	72,307,435	14	31	15	1	61	0.04	0.22	0.13	0.65	0.17	0.84
Middle East Combined	**192,689,873**	**37**	**55**	**40**	**4**	**136**	**0.05**	**0.23**	**0.10**	**0.51**	**0.14**	**0.71**

MTO	Medical Treatment Only	INCD = Incident Rate (200,000 manhours)	LTI INCD Rate = (LTIs + FTLs) * 200000 / Total Manhours DART INCD Rate = (RWTCs + LTIs + FTLs) * 200000 / Total Manhours RCRD INCD Rate = (MTOs + RWTCs + LTIs + FTLs) * 200000 / Total Manhours
RWTC	Restricted Work/Transfer Case		
LTI	Lost Time Incident	FREQ = Frequency Rate (1,000,000 manhours)	LTI FREQ Rate = (LTIs + FTLs) * 1000000 / Total Manhours DART FREQ Rate = (RWTCs + LTIs + FTLs) * 1000000 / Total Manhours RCRD FREQ Rate = (MTOs + RWTCs + LTIs + FTLs) * 1000000 / Total Manhours
FTL	Fatality		
RCRD	Total Recordables	DART = Days Away (LTI) cases + Restricted Work/Transfer Cases	

The high number of work accidents, as described above, can be a reflection of the major challenges in maintaining work safety in the high-risk and complex offshore oil and gas drilling industry.

Tabel 2. 4th Quarter 2024 of Rig Incident Statistic Program

IADC

International Association of Drilling Contractors
Rotary Rig Incident Statistics Program
2024 Summary Report By Category - YTD
4th Quarter Numbers

Category	Total Manhours	Total MTOs	Total RWTCs	Total LTIs	Total FTLs	Total RCRD	LTI INCD. Rate	LTI FREQ. Rate	DART INCD. Rate	DART FREQ. Rate	RCRD INCD. Rate	RCRD FREQ. Rate
US Combined	60,604,778	141	103	80	2	326	0.27	1.35	0.61	3.05	1.08	5.38
Canada Combined	9,592,268	0	51	12	0	63	0.25	1.25	1.31	6.57	1.31	6.57
Central America Caribbean Combined	4,793,044	1	9	4	1	15	0.21	1.04	0.58	2.92	0.63	3.13
European Combined	25,336,388	31	25	40	0	96	0.32	1.58	0.51	2.57	0.76	3.79
Africa Combined	56,127,822	42	93	62	0	197	0.22	1.10	0.55	2.76	0.70	3.51
Middle East Combined	192,689,873	37	55	40	4	136	0.05	0.23	0.10	0.51	0.14	0.71
Asia Pacific Combined	29,680,625	8	11	10	0	29	0.07	0.34	0.14	0.71	0.20	0.98
South America Combined	33,395,585	27	16	17	1	61	0.11	0.54	0.20	1.02	0.37	1.83
Australasia Combined	6,154,965	16	11	6	0	33	0.19	0.97	0.55	2.76	1.07	5.36
INDUSTRY TOTAL	418,375,348	303	374	271	8	956	0.13	0.67	0.31	1.56	0.46	2.29

Throughout 2024, approximately 300 rigs operated in Saudi Aramco's work areas. As one of the world's largest oil and gas producers, Saudi Aramco is committed to providing a safe work environment that protects workers, assets, and the environment.

As a practitioner in the field of OHS, the author observes that although various OHS programs have been implemented in accordance with existing standards—both internal policies and international standards—discrepancies still exist between technical implementation and expected results. For example, the high frequency or level of compliance with collected and reported Safe Observation Cards (SOCs) does not always correlate with the absence or reduction of workplace accidents, indicating that the implementation of the leading indicator program requires further review. Furthermore, Non-Productive Time (NPT) data resulting from equipment problems and inadequate maintenance can be a major cause of disruptions to drilling performance.

In a report published by the IADC, efforts to improve OHS culture and operational efficiency are increasingly focused on the use of real-time data and quantitative indicators in decision-making. "In today's offshore operations, safety is not only about zero incidents, but also about leading performance indicators that proactively shape safe behaviors and decision-making" (IADC, 2021). This quote emphasizes the importance of transitioning from a reactive to a proactive approach to OHS risk management.

In this research, Jack-Up Rig XYZ is the primary subject of study. As one of the rigs operating in Saudi Aramco's work areas for the past 12 months, its working environment reflects operational conditions in the Middle East region. The available data, covering various technical drilling parameters such as ROP (Rate of Penetration), Drilling Efficiency, and other OHS data, allow for comprehensive analysis without relying on survey or questionnaire methods, thereby increasing the validity of field data. Several publications from research conducted in the Middle East have shown that over the past 10 years, the effectiveness of implementing OHS indicators has increased, significantly contributing to operational performance. Al-Busaidi et al. (2018) revealed that a positive relationship between leading indicators and drilling performance outcomes can be clearly seen if these indicators are monitored consistently. The Saudi Aramco Safety Report (2020) reported that senior management involvement had a real and significant impact on reducing LTI rates by up to 23%.

In its reference publication, the IADC Guidelines[A1] for Safety Performance Indicators emphasize that "Proactive indicators must be closely linked to reactive results to measure continuous improvement effectively" (IADC, 2022). The 2021 HSE Benchmarking report states that aligning OHS indicators with operational KPIs is crucial to creating a sustainable OHS culture (Saudi Aramco, 2021).

This study is expected to provide a deeper understanding of the effectiveness of implementing OHS indicators in offshore oil and gas drilling activities, specifically on Jack-Up Rig XYZ operating in Saudi Aramco's work areas and under Saudi Aramco's supervision. As practitioners directly involved in Jack-Up Rig XYZ operations, we have access to actual data, which will provide a strong foundation for an evidence-based approach, so that the results are not only academic but also useful for improving the OHS management system and drilling performance, specifically on Jack-Up Rig XYZ.

METHOD

This study employed a quantitative research approach to empirically examine the relationship between safety indicators and operational performance. The research was conducted using secondary data collected from the actual reporting systems of Jack-Up Rig XYZ, operating in the Saudi Aramco work area. The study population comprised all daily operational, safety, and performance records generated by the rig over a continuous 12-month period. This population included datasets on leading indicators (e.g., number of Safe Observation Cards submitted, audit compliance scores) and [A1] lagging indicators (e.g., recordable incident rates, Non-Productive Time), as well as key drilling performance metrics such as Rate of Penetration (ROP) and overall efficiency.

A census sampling technique was applied, meaning that all available data points from the defined 12-month timeframe were included, resulting in a complete dataset (N=12 months of aggregated data) without the need for selection or omission. This comprehensive approach ensured that the analysis was based on the full spectrum of real-world operational conditions experienced by the rig. The research instruments were not surveys or questionnaires but rather the rig's own integrated real-time dashboard and daily reporting systems, which provided validated and objective metrics for all variables under investigation.

The data analysis techniques involved both correlation and regression analysis. First, Pearson correlation analysis was used to measure the strength and direction of the relationships between leading indicators, lagging indicators, and drilling performance. Subsequently, multiple linear regression analysis was employed to build predictive models and test the hypotheses, determining the extent to which variations in safety indicators (independent variables) could explain variations in performance outcomes like NPT and ROP (dependent variables). The analysis was conducted using statistical software, with results deemed significant at a p-value of less than 0.05.

RESULTS AND DISCUSSION

Correlation Test

Pearson correlation analysis shows that several leading indicators have a strong, negative relationship to incident outcomes and drilling efficiency. The highest correlation values were found between:

Table 3. Correlation Test

Correlations		Lagging Indicator	Leading Indicator	Kinerja Drilling
Lagging Indicator	Pearson Correlation	1	078	-.471
	Sig. (2-Tailed)		.809	.122
	N	12	12	12
Leading Indicator	Pearson Correlation	.078	1	-.633*
	Sig. (2-Tailed)	.809		.027
	N	12	12	12
Kinerja Drilling	Pearson Correlation	-.471	-.633*	1
	Sig. (2-Tailed)	.122	.027	
	N	12	12	12

*. Correlation Is Significant At The 0.05 Level (2-Tailed).

a) Relationship between lagging indicators and drilling performance

The table below shows a correlation analysis between three variables: the Lagging Indicator, the Leading Indicator, and Drilling Performance. The Lagging Indicator has a very weak positive correlation with the Leading Indicator (0.078), indicating that changes in the Lagging Indicator have little to no effect on the Leading Indicator.

The Lagging Indicator includes incidents such as LTI, HiPo, TRI, and Near Miss that have already occurred. In the correlation test, the Lagging Indicator showed a negative relationship with drilling performance with an r value of -0.471, but it was not statistically significant ($p = 0.122$). Practically, this indicates that while an increase in the number of incidents typically impacts drilling operations, in the context of Rig XYZ data over the past 12 months, this relationship is not strong. This may be due to the relatively small and controlled number of lagging incidents (only a few minor cases), which are not sufficient to substantially impact the final technical results such as ROP or delivery time.

b) Relationship between leading indicators and drilling performance

Correlation analysis shows a strong and significant negative relationship between leading indicators and drilling performance ($r = -0.633$, $p = 0.027$). This value indicates that better implementation of proactive indicators such as Safe Observation Cards, safety training, HSSE audits, and toolbox talks tends to improve drilling performance (in the context of faster drilling times and reduced NPT).

The negative correlation here reflects that higher leading indicators are associated with lower NPT or downtime, resulting in improved drilling outcomes. This is an important finding because it supports the assumption that investments in proactive safety systems have a direct effect on operational efficiency.

c) Relationship between leading and lagging indicators

The correlation between leading and lagging indicators showed an $r = 0.078$, with a $p = 0.809$, indicating an inverse relationship between the two.

Overall, the results of this analysis confirm that leading indicators have a clearer influence on drilling performance than lagging indicators, which did not show a significant relationship. The significant negative correlation between leading indicators and drilling performance indicates that increases in leading indicators, which often reflect problems or delays in the process, can potentially harm drilling efficiency and effectiveness. This indicates that better management of leading indicators can be a critical step in improving drilling performance.

By focusing on managing leading indicators, companies can identify and address potential operational issues before they become more serious. For example, implementing further training programs, improving communication between teams, and strengthening work procedures can help reduce lagging indicators and, in turn, improve drilling performance. Furthermore, continuous monitoring of leading indicators can provide valuable insights for management to make better and faster decisions. By mitigating the risks associated with leading indicators, companies can not only improve drilling performance but also optimize overall operational efficiency, ultimately increasing the profitability and long-term sustainability of drilling operations. Therefore, emphasizing leading indicator management is crucial to achieving higher operational goals and mitigating potential negative impacts.

Multiple linear regression test

Partial F-test / Multiple Linear Regression Test

Table 3. Partial F-test / Multiple Linear Regression Test

ANOVA[a]						
Model		**Sum of Squares**	**1. Df**	**Mean Square**	**2. F**	**3. Sig.**
1	Regression	92.616	2	46.308	6.216	.020[b]
	Residual	67.051	9	7.450		.
	Total	159.667	11		.	.

a. Dependent Variable: Kinerja Drilling

b. Predictors: (Constant), Laging indicator

The table below shows the results of the F-test (Partial) for a multiple linear regression model involving the Legging Indicator and Lagging Indicator variables with Drilling Performance as the dependent variable. The Sum of Squares value for the regression is 92.616, reflecting the total variation that can be explained by the model, while the value for the residual is 79.667, indicating unexplained variation. The degrees of freedom for the regression is 1, while for the residual is 12. The average variation that can be explained by the model (Mean Square) is 46.308, while for the residual is 7.450. The calculated F-value of 6.216 indicates the ratio between explained and unexplained variation. In addition, the significance value (p-value) of 0.020 indicates that the overall regression model is significant at the 0.05 level, meaning there is a significant relationship between the independent and dependent variables. Thus, the results of this analysis confirm that the multiple linear regression model constructed has a significant ability to explain variations in Drilling Performance, indicating that leading and lagging indicators contribute significantly to that performance.

Simultaneous t-Test / Multiple Linear Regression Test

Table 4. Simultaneous t-Test / Multiple Linear Regression Test

Coefficients[a]						
		Unstandardized Coefficients		**Standardized Coefficients**		
Model		**B**	**Std. Error**	**Beta**	**T**	**Sig.**
1	(Constant)	19.581	3.868		5.062	.001

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
	Leading Indicator	-5.876	2.121	-.600	-2.771	.022
	Lagging Indicator	-.811	.414	-.424	-1.958	.082

a. Dependent Variable: Kinerja Drilling

The table below shows the results of a multiple linear regression test involving leading and lagging indicators, with Drilling Performance as the dependent variable. The regression coefficient for the constant is 19.581, meaning that if both independent indicators are zero, Drilling Performance is predicted to be 19.581. For the lagging indicator, a coefficient of -0.811 indicates that every one-unit increase in the lagging indicator reduces Drilling Performance by 0.811, indicating a negative impact of the lagging indicator on performance. Meanwhile, for the leading indicator, a coefficient of -5.876 indicates that every one-unit increase in the leading indicator reduces Drilling Performance by 5.876, indicating a greater impact than the lagging indicator.

The significance value for the lagging indicator is 0.182, which is greater than 0.05, indicating that its effect is not statistically significant on Drilling Performance. However, the significance value for the leading indicator is 0.001, which is well below 0.05, indicating a statistically significant effect. This confirms that leading indicators have a more substantial and relevant contribution to drilling performance than lagging indicators. Overall, the results of this analysis indicate that, within the context of this regression model, greater attention needs to be paid to leading indicators to improve drilling performance.

Multiple linear regression test for the dependent variable NPT against two leading indicators: SOC and HSSE Audit Compliance

a) Regression model;
   NPT = 96.48 – 0.0137 x SOC – 83.07 x Audit
b) So;
   - Every 1 unit increase in SOC/day → decreases NPT by 0.0137 hours/month
   - SOC has a negative coefficient: every 1 unit increase in SOC/day → decreases NPT by ±0.0137 hours/month.
   - A 1-unit increase in audit score (from 0.80 to 0.81, for example) → decreases NPT by 83.07 hours
   - Audit compliance shows a very large impact: a 1-unit increase in audit score (for example, from 0.90 to 0.91) → decreases NPT by ±83 hours.
   - $R^2 = 0.914$ → the model explains 91.4% of the variation in NPT
   - $R^2 = 0.914$ → the model explains 91.4% of the variation in NPT, indicating a strong and significant relationship.
   - Rigs that perform SOC auditing and reporting in a disciplined manner have significantly better downtime performance.

Multiple linear regression test for the ROP (Rate of Penetration) variable against SOC and HSSE Audit Compliance

a) Regression model
   ROP = 44.76 – 0.0185 x SOC + 0.0843 x Audit
b) So;
   - The relationship between SOC and ROP is negative but very weak.
   - Audit compliance tends to increase ROP, but the effect is small.
   - R^2 = 0.019 → the model only explains 1.9% of the variation in ROP, meaning this indicator is less relevant to ROP outcomes.
   - ROP as a drilling parameter cannot be significantly predicted by SOC and audits, as it is more influenced by formation techniques, bit conditions, and mud pump specifications than by OHS factors. This reinforces the view that leading indicators are more effective in influencing safety and time, rather than directly affecting drilling productivity.

Regression Test Results with Research Hypotheses

Main Hypothesis and Partial Hypothetical

a) Main hypothesis
   - Hypothesis 1 (H_1): There is a significant influence of the implementation of leading and lagging indicators (X_1 and X_2) on work safety performance (Y_1).
   - Hypothesis 2 (H_2): There is a significant influence of the implementation of leading and lagging indicators (X_1 and X_2) on drilling performance (Y_2).
b) Partial hypothesis
   - H_1a: Safe Observation Cards (SOC) influence the number of incidents and NPT
   - H_1b: Audit compliance influences work time efficiency
   - H_2a: SOC and audit implementation influence ROP improvement

The results of the testing of leading and lagging indicators against the NPT, based on the results of previous regression;

NPT = 96.48 – 0.0137 x SOC – 83.07 x Audit

a) The coefficient values for SOC and audit are both negative, indicating the direction of the influence as initially expected.
b) The R^2 value is 0.914, meaning that 91.4% of the variation in NPT can be explained by the SOC and audit indicators.
c) The p-values for both variables (calculated previously) indicate that the effect is statistically significant ($p < 0.05$).
d) Conclusion: H_1 is supported by the data. The implementation of leading indicators has a significant impact on improving safety performance, particularly in reducing Non-Productive Time (NPT). This supports the Saudi Aramco Safety Indicator Framework, which states that proactive indicators such as training, audits, and observations can be used as early predictors of rig safety and productivity (Saudi Aramco, 2021).

Results of testing leading and lagging indicators on ROP. Second regression model:

ROP = 44.76 – 0.0185 x SOC + 0.0843 x Negative SOC Coefficient audits are very small, while positive audits are very weak.

a) The R^2 value is only 0.019, meaning only 1.9% of the variation in ROP can be explained by SOC and audit indicators.

b) Conclusion: H_2 is not fully supported by the data. Although leading indicators play a role in maintaining safety and time efficiency, their impact on drilling technical productivity (such as ROP) tends to be insignificant. Technically, ROP is more determined by: the geological conditions of the well formation, the type of drill bit (bit), mud pressure and flow, and other technical configurations such as Weight on Bit, Rotations Per Minute (RPM), and flow rate.

Regression Test Results with Research Hypothesis, Main Hypothesis and Partial Hypothesis:

a) Main hypothesis

Hypothesis 1 (H_1): There is a significant effect of the implementation of leading and lagging indicators (X_1 and X_2) on occupational safety performance (Y_1).

b) Partial hypothesis

H_1a: Safe Observation Cards (SOC) influence the number of incidents and NPT

H_1b: Audit compliance influences work time efficiency

H_2a: SOC and audit implementation influence ROP improvement. Implications of this study for fieldwork practices

These results provide two conclusions directly related to fieldwork practices, particularly for offshore oil and gas drilling activities such as the XYZ Jack-Up Rig.

a. Leading indicators are highly effective in controlling time and incident risks and can be used as indicators of the success of safety management system (HSE-MS) implementation. The implications of these findings suggest that companies should focus more on strengthening and monitoring Leading Indicators at every operational stage. With consistent implementation, companies can increase safety awareness among workers, reduce unwanted incidents, and ultimately improve operational efficiency. This will not only contribute to team safety but can also reduce incident-related costs and improve the company's reputation in a highly competitive industry.

b. Second, technical drilling performance, such as Rate of Penetration (ROP), should be analyzed separately, taking into account rig technical variables, geology, and applied engineering practices. The implications of this study suggest that a holistic approach to technical performance analysis is crucial. Companies should develop methodologies that allow for an in-depth evaluation of factors influencing ROP, including geological conditions and the drilling techniques used. By conducting a more detailed analysis, companies can identify areas for improvement and optimize the applied drilling techniques, thereby increasing efficiency and productivity in the field.

Overall, the results of this study encourage companies to adopt a more strategic approach to managing safety and technical performance in the field. By strengthening safety management systems and conducting in-depth analysis of technical performance, companies can not only improve operational results, but also create a safer and more sustainable working environment..

CONCLUSION

There is a significant relationship between leading indicators and drilling performance, with a significance value of 0.001, indicating that an increase in leading indicators contributes

substantially to improved operational outcomes through reduced Non-Productive Time. Meanwhile, lagging indicators do not show a significant effect on drilling performance, with a significance value of 0.182. The coefficient of determination (R^2) of 0.580 indicates that 58% of the variation in drilling performance can be explained by the tested independent variables, confirming that the regression model has good explanatory power for the factors influencing performance, although 42% of the variation may be influenced by other variables not included in the analysis. The F-test results show that the overall regression model is significant with a p-value of 0.020, indicating that the combination of both indicators can effectively explain variation in drilling performance. Overall, this study emphasizes the importance of focusing on leading indicators in drilling practices to improve operational performance, as well as the need for further analysis of other factors that may contribute to the results obtained. The integration of OHS indicators into the management system is demonstrated as a strategic step that can support work efficiency and safety in the field. Based on these findings, it is recommended that rig operators prioritize the systematic implementation and monitoring of leading safety indicators, establish real-time dashboards for proactive safety management, and conduct regular training programs to enhance the effective ness of safety observation programs. Future research should explore the influence of additional variables such as weather conditions, equipment age, and crew experience levels to provide a more comprehensive understanding of drilling performance optimization.

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