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Indicators as Early Warning Signal Performance to Solve Underlying Safety Problem before They Emerge as Accident Risks

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***Abstract*—**Because of the severe hazards that substantially impact workers' lives and assets lost, the oil and gas industry has established a goal of establishing zero occurrences or accidents in operations. Using leading indicators to measure and assess an organization's safety performance is a proactive approach to safety management. Also, it will provide early warning signals to solve inherent safety issues before they lead to an accident in the study industry. The analysis of these indicators' performance was based on a questionnaire-based methodology. A total number of 1000 questionnaires were disseminated to the workers, of which 327 were returned to the researcher team. The data collected were analysed to evaluate their safety perceptions on indicators performance. Data analysis identified safety training, safety system, safety supervision, safety rules and procedures, safety auditing, strategies and policies, management commitment, safety meeting and safety behaviour, as potential leading indicators that are capable of measuring organizational safety performance and as capable of providing early warning signals of weak safety area in an operational environment. The findings of this study have provided safety researchers and industrial safety practitioners with helpful information on the improvement of the existing safety monitoring process in the oil and gas industry, both locally and globally, as proactive actions.

***Keywords*—**Early warning, safety, accident risks, oil and gas industry.

I. Introduction

THE term "accident" indicates that no one is to blame; the occurrence could have been caused by risks or hazards that were not detected or appropriately handled. Furthermore, some researchers who investigate an unintentional injury, avoid using the term "accident" and instead focus on factors that raise the likelihood of severe injury and those that minimize the risk of severe injury [1]. On the other hand, the identification and management of early warning signals might assist the oil and gas industry in lowering the possibility of an accident occurring during their operations [2], [3].

Early warning signals are "a set of capabilities for producing and disseminating timely and useful warning information." [2]. The term "early" refers to the time before a weak signal becomes strong while an action taken can be eliminated the hazard or the impact of its consequence. A communication protocol or an event that warns that something wrong is happening might serve as a cautionary called "Warning." For example, the alarm system in the plant or site operating workers could send out a warning signal [2]-[4].

However, transmitting a signal to end-to-end connections, to those who are competent enough to identify the potential hazard from the information produced is of crucial importance as providing information on safety barriers and unsatisfactory performance to prevent a potential incident [5]. Still, physical or engineered systems and human activities led by procedures or organizational goals can operate as safety barriers. Hazards must be avoided, controlled, or mitigated by these measures [6]. An indicator associated with the manifestation of unwanted incidents could be an early warning signal outcome based on actual operational safety performance [7]. Early warning signals are also crucial in reducing the risks associated with process activities and the operational environment [8]. Some hazards have short warning times, which may be insufficient for preventative action at hazardous sites; e.g. an overfilled fuel (gasoline) storage tank at the Buncefield oil storage facility in 2005 in the United Kingdom was caused by the breakdown of an automatic tank measuring system. The alarm, for example, was sending signals to control systems, which was thought to be interfering with the other factors and was neglected by the workers [9], [10].

Furthermore, accident in the Gulf of Mexico in 2010 by British Petroleum occurred as a result of incorrect cement slurry instability and drilling equipment not properly sealed. The risk of a blowout in the well is ignored [11]. Another accident in Ukraine, Chernobyl nuclear disaster in 1986 was caused as a result of failure of the safety valves' inability to work with backup generators and transport water to cool the system in the case of a power outage. Additionally, the overheating of the plant is typical case of an early signal in terms of operational function. The same instance demonstrates the operational existence of warning signals. Furthermore, there are no clear instructions, and the young inexperienced senior engineer had only been in this post for three months [12].

Piper Alpha's accident in 1988 had such a significant human and social impact that it triggered an extensive and detailed public inquiry, leading to Cullen's popular report in 1990 [13]. The Piper Alpha incident prompted many to investigate the root cause. They discovered that the engineer on the duty failed to complete the work permit before going to the control room to make changes to the operations [3]. According to [14], lack of process safety analytical capabilities, safety management

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systems with insufficient control over potentially hazardous processes, and disadvantages of the current safety metaphors, models, and theories were some of the reasons for catastrophic disasters in high-risk industries in the 1970s and 1980s. However, workers in high-risk tasks and sectors need to be alert at all times in monitoring the signals of their operational facilities and the environment.

In the case of the Nigerian oil and gas industry, from 2009 to 2010, over 100 workers died in occupational accidents. The industry lost billions of dollars in investment [15]-[17]. However, the loss of human lives is unacceptable no matter how high the financial cost is. The K.S. Endeavour Explosion in 2012 was one of the two accidents in Nigeria's oil and gas industry [18] and the NPDC Gbetiokun oil field explosion in 2020 [19]. The industry has made contributions to the country's energy and financial needs. Developing preventative steps to prevent future accidents that will harm the country's and the population's well-being is necessary [20].

Using early warning signals as leading indicators will help reduce accident risk in the industry. Leading indicators can be defined as proactive, preventive, and predictive measures that provide information about the effectiveness of performance safety activities. It might also help an organization's attitudes and beliefs about safety and become an added value to the establishment of positive safety culture within the organization [21]. This research aims to:

- Investigate the performance of individual leading indicators
- Explore the relationships between leading indicators in the operational environment

II. An Overview of Indicators in the Oil and Gas Industry

The exploration, transportation, and processing of highly flammable or explosive materials are part of the processes in the oil, gas, and petrochemical industries. Explosions, fires, electrocution, chemical leaks, and other situations necessitate rigorous adherence to all safety precautions as well as the construction of advanced warning and notification systems [2], [8]. Many terms are used to indicate such indicators in operations, such as countermeasure, warning signals, management performance [22], [23]. However, these terms allude to physical or non-physical methods for preventing, controlling, or mitigating unwanted events or accidents [24].

According to [25], an indicator is a “measurable or operational variable, used to characterize the situation of event or feature of reality”. The level of safety in operational activity, on the other hand, is a condition of a high-occurrence event. Indicators are used to determine how safe a situation is, such as events, barriers, operational activity and safety programs [2]. Furthermore, potential accident cases could be identified in order to promote the deployment of suitable safety measures to address underlying safety issues before they come accident risks in the industrial level and plant operational unit level [26]-[29],[30]-[34]. For example, America Rockwell [35], [36] set out to create a set of indicators that were predictable, quantitative, and easy to grasp to track safety performance. In addition, the indicators should be dependable, reliable, change-sensitive, and cost-effective. Furthermore, the following are examples of indicators utilized by Rockwell in 1959 [35], [37]: working with loose tools underfoot, working without eyewear when required, working under suspended loads, failing to use guards as given, working in unsafe postures, wearing inappropriate or loose clothing, using shock instruments with mushroomed heads, inventing dangerous ladders and platforms, running, and misusing an air hose are known as unsafe act safety indicators. However, indicators exist in two main types; occupational and process. Accidents in the past, such as the Macondo Blowout in 2010 [28], [33], [37]-[39], demonstrate that occupational indicators are mainly for measuring injuries and illnesses. As a result, the indicators cannot track or monitor process risk changes. Furthermore, several strategies, such as leading and lagging indicators, are used to distinguish process safety indicators. However, this study is more concerned with leading indicators, considered more proactive on accident and risk prevention.

III. Leading Indicators

Leading indicators are indicators that monitor risk activity and quantify potential contributing circumstances to an event. Implementing leadership actions, practices, and initiatives and improving the operational environment and safety performance are among safety leading indicators [40], [37]. Audits, environmental and safety compliance, training, and worker perception surveys are leading indicators. Additionally, leading indicators benefit from being proactive; they report what people or organizations are doing to avoid incidents or improve the working environment. They can act as early warning systems by allowing risks or potential failures to be recognized and controlled before a disaster occurs [41].

Leading indicators, for example, would track the number of audits or training initiatives/sessions undertaken over time rather than merely reporting events while lagging indicators where audit procedures are implemented, and failure or improvement chances are found and addressed. Furthermore, safety procedures, accessibility, safety training programs, toolbox meetings, work procedures corrections, transfer of shifts, safety policy and safety communications, safety documentation, operational processes, correctness/availability, safety observations behaviour, unsafe situations and positive feedback are among the leading indicators [20], [40], [42]-[48]. Furthermore, there are two types of leading indicators: passive and active leading. Review and contract conditions requiring subcontractors to follow a site-specific safety policy or program are passive leading indicators [49]. These operations are unlikely to alter once the project is underway. They can be marked as implemented or not implemented before the process or construction in the oil and gas industry. A binary yes/no response is the most frequent way to enter information for these indicators. The most common example of passive leading indicators is workers' orientation on safety training, reward and safety inspections [49]-[51].

Active leading indicators are practices or observations related to safety that can be measured within the operating process and encourage positive responses. As the project progresses, these active leading indicators can be measured and altered to track and improve safety performance. The percentage of pre-task preparation, meetings attended, and management of random drug testing are all examples of active leading indicators. In addition, it also tracked the regularity of contractor internal safety audits utilizing information from the client's standardized safety management system software and a workers observation program for safety improvement [52]-[54].

TABLE I
RESEARCH QUESTIONNAIRE

S/N	Research questions
1. Safety Training	
Q1. Do you agree that workers receive insufficient training in their workplace?	
Q2. Do you agree that workers do not receive their mandatory safety training?	
Q3. Do you agree that workers are not aware enough of HSE procedures?	
2. Safety System	
Q4. Do you agree that workers have a difficult time locating the correct steering documentation?	
Q5. Do you agree that workers' work processes and directions are difficult to access?	
Q6. Do you agree that HSE procedures are insufficient to meet the needs of workers’ job responsibilities?	
Q7. Do you agree that employees are unsure about who they should report to inside the organization?	
3. Safety Supervision	
Q8. Do you agree that workers rarely talk to their supervisors about health and safety issues?	
Q9. Do you agree that the supervisor does not appreciate health and safety issues when workers bring up health and safety issues?	
Q10. Do you agree that supervisors do not take workers' proposals for safety responsibilities seriously?	
4. Strategies and Policies	
Q11. Do you agree that your company's safety management implements a Leading safety indicators system?	
Q12. Do you agree that Leading Safety Indicators are a useful concept?	
Q13. Do you agree that your company has a complete and established Health and Safety Policy?	
Q14. Do you think safety is a visible and systematic aspect of the company's stated strategy and plan?	
Q15. Do you agree that all key stakeholders are informed about your company's health and safety policy?	
5. Management Commitment	
Q16. Do you agree that management is actively involved and devoted to safety?	
Q17. Do you think management exhibits a zero-tolerance attitude toward non-compliance with safety policies?	
Q18. Do you believe that management has a system in place to recognize or reward appropriate behaviours?	
Q19. Do you think safety issues are brought up in management meetings?	
6. Safety Rules and Procedures	
Q20. Do you believe that violating job rules and procedures is the leading cause of accidents in the oil and gas sector?	
Q21. Do you believe that workers in the petroleum industry do not complain about rules and regulations?	
Q22. Do you believe that misinterpretation of safety information by personnel is a significant factor in the most serious oil and gas incidents?	
Q23. Do you agree that workers do not review job rules and procedures before executing any given task?	
7. Safety Audits	
Q24. Do you agree that a program of safety audits has been established?	
Q25.Do you agree that the score for the safety audit is computed and tracked?	
Q26.Do you agree that workers participate in safety audits	
8. Safety Behavioural Observation	
Q27. Do you agree that management and supervisors observe workers for the sake of safety?	
Q28. Do you agree that the observations of workers are documented and evaluated?	
Q29. Do you believe the severity of at-risk behaviours should be reported?	
9. Safety Meetings	
Q30. Do you believe there is a system in place to keep track of participation rates at safety meetings?	
Q31. Do you believe that workers' attendance at safety meetings is taken into account when evaluating their performance?	
Q32. Do you believe that management or supervisors should reward good attendance at safety meetings with positive feedback or incentives?	
Part-B: Lagging Safety Indicators	
1. Accident Investigation and Follow up	
Q33. Do you agree that accident/incident investigations follow a predetermined analysis procedure?	
Q34. Do you think it's essential for management to follow up on incident investigations?	
Q35. Do you agree that reported incidents undergo root-cause analysis?	
2. Near Miss Investigation	
Q36. Do you agree that the organization defines a near-miss event and communicates this description to employees?	
Q37. Do you agree that the organization has a mechanism for analysing near-miss events?	
3. Site Investigations after an incident	
Q38. Do you agree that risk assessments and hazard identification are investigated?	
Q39. Do you agree that hazard identification is used to establish corrective action plans for emerging threats?	
Q40. Do you agree that enough barriers have been put in place to protect against recognized hazards?	

IV. METHODOLOGY

The predictive performance of leading indicators is investigated in this research because of their early warning signs for inherent safety issues before the occurrence of an accident in the study industry. More also, to fulfil the research aims, several analyses were conducted, starting with the distribution of 1000 questionnaires to workers in the industry. After the survey excise, 327 were completed and returned to the research group. Furthermore, participants responded to the survey using a five-point Likert scale ranging from strongly disagree to agree strongly. Finally, SPPS was used to conduct statistical analysis to determine the indicators used for measuring safety performance and the relationships. Table I represents research questionnaire.

V. Results

According to the profiles of the individuals in the sample, 91.13% were male and 8.87% were female, based on descriptive analysis. The respondents' age ranged from 18 to 52 years old and they had worked for 2 to 10 years. The educational levels of the respondents ranged from a professional degree to a PhD or equivalent. The demographic information about the participants is depicted in Table II.

TABLE II
Demographics of Participants

Variables	Frequency (N = 327)	Percentage (100%)
Gender		
Male	298	91.13
Female	29	8.87
Age		
18-30	67	20.5
31-42	172	52.6
43-51	76	23.2
52 and above	12	3.7
Educational Level		
Professional Degree	34	10.4
Bachelor or Equivalent	211	64.5
Master or Equivalent	76	23.2
Doctoral or Equivalent	6	1.8
Work Experience		
Less than 2 years	45	13.8
From 2 to 5 years	71	21.7
From 5 to 10 years	91	27.7
More than 10 years	107	32.7
Not an oil and gas worker	13	4.0

Fig. 1 represents the performance of leading indicators in the study industry. It also assesses workers' overall attitudes toward workplace safety and workers' perceptions of operational safety cooperation.

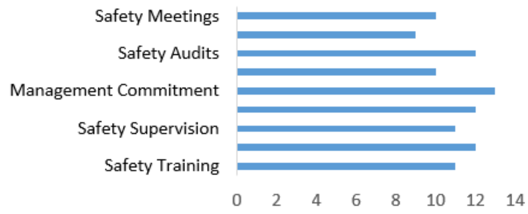

Fig. 1 Leading Indicators Performance

Fig. 2 provides an evaluation of accident and risk prevention events in the oil and gas sector before and after they occurred. The two indicators demonstrate how effective they are at preventing and analysing the effects of accident risk in the study industry.

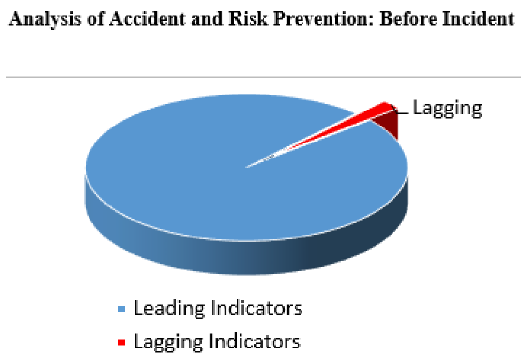

Fig. 2 Analysis of Accident and Risk Prevention

Table III represents descriptive statistics and correlation analysis. The Pearson technique was utilized to determine the relationship between the study's leading indicators. The indicators' statistical variances are determined. There was also a significant association between the indicators in evaluating their performance.

TABLE III
Descriptive Statistics and Pearson Correction

Variables	M	S.D	I	II	III	IV	V	VI	VII	VIII	IX
Safety Training	2.38	1.24									
Safety System	2.93	1.53	-.281**								
Safety Supervision	3.94	1.17	.044	-.98*							
Safety Rules and Procedures	4.49	.75	.097	.083	.104						
Safety Auditing	4.46	.68	-.036	.111	.073	.403**	.204**	-.064	-.007		
Strategies and policies	4.04	.92	062	.009	.153**	218**	.266**	.067	.181**	.276**	
Management Commitment	4.40	.85	.073	.111*	.212**	223**	.307**	-.036	.103	.238**	.069
Safety Meeting	3.72	1.01	.006	.103	.124	.068	.116*	.012	.115*	.064	.124*
Safety Behavior	2.81	1.35	-.024	-.029	.026	-.018	.336**	.232**	224**	-.014	.231**

Significant at p< 0.01. *. P< 0.05; M = Mean and S.D = Standard Deviations.

VI. Discussion

The effectiveness of different leading indicators and their key correlations were identified in this study, along with early warning signs to ward off potential accidents in their diverse operational environments. Leading indicators can avoid danger and accidents up to 98% in the operating environment and provide information of unforeseen risk as a piece of early signal information [2],[20], [44], [30], [31].

Participant responses to the examination of leading indicators examine only the quality of safety performance in the study industry, not the number of workplace occurrences and accidents. It also assesses workers' overall attitudes toward the importance of emphasizing workplace safety to avoid unfavourable situations.

The result indicates management commitment, safety auditing, safety strategies and policies, training, meeting, safety system, safety supervision, and safety rules and procedures are the top leading indicators of high performance in the study sector [52], [53], [34], [32]. In contrast, safety behaviour was the least among the leading indicators tested. We observed that the least safe behavioural observation results from individual character, understanding and relationship between management and workers regarding their safety at the workplace. Furthermore, the indicators were subjected to correlation analysis to determine their relationship, evaluate safety performance, and prevent accidents and risks. Again, a moderate correlation was found among the study indicators. Thus, the result indicates that choosing indicators for this study incorporated into each other will determine organizational performance safety [50], [51], [40], [37]. Furthermore, in exposing these underlying safety conditions, a negative correlation indicates the early warning signal of an area of weak safety performance that needs to improve or strengthen in operational safety [46], [8]. The indicators that have a positive correlation, such as safety systems, safety rules and procedures, safety meetings, and others, indicate active information of an unforeseen event during operations. It also displays the level of safety performance as an early warning signal, that will aid supervisors in putting remedial measures in place and detecting hazards and tackling inherent safety problems before they become accident risks as a proactive means [33], [34], [39].

VII. Conclusions

This paper investigates the performance of individual leading indicators on weak safety in the study industry and explores the correlations between leading indicators in the oil and gas environment. The results revealed both negative and positive correlations between study factors such as safety training, safety supervision, and safety commitment. On the other hand, a negative correlation indicates an early warning of a weak safety performance region by revealing these underlying safety issues. As a proactive measure, they also improve or reinforce operational safety in the study industry to reduce the likelihood of an accident.

The indicators that have a positive correlation, such as safety systems, safety rules and procedures, safety meetings, and others, indicate strong predictive of an unwanted event during operations. It also displays the level of safety performance and aids supervisors in implementing corrective actions and detecting hazards in the study industry to fix underlying safety issues before they become accident risks as a proactive early warning signal. The result indicates that the chosen indicators for this study incorporate each other in determining organizational performance safety. Lastly, the study outcomes have revealed important information on the use of leading indicators in assessing performance safety in an area where an organization's safety operations are lacking.

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