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Developing and Implementation of Leading and Lagging Indicators in Process Safety Management

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Abstract

Implementing process safety management alone does not guarantee the effective implementation of the safety system. Instead, the process safety management system's continuous review, modification, and improvement improve individual and process safety. Therefore, determining and deploying various performance indicators is particularly important. This article discusses the difficulties of determining and deploying leading and lagging performance indicators and their effectiveness in process safety management. Finally, in the form of a case study, the transfer of chemical products (crude oil) from producers to storage tanks and the transfer of feed to units have been discussed. In this research, Leading and Lagging indicators have been used to test the performance of process safety management to ensure the correctness of the management system, and protective layers have been selected. The final result is the addition of some indicators and the proposal to remove several Leading and Lagging indicators. According to the conclusions, some indicators should be replaced with new safety indicators, and the rest should be retained due to their efficiency in achieving progressive safety goals.

Keywords: Process Safety Management (PSM), Leading and Lagging Indicators, Key Performance Indicators

1. Introduction

In process safety management, researchers have conducted valuable investigations and research so far. Therefore, Process safety management is being implemented and reviewed worldwide with various methods. With this in mind, Safety indicators are used in multiple industries to monitor the safety efficiency related to economic activities and their consequences to help us prevent accidents [1]. The purpose of safety indicators is to show possible safety risks during or before operations, which can be done with the help of various methods using experimental facts, knowledge, simulation, and other approaches [2]. Accordingly, The Lagging indicators consistently record the safety information of the process or person after the occurrence of an event or illness, or injury. Still, unlike Lagging indicators, Leading indicators act preventive based on predicting accidents and events [3].

Moreover, Safety indicators play an essential role in predicting and preventing accidents. Consequently, using these indicators will not only help us advance the safety goals, but it is also a suitable measure to recognize the performance of the existing safety system. Hence, Safety performance indicators include various categories, so Leading and Lagging indicators are the frameworks for this research. Moreover, Leading indicators complete and improve Lagging indicators too. Due to that reason, these indicators became broad topics for researchers [4],[5]. In addition, to examine Leading indicators more effectively, it is recommended to collect and review the required information right from the target plant [6]. In addition, Leading indicators focus on identifying the weak points and strengths of the safety system to predict possible accidents [7]. Therefore, optimal deployment of these indicators needs checking them by a safety management method. So, the process safety management model of the Center of Chemical Process Safety creates a broader perspective to identify indicators.

2. Safety Model of Center of Chemical Process Safety

About fifteen years after the first release of the process safety management model of the United States Industrial Safety and Health Organization in early 2007, the Occupational Safety & Health Association (OSHA) also published an up-to-date and complementary model. Therefore, this system was experienced in various industries during its trial implementation in the United States. Moreover, OSHA's model focuses on the category of risk. Due to that reason, experts recall this model by the name of risk-based process safety management [8],[9].

Another essential element of this model is its emphasis on researching the root causes of accidents and applying lessons learned from accidents and near-misses because CCPS attaches great importance to the results obtained after accidents. Moreover, preventing the root causes of previous accidents can avoid the same accident's recurrence and many of the initial factors of other possible mishaps. The model presented by the Center of Chemical Process Safety (CCPS) includes twenty elements [8],[9]:

1. Process Safety Culture
2. Compliance with Standards
3. Process Safety Competency
4. Workforce Involvement
5. Stakeholders Outreach
6. Process Knowledge Management
7. Hazard Identification and Risk Analysis
8. Operating Procedures
9. Safe Work Practices
10. Asset Integrity and Reliability
11. Contractor Management
12. Training and Performance Assurance
13. Management of Change
14. Operational Readiness
15. Conduct of Operations
16. Emergency Management
17. Incident Investigation
18. Measurements and Metrics
19. Auditing
20. Management Review and Continuous Improvement

The CCPS model is much richer in content than other models presented in process safety management. In addition, its authors use the experiences of industries and their incidents to achieve and improve this model, which makes this model more applicable in the oil and gas and petrochemical industries [9].

2.1 Determining key performance indicators in Facilities

Four-tier approach: Major accidents rarely happen in oil and gas industries, and determining and identifying key performance indicators in this industry based on a few numbers of casualties with a low

probability of occurrence would be a complex task. So, this causes inadequate and limited information sources to avoid catastrophic events [10],[11].

Therefore, developing safety indicators can lead to the preparation of accurate information and statistics to prepare and establish protective safety layers. For this purpose, CCPS has provided a four-tier approach called the process safety indicators pyramid (see Figure 1).

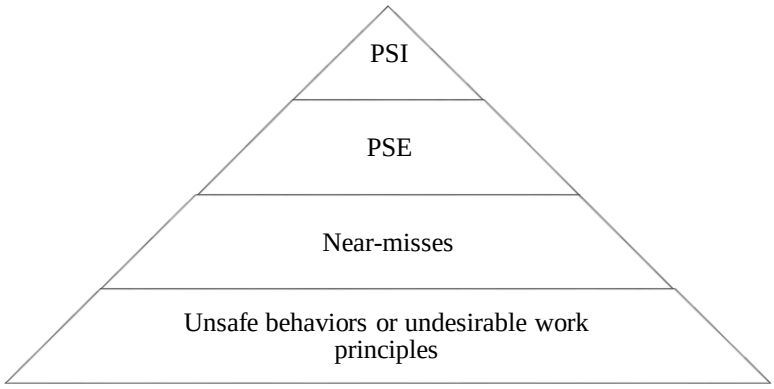

Figure 1: Process Safety Indicators Pyramid [10].

- P.S.I. Events with high intensity and consequences are known as Lagging indicators [10].
- PSE or process safety incidents are at a more limited level than PSI, which can lead to a process safety incident in the future [10].
- Near misses are on the third level of the process safety index pyramid; these events have insignificant consequences [10].
- Level 4 occurrence of an unsafe behavior or condition is considered a proactive indicator of the safety management system [10].

Determination of critical protection layers and selection of key performance indicators: Since the selection of effective indicators replicates challenges in front of the process safety management system, therefore, the selection of leading indicators that are placed in the 3rd and 4th levels of the pyramid of process safety management indicators will provide the most significant impact on protective layers of risk control [10].

In addition, based on the instructions provided by the government organization of Health, safety, and Environment of the United Kingdom, it is suggested to apply a six-step approach to select key indicators (see Figure 2).

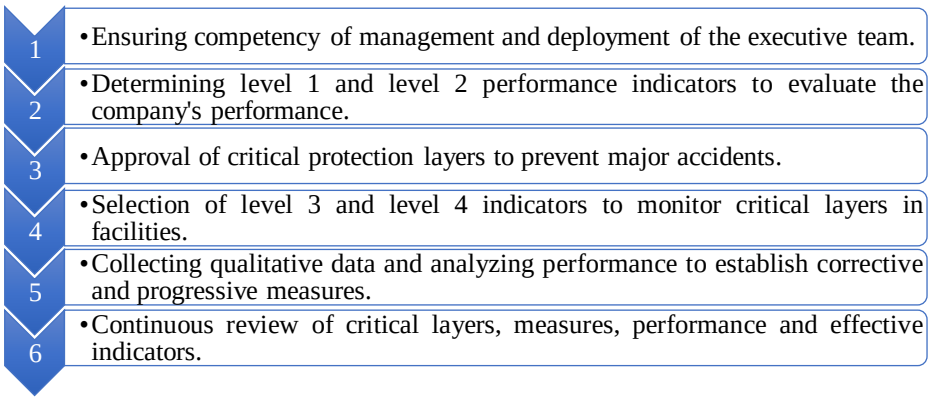

Figure 2: A six-step approach to select and review key performance indicators [10].

- Ensuring competency of management and deployment of the executive team:

It should be ensured that the output information and data are reviewed and modified at an adequate level for the organization's management to agree and implement necessary measures for the continuous development of the organization, including investing in the weak points of protective measures, prioritizing actions and recruiting human resources to advance and improve the performance of the process safety management system [10],[11].

Then, the first step to determine the key performance indicators is to select and establish a group consisting of operational people, safety experts, and managers of the organization at different levels [10],[11].

- Determining level 1 and level 2 performance indicators to evaluate the company's performance:

Lagging critical indicators of the performance of an organization or facility and the provider of the main line of the company's performance data play a facilitating role in analyzing these output data. Since level 1 and level 2, incidents and events of the organization provide basic information about the organization's performance. Still, due to the low frequency of incidents, they cannot be considered good statistical information. Also, level 1 and 2 key indicators are used based on the organizational definition and existing policies; these two indicators should be reviewed annually to evaluate the organization's performance [10],[11].

- Approval of critical protection layers to prevent significant accidents:

Leading portal

The Leading portal will recognize the dangers and risks that lead to a significant accident. The Leading portal determines and approves the appropriate protective layers with the correct placement to improve these protective layers to defeat most of the safety risks [1],[12].

External portal

The external portal includes experiences and the most efficient principles of risk control that have been made available through the publication of other production units of the oil and gas industries or other industries [12].

Lagging portal

The Lagging portal of the safety management system is based on the studies of root cause analysis of incidents or root cause analysis of high potential events [1],[11].

- Selection of level 3 and level 4 indicators to monitor critical layers in facilities:

Since selecting key performance indicators should reflect operational activities and activities of different management systems, it is possible to apply these indicators in different industries. Deduction and matching this level of indicators leads companies to determine or strengthen a part of the protective layers or identify existing weaknesses [10],[11].

- Collecting qualitative data and analyzing performance to establish corrective and progressive measures:

The effort to collect information to analyze the performance of indicators must not lead to the acquisition of fake statistics and points. Also, to gain trust in the studies, quality assurance processes should be useful to confirm the collected information's accuracy, compatibility, and completeness. Correlation and other statistical analysis should be applied to these indicators too. Functional data and frequent,

meaningful changes should be presented transparently for management to review corrective and proactive measures [10],[11].

- Continuous review of critical layers, measures, performance, and effective indicators:

The key performance indicators should be ensured to focus on the most critical safety barriers to prevent major accidents. The key performance indicators of level 3 and level 4 could provide information with a reported near miss or deviation in the lake of accidents. Therefore, the key performance indicators of levels 3 and 4 should be revised annually [10],[11].

3. Study of Leading and Lagging indicators in crude oil transportation

3.1 Inspection and Maintenance

- Process controls

Inspection and maintenance of systems.

- Desired safety outcomes

No unexpected leaks will occur due to the failure of flexible hoses and other equipment.

- Leading indicators

The percentage of safety devices or equipment with particular usage that works correctly in the inspection.

The number of maintenances carried out during the predicted time scale.

- Lagging indicators

The number of unexpected leaks due to the failure of flexible hoses and the rest of the equipment.

- Removed Lagging indicators

Clogging of the tanker outlet: This event can be registered with the tank defect detector.

Static electricity spark: It will be challenging to ensure that static electricity is the cause of fire and explosion, and such an event will be infrequent.

Several fires or explosions occur due to sparks from damaged electrical equipment: this event is infrequent and often preventable.

- Removed Leading indicators

Inspection program progress: Indicates the safe operation of critical equipment.

3.2 Workers competency

- Process controls

Competency of operators: selection, information, training, and evaluation.

- Desired safety outcomes

Operators and contractors have the knowledge and skills to effectively and efficiently transfer the product from the ship to the storage tank or road transit.

- Leading indicators

The percentage of employees who participate in transferring products that benefit from the level of knowledge necessary for successful transfer and accumulation of products.

- Lagging indicators

The number of times that the transfer does not go according to plan due to errors caused by employees who need to meet the knowledge required to do the job correctly.

- Removed Lagging indicators

Excess pressure or lack of pressure in the tanker: ensuring the competence of the tanker cleaning staff due to the possibility of error in complex tasks; complexity increases the probability of error due to insufficient qualifications.

3.3 Critical tasks that take place under dangerous conditions

- Process controls

Functional procedures: written structures and work exercises.

- Desired safety outcomes

Correct the tank's selection and the equipment's operation during the product transfer by ship to the storage tank and road transport.

- Leading indicators

The percentage of procedures and guidelines reviewed and revised over time.

- Lagging indicators

The number of times the product was not transferred due to wrong or unclear procedure.

- Removed Lagging indicators

Tanker over-pressurization or depressurization: It is better to focus on a more extensive set of actions because this will show a more comprehensive picture of the procedure's reliability.

- Removed Leading indicators

Before removing the procedures, it must be ensured that they are not common in primary activities (methods may be used in several activities).

3.4 Process or industrial unit out of safe condition

- Process controls

Process procedures: equipment and warning systems.

- Desired safety outcomes

Critical safety equipment and alarms detect conditions that exceed the minimum safety requirement.

- Leading indicators

The percentage of performance tests that equipment and safety alarms complete during the test program.

The percentage of repairs that are carried out to determine safety system errors according to the plan.

- Lagging indicators

The number of equipment and safety alarms that fail to function according to their design purpose during usage or testing.

- Removed Lagging indicators

The number of times the storage tank or tanker trailer has overfilled or experienced a pressure drop due to the malfunction of the level gauge.

The number of times the product has been moved at the wrong flow rate or pressure due to flow meter or pressure meter failure.

- Removed Leading indicators

The percentage of safety equipment that correctly detects the transfer conditions.

The percentage of safety equipment and alarms that are activated in predetermined conditions.

3.5 Unit changes

- Process controls

Industrial unit change system.

- Leading indicators

Percentage of potential risks and process risks that unit changes have eliminated.

The percentage of unit changes that have been reviewed before deployment.

- Lagging indicators

The number of times the equipment or industrial unit exceeds its safety standards during changes.

- Removed Lagging indicators

The number of incidents of leakage of hazardous materials or fire and explosion due to failure of a flexible hose and other equipment.

- Removed Leading indicators

Documenting changes and post-change reviews.

3.6 Industrial unit design

- Process controls

Industrial unit design system.

- Desired safety outcomes

The process units are optimal with equipment that works properly, and reliability is not affected by failure due to improper operation and design flaws.

- Leading indicators

The percentage of critical safety items of the industrial unit or equipment is consistent with the current standards and codes.

- Lagging indicators

The number of incidents from the unit associated with failure, leakage of hazardous material contents, or failure of safety equipment.

- Removed Leading indicators

In a specific period: the percentage of the unit or equipment critical items in harmony with the current standard.

3.7 Communication

- Desired safety outcomes

Effective management of movement and storage of products and effective warning notification for problems that need to be fixed.

- Leading indicators

The percentage of check times ensures that the pump is turned off and the valves are closed after pumping.

- Lagging indicators

The number of repetitions of times that the transfer command was ignored in the communication system.

- Removed Lagging indicators

Events based on the failure of defects are infrequent. It should be considered in the emergency order section.

- Removed Leading indicators

The percentage of moving products whose completion has been checked by communication.

The percentage of completed transfers approved to start in which the transfer rate was confirmed before the process began.

3.8 Work permits

- Process controls

Work permit system.

- Desired safety outcomes

High-risk repair tasks in a way that does not result in damage or injury.

- Leading indicators

Percent of work permits that face problems contrary to the planned arrangements.

Percentage of work done under work permit conditions.

- Lagging indicators

The number of events in which the equipment or industrial unit fails due to the failure of high-risk maintenance measures.

- Removed Leading indicators

The specific goals and basis of the work permit system: It is one activity that worsens over time.

Specific period of time: Although important, it is not considered a critical factor before the start.

3.9 Emergency arrangement and order

- Process controls

Emergency arrangement and order.

- Desired safety outcomes

The pressure of a massive event during product movement or stock reduction.

- Leading indicators

The percentage of interrupting the process or isolating the systems and achieving the standard performance during the test.

- Lagging indicators

The number of emergency elements of the procedure failed to achieve their intended performance in the design.

- Removed Leading indicators

The percentage of times that the fire pumps are activated automatically and detect fire during the test is a small result of what one of the sensors has received.

The percentage of employees or contractors trained to comply with the order in emergency conditions: this indicator does not provide information on how the system works and its results.

The percentage of emergency response experiences completed according to the plan: This indicator also does not provide information about how the system works or its future consequences.

4. Conclusion

Various methods are used to establish process safety management to make process industries as safe as possible, but more than simply establishing process safety management is needed. The safety management system's continuous improvement should be reviewed and revised frequently to ensure the effectiveness of the selected protection layers. For this reason, adequate protective layers are stabilized or strengthened, and inactive layers that do not play a role in preventing accidents are replaced with newer layers based on the needs of the organization. Moreover, the new protection layers will be selected by determining the leading and lagging key performance indicators.

Based on research, developing leading and lagging performance indicators is inevitable in all industries, and various industries can establish process indicators to achieve their goals in the safety field. Considering the need for organizations to implement a systematic and integrated method to develop leading and lagging performance indicators, it is necessary to have a way of developing leading and lagging safety indicators. The method presented in this article satisfies the needs of many organizations active in oil, gas, and petrochemicals, which are also used in the oil industries of the world's leading countries.

This research investigated transferring chemical products (crude oil) from producers to storage tanks and then sending the feed to the units. Leading and Lagging indicators were used to test the efficiency of process safety management to ensure the system works properly. So, nine layers of protection were selected for inspection and maintenance, workers' competency, critical tasks under dangerous conditions, process or industrial units out of safe condition, unit changes, industrial unit design, communications, work permits, and emergency arrangement and order. Then, the result is the addition of some indicators, the proposal to remove several leading and lagging indicators, and the retention of practical indicators.

Contribution of Researchers

All researchers have contributed equally to writing this paper.

Conflicts of Interest

The authors declare no conflict of interest.

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