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Process Safety Leading Indicators in Oil Storage and Pipelines: Building a Panel of Indicators

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The inherent hazards of crude oil and other hydrocarbons have led the companies that work with these products to act toward the prevention of major accidents, so that their activities do not cause damages to the population, property and environment, apart from guaranteeing the operational continuity and survival of business. Major accidents are caused when simultaneous failures of the protection layers of the process safety management system occur. Establishing leading indicators that demonstrate process safety performance is necessary to support decision-making and prevent the degradation of safety systems and to avoid major accidents. For the implementation of these indicators, it is necessary that the anomalies related to process safety are properly and separately appropriated from occupational safety anomalies. The methodological structure of this paper relies on a research, based on approach of process safety by important institutions of the world, focusing on what has been established for leading indicators in this area. A case study in storage and transport facilities for petroleum and oil products is developed. From the theoretical framework studied, an initial database of leading indicators of process safety was structured, which was carefully customized for the industrial segment studied and allowed the initial selection of a set of process safety leading indicators. This initial database was submitted to a group of selected experts who validated these indicators. Then, with the support of the fuzzy method, a final panel of process safety leading indicators was chosen and ranked.

1. Introduction

The inherent risks related to flammable liquids in terminals can compromise the operations continuity of storage and transportation of these products. According to Faneli (2014), major accidents involving fuel storage sites could cause a significant group of consequences including fatalities, injures, health issues, significant environmental damages, economical damages, production disruption, punitive and compensation damages, increase of risk insurance premium costs and company reputation damage.
When conditions for occurrence of major accidents are not identified in a company with a safety management system already established, becomes imminent the occurrence of major accident. In this case, the focus of the accidents management is the occurrence losses, such as personal injury, environmental and/or materials. It can lead to a wrong conclusion that the occurrence likelihood of serious accidents is minor. This analysis may not show the due importance of the conditions of the production process, demonstrating the lack or poor management of the process safety. The decrease of occupational accidents rate can give managers a sense of complacence, considering that accident risk from process safety also may be in decline (Coblentz, 2012).
It is important that company be able to develop actions to prevent these accidents. Since it is not possible to establish effective preventive action without previously being aware of abnormalities, the correct choice of process safety leading indicators, those reflect the trend of major accidents, is the main goal of any organization (Santos, 2018).

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The principal objective of this work is to present and develop a methodological framework centered on the selection of leading indicators related to process safety, applied to storage and transport facilities for petroleum and oil products.
An initial database was structured and with the use of a fuzzy method, the principal indicators were chosen initially by selected experts and subsequently ranked.

2. Process safety leading indicators versus lagging indicators

Process safety leading indicators are a group of metrics that indicates the performance of the main work processes and of the protection layers that prevent accidents (CCPS, 2011). These indicators are used to identify weaknesses of the management system of process safety (API, 2016). Lagging indicators are used to measure events related to process safety that have already occurred, including explosions, fires and releases of toxics and flammable material.
According to Alnashwuan (2015), the challenge is how to measure the process safety using leading indicators, because this involves the measure of possible events before the accident occurs. In addition, the author emphasizes that the safety cannot be guaranteed only on lagging indicators.
The lagging indicators are not useful enough during the continuous improvement of safety management system, because they are centered on measuring something that already occurred, such as accident rate. Then, it is necessary to use leading indicators because they act proactively, anticipating performance deterioration of safety systems. The chosen and use of the principal leading indicators, such as the rate of undue openings of hazardous products pipes, are the great objective of the high-risk industries (CCPS, 2007).

3. Process safety indicators versus occupational indicators

According to Daniellou et al (2011), the current way to deal with the safety does not reflect the risks of major accidents, though there may be a relation between the causes of all these accidents.
According to Hopkins (2009), there is a clear difference between the different types of dangers due to process safety and occupational safety. The author cites that statistics tend to reflect the results of the risks management of occupational safety, rather than process safety, since the most of the accidents and deaths are results of occupational safety.
Accidents reports show recommendations related to process safety management, including the development of specific indicators in petroleum area, as presented in the report of the Texas City accident (BP, 2007).
Hale (2001) asserts that there is an incorrect understanding of relation between major and minor accidents. The problem is related to correct interpretation of accident pyramid by Heinrich. Safety engineers link the minor accidents occurrence with major accidents. Hopkins (2009) considers that in some cases the occurrence of minor accidents can be an indicator of the occurrence likelihood of a major accident, if the events belong to the same accident population.

4. Methodological framework

Chapters two and three of this work emphasize the importance of using leading indicators on process safety. However, there is a question to be answered. How to choose the most appropriate indicators to the desired installation? The answer of this question is presented on the following methodological framework:

- Descript the industrial plant chosen for implementation of leading indicators;
- Define a general database of process safety leading indicators through the theoretical references;
- Define criteria to be used for selecting a set of process safety leading indicators related to storage and transport facilities for petroleum and oil products;
- Apply the criteria to create a specific database to be studied;
- Identify and select an experts group;
- Apply a fuzzy method for determining of the degree of importance of the experts and ranking of each process safety leading indicator;
- Develop a panel of process safety leading indicators to be applied in industrial installation studied.

5. Indicators

The industrials installations chosen for case study are petroleum storage terminals and pipelines transporting oil and oil products.
The pipeline term refers to the land or maritime pipeline, that transport and transfer oil, natural gas, condensate, liquefied gas of petroleum. The terminals serve as connection between the oil tankers and pipelines, which are appropriate facilities for transferring products of ships to earth and vice-versa, or between

ships. In the open sea, the mooring system of oil tankers to terminals is usually done by buoys, and in sheltered locations on piers. In this system, the production of oil is transported from the fields to the terminals or until refineries directly. Liquid fuels produced in refineries can be delivered directly to distributors or sent to other terminals by highways or waterways (ANP, 2018).

5.1 General database of process safety leading indicators

The identification of important elements to be monitored and to be used in the leading indicators panel can arise from several inputs: elements of the safety management system, applicable regulations, good industry practices, standards and references guides, learning from the experience of other accidents, among others. Initially, a general database of indicators was consolidated, consisting of 470 leading indicators. The database was developed through the use of the following documents:

- Applicable regulations; standards and references guides, safety research institutes: United Kingdom Health and Safety Executive - UK HSE; Organization for Economic Co-operation and Development - OECD; Petroleum Safety Authority Norway - PSA; Agência Nacional de Petróleo, Gás Natural e Biocombustíveis - ANP; Chemical Safety and Hazard Board - CSB; Center for Chemical Process Safety - CCPS; American Petroleum Institute - API; International Association of Oil and Gas Producers - IOGP; Australian Petroleum Production & Exploration Association - APPEA; Institution Chemical Engineers - IchemE;
- Fault elements described in the reports of major accidents analysis occurred in the terminals and pipelines;
- Relevant item presented in postulated accident scenarios during the transfer process and storage of oil;
- Health and Safety Guidance - HSG 254, named Developing process safety indicators: A step-by-step guide for chemical and major hazard industries (HSE, 2006);
- Metrics used in the petroleum industry and specific sector of terminals and pipelines: UK Petroleum Industry Association (UKPIA, 2018) and UK Tank Storage Association (TSA, 2018);
- Professional experience of the authors.

6. Methods

6.1 Selection criteria of process safety leading indicators

The 470 indicators were grouped by themes and identified those referenced by more than one safety research institutes and safety references guides.
The fault elements described in the reports of major accidents analysis occurred in the terminals and pipelines were analyzed and the leading indicators cited were selected, too.
The recommendations cited by Nolan and Anderson (2015) were used for the selection of leading indicators, such as leading indicators that include both specific operating parameters as the result of the protective barriers actuation.
After analysis of the general database, 76 indicators were selected, being subjected to the analysis and validation of experts group.

6.2 Identification and selection of an experts group

Initially, a group of 15 experts were selected and a questionnaire was used to determine the degree of importance of each expert. The criteria used were based on experience, work years and so on. Weights were attributed for each criteria. This questionnaire is an important part of the fuzzy model applied to indicators ranking.
According to Grecco (2012), a fuzzy model developed with the experts collaboration increases results accuracy. The expert chosen is a critical factor, because the reliability and quality of the results depend on the expert knowledge and experience. The heterogeneity of each expert contributes to the views diversity, and different weights are assigned for each expert. Every questionnaire answer would have a relevance given by the importance degree of the expert.

6.3 Using fuzzy method to determine the degree of importance degree of each leading indicator

A second questionnaire was developed with the objective to identify among the 76 leading indicators, those most important, and the leading indicators that are the most appropriate to identify proactively the performance of the process safety system in a terminal of transport of oil and oil products.
The results showed that only two of the 76 indicators were not chosen by any expert. These two indicators were excluded from further research. It was also suggested three new indicators, which were validated by all experts.

Then, a group of 77 indicators was defined to be used in this research. Subsequently, the Pareto principle was applied and the final group of indicators was defined as 44. According Grecco (2012) and Vianna Filho (2016), a decision-making fuzzy method was developed based on a procedure for the aggregation of opinions using the concept of fuzzy numbers. The indicator evaluation was obtained by linguistic terms, through experts opinion. The linguistic terms used were: Minor Important (MI); Important (I); Very Important (VI).
The method used linguistic terms represented by triangular fuzzy numbers. These numbers represent the degree of importance of each leading indicator.
According to Vianna Filho (2016), the use of triangular fuzzy numbers is an excellent solution to treat information with a high degree of uncertainty, as is the case of linguistic variables that reflect the experts opinion.
The phases of the fuzzy method are described below:

- Rank professional experience of the authors;
- Verify union areas and intersection areas of fuzzy opinion;
- Calculate degree of opinion;
- Develop agreement array;
- Calculate degree of relative agreement;
- Calculate experts consensus coefficient;
- Identify the fuzzy value of each one of the 44 process safety leading indicators;
- Rank the 44 process safety leading indicators using the indicators fuzzy value.

6.4 Results

The fuzzy method ranked the 44 leading indicators, as showed on Table 1, identifying the indicators as tier 3 or tier 4. The Table 1 results show that the greatest value of triangular fuzzy number occurred in tier 3 indicators called “Demand on safety systems”. All tier 3 indicators were among the top eight indicators of hierarchy. This can be justified by the fact that the events monitored by these indicators are very close to the accident occurrence.
Regarding management indicators, tier 4, the theme of Integrity mechanical, inspection and safety critical equipments maintenance had 50% of this category indicators located in the top 10 indicators of the hierarchy, which confirms the information of Milanese et al (2017) about importance of integrity management in reducing company risks and probability of catastrophic events.

Table 1: Ranking of process safety leading indicators

Hierarchy	Tier	Degree
1. Demand on safety systems: failure on demand or test in instrumented system	3	1.0000
2. Integrity mechanical, inspection and safety critical equipments maintenance: percentage of inspections of safety critical items of plant and equipment due during the measurement period	4	0.9729
3. Management of change: number of open management of change	4	0.9676
4. Demand on safety systems: number of safety instrumented system activations	3	0.8832
5. Safety culture: percentage of meeting that discuss about process safety	4	0.8600
6. Demand on safety systems: pressure relief device activations	3	0.8448
7 Hazard identification and risk analysis: process safety risk analysis progress (number open, number closed, time to closure)	4	0.8380
8. Demand on safety systems: number of high level and high-high level alarms activation in tanks	3	0.8090
9. Integrity mechanical, inspection and safety critical equipments maintenance: number of inspections or conformance tests indicate that vessels, tanks, pipelines or other equipments was operated with safe limit operating exceeded (results outside acceptable limits)	4	0.8087
10. Integrity mechanical, inspection and safety critical equipments maintenance: number of emergency work orders or corrective maintenance not planned	4	0.7784
11. Integrity mechanical, inspection and safety critical equipments maintenance: percentage of inspection recommendations completed	4	0.7769
12. Fatigue risk management: critical alarms per operator hour	4	0.7658
13. Emergency response plan: emergency response equipments in conformance to preventive or predictive maintenance schedule	4	0.7458
14. Integrity mechanical, inspection and safety critical equipments maintenance: maintenance backlogs	4	0.7307
15. Training and competency: training to critical positions in conformance with planned process	4	0.7060

safety management schedule		
16. Incident investigation: quality of incident investigation and analysis	4	0.7026
17. Actions items and audits follow up: number of process safety audits	4	0.7016
18. Fatigue risk management: number of false alarms and disabled alarms	4	0.6873
19. Training and competency: percentage of training, efficiency evaluate and grade average	4	0.6872
20. Fatigue risk management: number of extended shift per operator	4	0.6869
21. Incident investigation: number of lessons learnt communicated	4	0.6743
22. Safety culture: number of field inspections by managers	4	0.6703
23. Management of change: percentage of sampled management of change that satisfied all aspects of procedure requirements	4	0.6604
24. Management of change: percentage of sampled management of change that satisfied all aspects of procedure requirements	4	0.6600
25. Procedures: percentage of compliance with critical procedures by observation (safety critical tasks observed where all steps of the relevant safe working procedure were followed)	4	0.6550
26. Integrity mechanical, inspection and safety critical equipments maintenance: percentage of safety critical equipment operating within specification when inspected	4	0.6235
27. Emergency response plan: percentage of training to emergency response staff, per shift	4	0.6041
28. Safety culture: A/(A+B), that: A = frequency that employment was publicly recognized for recording safety events, worried about safety have became lessons learnt or that brought a good contribution for safety; B = frequency that employment was publicly recognized for accomplish production demands or deadlines	4	0.5975
29. Permit to work: unsafe conditions or violations by observations	4	0.5945
30. Incident investigation: percentage of corrective actions completed	4	0.5774
31. Hazard identification and risk analysis: percentage of process risk analysis current, accuracy and reviewed to plan	4	0.5724
32. Permit to work: percentage of permit work in conformance with procedure requirements	4	0.5236
33. Stakeholders engagement: number of complaints received in facility (community, workforce)	4	0.5111
34. Emergency response plan: emergency simulators completed versus emergency simulators have planned	4	0.4926
35. Hazard identification and risk analysis: number of trained leaders and participants in the hazard identification and risk analysis	4	0.4630
36. Actions items and audits follow up: percentage of corrective actions across the spectrum of Process Safety Management Systems completed on time	4	0.4200
37. Contractors management: frequency of negative performance in safety assessments, field inspections, safe work practice audits and safety related audits	4	0.4165
38. Emergency response plan: percentage of emergency response plans that are current, reviewed and revised within the designated period	4	0.4129
39. Incident investigation: average time to closure recommendations	4	0.4064
40. Contractors management: percentage of contractors with safety training schedule completed before work	4	0.3576
41. Workforce involvement: rate of suggestions by workforce or report about unsafe conditions or near misses and rate progress over time	4	0.3509
42. Actions items and audits follow up: average and maximum time to closure recommendations by Process Safety Management Systems	4	0.3367
43. Incident investigation: rate between accidents occurred and near misses reported	4	0.3233
44. Contractors management: percentage of attendance at safety meetings	4	0.2475

7. Conclusions

The accident prevention is very important for safe production of dangerous chemical products. High risk industries must include in safety management system, which often only consider occupational safety performance, deeper studies of the process safety management, so that the company can be able to take management actions to reduce the occurrence of a catastrophic accident.

In order to monitor the performance of process safety, before the occurrence of major accidents, this work aimed to develop a panel of leading indicators, applied to terminal facilities and pipelines operating oil and oil products.

Through the ranking result of the 44 process safety leading indicators, it is possible to prioritize and assist in the choice of more relevant indicators, in order to build a panel of leading indicators applied to petroleum storage terminals and pipelines transporting oil and oil products.

Through the indicators panel it is possible to carry out a critical analysis with focus on process safety and comprehensive view to scroll through various topics. The critical analysis must be assertive, with decisions capable of promoting the preservation of human life, property, environment, society, and business image, through the prevention of major accidents.
Conscious decisions must be based on real events related to production process, without the irresponsible manipulation of the metrics, in order to achieve apparent positive results, in order to hide dangers that may contribute to catastrophic accidents.

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