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ORIGINAL ARTICLE

Process Safety Indicators and Safety Culture Maturity: A Field Study in the Process Industry

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ABSTRACT

Background: There is growing agreement about using indicators for evaluating and measuring safety in major hazard facilities. This study aimed to investigate process safety indicators in the process industry in Iran. Additionally, the levels of safety culture maturity of the site employees and HSE (Health, Safety, and Environment) staff were assessed.
Methods: Data were collected from the process industry in Iran over three years (2014 to 2017) as part of a routine reporting process. Lagging safety indicators were established based on incident reporting and analysis. Leading indicators were developed based on the desired operation of risk control systems. The British Health and Safety Executive (HSE) safety culture maturity model was used to determine the levels of safety culture maturity among site employees and HSE staff members.
Results: According to the results of this field study in the process industry, total recordable injury rate and lost time injury frequency were identified as lagging indicators. Staff competence and safety training, operational procedures, permit to work, emergency arrangements, and inspections of safety-critical items were determined as leading indicators. The assessment of safety culture maturity among staff revealed that the maturity of most safety culture elements was at level three "involving," moving towards level four "cooperating." The safety culture was therefore relatively mature in the study industry.
Conclusions: The study showed that safety culture was relatively mature in the process industry, and process safety indicators such as leading and lagging indicators were already monitored. Thus, improvement in safety performance measurements was expected.

KEYWORDS: *Leading indicators, Lagging indicators, Safety culture maturity, Process industry.*

INTRODUCTION

Nowadays, there is growing agreement about using indicators for evaluating and measuring safety in major hazard facilities. In the process industries, fire, explosion, and toxic release are the main risks, with fire being the most frequent, while explosions have a greater potential for harm and property damage [1-4]. The creation of process safety indicators may aid in the prevention of significant accidents in process industries by providing early warnings [4].

There are two dimensions of safety indicators. The first dimension is personal safety versus process safety indicators, and the second dimension is leading versus lagging indicators. However, the distinction

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between the two (leading and lagging indicators) can be problematic [4]. Based on the definition of the Center for Chemical Process Safety (CCPS), "leading indicators are a forward-looking set of metrics, which give indications about the performance of the operating procedures, protection layers, and working processes that have the potential to prevent incidents." Lagging indicators are "a retrospective set of metrics that are based on information from past incidents" [5]. Leading indicators of process safety involve active monitoring based on the assessment of critical risk control systems and their effectiveness, which should be measured through routine systematic checks of key actions or activities. Leading indicators are a measure of process inputs that are essential for delivering the desired safety outcomes and are a good predictor of future levels of safety performance. In contrast, lagging indicators focus on incident reports and provide feedback on safety performance related to incidents and events [6-10].

Developments of process safety key performance indicators (KPIs) are important for measuring the effectiveness of hazard controls related to preventing process safety incidents and mitigation measures. Some proposed process safety indicators for an oil and gas client by Brown (2009) include the number of reported PSM (process safety management) incidents and the number of PTWs (permit to works) reviewed by managers during the designated period [11]. The Health and Safety Executive (HSE) provides site-level process safety indicators for a chemical storage site as a battle-proof example by considering hazard scenarios and risk control systems. An example of a proposed lagging metric is "the processes' failures due to erroneous or unclear operational procedures or due to unconsidered high-risk activities." An example of a leading indicator is "the percentage of procedures reviewed during the planned period and the number of tasks conducted regarding work permits on-site" [6]. Specific lagging metrics for process safety based on the CCPS guideline on process safety metrics include the total count of process safety incidents and severity rates. Some potential leading metrics include mechanical integrity (related to safety inspections), training and competency, and safety culture [5].

The Organization for Economic Co-operation and Development (OECD) has proposed and published safety performance indicators. The OECD guideline classifies safety performance indicators into two types: outcome indicators (lagging indicators) and activities indicators (leading indicators) [12]. OECD offers audit-type questions with extensive lists of organizational factors [13]. The American Petroleum Institute (API) divided process safety indicators (leading and lagging) into four tiers. Tier 1 is the most lagging (e.g., "loss of primary containment") and Tier 4 is the most leading (e.g., "operating discipline and management system performance indicators") [14]. The Energy Institute published human factors performance indicators based on human factors key topics proposed by HSE. Some of these indicators are managing human failures, procedures, training and competence, organizational change, safety-critical communications, and organizational culture [13].

Process safety indicators should match the organization's cultural maturity [13]. Safety cultural maturity is related to the organization's degree of readiness to prevent safety risks and is based on cultural and behavioral leading indicators [15, 16]. The safety culture maturity model allows organizations to understand their level of safety culture maturity. This maturity does not refer to the maturity of the safety management systems but rather the maturity of the organization's behaviors [15]. Fleming (2000) described five levels of safety culture maturity in the HSE model: emerging (Level 1), managing (Level 2), involving (Level 3), cooperating (Level 4), and continually improving (Level 5). This model includes 10 elements, such as management commitment and visibility, productivity versus safety, safety resources, and training [16, 18]. At the emerging level (Level 1), safety is not considered a business risk, and many accidents are regarded as unavoidable. At the continuous improvement level (Level 5), organizations use indicators to monitor performance, with a focus on preventing all injuries, both at work and home [16].

Additionally, based on Westrum's (1993) model, Hudson (2001) developed a safety culture maturity model. According to Hudson's (2003) model, the five levels of safety culture maturity include pathological (Level 1), reactive (Level 2), calculative (Level 3), proactive (Level 4), and generative (Level 5) [19-22]. In the pathological stage, the leading causes of safety problems are workers. In the generative stage, individuals actively participate at all levels, and safety is seen as an inherent part of the business [20].

Process safety indicators are leading when they prioritize preventative measures before accident occurrence and lagging when they are based on past operating system incidents. The creation of process safety indicators could help ensure that the process industry can perform its activities and operations without suffering from dangerous harm. Thus, the current study aimed to investigate process safety indicators in the process industry (the oil refinery industry) in Iran. The data related to injuries, incidents, and actions taken to prevent accidents, such as safety monitoring and safety activities collected from different industrial sites by the organization's safety department over three years, were considered. Additionally, the levels of safety culture maturity of the site employees and HSE (Health, Safety, and Environment) staff were assessed using self-reported tools.

MATERIALS AND METHODS

Identification of process safety indicators

Data were collected from the process industry in Iran over three years (2014 to 2017) as part of the routine reporting process. Lagging safety indicators were established based on incident reporting and analysis. Leading indicators were developed based on the desired operation of risk control systems. The effectiveness of the risk control systems is monitored by setting leading indicators. The safety indicators for the oil and gas industries were identified based on guidelines proposed for setting safety indicators for major hazard industries such as HSE (2006), OECD (2008), API (2011), CCPS (2011), and the International Association of Oil and Gas Producers (OGP) [5, 6, 12-14, 23].

Safety culture maturity assessment

A safety culture maturity assessment tool based on the HSE safety culture maturity model (or Fleming's maturity model (2001)) was used to investigate the current level of safety culture maturity of the organization. One hundred sixty-six (166) frontline staff (site employees) participated in the study. The assessment tool measured ten key elements of safety culture maturity across five levels [16]. Among the studied frontline staff, 15% were line managers and 85% were plant operators.

The framework proposed by Goncalves Filho (based on Hudson's (2001) model) for investigating the five levels of maturity, including pathological, reactive, bureaucratic, proactive, and sustainable, was used to identify the levels of maturity of safety culture in information, organizational learning, involvement, communication, and commitment for HSE staff [19, 22]. Thirty-five (35) HSE staff participated in the study. Plasticized cards were used to measure safety culture maturity, requiring HSE staff members to choose one of five levels for each of the dimensions [24].

RESULTS

Among the HSE staff, 74% had a BSc degree and 26% had an MSc degree in occupational health and safety.

Table 1. Identified lagging indicators in the study industry

Lagging indicator	Description [5, 6, 12, 23]
Total recordable injury rate (TRIR)	"The number of recorded injuries (such as fatalities and lost workday cases) per million hours worked"
Lost time injury frequency (LTIF)	The number of lost time injuries per million hours worked
Staff competence and safety training	"Number or percentages of incidents occurred due to lack of competence of staff, knowledge or experience" "Number of times operations did not proceed as planned due to lack of competence of staff and errors made by staff without the necessary competence, knowledge or experience"
Operational procedures	Number or percentages of incidents occurred due to incorrect or unclear operational procedures Number of times operations did not proceed as planned due to incorrect or unclear operational procedures
Management of change	Number or percentages of incidents occurred due to failures in the management of change process
Communication	Number or percentages of incidents occurred due to failures in safety communication "Number of times operations did not proceed as planned due to failures in safety communication"
Permit to work	"Number or percentages of incidents occurred due to failures in permits or failure in controlling high-risk maintenance activity"
Emergency arrangements	Number of elements of the emergency procedure that failed to function to the designed performance standard
Inspections of safety critical items	"Number or percentages of incidents occurred due to failures in inspections of safety critical items such as couplings, pumps, valves, flanges, and other equipment and instrumentation"
Plant design	Number or percentages of incidents in which deficiency in plant design and non-compliance with standards was identified as casual or contributory factors

According to the results of this field study in the oil industry, total recordable injury rate (TRIR), lost time injury frequency (LTIF), staff competence and safety training, operational procedures, management of change, communication, permit to work, emergency arrangements, inspections of safety-critical items, and plant design were identified as lagging indicators in the study industry (Table 1).

Table 2 shows the identified leading indicators and their descriptions. Staff competence and safety training, operational procedures, permit to work, emergency arrangements, and inspections of safety-critical items were identified as leading indicators in the study industry.

The assessment of safety culture maturity among frontline staff based on the HSE model [16] revealed that the maturity of most safety culture elements was at level three "involving," moving towards level four "cooperating." Therefore, the safety culture was relatively mature in the study industry. The levels of safety culture maturity varied between occupational groups (Table 3).

The assessment of safety culture maturity among HSE staff, based on the framework proposed by Goncalves Filho (2010) [22], suggested that the industry exhibits more characteristics of the "proactive" stage. The percentage of choices for each of the five dimensions from 35 HSE staff is shown in Table 4. The investigation of the information, organizational learning, communication, involvement, and commitment dimensions (most frequent choice) presents characteristics of the "proactive" stage of maturity. It is clear that the HSE staff members were more likely to characterize the industry as "proactive."

DISCUSSION

The current study aimed to investigate process safety indicators in the process industry (the oil refinery industry) in Iran. Data related to actions taken to prevent accidents, safety monitoring, safety activities, and injuries and incidents collected over three years

Table 2. Identified leading indicators in the study industry

Leading indicator	Description [5, 6, 12, 23]
Staff competence and safety training	Frequency with which the competence of the staff was assessed by related department
	"Number or percentage of staff involved in operations who have the required level of competence necessary for following successful operations"
	Number or percentages of staff trained in the planned period compared with the schedule
	Number of safety training sessions completed in the planned period compared with the schedule
Operational procedures	"Number or percentage of operational procedures that are reviewed/revised as compared with the total number of operational procedures"
	Number or percentage of errors found in operational procedures
	"Number or percentage of safety critical tasks for accomplishing those tasks appropriate procedures are in place"
Permit to work	Number or percentage of permit to work issued under the permit procedures and conditions
Emergency arrangements	Number or percentage of emergency exercises completed to schedule
	"Number or percentage of non-compliance with standards identified during emergency exercises"
Inspections of safety critical items	"Number or percentage of safety critical plant/equipment inspections/tests undertaken to schedule"

Table 3. The results of the assessment of safety culture maturity

Variable		Safety culture maturity				
		Level One: Emerging (%)	Level Two: Managing (%)	Level Three: Involving (%)	Level Four: Cooperating (%)	Level Five Continuous improvement (%)
Job title	Operational staff	2.90	8.70	53.80	25	9.60
	Supervisory staff	1.60	8.10	62.90	14.50	12.90
Education level	Master of Science	9.1	9.1	50	27.27	4.53
	Bachelor's degrees	0	13.64	57.57	21.21	7.58
	Associate degree	5	5	65	20	5
	Diploma	1.73	3.45	56.90	18.96	18.96

Table 4. Maturity of safety culture for each of the dimensions

Variable	Pathological (%)	Reactive (%)	Bureaucratic (Calculative) (%)	Proactive (%)	Sustainable (Generative) (%)
Information	0	5.72	11.42	77.14	5.72
Organization learning	2.8	5.72	11.42	74.34	5.72
Involvement	2.8	11.42	14.30	57.18	14.30
Communication	0	2.8	37.20	40	20
Commitment	0	2.8	37.20	37.20	22.80

from different sites of the industry by the safety department of the organization were taken into account. Additionally, the levels of safety culture maturity of the site employees and HSE staff were assessed using self-reported tools.

According to the findings of this field study, TRIR, LTIF, staff competence and safety training, operational procedures, management of change, communication, permit to work, emergency arrangements, inspections of safety-critical items, and plant design were identified as lagging indicators. In the Tang et al. (2018) study, the lagging process safety indicators based on actual safety data from offshore oil and gas platforms for the year 2016 were fatal incident rate, total recordable incident rate, lost time injury rate, and reported near-misses [25]. In the Reiman and Pietikäinen (2012) study, examples of outcome indicators (lag indicators) included industrial safety accident rate, maintenance backlog, number of reported near misses, number of safety events, and loss of primary containment [7].

The identified leading indicators in the current study were staff competence and safety training, operational procedures, permit to work, emergency arrangements, and inspections of safety-critical items. Lingard et al. (2017) suggested toolbox meetings, safety observations, occupational health and safety audits, and non-compliance as expected leading indicators in a large infrastructure construction program [26]. Webb (2009) established specific lagging and leading process safety indicators at Basell Company. The established lagging indicators (in terms of consequence) included explosion or fire, electrical short circuit, release of flammable material, and unplanned shutdown events.

The site leading indicators included safety inspection, communication, percentage of PTWs inspected during the planned period, and training [27]. In the study conducted by Pawłowska (2015), the number of occupational accidents, occupational accident/incident rate and severity were identified as lagging indicators. Additionally, the number of workplace health and safety training courses, safety and health inspections, and assessments of occupational risks were identified as leading indicators [28].

The results of assessing the current level of safety culture maturity among frontline staff based on the model proposed by HSE [16] revealed that the maturity of most safety culture elements was at level three “involving,” moving towards level four “cooperating.” Therefore, the safety culture was relatively mature in the study industry. According to the findings, the levels of safety culture maturity differed between occupational groups. Lardner et al. (2001) indicated that differences in levels of safety culture maturity between occupational groups can enable organizations to tailor improvement actions based on the needs and maturity of each group [29]. In organizations with a relatively mature safety culture, safety performance-related data is used effectively, and safety performance is actively monitored [16].

The assessment of safety culture maturity among HSE staff based on the framework proposed by Goncalves Filho (2010) suggests that the industry exhibits more characteristics of the “proactive” stage, which is relatively mature. In the proactive stage, people try to avoid accidents and start to take a more bottom-up approach [22, 24]. The results of a study conducted to assess safety culture maturity in some companies in Brazil indicated that, although most companies are trying to achieve and maintain high levels of safety performance, the study companies failed to achieve the highest stage of maturity. It takes time to establish a culture of safety [22].

According to the report of the UK Energy Institute (2010), process safety indicators in mature organizations can be selected from safety metrics already in use with other companies. In more mature organizations, the promotion of performance measurement and new thinking in safety metrics are expected. Performance reviews should be conducted at the starting level by less mature organizations [13].

In the study process industry, the safety culture was relatively mature, and process safety indicators, including leading and lagging indicators, were already monitored. The organization aims to improve safety performance and promote new thinking in safety performance activities to achieve high levels of safety performance and a high stage of safety culture maturity.

CONCLUSION

The findings of the study confirmed the importance of process safety metrics (both leading and lagging indicators) in process industries such as oil refineries. The assessment of current levels of safety culture maturity among frontline and HSE staff members suggested that the safety culture was relatively mature in the study process industry. Process safety indicators, including leading and lagging indicators, were already being monitored, and improvement in safety performance measurement was anticipated.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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