CHEMICAL ENGINEERING TRANSACTIONS

VOL. 36, 2014

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Valerio Cozzani, Eddy de Rademaeker

ISBN 978-88-95608-27-3; **ISSN** 2283-9216

DOI: 10.3303/CET1436010

Safety Performance Indicators: a Questioning Diversity

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Safety performance evaluation is an important issue of industrial risk management. If this statement is well accepted by the community, how to evaluate this performance does not meet consensus. The traditional incident-based approach has been shaken in 2007, after the Texas City refinery explosion. Accident report has pointed out confusion between personal safety and process safety, and between lagging and lagging indicators. Large number of thoughts and discussions has emerged regarding the use of safety performance indicators to measure level of risk. An indicator can be defined as a measurement, qualitative or quantitative, which provides information, in a specific objective of interpretation, in a particular context, for a specific actor. Almost 10 years after the Texas City accident, literature is now enriched with many proposals of set of indicators, emerging from scientific articles and industrial guidelines. Faced with this diversity of sources and management tools, we highlight the following question. What are the criteria for comparison, differentiation, and selection of these tools? Our study is based on an in-depth analytical review of the literature. As a result, several criteria seem to emerge: models used to design indicators, object of study, objectives of interpretation, terms of implementation and revision, actors affected by the outcome, and terms to validate the scientific relevance and operational feasibility. Multiplication of tools gradually improves the monitoring and driving of safety. However, our study shows that several criteria for indicators still need to be discussed, both theoretically and practically.

1. Introduction

Thirty years after the Indian Bhopal accident, major industrial accident is still threatening. Texas City, Deepwater Horizon, Fukushima, Lac Megantic, impose to adapt the safety of industrial systems, which is more relevant than ever in the spiral of the movement and the complexity. This finding and its environment requires us to stay close of a challenge based on the continuous evolution of models and tools for risk management. Risk analysis, reliability, human factor, and organizational approach ensure an industrial development, breaking the rupture with continuous activities. These technical approaches are further complemented by regulatory requirements, ethical considerations, participatory communication, and the implementation of public policies, which further improves the environment of high-risk industry. Therefore, although the number of actors and factors are multiplied by the interconnections, we nevertheless found similar causes in the most industrial accidents. Also, it is important to have indicators that, beyond existing performance, can be analyzed and challenged, in order to allow critical space by social sciences. In fact, in resilience-based environment, it is necessary to restore a doubt in the decision-making process, in relation with the concept of resistance, which highlights the rupture.
The traditional incident-based approach has been shaken after the explosion of the Texas City refinery in 2005 (Mogford, 2005). The inquiry pointed confusion between personal safety indicators and process safety indicators, and also between lagging indicators and leading indicators. Many discussions have emerged about the good use of performance indicators to measure the level of safety. Almost ten years after the Texas City accident, the literature is now enriched with numerous proposals for sets of indicators,

emerging from scientific publications and industrial guidelines. Given the diversity of these sources, which are the criteria for comparison, differentiation and selection of these tools? A review of the literature leads us to the following conclusions. Firstly, most of the proposed indicators serve the same purpose of industrial accidents anticipation. However, they are based on heterogeneous models, they seek to measure different aspects of organizations, and methods to design and implement them are varied. Secondly, consensus is done in the literature, on the need to measure safety performance. However, the question of the design and use of indicators is still debating. This article is organized as the following plan. The first part addresses the issue of dynamic risk level in industrial systems. The second part provides a comparison of the main industrial guidelines existing for design of safety performance indicators. A third party delivers a review of scientific literature on the subject. Finally, the fourth section provides a critical reflection on the role, design, and implementation of safety performance indicators, as part of management of major industrial hazards.

2. A dynamic level of risk

Table 1: Some of the major accidents in the process industry

Year	City, Country	Events	Consequences
2001	Toulouse, France	Ammonium nitrate explosion.	31 killed, 2,500 injured.
2005	Texas City, USA	Refinery explosion.	15 killed, 170 injured.
2005	Buncefield, UK	Oil storage terminal explosion.	43 injured.
2010	Deepwater Horizon, USA	Oil rig explosion.	11 killed, 16 injured, major oil spill.
2011	Fukushima, Japan	Nuclear accident.	Level 7 on the International Nuclear Event Scale.
2013	Lac Megantic, Quebec	Train derailment and oil wagon explosion.	47 killed.
2013	West, USA	Ammonium nitrate explosion.	15 killed, 160 injured.

What is the link between a leak in an Indian industrial site in the 1980s and an explosion in a small French industry in 2010? How to explain the paradox of the accident still possible in ultra-secure systems? A key to understand is the last evolution of organization in a more rapid and complex society (Richard et al., 2012). The main current industry trends create new previously unknown vulnerabilities. Factors of destabilization are numerous. We can cite exogenous factors: technological break, globalization of trade, worldwide competitiveness, normative explosion, new media treatment, and systems superposition: energy, telecom... and also endogenous factors : financial pressures, new methods of management, erosion of equipment and infrastructure, internal couplings , increasing margin tolerances, productivity pressure... This natural evolution permanently alters the scope of risk generated by the industrial process. He is no longer defined and localized, but erratic and diffuse. It is not constant, but dynamic and evolving. In this situation, it on the management level that is necessary to anticipate the major industrial accidents. Proliferation of standards and guidelines for the implementation of a system of safety management clearly shows this phenomenon. One way to understand the entire field of risk across the organization is the measurement of safety performance.

In the past 80 years, many advances have been made to manage industrial risks. Reduction of the consequences of technical failures, or human errors, and integration of safety barriers, led to a decline of the possibility of a major industrial accident. However, accident analysis (table 1) shows that the industrial accident is now taking a new configuration. Accidental chain is a combination of many causes. Accident is characterized by a deterministic nature, with the set of cause-consequence events in the accident chain, and also with a random nature, by the uncertainty of the place, date, and context of the occurrence of this chain. In this context, maintaining safety barriers is essential. To anticipate major accident, it's now necessary to take into account all level of management practices, and not only focus on the technical process. Technical integrity, training and skills, accident investigation, monitoring, communication relationship with authorities, organization of work… are many issues that influence the level of risk. Risk is diffuse, erratic, and progressive. Several mechanisms, also called risk factors (Knegtering et al., 2013), appear to affect it. For example, it may include the context in which the work is performed (shift turn-over, transition period (start-up…)), or internal mechanisms related to the work organization (risk homeostasis, compensation effect). This configuration has an impact on the use of management indicators. Measure the level of risk means taking into account diverse fields (behavior of mechanical components, operator practices, infrastructure monitoring, resource allocation...), and several organizational levels: operational, management, corporate, relations with the authorities. Legal standards also require indicators to have a dual role. Firstly, they provide information as part of the decision-making process. They support decision-maker on the description and representation of the situation. In this context, they are arguments to legitimize the decision and protect the decision-maker. Secondly, indicators have a role of communication to stakeholders, including regulators. This dual role challenge a unique method design of indicators, such as defined in most guides to good industrial practices.

3. An explosion of tools for a single goal

Table 2: Main guidelines considered

Nom	Organisation	Date	References
Developing process safety indicators: A step-by-step guide for chemical and major hazard industries.	HSE	2006	(HSE, 2006)
Safety performance leading indicators.	CBA	2009	(CBA, 2009)
Guidance on Developing Safety Performance Indicators.	OECD	2009	(OECD, 2009)
Process Safety Performance Indicators for the Refining and Petrochemical Industries.	API / ANSI	2010	(API, 2010)
Process safety leading and lagging metrics.	CCPS	2011	(CCPS, 2011)
Metrics for Safety Key Performance Indicators for the Performance Scheme.	EC, EASA, EUROCONTROL	2011	(EC, 2011)
Process safety - recommended practice on key performance indicators.	OGP	2011	(OGP, 2011)

Many guidelines, toolkits, or good practices have been published over the last ten years on the design and use of indicators of safety performance. The main ones are listed in the table above (table 2). A comparison of these main models reveals a diversity of approaches: multiple terms and definitions, types of indicators, measurement object, design methodology of the indicator, and recipients of the measure.

- Diversity of terms: process safety indicators, key performance indicators, risk-based indicators, resilience based indicators, positives performance indicators.
- Diversity of types of indicators: activity vs. results, input and output, leading vs. lagging, personal safety vs. process safety, direct vs. indirect.
- Diversity of definition: for example, the same term « leading and lagging » have several definitions, relating to each guideline (Hinze et al., 2013).
- Diversity of object measurement: risk level, safety, safety management system efficiency, safety culture, resilience.
- Diversity of design method: set of pre-designed indicators, method based on accident model (Heinrich's triangle, Reason's Swiss model, Kongsvik's organizational model), method based on indicator lifecycle, and integration of indicator at the process level (Pasman et al., 2013), or at the safety management system level (Reiman et al., 2012).
- Diversity of recipients: operation, management, corporate, national authorities.

The comparison of the main guidelines selected shows a diversity of approaches to design and use of indicators to measure safety performance. However, one common element is found in all the guidelines. The purpose of the indicators and their legitimation appears in every documents studied. It is interesting to note an expansion of different tools available, responding to the same legitimacy. At least two reasons could explain this finding. Firstly, the industrial areas that feed the reflection on indicators do not have the same level of knowledge. Chemical, nuclear, transportation... have different levels of understanding of how their organization is working. Advances in the design indicators are therefore disparate. Secondly, the diversity of concepts can be explained by an unceasing debate in the scientific literature on tools for measuring performance on industrial risks.

4. Measuring safety performance: still a scientific debate?

Design and use of performance indicators applied to industrial risk management is not a new question. However, this issue has been highlighted after the explosion of the Texas City refinery in 2005. Indeed, the investigators point weaknesses in the management of the industrial site, including the use of safety performance indicators. The Bakel panel (Baker et al., 2007) then initiates a reflection on two issues. The first relates to the existing confusion between personnel safety indicators, and those relating to the safety of industrial process. The second relates to the limits of results indicators, which describe the behavior of the system as it was in the past (few seconds ago, few hours or a few days ago...), and advocates the use of leading indicators. Propositions made by the Panel Bakel were then criticized by Hopkins. According to the author, as the guide provided by the HSE (HSE, 2006), the Baker Panel does not provide satisfactory evidence to distinguish leading and lagging indicators (Hopkins, 2009a). This answer was the starting point a discussion within the community of industrial safety on the definition of leading and lagging indicators (Hale, 2009). The journal *safety Science* invited researchers and practitioners to answer to the Hopkins publication (Hale, 2009). Twenty contributions then contributed to the debate (Hopkins, 2009b) , yet revealing the diversity of understandings and confusion of terms found in this area (Allford, 2009). The purpose of the safety indicators, however, appears to be a shared. Performance indicators have three goals: 1/ monitor the safety level of a system (a department, site, or industry), 2/ support the decision of where and when to implement corrective actions and 3/ motivate people in a position to act, to take the necessary measures (Hale, 2009). The debate then focuses on several aspects of the indicators: the underlying used to design indicators, measurement objects and types of measurements. Regarding underlying theories, several models are confronted. Major are issued from the Heinrich's triangle (Collins, 2011), the Reason's Swiss model (Reason et al., 2006), the systemic model (Leveson, 2004), and organizational model (Kongsvik et al., 2010). Based on these models, several types of measures are developed. According HSE (HSE, 2006), the measure of performance can be divided into leading and lagging indicators. "Lagging" means identifying, reports accidents and learns from feedback, while "leading" mean provide feedback on performance before an accident occurs. Several objects of measures are also developed in the literature. Risk indicators are derived from a risk-based approach (Oien, 2001), while the safety indicators can be derived from several approaches: safety performance (HSE, 2006), incident-based (Oien, 2008), and resilience (Oien et al., 2010). Nearly ten years after the Texas City explosion, the issue of indicators still feeds discussions. The term "safety indicators" is an umbrella for a variety of concept, sometimes used interchangeably. According to Oien (Oien et al., 2011), these discussions show a lack of knowledge of previous research conducted in the 1980s and 1990s. For example, the debate on leading indicators and lagging seem similar to the debate on direct and indirect indicators. Thus, the current need is not more to create new knowledge about the indicators that formalize and structure the generation of post- Baker panel indicators.

5. Needs for a formalization of a new generation of indicators

The utility of measuring safety performance as part of industrial risks management is well established. However, the design and use of indicators is still a challenge for both the scientific sphere as industrial sphere. We can cite several questions:

Challenges regarding the design of indicators:

- The diversity of fields to measure: can lead to a big quantity of information to manage. It is not possible to follow precisely that amount of indicators, which requires a lot of resources. The choice is made to focus on certain indicators considered as representative. How to select these special fields of measure, while accidents are resulting from many causes across the organization?
- Set of generic indicators: are designed with a low level a contextualization. How to transpose an indicator from an industrial domain to another, as they demonstrate ways of cleaved management (nuclear, chemical, transportation does not have the same level of knowledge)?
- The myth of measure: some critical aspects of the accidents are not measurable. How to take into account these aspects, and keep a necessary critical space regarding the management tool?

Challenges regarding the use of indicators:

- Control by indicators: the focus on the indicator results can lead to a change of behavior. How to ensure the safety management rather than management of the measure?
- Decision-making: most of the guidelines address the issue of reporting and indicators as a support for communication. However, none of them addresses the place of the indicator in the process of decision making. How to formalize the establishment of the indicator in the process of decision making?
- Variability of measurement: evolution of standards and the principle of continuous improvement, require to continually improving references and critical thresholds of indicators. How to change indicators, and in the same time allowing a long-term comparison of results?

Faced with these challenges, and in order to control industrial processes, design methods, and the practice of use of indicators in enterprises are challenged. The current diversity must give way to a generation of indicators ideas based on three ideas. The first idea is the lifecycle. This is not question to impose a typology of pre-designed indicators for a type of activity, but to propose a methodology for the design and use of indicators. Since the identification of issues of the organization in terms of industrial safety, to the critical reviewing, company has to develop its own system of measurement. The starting point could be the establishment of the purpose of indicators, and the description of the functions they might have (Grote, 2009)(Harms-Ringdahl, 2009). This is the case for the OECD methodology (OECD, 2009). The second idea is the integration of indicators in the process of decision making. The indicator should be placed in an ecosystem of decision in which strategies of action are defined before the measurement. The decision is no longer directly coupled to the indicator, but can be expanded with additional information: weak signals (Delatour et al., 2013), audit... Kjellén (Kjellen, 2009) propose a combination of performance data, risk assessment and expert judgment. Finally, the third point refers to the multidisciplinary field of measurement. The construction of indicators should be refer to a field of risk more deeply linked to all fields involved in the in the post-accident experience returns. Thus, the measurement model adopts the same logic as the construction of the industrial accident. The concept of safety indicator should be used with precaution. It is necessary to carefully define this concept, every time we use this term (Hopkins, 2009b). The challenge is to develop indicators that have the ability to predict future safety performance.

5. Conclusion

Measuring safety performance indicators play an essential role in the management of industrial risks. However, industrial accident has become a complex phenomenon. Understand this complexity using indicators is a challenge. Legitimized by several major accidents, many tools have been developed in recent years. They have limits, and leave behind shadow areas of weaknesses in the field of risk control. To be effective, management tools must be coupled with a critical space, and find counter-balance, allowing a different perspective of the same industrial system. Formalize a new generation of tools post Baker panel, including current developments of society, and its impact on the dynamics of the level of risk would have two advantages: allow a better understanding by industrial of how indicators are functioning and replace indicators into their role in the construction of the representation, and of protection framework for the decision-maker.

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