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Process safety indicators, a review of literature

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ABSTRACT

Indicators for process safety can provide insight into safety levels of a process or of a company, but it is clear that the 'silver bullet' has not yet been identified. In secondary literature a difference is made between leading and lagging safety indicators. Primary literature questions this distinction, as well as the quantification of safety indicators. Safety Indicators for management and organisation have an ambiguous relationship with latent errors and conditions, being mentioned over and over in retrospective safety analyses of major accidents. Indicators for occupational safety do not necessarily have a relationship with process safety. In addition, it can be expected that regulators of major hazard companies will ask to identify and implement both lagging and leading indicators, and anchor these indicators in a safety management system. Therefore, the subject 'safety indicators' will remain in the spotlight, at least in the time to come.

1. Introduction

In a competitive market environment, companies need to perform optimally if they want to survive in the long term and to be amongst the top of the sector. In the 1990s the term 'Performance Management' was introduced in management literature. Performance can be translated in this context as managing performance with the ultimate goal to perform better. First one thinks of financial and economic matters in terms of productivity, quality and environment. However, safety is also an important area for performance indicators. In practice, performance management becomes evident in the selection of representative indicators. These indicators reflect the status of the working environment and production processes realistically, and are used to obtain an optimal situation. A specific type of indicator for the safety domain is presented in this article, that is, the process safety indicator.

Literature on this topic sometimes refers to boilers of steam engines and trains. In the 19th century boilers exploded regularly, until it was understood that pressure, temperature, and strength-thickness of boiler walls were important technical indicators for these explosions (Fig. 1).

The frequency of these explosions dropped dramatically after the introduction of safety valves. In the second half of the 19th century, with the Siemens Martin and the Bessemer process, steel boilers could be produced and the strength of the boiler wall was under control (Rolt, 1955; Hijmans, 1963).

One hundred years later two publications on safety indicators for occupational safety appeared in America, one by Thomas Rockwell (1959) and one by William Tarrants (1963). Rockwell was looking for a measure of safety performance, and formulated requirements for indicators, which should be reliable, quantifiable and easy to understand. The indicator should also be stable, reproducible, sensitive to changes, and cost-effective. According to the author, accidents, with or without lost time did not meet these requirements. In line with a common safety metaphor of that time, Heinrich's domino's, unsafe acts were taken as starting point for indicators (Table 1) (Heinrich, 1941; see also Gulijk et al., 2015).

Four years later, William Tarrants doctorated at the University of New York on causes of accidents. Accidents and near-accidents were defined as unplanned events interfering with a job and not necessarily resulting in damage or adverse effects. This definition of accidents differed from Rockwell's focus on unsafe acts, and followed the insights after World War II of external factors as causes of occupational accidents, like for instance Winsemius (1951) (for an overview see Swuste et al., 2014). According to Tarrants, accidents

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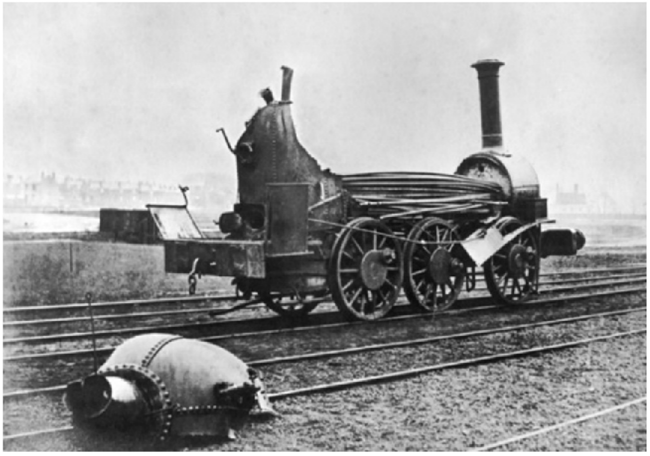

Fig. 1. Exploded train steam boilers.

Table 1
Unsafe acts as safety indicators (Rockwell, 1959).

1.	Working with loose tools underfoot
2.	Working without goggles when required
3.	Working under suspended loads
4.	Failure to use guards as provided
5.	Working in unsafe postures
6.	Wearing improper or loose clothing
7.	Use of shock tools with mushroomed heads
8.	Improvising unsafe ladders and platforms
9.	Running
10.	Misuse of air hose

were always preceded by errors or unsafe conditions, or a combination of errors and unsafe conditions (Tarrants, 1963, 1970). He proposed to include incidents and accidents as a basis for indicators.

Various authors indicated that well into the 1990s, and even till now, one particular indicator had been the key safety indicator in process industry, the LTIF, the Lost Time Incident Frequency (Visser, 1995; Hale, 2009; Harms-Ringdahl, 2009; Pasman and Rogers, 2014; Leveson, 2015; Pasman, 2015; Knijff et al., 2013). LTIF represents the number of days of absence to work due to an accident, per million hours worked. At that time, improvements in safety performances were equal to improvements in LTIF values. For example by Shell, between 1957 and 1994 the indicator dropped from about 20 to less than 2. The same focus on LTIF was present in many other companies in the process industry. Therefore many companies in the late 1990s promoted a zero accidents approach. This appeared to be a miscalculation. Obviously, process disturbances accelerating major accident scenarios might also induce scenarios of occupational accidents, meaning that occupational safety and process safety can be intertwined. But, because of the accepted difference between the origin and pathways of major accidents and occupational accidents, LTIF figures cannot be regarded as indicators of process safety.

In the 1990s major accidents in high-risk industries reoccurred (Kletz, 1993). Examples were: exploding tanks during welding, radioactive emissions, tripping reactors, overfilling storage tanks, failing pipelines, metal fractures by extreme temperature variations, etc. (Pigeon, and O'Leary, 2000; Hopkins, 2000; Körvers, 2004; Sonnemans and Körvers, 2006; Körvers and Sonnemans, 2008; Guillaume, 2011 Kidam and Hurme, 2013). Apparently companies were, and still are, unable to recognize so-called 'weak signals' or process deviations with potentially major effects. From the second half of the 1970s these weak signals and deviations were divided in three groups, being technical/process engineering, organisational and human factors, including the quality of leadership (see Swuste et al., 2015). A comparison of major accidents worldwide between 1970 and 1980 and the first decade of this century showed no difference between these two periods. Apparently recognition of weak signals at all levels of the organisation as well as by (sub) contractors work is still a problem, and managing disaster scenarios seems an extremely difficult topic (Table 2).

Apart from not recognizing these 'weak signals' as precursors to major accidents, other explanations are possible, like limited analysis capabilities of process safety techniques, safety management systems that do not have sufficient control over potentially hazardous processes, or limitations of existing safety metaphors, models and theories. However, these metaphors, models and theories are still too conceptual in nature to predict accidents and to deduce relevant safety indicators (Knegtering and Pasman, 2009; Le Coze, 2013). Also, the increased numbers play a role. There are ever more nuclear plants operating, ever more process installations, air traffic increased substantially, etc. Furthermore, the vulnerability of these systems is enhanced by an increased complexity and dominant market forces. This latter influence leads to outsourcing, increased production efficiency and modular or fragmented organisational structures (Le Coze, 2014). Against this background, this article answers the following two questions:

> Can process safety indicators provide insight and knowledge in levels of safety of processes or business, both current and future? And if so, which indicators are qualified?

2. Materials and methods

In 2009 Andrew Hopkins and Andrew Hale issued a Safety Science special issue on process safety indicators (Hopkins and Hale, 2009), with nineteen different contributions from researchers, consultants and safety experts working in large companies. This issue was the start of this literature review, both in scientific and in professional literature. Scientific literature publishes results of original studies, and includes a formalized, anonymous referee system. Professional literature can be original work, or can report, summarize, comment on scientific literature, making it accessible to a wider audience than the scientific community and interested parties. Usually a referee system similar to scientific journals, is lacking. The scientific journals in this overview, presenting papers on this topic from North American, European, Central Asian, and Australian authors, were restricted to Ergonomics, Journal of Hazardous Materials, Journal of Industrial Engineering, Journal of Loss Prevention in the Process Industries, Journal of Management, Journal of Safety Research, Process Safety and Environmental Protection, Reliability Engineering and System Safety, Safety Science, and the Dutch Journal of Occupational Sciences.

Professional literature was mainly restricted to reports of national organisations, like the American Baker report (2007), reports of the Centre for Chemical Process Safety (CCPS, 2010, 2011, 2014), British reports of the Control of Major Accident Hazards (COMAH, 2012), of the Health and Safety Executive (HSE, 2006) and of the UK Oil and Gas Industry, "step change in safety" (2006). Professional literature from international organisations comes from the International Organisation of Oil and Gas Producers (OGP, 2011) the Organisation for Economic Cooperation and Development (OECD, 2008a, b), the European Process Safety Centre (EPSC, 2012), and the European Chemical Industry Council (Cefic, 2011). Professional literature includes books on management, as Olivier and Hove (2010), Heuverswyn and Reniers (2012), and Pasman (2015). For