CHEMICAL ENGINEERING TRANSACTIONS
VOL. 31, 2013
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet
Guest Editors: Eddy De Rademaeker, Bruno Fabiano, Simberto Senni Buratti

ISBN 978-88-95608-22-8; **ISSN** 1974-9791
DOI: 10.3303/CET1331066

Process Safety Performance Indicators in Chemical Industry – What Makes It a Success Story and What Did We Learn So Far?

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Latest with the publication of the Baker Report (2007) triggered by the Texas City tragedy, it became obvious to the chemical industry that process safety leadership and incorporation of process safety into management decisions cannot be achieved without measuring and reporting process safety performance. To sustainably maintain and continuously improve process safety culture it is at the same time essential that process safety performance indicators (PSPIs) are meaningful and easy to understand for the entire organization from shift operators, plant engineers and plant managers to the top management.
Bayer MaterialScience initiated its process safety performance indicator program several years ago. After piloting in selected plants it was globally rolled out and implemented. Factors supporting the successful implementation were face-to-face meetings with Production and Technology (P&T) managers, incl. plant managers and engineers in most of our facilities explaining the concept and the full integration of the selected indicators into the existing management system and software as far as possible.
The selected performance indicators are reported to the BMS management and discussed in safety meetings. The Bayer MaterialScience community of plant and process safety experts is regularly reviewing and analysing data to further improve consistency and reporting efficiency but also discussing options for further PSPIs as well as measures to improve process safety performance.
This paper provides insight in the system of PSPIs developed at Bayer MaterialScience as well as in major conclusions drawn and actions taken to maintain and improve excellence in process safety.

1. Introduction

Several industry groups and associations have concentrated on developing guidelines for process safety metrics in the recent years. Prominent publications stem from CCPS (2010, 2011), API (2010) and Cefic (2011) and a first international conference on process safety performance indicators was held in Brussels (Cefic and EPSC, 2012). From the three types of metrics which are usually described in the above mentioned guidelines (e.g. CCPS, 2011)

- Leading metrics
- Lagging metrics
- Near Miss and other internal lagging metrics

Bayer MaterialScience has selected performance indicators which specifically address essentials for the integrity of the overall safety concept of a plant throughout the entire life cycle.
The overall safety concept of a process or plant usually consists of the following elements:

- Robust operational concepts
- Reliable prevention concepts
- Effective mitigation concepts

It must be thoroughly developed, implemented, operated, maintained and inspected to ensure the safe and reliable operation a plant.

Please cite this article as: Klein T. and Viard R., 2013, Process safety indicators in chemical industry - what makes it a success story and what did we learn so far?, Chemical Engineering Transactions, 31, 391-396 DOI: 10.3303/CET1331066

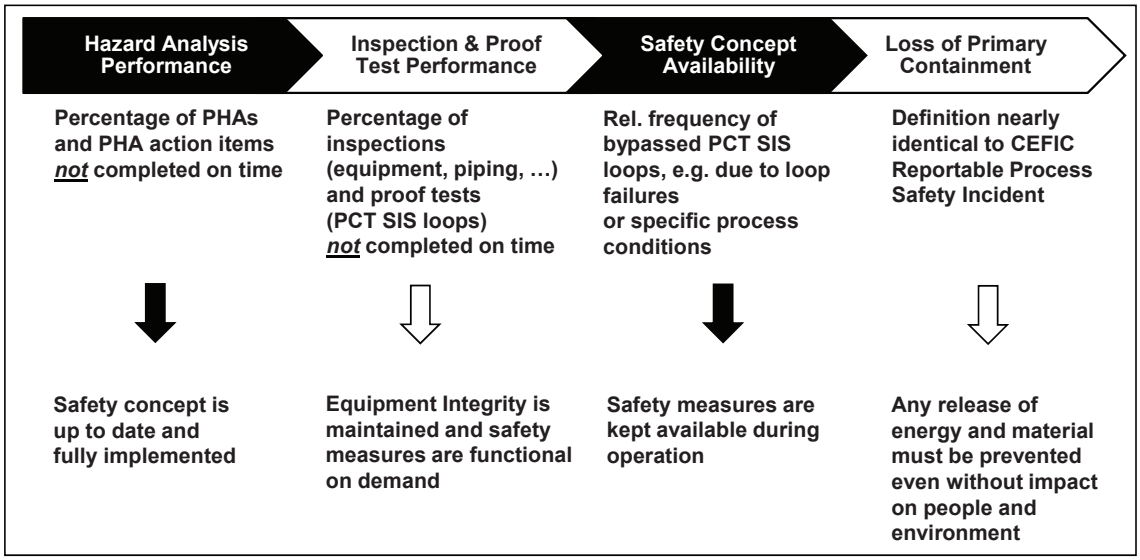

Figure 1: Bayer MaterialScience Process Safety Performance Indicator System: Four Indicators

2. Selected PSPI system

Four performance indicators were chosen. They are summarized in Figure 1 above and explained in more detail in the chapters below.

2.1 Hazard Analysis Performance

The first performance indicator called Hazard Analysis Performance (HAP) is addressing the development of the safety concept in process hazard analyses (PHAs), based on a Bayer-adapted HAZOP methodology and the implementation of defined action items and measures either prior to start-up of a new plant or in a timely manner in case of plants in operation. Its intent is to ensure and demonstrate that the safety concepts of our plants are kept up-to-date and no plant is operated without an up-to-date safety concept being in place.

HAP is calculated as number of overdue PHAs plus number of overdue pre-start-up/acceptance safety reviews divided by two times the number of existing PHAs. The value is than multiplied by 100 to give a percentage.

Pre-start-up safety reviews are performed to verify that all defined safety measures are in place and functioning prior to starting up a new plant or unit operation. For plants in operation, acceptance safety reviews are performed to verify that action items and measures defined in the last PHA revalidation were implemented and are functioning.

At Bayer, this indicator was first implemented in Bayer MaterialScience and then rolled out to other Bayer Companies. The Hazard Analysis Performance is reported quarterly. This is an appropriate frequency as PHAs are to be updated every few years.

Please note that the best value of the HAP indicator is zero percent, i.e. there are no overdue PHAs or pre-start-up/acceptance safety reviews. So, whenever trend charts with leading and lagging indicators are shown, decreasing numbers always reflect a positive development. Also, in doing so, attention is automatically drawn to the areas which require further action.

2.2 Inspection and Proof Test Performance

The second performance indicator is called Inspection and Proof Test Performance (IPP). Mechanical integrity is a key passive measure to prevent a release of substances from a chemical process and the on-time execution of inspections is essential to ensure the integrity of equipment. The inspections part of the IPP indicator comprises time-based and risk-based inspections of process-related equipment and piping as well as safety relief valves.

Active safety measures like safety interlocks realized in safety instrumented systems (SIS) are as well essential elements of the process industries' safety concepts. Regular proof tests are performed to ensure that potential dangerous undetected failures are identified and safety interlocks are reliably functioning on demand.

The IPP indicator is defined as the percentage of inspections and proof tests not completed on time, i.e. that the total number of inspections and proof tests to be performed in a calendar year is used as denominator. Again the best value is zero percent and reporting is done quarterly. The IPP indicator covers legally required inspections as well as such inspections and proof tests which are performed according to company internal rules. A deviation from zero percent is therefore not necessarily indicating a legal compliance issue but IPP supports managers in production and technology in identifying potential shortcomings.

2.3 Safety Concept Availability

The third indicator is called Safety Concept Availability (SCA). The lessons learned from several incidents in chemical industry show that bypassed (deactivated) safety interlocks were contributing factors. Because being bypassed they did not prevent the occurrence of the incident or mitigate the consequences. Therefore the SCA indicator counts the percentage of safety interlocks realized in SIS or equivalent that were bypassed for unintended reasons. As this indicator is again reported quarterly it is calculated as number of bypassed safety interlocks in the quarter of the year under report divided by the total number of safety interlocks. The value is then multiplied by 100.

Bypasses which must be counted usually occur because of a malfunction of a component of a safety interlock like a sensor or final element.

Safety Interlocks are also temporarily deactivated during start-up, shutdown or during proof testing. However, proof testing is a strictly regulated process with specific proof test procedures and clearance and acceptance of work governed by a temporary management of change or work permit process. Thus proof tests of safety interlocks are not counted by the SCA indicator.

The main advantage of this indicator is clearly on increasing and maintaining the focus and awareness of operations for bypassed safety interlocks and enforcing the requirement to regular check the status of the safety interlocks in the plant.

2.4 Loss of Primary Containment

The Loss of Primary Containment (LoPC) indicator was introduced 2009 and it turned out later that its definition is almost identical to the process safety incident definition of Cefic (2011). Currently a baseline is being established by counting the number of LoPC incidents and investigating the causal factors for these incidents. As for the other indicators the number of LoPC incidents was initially reported once per quarter. It is now being integrated into monthly reporting and a LoPC incident rate is being defined which will allow monitoring and communication of LoPC incidents with the same tools and layout as is used in occupational health and safety for recordable injury rates (RIR).

3. Other potential indicators – safety interlock activation

While HAP, IPP and SCA are leading indicators and LoPC is a lagging indicator we were also trying to identify a useful indicator for counting process safety-specific near misses. Safety interlock activation was a promising candidate. On the one hand, a safety interlock is preventing a process from leaving its safe operating window, thus preventing an incident and on the other hand its activation is indicating that there might have been a process deviation with a safety-relevant potential. Also, modern IT tools allow the detailed analysis of basic process control system (BPCS) and safety instrumented system (SIS) loop actions.

A pilot study was performed in our operations to analyse the safety interlock activations that had occurred during several months. The raw data was categorized into interlock activations which

- •• are due to start-up, shut-down or integral part of batch process control
- •• occurred due to proof tests
- •• occurred during maintenance while the equipment was idle
- •• could have had a safety-relevant reason

A deeper analysis of the latter category revealed that none of these activations happened because of a critical process condition but due to the chosen loop parameters. To prevent such causes is already in the scope of alarm management programs which Bayer MaterialScience is performing intensively to further reduce the number of unnecessary alarms. The pilot study also showed that detailed data on interlock activations is not available without further analysis and only a very small percentage of interlock activations may be caused by a critical process condition if at all. We therefore encourage production personnel to report process safety-relevant near misses directly via our near miss and incident information and management system.

4. Implementation of PSPI system and general experience

Bayer MaterialScience initiated its process safety performance indicator program several years ago. After piloting in selected plants it was globally rolled out and implemented. Factors supporting the successful implementation were face-to-face meetings with Production and Technology (P&T) managers, incl. plant managers and engineers in most of our sites explaining the concept and the full integration of the selected indicators into the existing management system and software as far as possible.
It must be emphasized with respect to the selected indicators that they are mostly quantifying and aggregating what was already required by our integrated management system and considered best practice before the implementation of this PSPI system. In addition top management had already prepared the ground for the implementation of these indicators by requesting regular reporting of selected process safety topics in the previous years. However, these indicators made process safety performance globally visible the first time.
From the start we were striving to generate as much performance data as possible directly from software and systems the majority of our plants is using daily for operational purposes anyway. Our asset management systems are used to document if equipment has to be risk assessed in a PHA and to track the due dates of PHAs and pre-start-up/acceptance safety reviews. The same approach is used for IPP. For SCA reporting bypasses of safety interlocks are flagged in the electronic work order.
Data is then centrally extracted from these systems wherever possible and processed further to generate the respective reports. The global standardization of software and the integration of further sites is a still on-going process.
Near misses and incidents are reported via a global near miss and incident information and management system. To integrated the LoPC incident reporting criteria into the current system was system-wise straightforward, however, plant personnel needs expert support to fully understand the LoPC definition where other criteria than a pure substance release apply. The term “Loss of Primary Containment” is easily associated with substance releases while the connection to injuries due to chemical substances or processes as well as fires or explosions is not always readily understood.
The global PSPI data are reported to all levels of the P&T organization up to the Executive Committee. More detailed data is presented and discussed in local or Business Unit safety meetings. There we observe also an increased number of lessons learned which were derived from investigations of LoPC incidents. It is expected that visibility of process safety performance is taken to the next level by monthly reporting of LoPC incidents, the introduction of a LoPC incident rate and the definition of a quantitative reduction target for LoPC incidents. Nevertheless qualitative and quantitative targets for process safety performance are already part of the annual performance management process at Bayer MaterialScience for all levels of the P&T organization.

5. Specific observations and conclusions

5.1 Hazard Analysis Performance

The HAP indicator has proven to be an excellent tool for the global Bayer MaterialScience community of plant and process safety experts (PPS experts) to initiate discussions about harmonizing process safety management globally, for example:

- How many PHAs should a plant have?
- How do we share process safety-relevant information globally?
- How do we exchange PHA information in order to a consistently high level of safety in all processes and plants?
- What is the most efficient approach to prepare PHA revalidations?
- What is the global approach for Management of Change?
- How do we organize current and future PHA work?

A discussion of these topics in more detail shall be subject of another paper. But to us it is evident that making Hazard Analysis Performance visible allows us now to have an even better coordinated global approach together with the P&T organization to look ahead and plan PHA revalidations for plants in operation and project PHAs as well as to allocate PPS experts with the required special knowledge and expertise throughout the entire Bayer MaterialScience operations.
As Bayer MaterialScience is operating plants with the same chemical processes in several sites around the world it is obvious that this approach must be supported by a global management of PPS knowledge and information. This refers to information about potential hazards of our processes and the properties of handled substances as well as to the implemented safety concepts which are described in detail in the

respective PHA documents. In every PHA the PHA team shall have the opportunity to retrieve the available safety-relevant information as well as to consult a PHA document of a sister plant, i.e. a plant that uses the same materials and processes as the plant which is being examined.
Therefore we make measurements of safety-relevant properties of substances and mixtures as well as investigations with materials under process conditions, which were performed in Bayer safety laboratories available to PPS experts and plant managers worldwide.
While PHA documents have always been exchanged as requested and best practices were adopted where appropriate as part of the technology transfer within Bayer, the increasing global collaboration among our PPS experts has created additional needs. In the future PHAs shall be documented in a common uniform global template to facilitate their use in sister plants. Accessibility of PHAs and efficiency in documentation and follow-up, tracking and closure of action items defined in the PHA can be increased by using a common global database for all PHA documents.
At the same time, moving to such a database also requires to harmonize the rules and practices of PHA management even further than with the current HAP indicator. This will influence the way how PHA revalidations are prepared and performed and action items are implemented and tracked as well as the way how Management of Change (MoC) procedures and requirements are complied with.
A MoC process is to be followed whenever a modification of a predefined specification is initiated. This involves often changes to a chemical process or plant which are risk-assessed with the same methodology as used in the PHA. It is a frequent practice to document such changes directly in the PHA by creating an evergreen PHA document where changes compared to the last revalidated PHA are clearly marked and identifiable. We believe, that establishing a globally uniform approach how MoC is managed and documented in a global PHA database will allow us to advance further beyond PHA revalidation and to include MoC performance into our current hazard analysis performance metrics.

5.2 Loss of Primary Containment

As LoPC incidents were fully integrated in the incident management, investigation and reporting requirements of Bayer MaterialScience we have after 3 years of reporting a statistical basis to analyse the causal factors of LoPC incidents. Generally we observe a higher percentage of technical causes than in occupational health and safety which is dominated by human factors. This is partially due to the nature of the events. However, more detailed root cause analyses of LoPC incidents indicate that again the human factor plays an important role: A flange may be leaking after being in service for already some time because a contractor did not tighten all screws with the correct torque.
This may serve as just one example to illustrate that an effective measure to reduce the number of LoPC incidents may need to address P&T employees as well as contractors. It also indicates that many measures to improve our process safety performance will not differ significantly from the successful occupational health and safety concepts the chemical industry is applying to reduce injury rates and improve the overall safety culture.
Another result of our analysis confirms the principles of the well-known incident pyramid theory (Heinrich, 1931). Plants which for themselves initiated spill reduction programs were recording plant-internal substance releases especially with quantities well below the LoPC reporting thresholds. By looking at these very small releases they were able to systematically identify the concrete equipment and the corresponding patterns which resulted in these leaks. Looking at the very small number of LoPC incidents alone was normally not sufficient to implement effective corrective and preventive actions.
Looking at such examples we also noted positively that just the implementation of the LoPC indicator without any defined quantitative reduction targets was encouraging plant managers to take action in their plant. This makes us optimistic that we will be able to make good progress in the years to come.

6. Conclusion

The introduction of the Bayer MaterialScience PSPI system has clearly supported our efforts to emphasize the importance of plant and process safety by

- Providing conversation topics on process safety
- Enabling all levels of management to express their commitment to process safety
- Introducing process safety into annual target setting and performance management
- Raising the awareness of plant personnel for process safety

It also pushed Bayer MaterialScience PPS experts to a focussed review of current practices and approaches and initiated strategic developments which will enable PPS to contribute even better to the safe and reliable operation of our plants.

Our leading PSPIs have proven to be useful in identifying room for improvement and driving change. Even when they indicate a high performance level they are regularly monitored to ensure that performance is not decreasing unrecognized.
A suitable lagging indicator like LoPC has the potential to become the long-term standard process safety performance metrics across the entire chemical industry. Hence we welcome the industry associations' dialogue (Cefic and EPSC, 2012) on the harmonization of their current process safety incident definitions.

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