PROCESS SAFETY PERFORMANCE INDICATORS – EXPERIENCE GAINED FROM DESIGNING AND IMPLEMENTING A SYSTEM OF PSPI'S FOR DIFFERENT CHEMICAL MANUFACTURING OPERATIONS

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Ciba started looking at PSPI's in 2006. The work started with an information gathering and scope definition phase. It was then decided to start with a pilot project on one plant on a 'Top Tier' COMAH site. The project started with a workshop which was facilitated by the HSE using a plant specific approach for identifying PSPI's. It was soon identified that this approach duplicated a lot of work which had already been completed in risk analyses and the Safety Report. Ciba therefore decided to customise the HSG254 (HSE, 2006a) approach to fit it in with established corporate systems and procedures.

A number of PSPI studies have been completed on 'Top Tier', 'Lower Tier' and non-COMAH sites. Experience has now been gained in measuring, reporting and reviewing PSPI data for batch and continuous manufacturing plants, tank farms and polymer production plants. This paper describes the PSPI methodology that Ciba has developed and summarises the experience that has been gained.

KEYWORDS: process safety performance indicators, COMAH

INTRODUCTION

THE NEED FOR PSPIs

History tells us that major accidents continue to occur in the process industries. In 2006, the HSE reported that accidents linked with major hazards were occurring at the following rate (HSE, 2006b):

- 60 reported RIDDOR (RIDDOR, 1995) dangerous occurrences involving the accidental release of substances in the UK every year.
- 34 RIDDOR dangerous occurrences involving fires or explosions in the UK every year.
- 1 major incident in the UK onshore chemical industry every 3 years on average.
- 5 major incidents in the European chemical industry every year.

Worldwide, major accidents continue to occur at a regular rate, often with devastating consequences. A major explosion in Toulouse, France in 2001 caused widespread offsite damage, including 29 fatalities (HSE, 2001). A high pressure gas pipeline explosion in Ghislengien, Belgium caused 24 fatalities in 2004 (HSE, 2009). A major explosion at the Buncefield oil storage terminal caused widespread plant and environmental damage in the UK in 2005 (BMIIB, 2008). An explosion at BP Texas City in 2005 caused 15 fatalities and more than 170 injuries (BPRISRP, 2007).

The detailed accident investigations that follow this type of major accident tend to highlight a range of direct and indirect causes. These cover issues such as:

- **Procedural failings**, including incorrect handling and storage of chemicals, errors in procedures, ambiguous procedures, procedures which have not been accepted by the front line workforce, the deliberate violation of procedures and a failure to follow procedures. These are frequently associated with unusual operations such as start-up and shutdown.
- **Line manager mistakes**, including failures in supervision, failure to complete regular plant checks, missing trends in plant performance, not responding to alarms correctly and failing to diagnose faults correctly.
- **Control system malfunction**, taking the plant outside it's safe working envelope of flow, level, temperature, pressure, concentration and phase.
- **Technical deficiencies**, where installed plant is not fit for purpose. Technology may be obsolete or inappropriate. Plant and safety systems may be unreliable or may have been poorly maintained.
- **Inadequate risk assessment**, where the hazards were not properly identified and understood, the wrong control measures were employed or important control measures were not specified and installed.
- **EHS management system failures**, often associated with failures of Permit To Work systems, inadequate management of contractors, poor management of change and ineffective auditing.
- **Inadequate emergency planning**, often associated with unanticipated practical problems, lack of preparedness, poor co-ordination and communications problems.

Following on from the Texas City explosion in 2005, the Baker report focused much more attention on the systemic failure of process safety oversight by senior managers. They often lacked an understanding of process safety and viewed safety in terms of lost time accidents (LTA). Statistics tended to show a steady improvement in LTA rates and excellent performance against industrial benchmarks. This gave an illusion that critical safety issues were under control. For example, at BP, published LTA rates were following a generally declining trend, but the loss of containment rate at the Texas City refinery was increasing steadily.

The Baker report stressed that process safety had to have a much higher priority at senior manager level in major hazard industries. Careful management oversight is required to ensure that the critical elements of process safety are under control, looking at a range of trends to detect deterioration in achieved standards. This really has to focus on a range of levels, looking at operational control (procedures, control systems, plant inspection), failures of control (leaks, fires, failures of safety systems on demand) and management system corrosion (risk assessment, training, maintenance, auditing). Senior managers require additional tools to allow them to perform the critical oversight role effectively. PSPI is one of these tools, targeting process safety performance measurement within an overall corporate management system.

SENIOR MANAGER ENGAGEMENT

Industry has a long history of measuring safety performance based on lost time accident (LTA) rates. LTAs measure occupational safety and tend to be dominated by the higher frequency, lower consequence accidents such as slips, trips, falls and workplace injuries. Safety is taken very seriously by most organisations and senior management take an active interest in reducing LTA rates, providing leadership and resources aimed at improving performance. Statistics show that these efforts have had a dramatic effect in driving down LTA rates in the process industries.

Unfortunately, LTAs do not show senior managers how well the low frequency/high consequence accidents are being managed. Incidents involving the failure of process safety can be devastating with the potential for multiple fatalities, offsite impacts and large scale environmental damage. Managers often fall into the trap of believing that a low and reducing LTA rate means that corporate safety is under control. History shows us that this is often not the case. Incident reports increasingly show how plant, site and corporate systems have deteriorated or corroded over time. This can be due to changes in hard issues such as technology, management, manning levels, resources and operating strategies and softer changes such as safety culture, people's behaviour and attitudes. If process safety is to be managed effectively in the Boardroom, more sophisticated systems will need to be introduced for measuring process safety.

This will allow senior managers access to up-to-date process safety information, focused on a range of key indicators and trend analysis. Incipient problems can then be identified early and additional resources can be provided to prevent them from growing into a major process safety problem. By engaging more directly in process safety, managers should become more confident in providing process safety leadership. With this in mind, the CIA issued guidance in 2008 (CIA, 2008) to promote best practice in this area, focusing on a number of key issues, including process safety performance measurement based on a system of PSPIs.

I HOPE, I THINK, I KNOW

In general, senior managers in major hazard industries in the developed world are committed to the safety of their workforce and the people who are affected by their operations. They are well aware of the legal penalties which can be imposed for poor performance. Unfortunately, history shows us that they do not always devote enough resources to the monitoring and oversight requirements for process safety. Senior managers are at one of three levels of safety assurance:

- **I hope** that process safety is properly controlled. Managers have good intent but they have no systems in place to provide feedback on problems, near misses, critical system status and process safety performance. Senior managers are essentially operating with a process safety blindspot.
- **I think** that process safety is properly controlled. Managers have an understanding of critical process safety issues and are close enough to site operations to have a feel for the status of process safety but this is subjective and cannot be proven. Comfort is often provided by the extent of regulatory intervention but there is no evidence to support their position.
- **I know** that process safety is properly controlled **and I can prove it**. Managers have implemented a systematic way of measuring process safety performance; process safety is well understood at the highest levels in the company; regular reports are provided about process safety status; trends are analysed; critical process safety actions are resourced and followed up.

The PSPI approach provides a tool which can help staff at all levels in the company to reach the highest level of assurance, knowing that process safety is being controlled, supported by relevant evidence.

UK LEGAL POSITION

Recognising the useful role that PSPIs can play in improving process safety, the HSE (UK Health & Safety Executive) and the CIA (Chemical Industries Association) jointly issued PSPI best practice guidance in 2006 (HSE, 2006a). This guidance has particular applicability in the major hazard industries. It therefore now forms a critical element of legal compliance in regimes such as COMAH (COMAH, 1999). Under COMAH, the Regulatory Authorities expect that all 'Top Tier' sites will have established their PSPI's by the end of 2009 and that they will be actively using these PSPIs within their safety management system from 2010 onwards.

PLANNING

PROJECT DRIVERS

The four largest UK Ciba sites developed an interest in PSPIs for a number of reasons, including:

- Raising the profile of process safety on the corporate agenda.
- Increasing senior management involvement in process safety.
- Implementing a new tool for performance improvement.
- Complying with current best practice in safety management as defined by the CIA.
- Maintaining the COMAH site 'license to operate'.

INFORMATION GATHERING

Within Ciba, the safety management system is developed and monitored by the corporate EHS department in Basel, Switzerland. This promotes global consistency and is defined in corporate EHS Guidelines and Guidance Notes. Safety performance is principally measured using LTA rates. Some business segments have started to collect loss of containment data to supplement LTA data but detailed PSPIs do not form part of the corporate management system. It was, however, recognised that PSPIs would become an important aspect of legal compliance and best practice in the UK. The Ciba UK sites therefore developed the PSPI approach to suit local requirments.

UK senior managers were committed to the project and were keen to implement PSPIs. They had attended a number of HSE and CIA events and asked the EHS department to investigate the different approaches that could be used for implementing PSPIs. Useful information was collected from conferences, CIA and CEFIC meetings, talking with peer group companies, internet searches and published guidance, particularly HSG254 (HSE, 2006a).

The following critical success factors were identified for the project:

- Reporting relevance at different management levels: plant, site, business segment, corporate.
- Clarity of data presentation and concise reporting tools.
- Ease of data collection, with minimal additional time input.
- Using existing meeting structures at plant, technical operations and site leadership team levels.
- Fit with existing major hazards management systems – risk analysis, risk portfolios and the COMAH Safety Report.

The findings were then presented to the site management team, who approved the project and agreed to support the project as a key EHS initiative for the site.

METHODOLOGY SELECTION

Three different ways of selecting PSPIs were identified.

Generic PSPIs

Several industry groups were working to develop standardised PSPIs in a format that could be reported across different industry sectors for benchmarking purposes. These had a focus on issues such as loss of containment incidents, demands on safety systems, failures of safety systems, compliance with maintenance plans, completion of outstanding actions and completion of audits. Some of these approaches have now been published, for example, the OECD guidelines (OECD, 2003). This approach was rejected as it was considered to be too generic, losing the link with the plant specific risk control issues in the diverse operating environment of the speciality chemicals industry. It was accepted that there was a role for generic PSPIs, but these will be defined from detailed plant studies using a 'bottom up' rather than 'top down' approach.

Brainstorming Plant Specific PSPIs

By gathering a group of experienced staff, it should be possible to summarise the most important major hazards, identify critical controls and derive relevant performance measures. This approach was rejected as it was considered to be too subjective and it did not produce a clear audit trail of the decision making process for demonstration under the COMAH regime. It was, however, recognised that this approach would be time and resource efficient. It was later found that this type of approach tends to identify the obvious PSPIs with good agreement to the plant specific approach but it can miss some of the more subtle PSPIs which only become obvious following detailed discussions.

Plant Specific PSPI Methodology

The HSE and CIA had published the HSG254 guidance, focusing on the specific critical risk controls that are applicable to a major hazard site. This approach was selected for two main reasons. Firstly, it was more relevant to actual plant operations and secondly, it provided a clear legal compliance pathway for 'Top Tier' COMAH sites, linking in well with the way that the Safety Reports had been constructed.

COMPETENCE BUILDING

Nobody within Ciba had experience in the practicalities of implementing HSG254 on a real plant and very few companies had trialled the approach when the Ciba project started in 2006. It was recognised that some external help would be required. The HSE agreed to facilitate a pilot study/workshop at the most complicated UK site as part of the COMAH intervention plan. This provided a very useful and proactive opportunity for a range of senior managers, EHS specialists and corporate staff to understand how to develop and use PSPIs. Ciba's Group Safety Adviser attended from Switzerland, so that links could be made with the relevant corporate systems. The workshop proved to be very successful and gave site staff the confidence to start rolling out PSPI studies at all of the UK sites.

It was then decided to develop a half day training course for staff who would be participating in a future study. This explained the background to PSPIs, how they are selected in Ciba and how the data is collected and used. This means that participants in PSPI studies have the basic knowledge to prepare for and contribute to a study, saving considerable amounts of time.

PILOT STUDY

It was recognised that there were about a dozen site areas which required a PSPI study. One area was a standalone site linked to a larger site. This was selected as it had a good mix of different hazards, storage operations and batch chemical processing. A team was set up with a similar composition to that which would be used for a risk analysis or hazop. Key team members included the plant manager, a design engineer, the maintenance engineer, the production support specialist and a leader from the EHS department. Other staff have joined subsequent studies as part of their major hazards training. These people include plant chemists, trainers and safety reps.

Twelve PSPIs were specified in the pilot study, covering a range of procedural' technical and systems controls (see Table 1). Seven PSPIs were plant specific and five PSPIs were programme indicators for the whole site.

PROJECT ROLL OUT

The PSPI methodology was regularly reviewed and modified during the pilot study to produce an efficient PSPI tool that can be used for assessing all of the UK plants. It was decided to record results and decisions on a spreadsheet using a 5 stage process. Each stage includes standard guidewords to promote consistency and completeness. This allowed the time required to complete each study to be halved from 6 sessions for the pilot study to 3 to 3.5 studies for subsequent studies. The faster study times could only be achieved by:

- Training all team members prior to the study, so they had a background awareness of the subject and a detailed understanding of the Ciba methodology.
- Completing the first 3 stage sheets before the meetings and using the meetings to review and agree this work. The first three stages involve summarising the hazards and controls for the plant and agreeing which of these hazards and controls are most critical. This basis of safety information should be fully understood on a well run plant.
- Using an experienced PSPI study leader to guide the team through the process, helping them to focus on a fairly small number of critical controls and PSPIs from the large number that exist on a typical plant.
- Documenting the reasons for screening out hazards, controls and possible PSPIs, so that the decision making logic could easily be followed from study to study.
- Involving the person who will be responsible for data collection and reporting in the study to check that the results are practical.

A plan was then developed for the site, involving 12 PSPI studies. The methodology was also applied at three further UK sites: a ‘Top Tier’ COMAH site; a ‘Lower Tier’ COMAH site and a non – COMAH site.

METHODOLOGY FOR PSPI SELECTION

Figure 1 summarises the 5 stage PSPI methodology. The bulk chemical inventories and hazardous properties are listed in Stage 1. Any chemicals or plant areas which have no or very limited major hazard potential are screened out. Accident scenarios are then identified in Stage 2, together with the potential consequences of the accidents. The team highlights the scenarios and consequences which are associated with the worst case plant accidents. The

Table 1. PSPIs specified from pilot study

Tank farm	Batch plant
1. Loss of containment incident	1. Number of maintenance errors
2. % completed tank farm inspections	2. Number of manual sampling errors
3. Number of identified procedural errors	3. % completion of SIL system tests
4. Number of tanker delivery paperwork errors	4. Number of SIL system trips
	5. Maintenance backlogs (%)
	6. % of time batch is within safe working envelope
	7. Number of Permit To Work errors
	8. Number of incorrect management of change assessments

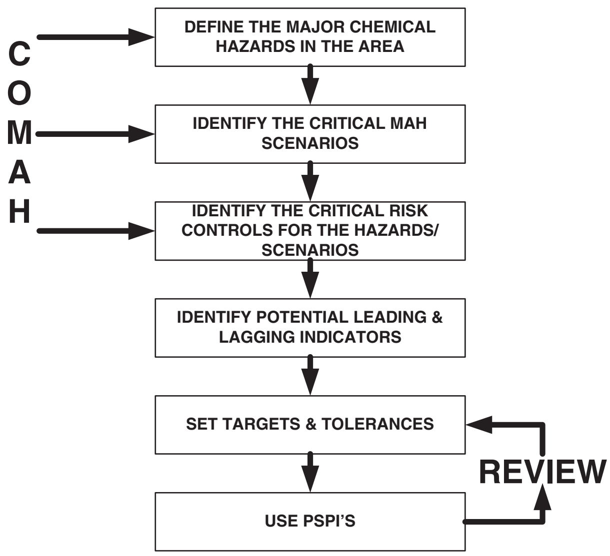

Figure 1. 5 stage PSPI methodology

Table 2. Typical scenarios for failure mechanisms

Wear	Hose splits causing road tanker offloading leak
Corrosion	Gas main leak, ignition and explosion
Damage	Fork lift truck crashes into solvent pipe
Over/under pressurization	Reactor runaway
Fire/explosion	Dust explosion in fluid bed drier
Overfilling	Solvent storage tank overfill
Mechanical failure	Agitator failure, poor mixing, reactor runaway
Accidental release	Maintenance error, leak through open pipe
Loss of inhibition	Uncontrolled polymerization in monomer tank

failure mechanisms leading to the accident scenarios are then listed in Stage 3. The team selects one (or sometimes two) scenarios for each failure mechanism and screens out any failure mechanisms which have minor hazard potential on the plant. For example, corrosion is often screened out of studies for our operations because of the chemicals being handled and the overspecification of the containment materials (e.g. stainless steels). Table 2 shows a typical set of scenarios linked to each of the failure mechanisms. This example is taken from a PSPI study for a whole site, involving road tanker offloading, bulk chemical storage, reactions, powder handling, warehousing and utilities. The critical risk controls which prevent and mitigate the most critical failure mechanisms are then highlighted by the team. The final PSPIs will be directed at these risk controls.

This involves developing an understanding of each risk control. It is important to identify what success looks like if the risk control is working properly. This must not be too general. Descriptions such as 'everything working fine' and 'no safety problems' are too vague. Workable definitions are more specific. For example, in a reactor feed control system, success could be defined as 'conditions maintained within the safe working envelope of 16–24% concentration and a temperature less than 95°C'. The key elements of the risk control which deliver success then have to be identified. The team then need to look at all of these elements and identify possible leading or lagging PSPIs. Each control would then typically generate 0 to 10 possible PSPIs. These possible PSPIs then need to be checked to find one or two critical PSPIs which can be easily measured using existing data recording systems and which give useful information about the status of major hazard control on the plant. Figure 2 illustrates how this screening process can be developed for a typical critical risk control – operator plant checks which are carried out every 2 hours. Experience has shown that 4 to 6 critical risk controls need to be analysed in this way in a typical PSPI study. This would typically generate 20 to 50 possible PSPIs, which have to be screened down to a workable number of 6 to 8 PSPIs.

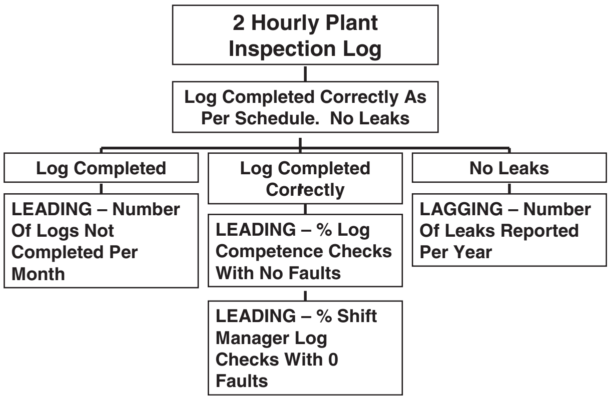

Figure 2. PSPI specification example

Target values for each of the selected PSPIs are proposed in Stage 5, together with a tolerance band. The tolerance band defines the point at which each PSPI has slipped to what is considered to be a danger level. The PSPI study is now complete and the team can progress to data collection and using the PSPIs.

PSPI CATEGORIES

Three main types of PSPI have been identified in the studies which have been completed to date:

- **Operational control indicators**, based on the individual plant PSPIs tailored to specific risks such as feed control, leak prevention, reactor control etc within a defined safe working envelope.
- **General site indicators**, linked to critical site safety systems such as management of change, Permit To Work and risk assessment.
- **Programme indicators**, measuring the completion status of large numbers of similar critical activities such as % of procedures which are up to date, % of required competence assessments completed, % of planned audits completed and % of scheduled maintenance completed.

They all measure the health of different elements of process safety but are used in different ways. The Ciba methodology is very much focused on operational control indicators, close to plant operations. As such, they have to be supplemented by additional sitewide indicators, including programme indicators, some of which will be directly linked to PSPI studies.

Another useful way of categorizing PSPIs is to consider whether they are **leading** or **lagging** indicators. Leading indicators are a proactive measure, looking at the performance of safety systems that prevent a loss of control from occurring. Lagging indicators, on the other hand, are reactive, and measure performance in terms of the number of recorded failures in control. This will involve measures such as leaks, operation outside safe working envelopes and failures of safety critical instruments and equipment.

DATA COLLECTION AND ANALYSIS

On completion of the PSPI planning phase, a manageable number of PSPIs will have been defined for the plant, together with numerical targets and tolerances for each PSPI. It is now possible to start using the PSPIs to measure process safety performance, identify deteriorating trends in system performance and provide additional resources to correct any problems. Teething problems often occur during this phase. They can be minimized by taking measures such as:

- Appointing a data collector within the study team. This person must be involved with the study to provide understanding and buy in. They should check that there are practical ways of collecting all of the recommended PSPIs.
- Providing management support and leadership to the team.
- Developing a clear reporting format for the PSPIs. PSPIs will be reported on a monthly basis in most cases. On a site with a diverse range of operations, it is possible that each plant will develop it's own distinct reporting system, reflecting the different risk controls which are used to control the major hazards on each plant.
- Defining the forum for reviewing PSPIs. Most plants prefer to use existing meetings such as Site Leadership Team meetings, production managers meetings, safety committee meetings and shift team meetings.
- Providing a link from the plant level PSPIs up to a site level of PSPIs without producing data overload. Some form of 'management dashboard' will be required, highlighting deficiencies and problems quickly, bringing any problems to the attention of senior managers.
- Agreeing a review period for PSPIs to check that they are still relevant, that targets and tolerances are appropriate and that the PSPIs reflect any plant changes.

Ciba have tried to make use of existing data recording systems for measuring PSPIs wherever possible. This removes the need to deploy additional scarce resources simply to collect and process data. It is, however, important to recognise that it may occasionally be necessary to implement new data collection systems to provide confidence that critical controls are healthy. There are also situations where data collection is difficult and time consuming. For example, if a site wishes to measure compliance with preventative maintenance plans, this may involve thousands or tens of thousands of activities. Maintenance planning may be centralized, using spreadsheets, maintenance management software systems or corporate enterprise resource management software. It may, equally, be fragmented across multiple departments and management systems.

Problems can also be encountered at small sites where controls are very people focused and operations are 'bureaucracy light'. Larger organizations tend to deploy more data gathering and analysis systems, and these can be used as input data for PSPI programs.

Typical data sources for chemical industry operations include:

- Batch and plant log sheets showing the results of operator and line manager checks and batch lifecycle histories.
- Laboratory test results sheets and sampling sheets.
- DCS (Distributed Control System) computer records. A large amount of objective data is often generated. Most of this is underused and it is often overwritten after a defined time period. Modern software exists to extract, trend and summarise this data in a format which is ideal for PSPI measurement. It is also possible to produce reports of alarm rates and interlock activations. Critical safety system activations are also often logged on separate systems due to their importance.
- Maintenance records from paper records, spreadsheets and software systems.
- Staff training and competence assessment records.
- Near miss reports and loss of containment reports. If this data is only collected at a very serious level of incident (e.g, RIDDOR report), it is unlikely to be useful for PSPI measurement, as it is likely to be measuring a small data set at plant or site level. Staff generated near miss reports are much more useful in this area.

There are many ways in which plant PSPI data can be reported using numbers, matrices, graphs, normalised graphs and colour coding systems. In some cases, rolling average trends may be most appropriate. In others, individual monthly data is more useful. Lagging indicators are often best presented as a number of occurrences in a defined time interval e.g. failures per month. Leading indicators are often best presented as percentages e.g. % non-compliance in all monthly activities. Figure 3 provides one example of how data could be presented based on a real PSPI study.

This illustrates some typical PSPI characteristics based on the four measured PSPIs:

1. % of fire system failures identified during weekly fire system inspections and tests. No failures were reported over 5 months. This reflects the strict maintenance regime and insurance company oversight which is delivering high reliability. If this continues over time, it may be worth changing to a less perfect PSPI, where more improvement opportunities exist. It would also be valid to keep the PSPI if it is critical, as this is showing that this part of process safety is healthy.
2. % of time that reactor was operated within it's design limits to avoid accumulation and the risk of an uncontrolled runway reaction. PSPI values >95% are being achieved; opportunities exist for improvement and positive and negative trends are discernible. This is a useful PSPI and shows management where they can make improvements.

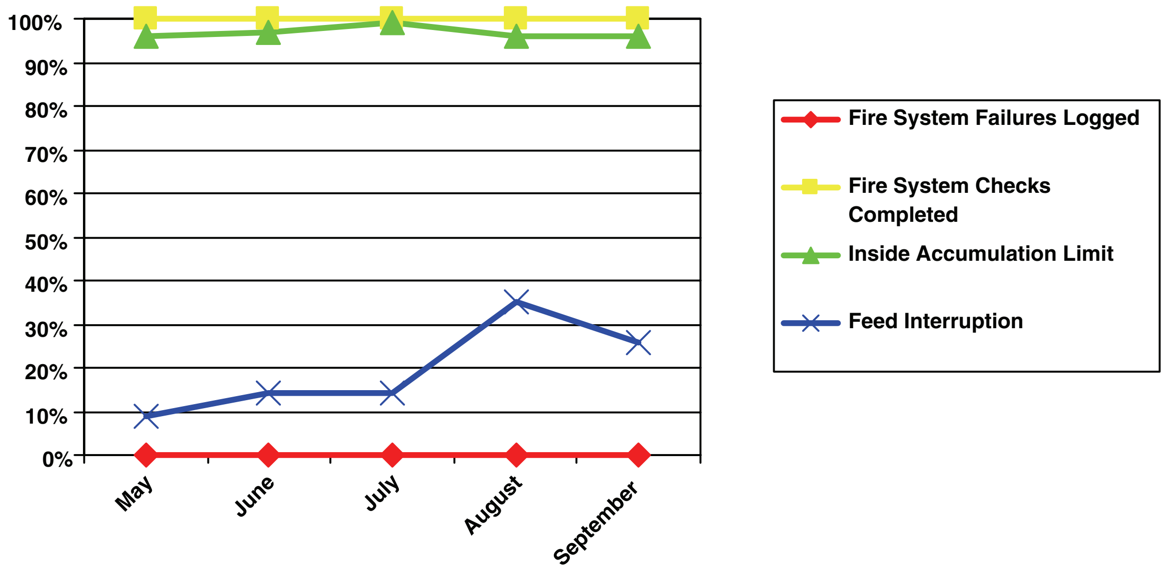

Figure 3. PSPI data presentation example

3. % of fire system checks completed against schedule. This shows a consistent 100% PSPI, indicating a high level of operational discipline and control in this area. It may be worth evolving this PSPI at a future date to focus on the quality of the checks that are being carried out rather than on the quantity. This will be more difficult to measure but it will provide a more sophisticated measure of process safety in this key area.
4. Number of feed interruptions during batch reaction sequences. These occur when an interlock operates or an operator puts a batch into 'hold' and lead to a higher risk of accumulation and runaway reaction. There are some problems with measurement, but the PSPI measure is consistently high, again with some discernible trends.

INTEGRATION WITH SAFETY MANAGEMENT SYSTEM

PSPIs have the potential to play an important role in a site safety management system, providing the key 'monitoring' system for process safety. As such, they need to be embedded into the management system with appropriate links to other important elements such as management of change, major projects, risk analysis and risk management. For 'Top Tier' COMAH sites, the Safety Report will also need to be updated to show how PSPIs are used to control major hazards.

CONCLUSIONS

PSPIs can play an important role in managing major hazards and improving process safety performance. It must, however, be remembered that they are a process safety measurement tool and will not, in themselves, deliver high levels of safety. This comes from resourcing and managing all of the site risk controls in areas such as inherent safety, people, control systems, technical measures and systems.

Distortions can occur with PSPI systems. In particular, "NHS syndrome" must be avoided, where staff distort their working practices purely to achieve good PSPI scores to the detriment of wider issues, only focusing effort on things which are being measured. PSPIs only measure a small number of the most critical controls. Like all measurement systems, they rely on the integrity and accuracy of data recording. Results could be manipulated, but this would deliver no value to the organization, serving only to promote a false sense of security and complacency at the expense of continuous improvement.

Ciba has found that PSPIs are most effective when there is a strong PSPI champion at senior management level, providing leadership for the project. The number of PSPIs have to be kept to a sensible level, fitting in with existing systems wherever possible. There are clear links that can be made to existing elements of the safety management system, particularly risk analysis, Safety Reports and human factors assessments. By focusing on operational indicators, considering process deviations from the desired operating parameters, there are also clear links with process optimization and quality improvement. PSPIs also raise the profile of COMAH at different levels in the organization, providing a focus on the site's critical process controls.

NOTE – Ciba became part of BASF in 2009.

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