

DETERMINING PROCESS SAFETY PERFORMANCE INDICATORS FOR MAJOR ACCIDENT HAZARDS USING SITE PROCESS HAZARD INFORMATION

Jo Fearnley and SreeRaj R. Nair
Aker Solutions, Phoenix House, 3 Surtees Way, Surtees Business Park, Stockton on Tees, UK, TS18 3HR; Tel: +44 (0) 1642 334053, e-mail: jo.fearnley@akersolutions.com

Historically process plant key performance indicators (KPI) for safety have been developed through the experience of the site safety/operations personnel and considering information which was easily available. The information mainly included the records of compliant and non-compliant maintenance/inspection/testing routines and the historic incident/near miss data.

Such performance indicators are mostly retrospective, or lagging, as they are based on data relating to how the plant had been operated. Although this is a good record of the historic performance, such indicators do not predict the future performance or trends of the assets. To do this leading performance indicators are required which can help to improve the safety/environment performance of the assets, by showing where there are potential weaknesses in the systems which need addressing before an incident occurs.

The UK Health and Safety Executive (HSE) are in the process of addressing this discrepancy through the roll out of the implementation and follow-up to HSG 254 – Process Safety Performance Indicators (PSPI). The guidance is based on how safety and environmental performance measurement is related to major hazards associated with the process and site. The guidance, and HSE's associated training package, enables operators to determine relevant leading and lagging indicators based on a systematic review of the hazards of the site.

High hazard process sites in the UK have identified major hazard scenarios in order to comply with COMAH regulations, and most other non-COMAH sites have some form of hazard identification record.

This paper describes how the systematic development of PSPIs can be managed with the minimum of additional work, by using data from existing hazard identification studies (for example those developed for COMAH compliance). The methodology defines/selects leading and lagging PSPI to address the highest safety and environmental risks identified which ensures that relevant information is used to drive the performance improvements for the assets.

This paper also addresses how PSPI can be developed, using slightly modified hazard identification techniques, where asset hazard identification documentation is not readily available.

KEYWORDS: process safety performance indicator, hazard identification, safety performance measurement

INTRODUCTION

Over the years major incidents have identified the need for improving industrial safety and more recent events have highlighted the significance of process safety management.

The original response from organisations was to monitor safety by monitoring and investigating accidents, incidents and near miss events to determine root causes to target actions for reducing the risk of a repeat event. Typically these events are due to occupational safety, which looks at personnel behaviour and the working environment. Investigating such events has reduced occupational injuries significantly over the years, and it is valid to still continue to monitor and learn from incidents and near misses.

Process safety considers how installations are operated and maintained, and whilst incident investigation will identify some root cause improvements, the significant process safety risks are often not identified from such investigations. The next improvement was for organisations to record historic data such as equipment or systems failure, which identifies where there are weaknesses in the operating equipment to enable reliability to be increased. The consequence of this approach is that improvements or changes are only determined after something has gone wrong. Whilst this is important in managing some aspects of safety, an additional methodology is also required, which identifies and drives compliance of risk control measures which will prevent or minimise the risk of major accident hazards.

Effective management of major hazards requires a proactive approach to risk management, so information to confirm critical systems are operating as intended is essential. Investigation of the major incidents at chemical and major hazard installations have also shown that it is vital that chemical companies know that systems designed to control risks operate as intended.

INCIDENT INVESTIGATION REPORTS

Incident investigation reports over the years have highlighted process safety failures, from Flixborough to Buncefield, which have all related to loss of control as a result of the loss of control of systems in place to manage risk. The BP Grangemouth and BP Texas City incident investigation reports have made specific recommendations concerning the need for an improvement in the monitoring of process safety performance.

BP Grangemouth had three incidents between 29th May and 10th June 2000 which lead to a major incident investigation. One of the report conclusions was:

> *"...companies should develop key performance indicators (KPIs) for major hazards and ensure process safety performance is monitored and reported against these parameters..."*

BP Texas City refinery explosion and fire (March 23rd, 2005) investigation conclusions can be found in the Baker Panel Report. In addition to a general recommendation to improve BP's safety oversight, safety culture corporate and site safety management systems, one specific report conclusion was:

> *"...develop, implement, maintain and periodically update an integrated set of leading and lagging performance indicators for more effectively monitoring the process safety performance.."*
>
> *Cascading from this investigation the Chemical Safety Board (CSB) have recommended, that the American Petroleum Institute (API) and United Steel Workers (USW) should*
>
> *"...create performance indicators for process safety in the refinery and petrochemical industries and involve relevant scientific organizations and disciplines in this work..."*

Further the Centre for Chemical Process Safety (CCPS) has initiated the Metric Project, following recommendations in the Baker Panel Report and the CSB Report to also identify how performance indicators can be developed.

In the UK the Health and Safety Executive (HSE) have over the years looked at how companies can achieve a significant reduction in the number of reportable incidents, addressing both occupational and process safety. For example the "Revitalising Health and Safety" strategy document (2000) from the HSE set a goal to "prevent major incidents with catastrophic consequences occurring in high-hazard industries" and set a target for reduction in RIDDOR dangerous occurrences and COMAH Regulation 21 major accidents (accidents of sufficient seriousness to require notification to the European Commission).

DEVELOPING PROCESS SAFETY PERFORMANCE INDICATORS

In 2006 the HSE issued a step-by-step guide for chemical and major hazard industries to support improvement in process safety: 'Developing process safety indicators' (HSG 254). The guidance is based on how safety and environmental performance measurement is related to major hazards associated with the process and site. The guidance facilitates organisations to establish relevant leading and lagging indicators based on a systematic review of the hazards of the site. Leading indicators are a form of active monitoring which determine that risk control systems are operating as intended, whilst lagging indicators are a form of reactive monitoring which identify failures in operation of the risk control system.

To support PSPI the HSE recommends six steps to ensure that the overall system operates correctly:

- *Step 1*: Set up management support and identified people to deliver the system
- *Step 2*: Identify the potential hazardous scenarios and hence the scope of the system
- *Step 3*: Identify the existing risk control systems in place, and relevant lagging indicators
- *Step 4*: Identify the critical elements of the risk control systems and hence relevant leading indicators
- *Step 5*: Collect and report data
- *Step 6*: Review performance of systems/leading and lagging indicators selected/data gathered and adjust if not effective or suitable

The underlying basis of the development of PSPI from HSG 254 is to identify what can go wrong on the site, what the causes are, and what is in place to prevent, control or minimise that risk. The leading and lagging indicators for the important risk control systems should be defined to control or mitigate against the major hazards.

For many sites, but in particular for top tier COMAH installations, the major hazards are identified by a systematic method which assesses each area of the plant to determine all the hazardous scenarios, the potential causes of each hazardous scenario and the range of associated consequences. This process has many names, ranging from a hazard and operability study (HAZOP Study 2), to a process hazard assessment (PHA) or a process hazard review (PHR). Whatever the name the basis is similar, and it provides the information equivalent to what is needed to satisfy the second step of the HSG 254 process.

For COMAH top-tier installations, the hazard and the risk control systems will also be defined and described in the safety report. Where the hazards and risk controls have been already compiled for the safety report, this can be used directly as an input to developing suitable and effective PSPI. Where such information is not available, or where a routine update of the information is required, for example to satisfy 5-yearly reviews, then using the PHR methodology is a means of optimising workload whilst meeting the demands of safety report updates, process safety understanding and PSPI development in a systematic way.

This paper explains the use of PHR technique as the basis for developing suitable and effective PSPI.

PHR TO PSPI

The use of the process hazard review methodology will ensure that there is a systematic, up to date risk identification and assessment document for the plant, considering the current plant configuration and operating conditions. The approach identifies the major hazards, analyses the risk and determines the risk control measures. The risk control measures are then assessed to identify whether they are adequate to reduce the process risk. The additional steps which are introduced by the link to PSPI is to review the risk control measures identified, determine which ones are critical to process safety, and then to develop the appropriate leading and lagging indicators which will support the proactive and reactive management of process safety.

PROCESS HAZARD REVIEW AND RISK MATRIX

PHR uses a guideword basis to systematically identify the potential hazardous scenarios, and their causes, through the use of questioning. The process is split down into logical areas, for example feed handling, reaction, purification, storage and export, and the guidewords used for each area in turn to determine the range of hazards for that area. Where a potential hazard exists, the range of initiating events is identified, and the estimated worst case frequency of each recorded. This initiating event frequency, in conjunction with the worst case potential consequence determined, form the basis of the unmitigated risk. When completing a PHR across the whole of a facility a large number of potentially hazardous scenarios are typically identified, with a spectrum of consequential harm and likelihood of occurrence.

There is a limit to how many PSPI can be realistically be generated and reviewed, and so a basic step is to categorise the hazardous scenarios identified to screen out those of low risk.

To do this risk ranking a range of frequency and consequence descriptors for safety and environment need to be defined based on the hazardous nature of the operations, the organisation's corporate standards and compliance with regulatory requirements. Although some companies try and use a generic risk matrix, the use of a site/company specific one enable the operator to ensure that all specific concerns for that site are considered. For example some chemicals are low hazard but highly odorous in which case a small release will lead to numerous external complaints if operated close to a populated area, whereas a release of a similarly hazardous material with a higher odour threshold will not cause the same response.

Each hazardous scenario risk is assessed based on the relative frequency and severity of the consequence of the event and the acceptability is defined from the risk matrix. Dependent on where the risk falls on the matrix, the event may be classified as broadly acceptable, tolerable if as low as reasonably practicable (TifALARP) or intolerable. An unmitigated risk which falls into the broadly acceptable region of the risk matrix is considered sufficiently low risk that it is not necessary to address this risk further, assuming that all industry guidance and requirements have been met. This leads naturally on to the conclusion that such risks are not the ones which required development of an associated PSPI.

An example risk matrix is shown in Figure 1.

The hazardous scenarios are initially classified considering unmitigated risk, and those with a higher risk ranking (i.e. these not in the broadly acceptable region) are further assessed. This further assessment identifies the existing risk control measures which are in place on the site, by systematically identifying the measures which will either reduce the frequency of the event from the worst case originally determined, or by reducing the severity of the event. The reductions in frequency and severity need to be carefully considered and justifiable. For frequency the value can be estimated by using a similar methodology to that used for layer of protection analysis in safety integrity level assessments, where the initiating frequency is multiplied by the probability that each layer of protection available fails. From this reassessment of risk the mitigated frequency and consequence is determined, and the mitigated risk determined from the same risk matrix.

An example template for recording the PHR unmitigated risk is given in Figure 2. Figure 3 gives an example template for recording the PHR mitigated (residual) risk, with the associated risk control systems identified.

RISK CONTROL SYSTEMS

All hazardous scenarios (unmitigated risk) identified in the PHR which fall in a TifALARP or intolerable band of the risk matrix are further considered to determine whether sufficient risk reduction measures exist to reduce the risk. The ideal is to reduce all risks to the broadly acceptable region, although realistically some will end up in the TifALARP region, as additional risk reduction would cost so much

Risk Matrix	Extremely Unlikely	Very Unlikely	Unlikely	Possible	Regular
Catastrophic	TifALARP	Intolerable	Intolerable	Intolerable	Intolerable
Major	Broadly Acceptable	TifALARP	Intolerable	Intolerable	Intolerable
Severe	Broadly Acceptable	TifALARP	TifALARP	Intolerable	Intolerable
Serious	Broadly Acceptable	Broadly Acceptable	TifALARP	TifALARP	Intolerable
Minor	Broadly Acceptable	Broadly Acceptable	Broadly Acceptable	Broadly Acceptable	TifALARP

Figure 1. Risk matrix

HAZID Ref #	Hazardous Event and Initiating Cause		Cause / Event		Consequence / Harm			Risk Ranking (based on risk matrix)	
	Catastrophic / Leaks/ Openings/ Composition	Initiating Cause	Initiating Event	Frequency	Worst Case Consequence	Safety	Environ mental	Safety	Environmental
1									
2									

Figure 2. PHR unmitigated risk template

that it would be grossly disproportionate to take those additional precautions.

For each scenario considered the existing risk control systems in place are reviewed to identify which are applicable for mitigating the risk.

The HSE in their training package for HSG 254 have identified the categories in which they expect to see PSPI, and hence this list is used as the basis for identifying relevant risk control systems:

- Inspection/Maintenance
- Staff Competence
- Operating Procedures
- Instrumentation and Alarms
- Plant Change
- Communication
- Permit to Work
- Plant Design
- Emergency Arrangements

For each of these a sub-set of actual risk control systems in place for the site needs to be developed. For example when considering staff competence there are various areas/groups of people where management of standards of competence may be controlled by a system, which may differ between them, for example:

- Staff Competence
  - Process operation
  - Maintenance
  - Inspection and testing
  - Design
  - Contractor/external personnel

Hence although the categories of risk control systems can be specified, the detail of the actual systems which are in place, or need to be, will differ between sites.

SELECTING RELEVANT RISK CONTROL SYSTEMS

For all hazardous scenarios identified as requiring further assessment, the review team need to identify what design or inventory control risk reduction measures are in place, and also the prevention, control and mitigation risk control measures. Each of these risk reduction measures will fall into one of the categories identified. The actual existing risk control system within that category is then identified. Where there is no formal system in place to control the risk reduction measure, no credit can be taken.

For some scenarios it may be determined that there is no current risk reduction measure on the site, or, if there is, then there is no control system to ensure the risk is adequately managed.

For each scenario a decision is taken, and recorded, by the review team on how much the existing risk control measure(s) reduce the risk, either by reducing frequency, consequence, or both. The resultant mitigated risk is documented, see Figure 3.

Where mitigated risks fall into the broadly acceptable region on the risk matrix no additional action is required, although where low cost risk reduction measures are evident from the discussions, or where it is identified that industry guidance is not being followed, these should be documented as actions to reduce the risk further. Credit cannot be taken for proposed actions until they are actually implemented.

Where mitigated risks still fall into the intolerable region, action(s) need to be identified which would reduce the risk. Typically this occurs where there are insufficient risk control measures in place, or where the discussions identify that some measure exists by it is not controlled in any way. The effectiveness of the actions identified should be assessed to ensure that they will reduce the risk to at least the TifALARP region.

Where mitigated risks result in a TifALARP level of risk the risk assessment process needs to identify whether

HAZID Ref #	Hazardous Event and Initiating Cause		Prevention and Mitigation Measures		Risk Control System					After Mitigation (Frequency and Consequence)			Risk Ranking (based on risk matrix)	
	Catastrophic / Leaks/ Openings/ Composition	Initiating Cause	Prevention / Control Measures	Mitigation	Inspection and Maintenance	Staff Competence	Permit to Work	Procedures	Emergency Arrangements	Frequency	Safety	Environ mental	Safety	Environ mental
1														
2														

Figure 3. PHR risk control system and residual risk template

there is an action which could reduce the risk further. Any action identified then needs to be assessed using the as low as reasonably practicable principle. If the action is likely to be cost effective; i.e. a cost benefit analysis will not determine that the cost involved is grossly disproportionate to the risk reduction achieved; then it should be progressed to reduce the risk further, and an appropriate control measure put in place. The use of the structured categories of risk control systems can support this decision making.

SELECTION OF PSPI

The final output from the adapted PHR indicates the level of risk resulting from the current risk control measures in place for the installation, i.e. the current mitigated risk. Actions necessary to reduce the overall level of risk to at least the tolerable if ALARP region will have been determined, and hence the standard output from the PHR methodology is still achieved, i.e. a set of actions to reduce risk, but these are targeted to controlled risk control measures which are most effective for improving process safety.

Using the output of the PHR/risk control measure identification process, the key risk control measures are identified. The importance is determined either through the effect they have on the level of risk, or due to the frequency with which they are referenced. For example the use of on-site and off-site emergency plans to mitigate risk is valid for all scenarios, so these are considered key risk control measures.

A number of risk control measures are selected for development into the site PSPI. For each selected risk control measure leading and lagging performance measures are identified which would indicate whether that aspect of process safety is under control. This includes not only the description of what should be measured, but also how it should be measured. Examples could be compliance (i.e. target is 100% of total assessed are compliant), non-compliance (i.e. target is 0% of total assessed are non-compliant), or numerical non-compliance (i.e. target is 0 non-compliant events within a period of time).

The selection of appropriate leading indicators is often considered more difficult than selecting lagging indicators, as identifying proactive measurement is not as obvious as measuring a deficiency.

Examples of leading indicators are:

- Inspections and testing completed to schedule
- Refresher training (e.g. an emergency exercise drill) completed to schedule
- Instrument actions (trip or alarm) performed correctly on testing

Examples of lagging indictors are:

- Failure of protective device on demand/at correct setting (e.g. alarm, trip, relief valve)
- Equipment failures in service leading to loss of containment
- Non-compliance with procedural controls (e.g. permit to work, operating procedures)

CONCLUSIONS

It is important that initial selection of PSPI is based on data which is readily available, to encourage use of the system. The key PSPI have been identified, and where there is obviously no existing system in place, or where data to support monitoring of PSPI is not readily available, these should be developed over time and then introduced as formal PSPI at a later date to ensure the system is operable and the data valid.

As with most process safety systems, active management of PSPI is needed for it to improve safety. If deficiencies arising from the leading and lagging indicators are not actively followed up and addressed then site personnel will not support the concept in the longer term. Care is also needed to investigate deficiencies to determine if they are single failures arising or ongoing failures which are cascading from one monitoring period to the next. 100% compliance against all indicators at all time is not necessarily indication of a system in total control, as it may indicate that incorrect measures are being monitored.

Part of the PSPI methodology is to review the outputs and the validity of the indicators selected routinely, rather than assume that a one-off process will provide all the answers. It is therefore logical to add indicators which have been developed to address identified risks which were not previously adequately controlled. Similarly indicators should be altered or removed over time where it is considered that they are not providing valuable information, typically because they are not measuring the correct aspect of the control system. Data gathering can be a time-consuming activity, so trying to establish the PSPI into the standard operating fabric of the facility will help to make the system robust.

REFERENCE

Chemical Industries Association, 2006, Developing process safety indicators – A step-by-step guide for chemical and major hazard industries, *HSG-254*, HSE Books.

The safety of our plants and processes is a key element of our environmental stewardship efforts. This approach allows us to protect both our workforce and the people in the vicinity of our sites. Furthermore, high-performance safety systems help minimize production errors, which in turn lowers the risk of financial losses. Our approach to plant and process safety. We seek to eliminate manufacturing hazards wherever possible in order to prevent workplace accidents, production outages and chemical leaks. We train our employees regularly in an effort to minimize human errors and also to detect t The performance indicators are linked to a reference values or policy targets, illustrating how far the SMS is from the desired level. We developed a system of performance indicators for SMS in chemical industry by using the concept of environmental performance indicators defined in standard ISO 14031. A set of three types of safety system performance indicators was proposed: management performance indicators, operational performance indicators and safety status indicators.Â safety regulations on major chemical accidents con-. trol in Serbia have not been satisfactory, mainly due. to lack of awareness and weak management in the.