National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

A literature review on safety performance indicators supporting the control of major hazards

RIVM Report 620089001/2012

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This investigation has been performed by order and for the account of Ministry of Social Affairs and Employment, within the framework of Seveso III

Abstract

A literature review on safety performance indicators for supporting the control of major hazards

Companies working with large amounts of hazardous substances fall under the Major Accident Risks Decree 1999. These companies must conform to specific requirements to prevent major accidents with serious consequences for man and environment. These companies are regularly visited by regulatory bodies such as the Labour Inspectorate. The inspectorate focuses on the risks to workers and evaluates whether these companies have a safety management system. It is important whether this safety management system is tailored to the risks involved and whether it works well.

Indicators: how well a company manages risks
The RIVM has explored whether it is possible to evaluate the major accident risks of a company based on safety performance indicators. Safety performance indicators are intended to provide information on the safety performance of a company. A set of indicators helps managers and employees of the company to focus on the important risk factors and helps the regulator determine how well the company is managing its risk controls and whether it is improving. Safety performance indicators should be tailor-made when used by a company but will need to be generally applicable, communicable and unambiguous when used by the regulator. Indicators may develop over time, based on experience as to which provide the most effective and efficient information about the safety performance of a company with respect to the potential for a major accident.

Criteria for the development of safety performance indicators
It is recommended to develop indicators based on a list of 30 criteria. For example, an indicator should have a causal link with the risk. In addition, a concrete action on the indicator may be attached, such as improvement interventions. The indicator set should also be sufficient in number and frequency to be able to identify trends. For the research, the scientific literature as well as guidelines from industry and regulators were explored.

Keywords: safety performance indicators, major hazards, safety management, safety culture

Rapport in het kort

Een literatuuronderzoek naar veiligheidsperformance-indicatoren ter ondersteuning van het toezicht op de beheersing van zware ongevallen

Bedrijven die met grote hoeveelheden gevaarlijke stoffen werken, vallen onder het Besluit risico's zware ongevallen (BRZO). Deze bedrijven moeten aan specifieke regels voldoen om zware ongevallen met grote gevolgen voor mens en milieu te voorkomen. Daarnaast staan deze bedrijven onder toezicht van o.a.de Inspectie SZW (voorheen de Arbeidsinspectie). De Inspectie richt zich op de risico's voor werknemers en beoordeelt onder andere of er binnen de desbetreffende bedrijven een zogeheten veiligheidsbeheerssysteem is. Daarbij is het van belang of dit systeem is toegesneden op de aanwezige risico's en of het goed werkt.

Indicatoren: hoe goed beheert een bedrijf gevaren
Het RIVM heeft daarom bekeken of het mogelijk is om de veiligheid van een bedrijf te beoordelen op basis van veiligheidsprestatie-indicatoren. Veiligheidsprestatie-indicatoren zijn bedoeld om informatie te leveren over de veiligheidsprestaties van een bedrijf. Ze kunnen managers en werknemers van het bedrijf helpen om te focussen op de belangrijkste risico's. Daarnaast kunnen indicatoren de inspectie helpen vast te stellen hoe goed het bedrijf met risico's omgaat en of dit zonodig verbetert. Indicatoren moeten op maat worden gemaakt als ze worden gebruikt door een bedrijf. Voor de inspectie zijn juist indicatoren nodig die algemeen toepasbaar, communiceerbaar en ondubbelzinnig zijn, zodat bedrijven met elkaar kunnen worden vergeleken. Indicatoren kunnen zich door de tijd heen ontwikkelen op basis van de ervaringen met indicatoren die het meest effectief en efficiënt informatie geven over de mogelijkheid op een zwaar ongeval bij een bedrijf.

Criteria voor de ontwikkeling van veiligheidsprestatie-indicatoren
Aanbevolen wordt om indicatoren te ontwikkelen op basis van een lijst van 30 criteria. Zo moet een indicator een oorzakelijk verband hebben met het onderdeel dat daadwerkelijk een risico kan vormen. Daarnaast moet er een concrete actie aan de indicator kunnen worden verbonden, zoals een verbeteractie. Om trends te kunnen waarnemen is een set van indicatoren nodig die voldoende frequent worden gemeten. Voor het onderzoek is de wetenschappelijke literatuur onderzocht, evenals richtlijnen van industrie en inspecties.

Trefwoorden: veiligheidsmanagement, veiligheidscultuur, veiligheidsprestatie indicatoren, zware ongevallen

Contents

Summary

The Ministry of Social Affairs and Employment commissioned RIVM to develop key performance indicators (KPIs) for safety in the process industry. The purpose of this literature review is to provide a background, based on the referenced literature, for establishing key safety performance indicators in the Netherlands and which could be used by the regulator for Major Hazard Control to assess safety management system performance in controlling major hazards.

The review concentrates primarily on peer reviewed literature and industry- and regulator-produced guidance. This is not a comprehensive research review but rather focuses on coming up with some points for what is important in a safety indicator system with emphasis on coupling with process safety management and major hazard safety performance. In this respect it is fit for purpose rather than an all-embracing coverage of a wide subject area. Details of the management science background relating to the history and use of key performance indicators are not included. In the safety world the new challenge is developing leading metrics of safety to predict future performance, rather than only evaluating performance from data on deaths, injuries, spills and releases, the so-called lagging indicators.

Safety indicator systems are developed by companies primarily for the purpose of learning about risk control and its adjustment and improvement through safety management processes. Process safety performance indicator systems are required in order to avoid the forming of management blind spots and stepping outside the boundary of good process safety performance. Their purpose is to provide information on safety performance through the use of measurement of progress towards measureable targets, which are the operational performance goals. They also fulfil an important communication role in telling stakeholders how well the company appears to be doing in managing the major hazards.

There is already a wealth of guidance on safety performance indicators (e.g. Deltalinqs, HSE, OECD, CCPS) with the suggestion that a well-designed monitoring and improvement system is beneficial and revealing. Scientific research still has to find significant quantitative relationships between methods, metrics and outcomes for major hazards. It is generally agreed that lack of a major accident does not indicate that a plant is safe. For this reason so-called ‘leading’ indicators are sought, these being precursors, ahead of so-called ‘lagging’ indicators, a term which is predominantly used to mean safety outcomes like harm (e.g. fatalities) and loss (e.g. spills). A whole controversy about what is leading and what is lagging has emerged. In effect all indicators are after the fact but the distinction is useful to separate management input indicators from output indicators or activities indicators from outcome indicators or precursors from incidents.

What is safety then? Of course ultimately it is the absence of events which cause harm but if the hazard is present there is always a chance of loss of control. The very low probabilities in major hazard systems with defence-in-depth render the need for more frequent events to be used if safety is to be measured over time. If the regulator is to use indicators as part of the enforcement strategy then these indicators must be aligned to this strategy. High frequency risk sensitive events are therefore a fundamental requirement to give timely information upon which action can be based. Quantitative risk assessment, which is used in the Netherlands, is currently still too generic to accommodate safety management

system inputs to be continuously updated. The safety performance indicators system has to be modelled instead to supplement more static risk evaluation measures. It needs to be tailor-made for a company/site and developed over time as the company learns what indicators are the most effective and efficient to measure in relation to risk. Absence of incidents, or indicators which are always 100% on target or always within tolerances should trigger the search for new indicators, targets and tolerances.

Safety, in the new perspective of indicators, could be represented as a learning and adjustment process whereby the process safety indicator metrics provide feedback for controlling actions that ensure the technical systems remains within the safe envelope of the design. For the regulator these indicators also have to distinguish between the good and the bad in the measured population if it is desirable to use them as safety benchmarks or to learn how to shift the mean of the population in the good direction. KPIs are also sought for providing key information to higher level management and the public.

The basis for most safety performance systems is Reason's Swiss cheese model of lines of defence or barriers and Heinrich's famous accident triangle. Approaches are primarily guidance driven, together with analysis of causes of incidents such as so-called 'near misses', the indicators themselves being thought up by workforce teams. Use of new technology can support data collection and aggregation.

Safety culture or climate measurement is barely touched on in indicator guidance despite being considered important. There is also criticism of the linear accident modelling approaches typically found in safety performance indicator guidance with the development of the idea of 'resilience'', an organisation's ability to recover from deviations and to stay within the safety envelope. How to measure elasticity as a safety performance indicator was not clear. Rasmussen's concept of 'drift' towards the boundary of acceptable safety performance seemed to have more practical relevance suggesting the need to measure (and halt) developing trends in this direction and the factors which drive them. However no-one is suggesting measuring these potential safety antagonists directly, but only indirectly through the perceptions and attitudes of the workforce as measured with safety climate tools.

A good safety culture is reputedly critical for high hazard operations. It can only be measured, assuming it can be measured at all, by such tangible artefacts of safety culture as the shared belief, attitudes, perceptions, practices and behaviours that affect safety performance of high risk operations. In other words, how people feel about process safety. For example, feeling 'chronic unease' in the face of lack of incidents has been identified as a characteristic of high reliability organisations. Safety culture and climate tools have been developed to provide measureable snapshots of attitudes and beliefs through self-report questionnaires. Correlations with injury statistics have been shown and there are rare instances of correlations with technical integrity failures.

As a result of the current review 20 aspects are considered important, but not necessarily complete, for the design and operation of a safety performance indicator system:

1. a link (usually causal) to the major hazard (process) risks, with appropriate coverage and priorities in the (safety) management system;

2. sufficient in number and frequency to be able to identify trends (e.g. quarterly, yearly, three-yearly), including any ‘Rasmussen drift’ effects towards boundaries of safe operation to allow appropriate recovery in time;
3. tailor-made for the company/site;
4. metrics distinguish between good and bad in the population distribution (this also facilitates benchmarking);
5. consideration of published guidance (HSE, CCPS, OECD, API, Deltalinqs, CEFIC etc.);
6. quantitative measureable indicators associated with defined objectives;
7. precursor (prior to loss/harm) indicators of sufficient scope and sensitivity to give sufficient and timely ‘warning’ of deviations from safe standards of design and operation;
8. precursor indicators on management system inputs to major hazard risk control processes and indicators on related outputs of these processes;
9. evaluation of management inputs, outputs and incidents for relationships, interactions, causes and major hazard risk potential;
10. specification of indicator tolerances with justification in safe boundaries of operation and associated with action levels;
11. specification of indicator targets, especially in relation to the objectives of the major accident prevention policy;
12. a selection of KPIs for reporting to the top management;
13. indicators that are actionable, in that there is a connection between the indicator and the actions which should affect it;
14. a reporting culture involving the whole workforce who have responsibilities in the control of major hazards;
15. workforce involvement in indicator development and reporting programmes;
16. a leadership which maintains the reporting culture and which ensures actions are carried out in time;
17. a leadership which positively influences safety culture through interactions with the workforce, safety improvement (programmes), and measuring the effect on safety attitudes and awareness;
18. consideration given to using metrics that could be sensitive to changes in the external system climate (such as economic pressures, takeovers, new knowledge) and their impact on safety at the plant;
19. indicator review and improvement at least on a yearly basis;
20. use of indicators also by external bodies about their own performance, particularly emergency response organisations. This point has not really been elaborated in the review, but it suffices to say that if they are part of the socio-technical safety system affecting plant then perhaps emergency responders should also be part of the measurement system.

Distilled from the review, a further ten points are considered specifically for the regulator:

21. Leading KPIs should give signals for concern about future safety.
22. Lagging KPIs should show past performance.
23. KPIs should identify degradation in safety performance as early as possible.
24. KPIs should be designed according to the way they are to be used by the regulator.
25. Consideration should be given as to whether indicators can be used standalone.
26. Aligning action levels with KPI measurement should be possible.
27. KPIs should be clearly defined and unambiguous to ensure accurate communications with stakeholders.
28. KPIs should not be capable of being manipulated.
29. Learning from the use of indicators may require changes in the set of KPIs used or associated action levels over time.
30. Standardisation, e.g. based on number of hours worked, could facilitate comparisons between companies.

1 The context for reviewing safety performance indicators

The Ministry of Social Affairs and Employment commissioned RIVM to develop key performance indicators (KPIs) for safety in the process industry. The purpose of this literature review is to make recommendations, based on the referenced literature, for establishing key safety performance indicators in the Netherlands, and which could be used by the regulator for Major Hazard Control to assess safety management system performance in controlling major hazards. This concerns companies that fall under the European Seveso II Directive (European Council Directive, 1996). The context of the review is the development of indicators for the purposes of supporting the development of guidelines for these companies and for enforcement by the Dutch regulator.

The focus is on indicators of safety management system performance which can predict safety performance, with consideration also to be given to the related subjects of safety culture and leadership.

It is these factors which are now considered important in Major Hazard Control. They have been implicated as causal agents in big accidents over the past two decades, since the Chernobyl accident in 1986 and more recently with the BP Texas City explosion in 2005 where the Baker Panel Report (Baker, 2007) highlighted how BP's safety indicators failed to indicate the poor level of process safety management which led to the accident.

The current review was undertaken by searching the peer-reviewed literature using specific search criteria associated with safety management, performance , process safety, indicators, loss of containment, leading, lagging and various combinations of these. A list of about 400 articles was obtained and, given the limitations of the study, the most recent and most relevant as could be determined from the abstracts were used. For example, occupational safety performance was not of primary interest. Internet searches were also made where general industry guidance on performance indicators and research reports could be identified and obtained. Contact was also made with academic experts in major hazards and safety culture such as University of Aberdeen Department of Psychology (e.g. Mearns and Flin, 1999), the Health and Safety Laboratory (Sugden, 2011), attendance at a cross-industry safety culture workshop (Network Rail, 2011) and a performance indicators conference focused on industry (CEFIC-EPSC, 2012).

In the current review the terms safety performance indicators (SPIs), and key performance indicators (KPIs) for safety are both used. KPIs are usually linked to a target and are key in helping managers determine if they are on track in relation to goals and objectives and what actions to take. The information is key to the company objectives. However many articles about performance indicators and safety refer simply to safety performance indicators (SPIs) or as process safety performance indicators (PSPIs) to distinguish them from indicators of occupational safety, using the term in the sense of a piece of information that says something about safety performance. Both process safety KPIs and SPIs may be used together in an organisation.

The main points for the review are as follows:

1. The review will inform the design of the enforcement regime concerning KPIs for process safety for Seveso companies. Issues include:

- purpose of KPIs for process safety (what and why);
- types of indicators (metrics);
- what is being measured (goals, coverage);
- the process of selection of indicators (tailoring);
- tolerances (cue for action);
- follow-up, learning, assurance (intervention and improvement);
- motivation and incentives (drivers).

2. The review will inform the development of guidelines for making company specific process safety performance indicators in the Netherlands for Seveso companies and for developing KPIs for use by the regulator as part of the enforcement regime. This is linked to point 1 since the guidance and enforcement have to be connected, so the same basic issues apply. Existing guidelines are examined on the basis that a lot of thought from companies and regulators has already gone into their making and common basic principles and experience can be extracted for further consideration.

3. The review only considers current work on researching and developing safety performance indicators concerned with major hazards. Occupational safety performance indicators work is only of interest if of relevance to major hazards. In that respect work in the area of occupational safety is largely ignored unless the results can be generalised.

4. Industries besides major hazard chemicals that are relevant include the nuclear industry, which already has a history of using performance indicators and examining safety culture. These other industries are examined only in so far as they are considered useful for 1 and 2.

5. Sources of information include peer reviewed journal articles, conference proceedings and currently available guidance and any tools or questionnaires available.

6. The requirements for a safety management system are currently specified in the European Seveso II Directive (See Annex I). A new area on performance indicators is expected to be in the forthcoming Seveso III. The current review focuses on KPIs for the safety management system with additional consideration of safety culture and leadership issues.

7. Issues with respect to KPI's, the safety management system and relationships with culture and leadership are broadly defined and critically addressed within the current review. Use is made as far as possible of previously undertaken reviews by specialists in the area.

8. Finally, the review considers whether there is any evidence that companies are actually using process safety KPIs.

The review is organised as follows:

- Chapter 2 addresses the purpose of having indicators.

- Chapter 3 looks for evidence of links between safety management, safety culture and safety performance.

- Chapter 4 summarises guidance for the industry, supplemented by Annex 2 giving details for selected guidance.
- Chapter 5 briefly considers what companies are currently doing in developing key performance indicators.
- Chapter 6 provides conclusions on key factors in designing a system.

2 Purpose of key performance indicators in process safety performance measurement

2.1 Introduction

‘The blast at Chevron in Pembroke was a "tragic incident"’, the prime minister said….Speaking during Prime Minister's Questions on Wednesday, he added: ‘I am sure there will be lessons to learn but as you said ***it has had a good safety record*** *and a good safety record in an industry in which there really are some inherent risks.’ BBC New South West Wales (online) 8 June 2011*

The feeling of safety derives from not having accidents. Although the absence of accidents may give a sense of security, it is no guarantee to safety when there are hazards present. Low probability high consequence events that characterise the major hazard industries are, by virtue of being low probability, not regular occurrences. When such events do actually occur they trigger attempts to understand and improve major hazard control. Quantitative risk criteria in the Netherlands (Ale, 2005) give some idea of what low probability means in this context.

Improving process safety means reducing the probability of harmful consequences from toxic, flammable and explosive hazards. The probability factor cannot, unfortunately, be measured directly. Target zero will never be reached unless the hazard is removed altogether, so absence of an accident is not informative. On the other hand when a major accident actually occurs all kinds of causal factors are identified which could have been better monitored and controlled. As a result, one drive for improvement which has risen in importance over the past decade is the introduction of key performance indicators (KPIs) into the process safety management system.

The KPI is a well-known business management term referring to the measures that monitor the performance of key result areas of business activities. KPIs represent a set of measures focusing on those aspects of organisational performance that are the most critical for the success of an organisation. Parmenter (2006) cites the financial turnaround of British Airways in the 1980s, claiming it resulted from the focus on late planes as a KPI. The number of late planes can impact on a number of critical success factors like costs, customer satisfaction, internal business processes and learning and growth. These critical success factors are taken from an approach to business management developed by Kaplan and Norton (1992, 1997) which requires managers to focus on a small number of critical measures (the ‘balanced scorecard’) and takes a goal-directed rather than control-directed approach. The measures are designed to pull people toward the overall vision by whatever actions are necessary rather than trying to specify what those people’s behaviour should be under constantly changing conditions.

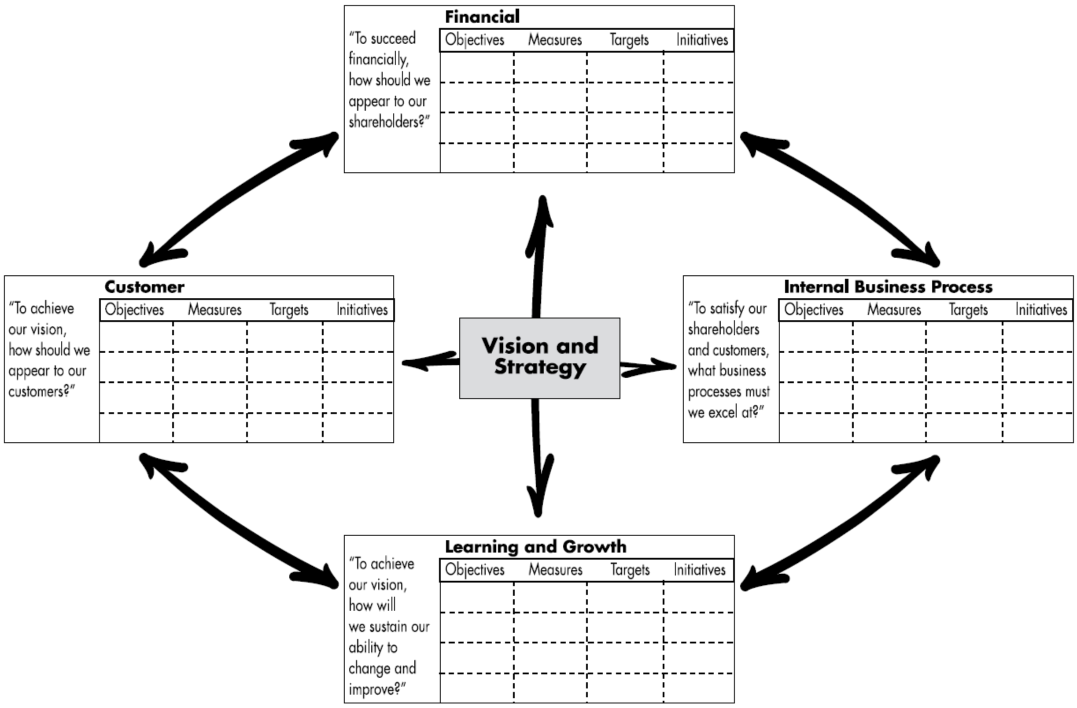


Figure 1 The balanced scorecard of KPIs (from Kaplan and Norton, 1996)

KPIs developed for process safety performance could serve similar functions to those developed for realising financial goals:

- to help a company monitor and manage its level of safety performance by evaluating its progress towards safety goals;
- to give assurance to stakeholders that a plant is being well-managed with respect to major hazards;
- to find ways to continuously improve safety.

A set of performance measures will be part of a company's own general monitoring system, providing intelligence about the major hazard control system and how it is performing. The system has to be part of the company and it should be adapted and improved over time as part of the learning process.

From the perspective of the regulator, KPIs could serve a different function, informing on the current and future level of safety for the purpose of planning inspections and interventions. The international Committee on the Safety of Nuclear Installations and Committee on Nuclear Regulatory Activities (CSNI/CNRA) published a report on this area (OECD, 2006) stating that safety performance indicators alone have no value unless they are to be used for a specific purpose. These uses should be defined. A survey of regulatory bodies showed that the main uses were:

- to measure safety performance as a way of judging licensees performance, together with inspection, scrutinising documents, investigating events, and interviews with personnel and judging whether their systems for managing safety were effective and improving;
- to improve their own regulatory activities as a tool for targeting resources;

- to communicate about safety with stakeholders.

It was also recognised that nuclear power plants have different needs to regulators and that their performance measurement systems are likely to be larger and deeper than those of regulators. No clear agreement emerged on indicators of safety management and safety culture, although self-assessment and continuous improvement by such plants were central points.

A summary of regulator responses is shown in Figure 2.

Used of indicators by Regulators	BE	CA	CH	CZ	DE	ES	FI	GB	HU	JP	KR	SE	SK	SL	US
Development of inspection program based on PI data			x	x			x			x			x		x
Increased RB response when threshold values are crossed			x						x	x			x	x	x
Regulatory action determined by integrated picture (PI combined with other info)	x	x		x			x					x			x
Indicator trending used internally to focus on problematic areas		x		x		x	x							x	x
Regulatory action depending on trend violation and margin to safety		x					x								
Indicators are compared among plants to rank regulatory responses		x				x									
Indicators are compared with those of foreign plants (performance evaluation)						x									
Annual reports with evaluation of safety level of NPPs from PI point of view	x	x		x			x							x	
Indicators are reported to parliament						x								x	
Reporting of selection of indicators to host ministries							x							x	
Selection of indicators are made public (through website, annual report …)			x				x				x				x

Figure 2 Overview of replies about the objectives for the establishment of a regulatory safety performance indicators system in the nuclear industry (OECD, 2006)

The use of experience in the nuclear industry is not necessarily helpful in the current process. In the chemical industry the different manufacturing processes, products, not to mention the possible scenarios that could develop depending on these technologies and chemical properties, compared to the limited processes of the energy sector, is a much wider spectrum to be addressed.

2.2 Safety performance measurement

Safety improves or degrades in relation to boundaries of acceptability and the availability and application of standards. Safety is driven by social forces, common and competing goals, and underpinned by the technical and financial possibilities to resource its improvement or prevent its decline. But is it possible to measure safety to determine whether current activities lie within acceptable safety boundaries or whether trends in performance decline or improvement are occurring? Indicators offer the possibility of defining acceptable or tolerable boundary limits or trends, expressing tolerances as to how close to the boundary one can get and associating these with levels of action. Can the ‘Rasmussen drift’ (section 2.3.6) to the boundary of acceptability be measured?

Measurements have to be taken to indicate safety performance. Two modes of measurement are generally considered in relation to safety management and safety culture:

1) Measure the inputs of the management system to the safety processes and the outputs of these processes using leading and lagging indicators.

2) Measure the safety culture (beliefs and attitudes) or safety climate (perceptions about safety and risk) which is believed to underpin safety at a collective level, across the organisation.

Most published guidance on KPIs in process safety concerns (1) – see chapter 4 and Annex 2. Issues related to (2) are discussed in chapter 3.4.

Many see the new breed of performance indicator as another layer of Heinrich's triangle (Heinrich, 1931) as shown in Figure 3, or one step deeper setting metrics at management level in the sociotechnical system as shown in Figure 5 and Figure 10. There is talk of a 'management dashboard' which will provide the necessary parameters for using the safety controls.

To be able to say that safety is getting better (or worse), like saying whether the speed of a car is faster or slower, appropriate measurements have to be taken. It is generally agreed that safety performance indicators should be a driving force for learning and improvement. That will only work if organisations direct attention in the right places. That was the conclusion of the Baker report after its review of BP's US refineries (Baker, 2007) following the 2005 Texas City explosion.

> 'BP primarily used injury rates to measure process safety performance at its U.S. refineries before the Texas City accident. Although BP was not alone in this practice, BP's reliance on injury rates significantly hindered its perception of process risk. BP tracked some metrics relevant to process safety at its U.S. refineries. Apparently, however, BP did not understand or accept what this data indicated about the risk of a major accident or the overall performance of its process safety management systems. As a result, BP's corporate safety management system for its U.S. refineries does not effectively measure and monitor process safety performance.' xiv (Baker, 2007).

The panel concluded that BP should develop, implement, maintain, and periodically update an integrated set of leading and lagging performance indicators for more effectively monitoring the process safety performance of the U.S. refineries by BP's refining line management, executive management (including the Group Chief Executive), and Board of Directors.

In conclusion, it makes sense that regulators and companies are looking to:

- establishing indicators as predictors (leading indicators) of a potential loss of control that could lead to harm or damage;
- establish common indicators for benchmarking, especially unwanted consequences (lagging indicators);
- the safety management system as inputs to risk control as a place to locate leading indicators;
- critical parts of the total output such as failures in safety-critical equipment.

Questions about what to address include:

- What functions are indicators intended to perform?
- Can causal modelling assist the selection of performance indicators?
- Can culture measurement provide a suitable major hazard safety metric?
- Are there enough events of the necessary diversity illustrating the key issues?
- What and how many indicators would one need to include to give a broad and critical safety coverage?

- How would they be measured (and how often)?
- What would the criterion be for taking follow-up action?
- What are current SPI measurements telling us?

The subject is gaining increased attention at conferences and workshops (e.g. Wood, 2010; CEFIC-EPSC, 2012). The following sections attempt to deal with some of the main issues.

2.3 Performance indicators as predictors of safety

2.3.1 Event frequencies

'Although it has been involved in at least 68 fatal crashes in the last 43 years, aviation experts say that ***the 737 has a good safety record*** *when the sheer number of miles it has flown is taken into account.'*

The occurrence of an accident does not by itself say something about the quality of the installation, personnel or management (Ale, 2009). Similarly even if everything is good and functions as intended there still remains a probability that an accident will occur.

Some things are very rare, others frequent. Maybe we will only see them once in a lifetime, or maybe many times. Safety management failures like having blind spots and not keeping to their own procedures have been identified multiple times in investigations of the larger scale accidents. Why did the management not see this beforehand? Was there a 'drift' into failure which could have been measured by some trend?

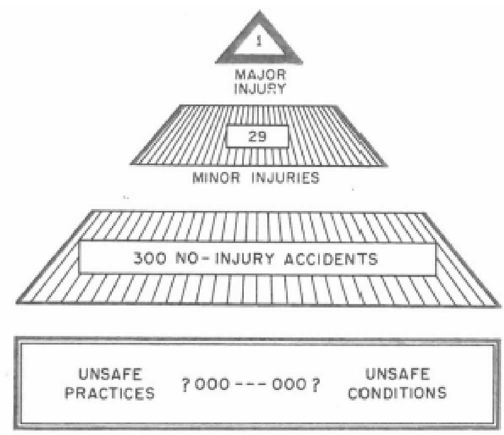


Figure 3 Heinrich Triangle (Heinrich, 1931)
Can this concept be similarly applied to major accidents and is there a causal relationship between the layers?

The Heinrich concept initiated the idea that near misses help point to less frequent bigger accidents. Perhaps near misses and other less severe outcomes could point to weaknesses in the system which contribute to major accidents.

For example, measured outcomes could point to holes in the 'Swiss cheese' (Reason, 1990, 1997) of already penetrated barriers (Figure 4).

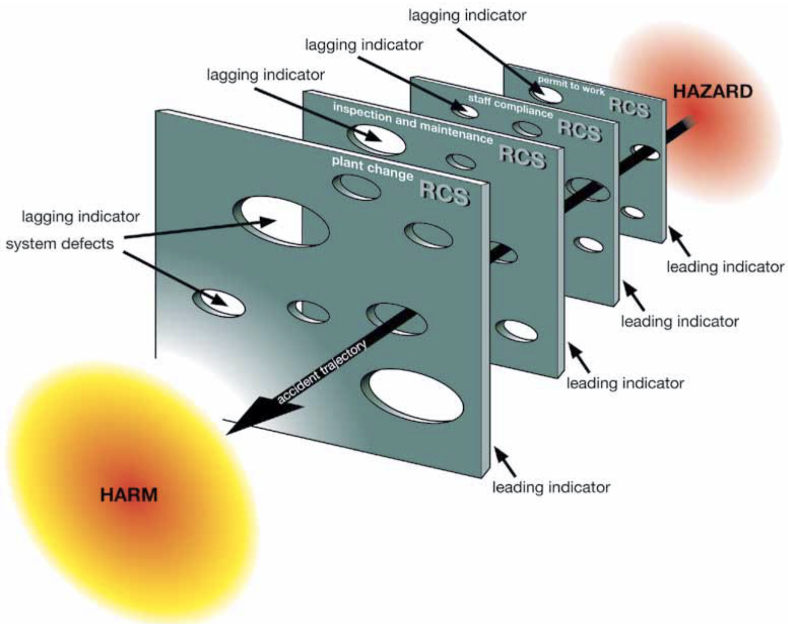


Figure 4 Swiss cheese model illustrating leading and lagging indicators (from HSE 2006)

However, the Energy Institute (2005) criticises the idea that the smaller Loss Of Containment (LOC) accidents predict the bigger ones and therefore looking at more frequent near misses as performance indicators could be a diversionary effort. This conclusion was based on an evaluation of the potential for smaller LOC related accidents to have been bigger or that a number of smaller LOC accidents are correlated with the number of bigger accidents. The conclusion was that the predictive power of near misses was not so good for major hazards. However, there are data on underlying causes from the more serious chemical accidents to highlight events which play a role in the accident sequence (Arbeidsinspectie, 2011) and which show that self-assessment by companies of potential scenarios and how to avoid them could be improved. The analysis of incidents in the years 2008-2010 showed that accidents begin with deviations in the material specifications and conditions, in process control or in safeguarding equipment for maintenance or at start-up or due to loose connections between connecting points in the containment system and that in more than half of the cases deviations were not detectable because of lack of indications. In this way deviations can develop into full blown incidents exacerbated by subsequent mitigation failures, particularly shutting off the release. In around half the accidents non-compliance with legal obligations were identified, amongst which failures in the safety management system.

Small deviations, which could have been recovered, developed into incidents. The point about the Heinrich triangle is that it has stimulated companies to conduct self-assessment using smaller incidents (Anderson and Denkl 2010) but the assessment of small developing into big has to compare like with like. Guidance on developing performance indicators often refers to using near miss data but it needs to be clearer what near miss means in the major hazards context and how to best evaluate such more frequent data including the risks associated with deviations as well as the safety management strengths and weaknesses.

2.3.2 *Performance indicators as alarms*

Many major accidents are considered to have harbingers which a company should have recognised, such as should have warned BP before Texas City. BP's measured loss of containment incidents had got steadily worse in the preceding few years (Baker, 2007, p.187) but they ignored them. Outcome indicators which are harbingers should play an alarm call role but these can fall in the management blind spot.

Even at the technical level, where there are interfaces with human detection capabilities, one of the notable high frequency nodes in the sequence of precursors is a lack of any indication or signal that a deviation has occurred, so the deviation is not detected and goes on to develop into an accident. This has been found in analysis of data from the MARS database (Bellamy and Baksteen, 2009), and in Dutch major hazard LOC data (Mud et al 2011, Bellamy et al, 2012) and in UK data (Lisbona et al, 2012). Is management measuring these deviations and understanding why they occur? SPIs could be more focused on the predictive indicators at the organisational level that underpin these deviations and the ability to detect and respond to them. Körvers and Sonnemans (2008) have also argued for a focus on these kinds of precursors which they found to frequently recur in accident reports: '… it is striking to see that these disruptions are not used for constructing pro-active Sis; neither are they emphasized in accident reports as pre-warning signals.' (p.1076). The emphasis on looking at precursors and addressing the underlying root causes is further elaborated in Sonnemans, Körvers and Pasman (2010), especially the question as to what, why and how it is that these events develop into accidents.

2.3.3 *Causal links to risk*

A link with the risk may be represented in models analysing accident causation (RIVM 2008) involving direct and underlying causes, built around a socio-technical concept like a risk control system as in the UK Health and Safety Executive's (2006) guidance on developing performance indicators. Or it may be considered at a more social than technical level which conceives of risk control as a safety culture issue - a set of assumptions, beliefs, values and feelings and visible artefacts (Schein, 2004).

An obvious and predominant line of thinking is that accidents, being negative events, had to have had causes that are also negative events. So, by identifying the potential weaknesses of an organisation and management system in advance, it may be possible to intervene before an accident takes place.

To make the connection between safety and indicators it is generally agreed that in practice the safety performance indicator system should be linked to the risk in some way, even if it is just going round the installation and spotting areas of concern. Grote (2009) suggests that central to the debate on SPIs is sound knowledge about cause and effect relations in order to predict safety performance from any set of indicators. In practice, sound knowledge may be substituted by risk perceptions and experience:

'We asked the team to brainstorm around the question: *"As you go about your work what are the things which make you feel uncomfortable about process safety"*…..The only constraint we put on the brainstorming was that, for a weakness to be added to the list, the proposer had to give an example of how it had in his experience given rise to the risk.' (Webb, 2009).

It is not to say that this is not a valid approach. It is a substitute for an absent model, so the ones in the heads of the workforce are used instead.

In general, looking at guidance approaches, performance indicators are focused on the management inputs to and outputs of risk control such as the HSE (2006) guidance. This shows the risk control system to be a constituent part of a process safety management system that focuses on a specific risk or activity. The input might be the testing of a critical safety system. The output might be the result of the test. The approach is ultimately meant to be about causal relationships underpinning the selection of performance indicators. However, the strengths of the relationships between indicators and safety are not generally known. As the Health and Safety Laboratory reports (Sugden et al, 2007) there is a lack of literature concerning the success or otherwise of SPIs:

'Most performance indicators seem to have been developed in the absence of any underlying rationale or holistic model. There are some suggestions that the use of performance indicators leads to improvements in system safety, but no concrete evidence of this' (p.3).

Similarly there is little apparent underpinning using causal modelling although there are many references to the Reason (1997) Swiss cheese model which is a metaphor for the concept that accidents occur because of weaknesses in lines of defence represented by holes in slices of cheese. Indicators should then perhaps measure the holes in the cheese.

Hopkins (2009) talks about failures which identify how well the process safety controls are functioning like plant trips and alarm rates, or delay to repair. Hudson (2009) responds similarly with a bowtie model of managed barriers and needing to know how threats to the barriers relate to consequences in order to develop feedforward indicators. Vinnem (2010) describes the risk level project of the Petroleum Safety Authority to identify levels of risk from indicators. Vinnem distinguishes technical barriers from the human element. Technical barrier indicators of safety critical systems are used with measures of test success/failure reported by the installations for these barriers such as emergency shutdown valves, fire detection, pressure safety valves. Barrier performance panels are proposed which could be updated every 3 or 6 months with a rolling 12-month average, showing status and trend direction which would maintain motivation and awareness on the major hazards. However, barrier performance did not correlate significantly with hydrocarbon leaks (Vinnem et al 2010).

What is the source of causal data? Accident analysis, near miss reporting, bowtie modelling and risk assessment are all candidates. However, how far do these get in linking the management system to the causality and whether management can handle the risks? Chapter 3 looks at some of the accident analysis evidence. Risk assessment is considered below.

2.3.4 *Technical-organisational links*

The risk model developed by RIVM (2008) for the Dutch Ministry of Social Affairs and Employment used accident data as a basis for logical modelling. The logic of the model is built by organising the precursor events (previous to outcome) from the accident analysis and relating these to outcomes using probabilistic modelling. The accident analysis includes eight management delivery systems and four barrier tasks as shown in Figure 5, but omits these elements from the logical modelling because of the potential explosion in the number of scenarios. The logical model therefore lacks the 'socio' element of sociotechnical. This is quite typical in risk analysis. The question is whether it can even be included in risk analysis, especially the cultural element.

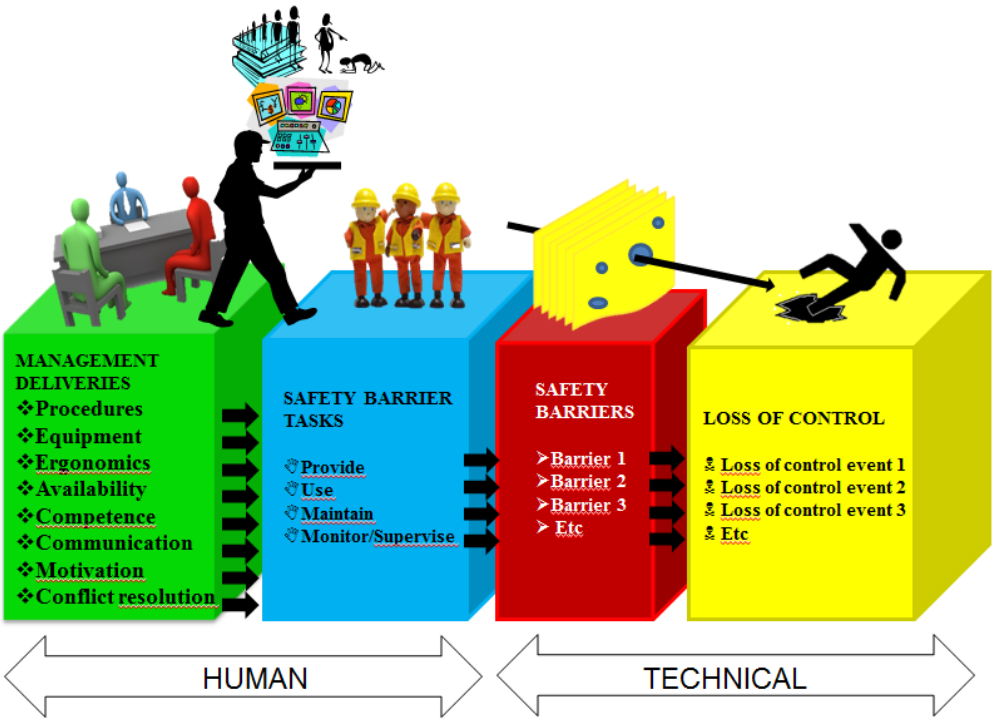


Figure 5 The barriers model showing an interface between the human and the technical system (After RIVM 2008)

The problem partly resides in the fact that we do not know the best way to measure the socio factors in such a way that we could incorporate these into risk assessment, although there have been attempts to do so (I-Risk and ARAMIS projects) in order to bring more focus on risk related management issues for low probability high consequence risks (Bellamy et al, 1999; Duijm and Goossens, 2006).

The causal relationship is based on the premise that deficiencies in process safety management outputs are linked to deficiencies in the technical system components through an influence on their probability of failure. Duijm and Goossens (2006) point out that the argument against including safety management in risk assessment is that the SMS is changing fast and so cannot be used for e.g. land-use planning quantitative risk assessments as done in the UK and the Netherlands. However, the authors point out that inclusion of safety management evaluation would lead to more conservative risk estimates meaning more robust estimates over the long term. 'Neglecting the safety management efficiency means neglecting the possible degradation of the safety barriers under the presumably volatile safety management regimes'.

The modification of risk (MOR) approach, which is designed to incorporate the management factor, requires scenario-based auditing (Bellamy, 1998). This kind of audit tool can show up differences across sites (Hurst, 1997). However it can be very resource intensive. A child of this approach called AVRIM2 (Bellamy and Brouwer, 1999), was introduced into the toolkit of the Dutch Labour Inspectorate for major hazard control accompanied by an organisational typing tool. This tool was based on an extensive mapping of mental constructs of Dutch major hazard inspectors using factor analysis and which could help to predict the strengths and weaknesses of the management system (Bellamy et al, 1995a, 1995b). Strength-weakness constructs were, for example, adherence to procedures, awareness of the risks, resources available for safety, knowledge/skill of management, commitment to safety, delegated responsibility to front line, level of emergency preparedness. These are areas which are potential SPI candidates and which fell into the following categories:

- Design and Condition of Installation;
- Procedures, Rules and Written Material;
- Skills, Knowledge and Training;
- Use of Contractors and External Expertise;
- Pressures and Resources;
- Culture and Attitudes;
- Maintenance and Checking;
- Communication (between management and workforce);
- Level/amount of control;
- Care for Workforce/Job satisfaction;
- Standards of safety reports and attitudes to the Labour Inspectorate;
- Organisation and Systems;
- Event Reporting and Investigation.

The most important organisational typing variables for predicting strengths and weaknesses based on both frequency of occurrence and the amount of explained variance in inspectors' evaluations were size (of company, site, installation, workforce), documentation (existence of, quantity of; rules, written documentation, paperwork, procedures), complexity of process or operations, age, degree of centralisation of standards and the influence of parent company, nationality, single or multiple products/hazards, primary or secondary role of the hazardous chemicals in business. Different organisational types would therefore be expected to have different candidate SPIs.

2.3.5 *Resilience and safe envelope*

Systems modellers (e.g. Hollnagel et al, 2006) consider the concept of a chain of causes or of holes in slices of cheese too linear. The graphic modelling of fault and event trees is too constraining. The system modelling perspective looks at hierarchies of control. There has been a tool developed called STAMP (Systems Theoretic Accident Modelling and Processes) that integrates all aspects of risk including organisational and social (Leveson et al, 2006). The most basic component is a 'constraint'. The modelling makes sense for controlling safety systems with their dynamic boundaries. The control hierarchy has downward communication imposing constraints and has a measuring channel to provide feedback about effective constraint enforcement.

The system modellers would argue that the typical modelling approaches of accident analysis and risk assessment are not good at modelling what may be non-linear effects. The resonance of concurrent events which influence each other is targeted in the resilience concept of Hollnagel et al (2006). Hollnagel calls into question whether safety performance alone can be proof of resilience. In a system modelling approach, rather than one that focuses on component failures, resilience is not the classic definition of safety as being resistant to causes. Rather it is the organisation's ability to adjust to harmful influences. An unsafe state can arise because of insufficient adjustments rather than because something fails. Resilience, according to Hale and Heijer (2006), could be defined as the ability under difficult conditions to stay within the safe envelope and avoid accidents. Indeed, as Rasmussen and Svedung (2000) point out, most major accidents have been caused by organisations operating outside design envelopes due to economic pressures.

'Safety control should then be based on a facility enabling managers to compare operational conditions to the assumed preconditions of safe operation. This implies that, in the first approximation, measuring safety involves measuring the margin between the safety design envelope and the actual state of system operation, a problem that is realistic as long as the particular system design has been based on an adequate definition of the boundaries of safe operation.' p48. The point, according to Rasmussen and Svedung (2000) would be to have:

- explicit formulation of the boundaries of safe operation (e.g. defence in depth philosophy of probabilistic risk assessment);
- communication of design envelope to operating organisation;
- risk management as part of operational line management;
- design of managers' system information interface.

That last point highlights the concept of the important SPIs that could be informing management –the concept of the management dashboard.

Some of the issues pointed out by the system modellers should perhaps be considered in the dashboard. The modelling of system dynamics is exemplified in Figure 6. This shows how an incident reduction programme could lead to reduced situational awareness because of reduced incidents. The model only looks at the interaction of the variable 'number of incidents'. However, it does show that incidents should not be the lone source of information. It is also implying, paradoxically, that incidents are needed for safety.

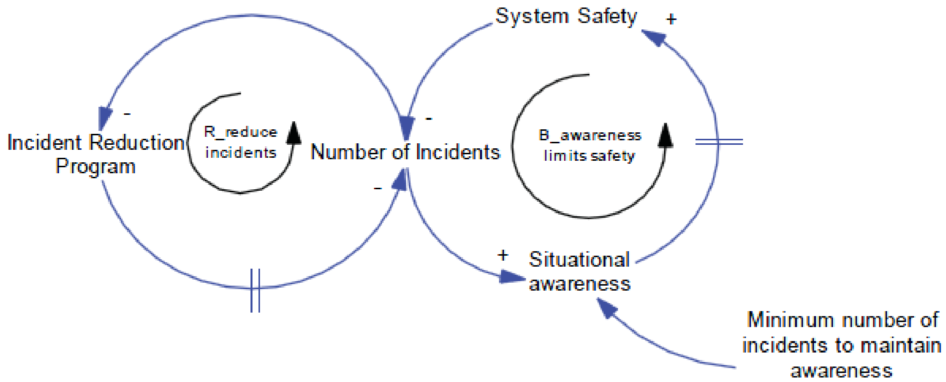


Figure 6 Archetype of decreasing safety consciousness (Marais and Leveson, 2003) The + and – signs indicate increases and decrease in the variables

2.3.6 *The Rasmussen Drift*

Rasmussen (1997) says that ‘under the presence of strong gradients behaviour will very likely migrate toward the boundary of acceptable performance’. This is shown in Figure 7. This so-called ‘Rasmussen’s drift’ is regarded as a natural process of local adaptation to the situations and demands encountered which bring actors closer to the edge of the safe envelope, with factors like cost effectiveness dominating. Irreversibly crossing the boundary can result in an accident. Boundaries are hard to see.

Safety management according to this model is then understood as requiring a dynamic process dealing with the dynamics of the pressures to migrate towards and across the boundaries and of developing coping strategies for close boundary interactions. From that perspective safety performance indicators can be imagined as migration meters continuously keeping track of the dynamics of what is happening within the safe boundary.

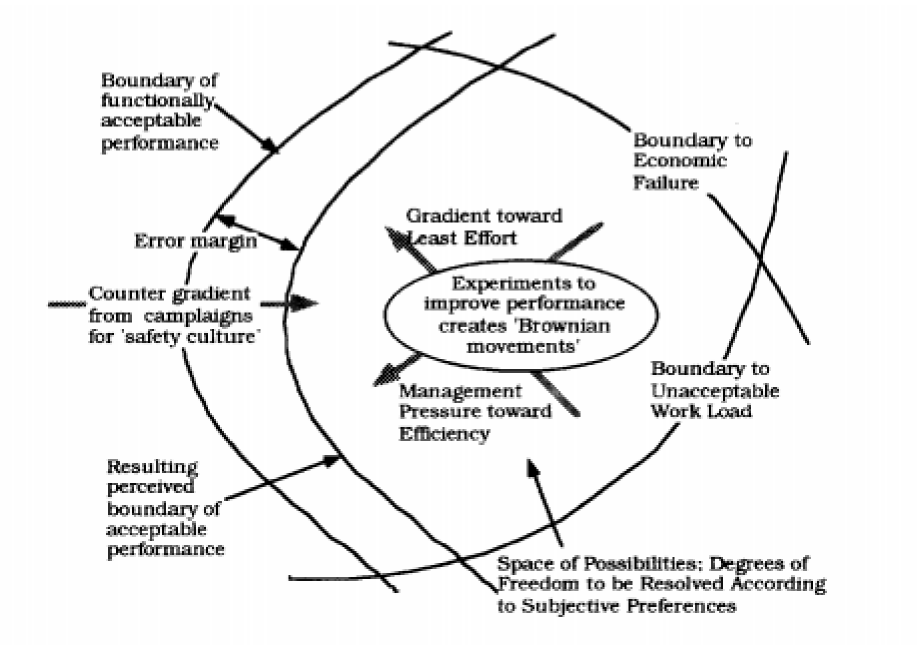


Figure 7 Rasmussen drift (Rasmussen, 1997)

2.4 SPIs for comparison over time

Descriptive indicators are monitors that can be used for comparing performance over time. The indicators should give an idea about how well safety controls are functioning and be capable of showing trends. The UK Petroleum Industry said that effective key performance indicators (KPIs) should provide a measure of the annual improvement for individual sites (Energy Institute, 2005). Indicators that can be more frequently measured are important so as to be able to talk about a rate (Hopkins, 2009).

Hopkins (2009) emphasises measuring two things:

1) whether monitoring is being carried out (management input measure) and

2) what the monitoring is finding out (output measure).

2.5 SPIs for comparison across a set of many organisations

Stough (2011), from a research study of a large energy industry data set, claims that the most meaningful key performance indicators are those for which there is variability i.e. there are score differences across many organisations – some good, some average, some bad. Improving the scores of poorer performers is an opportunity to improve aggregate outcome performance.

2.6 Deciding where and how to take action

In order to decide where to take action there needs to be an understanding of causal links to indicate where action is needed (Hale, 2009). Similarly, for driving leadership behaviour leading indicators must offer a practical solution by being 'actionable'" as well as being routinely measureable, believable and predictive (Stough, 2011):

'To attain the full commitment of field-level leaders, the leaders must believe that outcome performance can be affected with proper changes to performance in the leading KPI.'

Stough identified that the typical pattern in many QHSE business processes is (1) Obtain/review data from reported incidents, (1a) Measure potential risk, (1b) Identify failed controls, (2) Implement/repair controls to reduce risks. (1) is affected by reporting culture and (2) by leadership response. The traits of a high performance culture were:

- strong culture of reporting and fixing;
- high rate of action with high percentage on-time completion;
- responsive, disciplined leadership involvement.

2.7 Performance indicators as motivators

In driving improvement, giving incentives is one of the functions identified by Hopkins (2009). There could be financial incentives if, for example, SPIs are linked to bonuses. Hale (2009) reports that setting intermediate performance indicators on management drives up the reporting of intermediate events which appears to be a success factor in lowering accident rates. The reporting included dangerous situations and their resolution or observation rounds coupled with discussions with the workforce on good and bad practices. Hale and Guldenmund (2008) also indicate a three times greater chance of success with culture interventions when site directors are supportive, active and participative.

Motivation is generally described as goal directed behaviours such that it is logical to conclude that target setting in terms of safety indicators should be motivating. That might be placed in a broader context of need, such as that of Maslow (1943). Achieving higher levels in the hierarchy means satisfying the lower levels first. Attaching SPI's to pay would be low in the hierarchy (safety/security level), whereas safety achievement being motivated as a matter of self-esteem would be higher and safety as a moral value even higher. One might wonder therefore whether linking performance targets with financial reward systems has less impact than providing achievement rewards that raise self-esteem. Concepts like trust and commitment which appear to be positive aspects of safety culture (see section 3.4) also look to be more aligned to the higher levels.

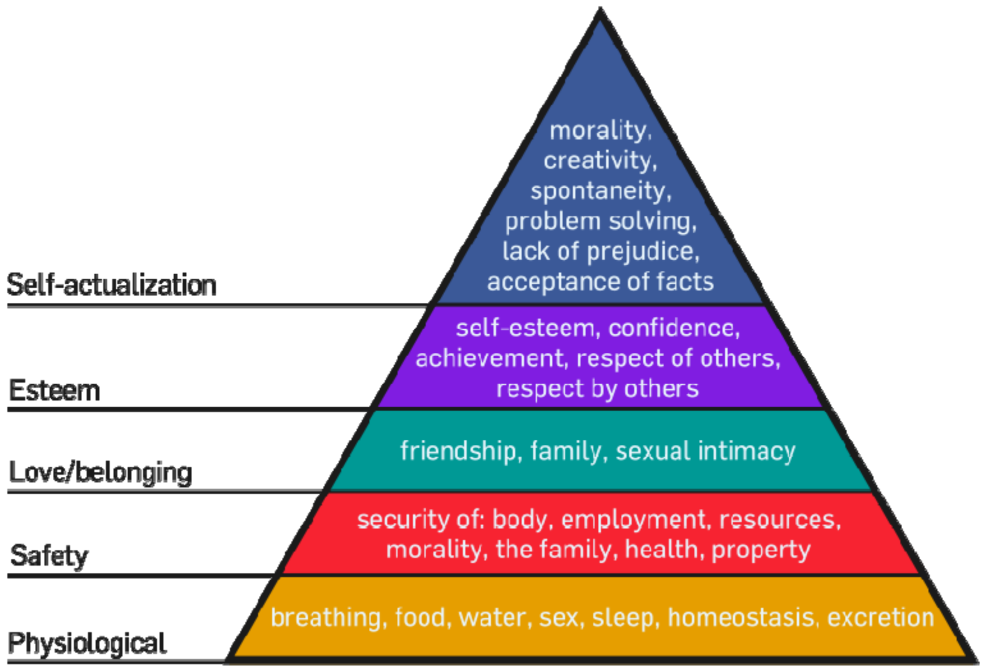


Figure 8 Maslow's hierarchy of needs (Maslow 1943)

2.8 Part of the problem solving process

We might regard SPIs as part of the problem solving process of how best to manage process safety. According to Schein (2004) the culture of a group can be defined as a 'pattern of shared basic assumptions that was learnt by a group as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think and feel in relation to those problems.' p17. The tasks of safety management can be seen as part of this problem solving cycle – a set of feedback and learning loops operating at different levels in the sociotechnical organisation (Hale et al, 1999).

3 Safety management and safety culture

3.1 Safety management system requirements

The requirements for a safety management system according to the Seveso II Directive is given in Annex I. Various guidance and standards have been produced indicating what a safety management system should contain including Mitchison and Porter (1998) and NTA 8620 (NEN 2006) focused on major hazard safety management and at a more general level ILO-OSH (2001) and OHSAS 18001 (2007).

3.2 Accident analysis and safety management causes

The primary link between safety management and safety performance is hindsight. Lessons learnt from accidents repeatedly address failures in the safety management system. An example is given below.

Bellamy, Geyer, Oh and Wilkinson (2008) analysed the weaknesses in BP's system underlying the Texas City accident based on the Baker report (Baker, 2007) and the Chemical Safety Board (US CSB, 2007) investigation. The analysis used a model developed from analysing a small number of major accidents where very detailed investigation reports were available (Bellamy and Geyer, 2007). The model encourages thinking within four themes which influence human performance:

- failure by people with major accident prevention responsibilities to understand the risks;
- failure to competently perform tasks related to the integrity of major accident risk control measures;
- failure to prioritise and give due attention to resolving task demands and human performance capacities, particularly through communications and workforce involvement;
- failure to give assurance that there is a knowledgeable learning organisation.

BP weaknesses found across all themes were superimposed on the model. This is shown in Figure 9

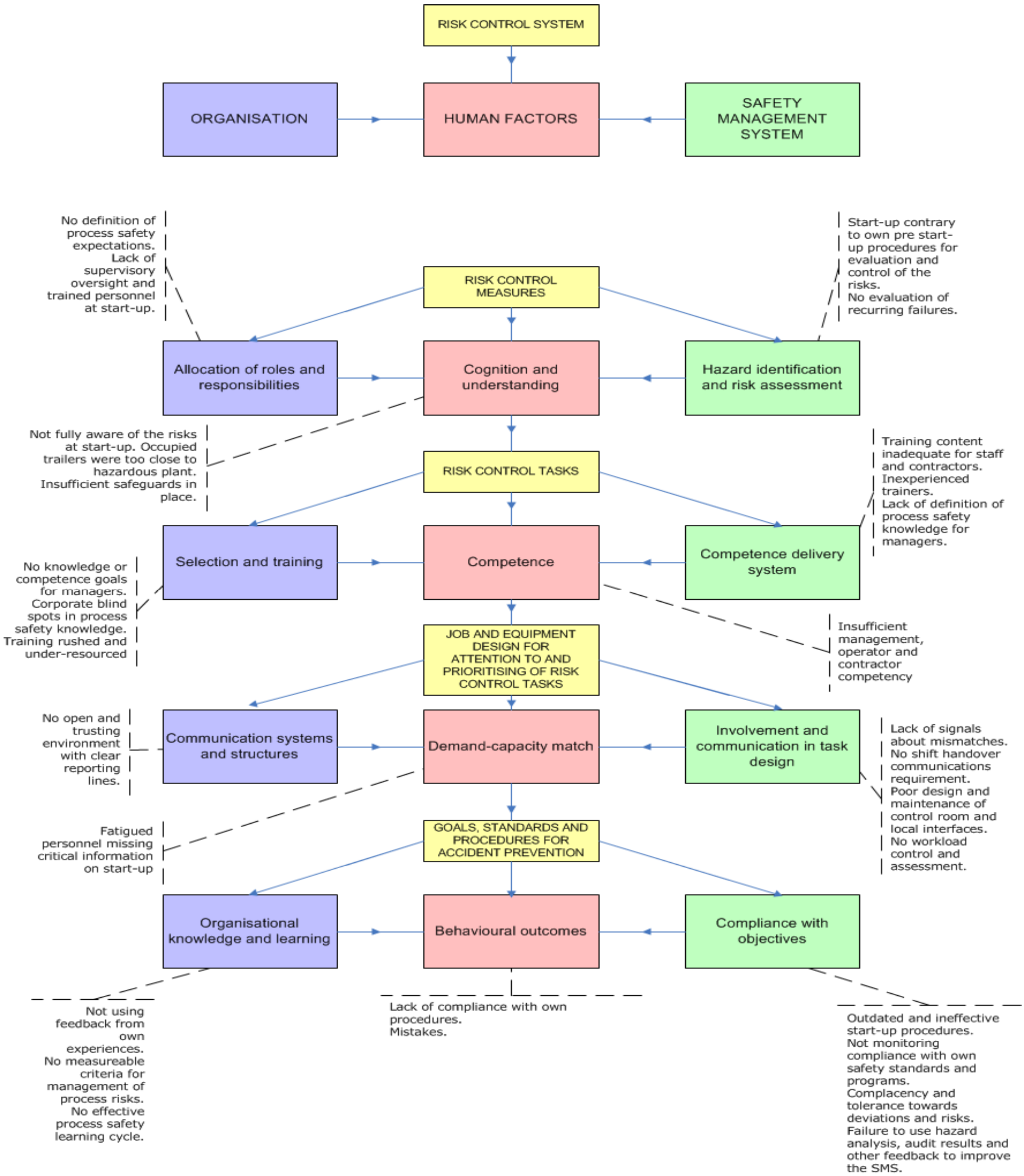


Figure 9 BP weaknesses superimposed on a working model developed from major accident analysis (Based on Bellamy and Geyer, 2007; Bellamy, Geyer, Oh and Wilkinson 2008)

3.3 Lagging indicators of the regulator

Kawka and Kirchsteiger (1999) examined the EU Major Accident Reporting System (MARS) in the context of the 'sociotechnical pyramid' (Hurst et al, 1991; Bellamy and Geyer, 1992), a hierarchical model of risk control (Figure 10). They found that, using 230 accidents from the MARS database, around 66% of the accidents occurred due to latent Safety Management System (SMS) failures and 8% from factors in the system climate. The mean severity of the accidents increased with the level depth of the pyramid. It seems that failures at the deepest levels of the sociotechnical pyramid give rise to the severest accidents. It was shown that severity in MARS data was unrelated to the length of the accident description. Neither was the length of the accident description related to the level in the sociotechnical pyramid.

The distribution of results support the idea that failure events at levels 1 and 2 of the type found in major accidents (equipment and human failures) are for a large part (around 75%) outcomes of an underlying loss of control by the management system.

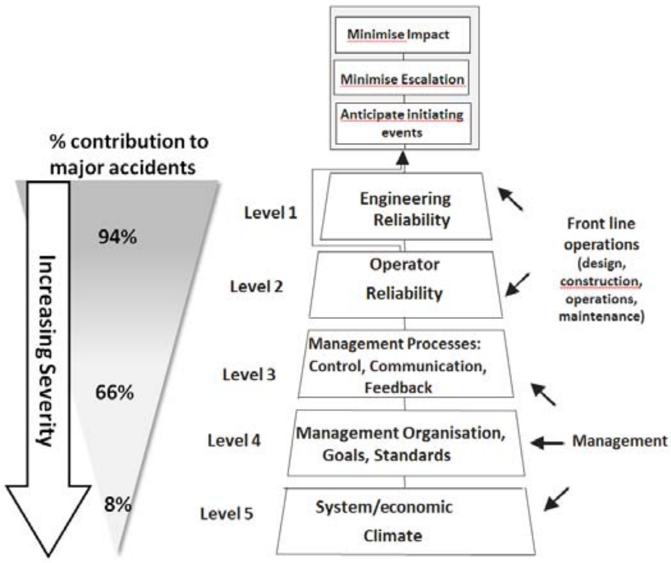


Figure 10 Sociotechnical pyramid showing on the left % contribution of causes to 230 MARS accidents (after Kawka and Kirchsteiger, 1999)
66% were due to latent safety management system failures at levels 3 and 4 and accident severity increased with depth of cause.

Figure 11 shows components of the SMS identified by regulatory authorities in incidents and comparing Dutch (Arbeidsinspectie, 2011; Mud et al, 2011) and Italian (Basso et al, 2004) findings. The Dutch data are based on the analysis by the Labour Inspectorate. The Italian data are based on analysis by the companies themselves of both accidents and near misses.

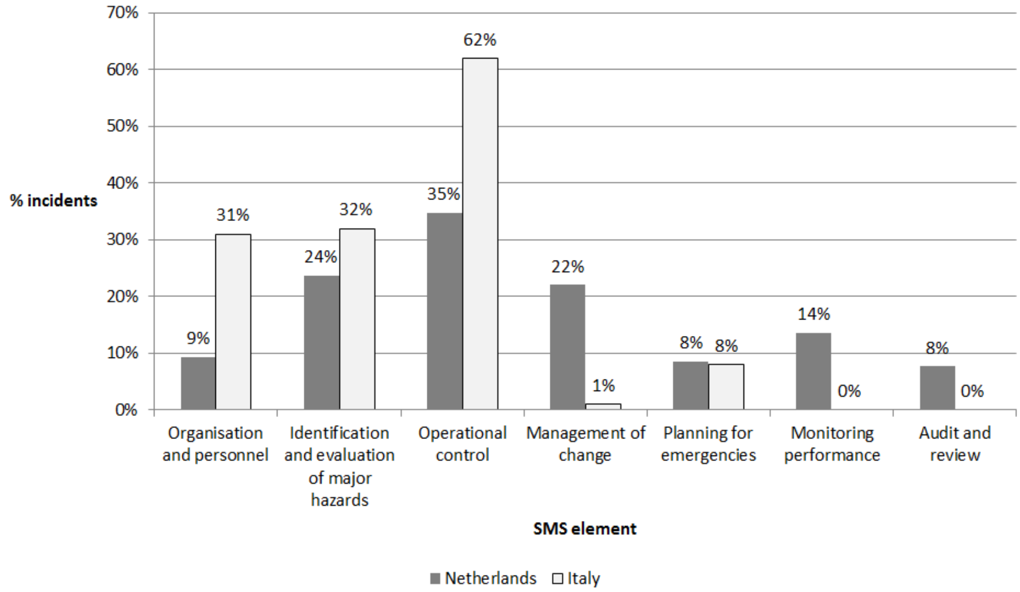


Figure 11 Distribution of incidents according to involvement of the SMS as a % of the total incidents for the MAPP and the seven Seveso safety management system elements according to investigations in the Netherlands (Arbeidsinspectie, 2011; Mud et al, 2011) and company incidents reports to the inspectorate in the Piemonte region of Italy (Basso et al, 2004)
Number of events NL = 118, I= 277.

Basso et al (2004), reporting on the Italian study, identified that the monitors set by operators were not related to the objectives of the policy but to measuring a part of the system. The authors recommended a method for targeting SPIs that should be focused on achieving the targets of the major accident prevention policy. Some suggested areas were:

1. Organization and personnel
   - investments in preventive or protective measures to limit the consequences of major accidents (from budget);
   - hours for safety training per person (from training minutes);
   - percentage of right answers for person (from tests to evaluate the effectiveness of training);
   - percentage of incidents when correct response was taken (from incident reports).
2. Identification and evaluation of major hazards
   - number of hazard evaluations conducted;
   - number of incidents happened in the establishment not previewed by the risk analysis (from risk analysis and incident reports).
3. Operational control and management of change
   - non-compliance about procedures, instructions and all documents necessary to describe dangerous substances, processes, plants and pieces of equipment (check list of audits);
   - technical inspections for control and maintenance of critical plants and pieces of equipment (from records);
   - number of incidents due to wrong observance of procedures and instructions (from incident reports);
   - number of incidents due to wrong management of change (from incident reports).

4. Planning for emergencies.
    - percentage of hours for safety training specific to the planning for emergencies (from training minutes);
    - number of incidents happened in the establishment not considered or badly planned by the emergency plan (from emergency plan and incident reports).
5. Audit and review
    - number of audits;
    - number of reviews of the major accident prevention policy and the SMS.

Combined with:

- incident investigation to find out the critical issues of the safety management system;
- choice and analysis of performance indicators and their thresholds;
- correlation between the indicator tolerance and the severity of the issue of the safety management system.

Further analysis on the data set of the Dutch LOC accidents over the period 2006-2010 by selecting only the Seveso plants incidents that were entered into the tool Storybuilder™ (Bellamy et al, 2006) reveals that for Operational Control barriers the main preventive barrier failures were as shown in Figure 12 - mainly safeguarding, flow and equipment condition failures. Figure 13 then shows the relationship between failure of one of the barriers (safeguarding) and the barrier tasks and management delivery systems failures associated with it. Dominant failures are in delivering adequate procedures (50% of safeguarding failures) in providing (45%) and using (41%) the barrier.

The purpose here has been to show that by collecting a large amount of incident information, links can be made between the management system and incidents. Data within individual companies may not be sufficient to show such results, such that it is helpful for companies and regulators to share data for the purposes of large scale analysis. With improved safety and reduced incident data, the opportunities to identify underlying problems in the higher severity events becomes more challenging.

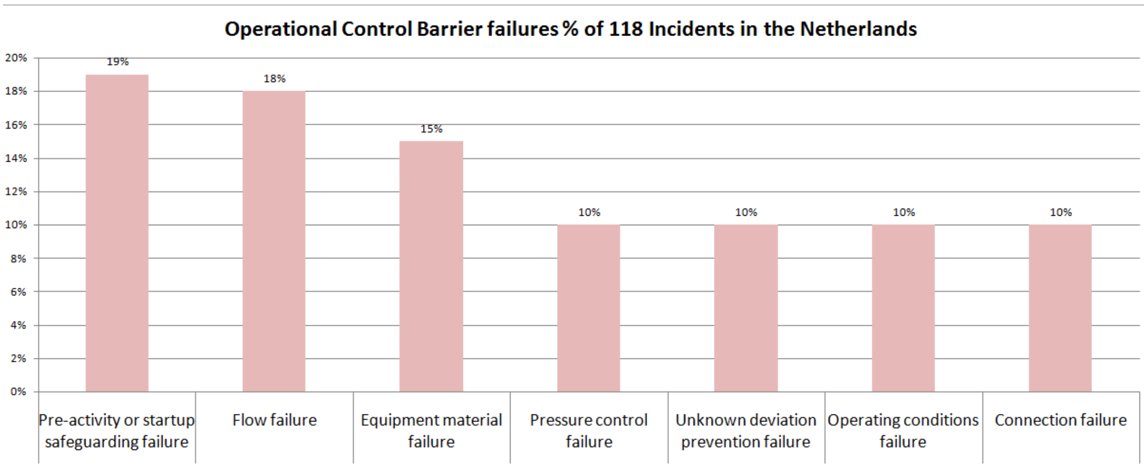


Figure 12 Analysis of Operational Control Barrier failures in Dutch Seveso plants 2006-2010

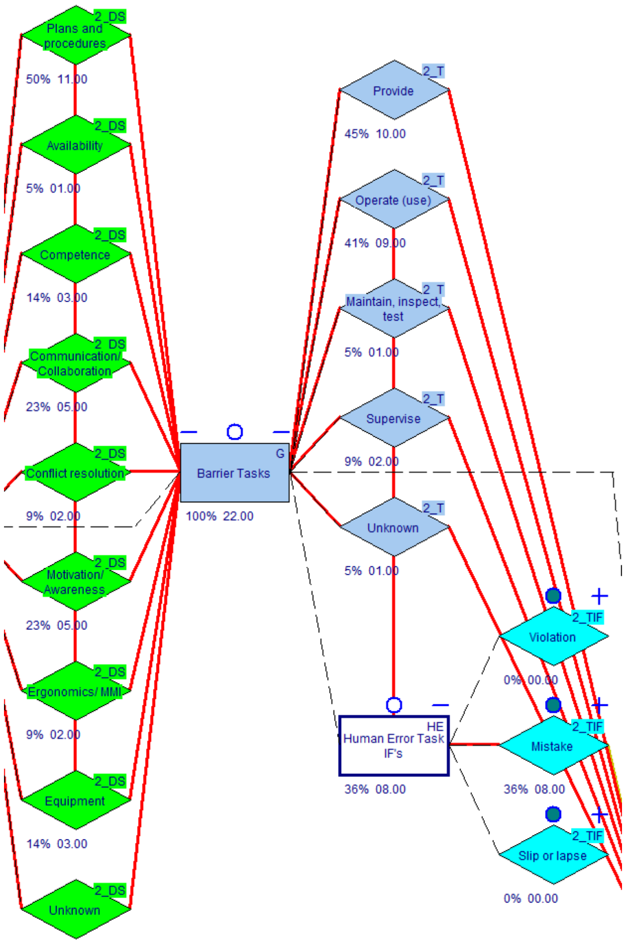


Figure 13 Percentage and number of barrier management failures (shown below boxes) for the safeguarding barrier (safeguarding before starting up an operation or beginning an activity) in 22 accidents identified from incident investigations
% of total and numbers of accidents are shown below the boxes. Plans and procedures failures in providing and using safeguarding dominate and in 36% of these incidents mistakes could be identified as having occurred.

3.4 Safety culture

3.4.1 Definitions of safety culture

The term 'Safety Culture' was first introduced in the Post-Accident Review Meeting on the Chernobyl Accident in 1986. The International Nuclear Safety Advisory Group later produced INSAG-4 ‘Safety Culture’ (IAEA, 1991), which deals with the concept of Safety Culture as it relates to Organizations and Individuals engaged in nuclear power activities, and provides a basis for judging the effectiveness of Safety Culture in specific cases in order to identify potential improvements. A later review of the accident in INSAG-7 (IAEA, 1992) found that design flaws were in fact primarily responsible which led INSAG to shift the emphasis of its conclusions from the actions of the operating staff to faulty design of the reactor's control rods and safety systems.

The safety culture concept emphasises safety at a group level. The commonality in culture is a sharing of ideas, beliefs, values. Culture is a term used by anthropologists which has become instrumentalised by management theorists (Haukelid, 2008).

There has been a recent shift towards talking about organisational culture, a shift apparently being referred to as the 'third age of safety' after hazard control technologies and human factors (Mengolini and Debarberis, 2008). According to these authors safety culture in the nuclear industry is now regarded as a specific type of organisational culture in high reliability organisations. The concept of 'leading' indicators which can be used to predict safety performance as opposed to 'lagging' or output indicators which reflect past performance is the challenge for monitoring these organisational factors.

Guldenmund (2000, 2010) defines safety culture as the aspects of the organisational culture which will impact on attitudes and behaviour related to increasing or decreasing risk. He argues that it is not possible to measure culture directly. Culture is an unmeasurable set of unconscious basic assumptions that can only be interpreted through 'espoused values'. Schein (2004) explains that organisational culture is a pattern of assumptions in relation to problems with external adjustments and internal integration that have functioned well enough to be perceived as true, and are passed on to new members as the right way to conceive, think and feel. These basic assumptions are apparently non-negotiable and those not holding them are outsiders. Members of the culture depict these basic assumptions through espoused beliefs, values, norms, and rules of behaviour that members of the culture use to depict the culture to themselves or others. The tangible overt manifestations of culture are called artefacts – the architecture of the environment, the language, the technology, style, manners, myths and stories, rituals etc.

The term 'safety climate' is often heard alongside that of culture. 'Safety climate' describes employees' perceptions (as opposed to attitudes and beliefs) about risk and safety, providing a 'snapshot' of the current state of safety (Mearns and Flin, 1999). Safety climate can be seen as an 'artefact' of the deeper cultural level and is the visible behaviour of its members. Artefacts include organisational processes which render certain behaviours routine.

3.4.2 *Leadership and culture*

The Harvard Business Review (1998) on Leadership gathers together key articles from eminent thinkers on management and leadership. From this can be distilled that leadership is about bringing about and adapting to change. It is about vision and strategy, gathering and analysing information, and giving direction. It is about protection, orientation, managing conflict and shaping norms.

Leadership failings have recently become the hue and cry of the major hazard safety industries but with 'little theoretical development or empirical research directly assessing the relationship between leadership and safety' (O'Dea and Flin, 2003). Apparently there has been a long held proposition, since 1939, that leaders create climate. According to Zohar (2010) interactions and exchange between leaders and their group members are part of a social learning process for how to interpret the organisational environment. This gives leaders an important role in informing group members of how to behave, what the priorities are and what behaviour gets rewarded. Organisations with lower accident rates are characterised by the presence of upper managers who are personally involved in safety activities (Mearns et al, 2003). According to Human

Engineering (2005) senior management commitment is demonstrated by providing sufficient:

- health and safety budget;
- opportunities for safety communication;
- health and safety training;
- support to personnel;
- manpower (including health and safety specialists).

3.4.3 *Climate and culture tools*

Whereas identifying barrier failures might be one way to measure the performance of the technical system, climate tools are one way to measure the human part of the system. Mearns et al (2003) suggest that examination of safety management practices should be considered an adjunct to the assessment of safety climate within an organisation. The authors say that ideal practices, looking at aspects relating to reduced occupational accidents and successful safety initiatives, appear to be the following:

- genuine and consistent management commitment to safety;
- communication about safety issues;
- involvement of employees.

Climate is a psychological factor concerning individual perceptions. Safety climate is a term originally coined by Zohar in 1980 (Zohar, 2010). Reviewing the research he reports correlations between climate measurement and injury rates (mean correlation of -0.38) and in that respect, given a large number of independent samples, he considers it demonstrates the predictive validity of safety climate as a leading safety indicator. Vinnem et al (2010) found that safety climates measured by a questionnaire for offshore installations explained up to one fifth of hydrocarbon leak variation.

There are a large number of safety climate tools that have been developed in the past 20 years (Human Engineering, 2005; Mearns et al, 2003). It is not the intention to review these tools again. Recurring themes across safety climate tools include:

- management commitment;
- supervisor competence;
- priority of safety over production;
- time pressure.

As an example, the Health and Safety Laboratory (2011) in the UK has developed a safety climate tool which is a valid psychometric instrument (Sugden et al, 2009). The survey comprises of 40 statements which map onto one of eight factors:

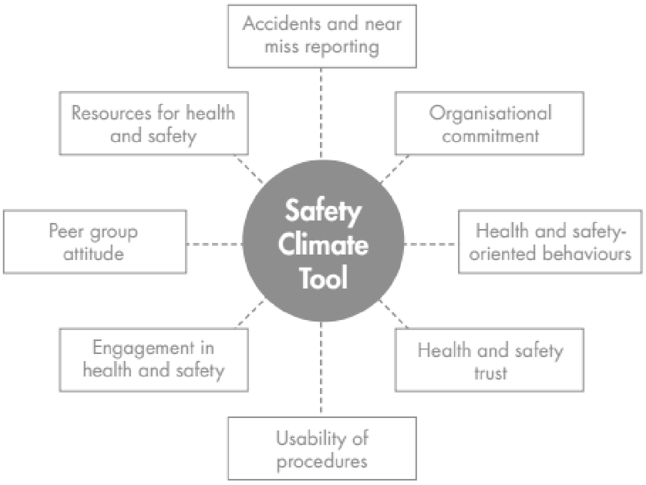


Figure 14 HSL's climate tool factors (HSL 2011)

An attempt had been made to refine the climate tool for the high hazard process industry (Butler, Lekka and Sugden, 2010). By looking at a number of information sources - previous process safety related serious accidents worldwide, a wide trawl of other tools including audit methods, and performance of high reliability organisations - the following areas were considered for development of questions, ending in a set of 60 question statements:

- Training and Competence;
- Communication;
- Maintenance of equipment;
- Procedures;
- Management commitment;
- Contractors;
- Process Alarm Management;
- Reporting and Investigating;
- Permit to Work System;
- Management of Change.

The tool was administered at four multinational (chemical, pharmaceutical, oil and gas) companies. The results were later supplemented with data from two additional companies. Sugden (2011, personal communication) says that this work led to the conclusion that the process safety questionnaire was currently not good at distinguishing between companies. The perception that the companies with whom the tool was piloted contained poor performers was not reflected in the results. The results were suggesting all the companies had a good safety climate, for example in maintenance which is a well-known problematic area for major hazards. Face validity was therefore poor.

Lardner et al (2011) used a safety culture approach derived from the scientific literature and which focuses on Standards, Communication, Risk Management and Involvement as the crucial themes. The themes are linked via three occupational groups – Managers, Supervisors and Everyone. Positive and negative safety behaviours within each theme for each group were identified. Various validity tests were carried out. Strong correlations with process safety performance data (technical integrity incidents) were found. This was as high as -0.73 for supervisor behaviours.

3.4.4 *Safety improvement programmes*

In 1986 Shell E&P embarked on its 'Hearts and Minds' programme of improving its understanding of human behaviour and its role in safety (Hudson et al, 2000). The programme, which is still active today, involved psychologists from the Universities of Leiden, Manchester, and Aberdeen. The tools developed include Tripod (Groeneweg, 1996) and Shell's Safety Culture Ladder as shown in Figure 15. The Hearts and Minds toolkit is currently offered by the Energy Institute (2011) and Tripod Delta from Advisafe (2011).

In the model companies higher on the ladder are considered to be safer.

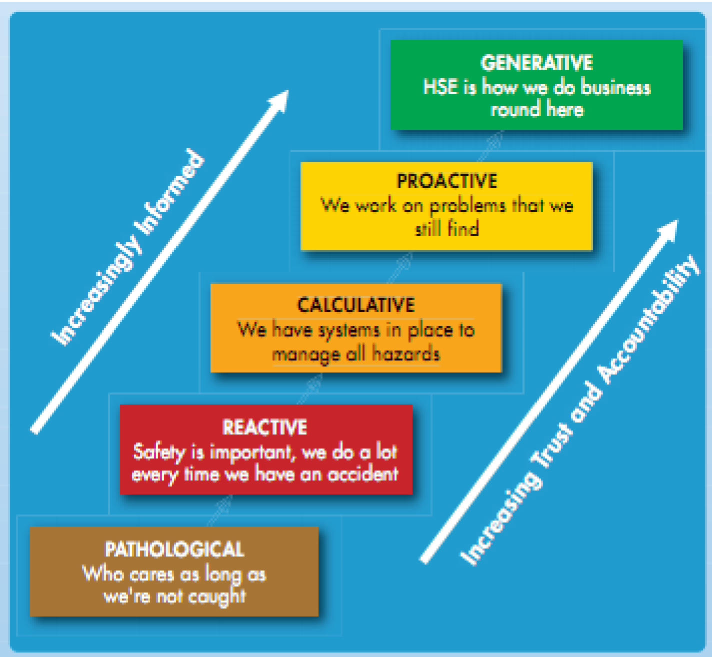


Figure 15 Shell's safety culture ladder (Energy Institute 2011)

In the Netherlands the TRIPOD system is an often quoted tool. The basic risk factors (BRFs) from Tripod are as follows, not unlike the Management delivery systems and tasks of the RIVM (2008) model described in section 2.3.4:

Ten prevention BRFs

- Design (DE): ergonomically poor design of tools or equipment;
- Hardware (HW): poor quality, condition, suitability or availability of materials, tools and equipment;
- Maintenance (MM): no or inadequate performance of maintenance tasks and repairs, bad planning;
- Housekeeping (HK): no or insufficient attention given to keeping the work floor clean and tidied up;
- Error Enforcing Conditions (EC): unsuitable physical conditions (cold, heat, noise, darkness, etc.) or personal factors (motivation, boredom, stress, complacency, etc.) influencing human functioning;

- Procedures (PR): insufficient quality or availability of procedures, manuals and written instructions;
- Training (TR): inadequate planning, ineffectiveness of trainings, insufficient competence or experience of personnel;
- Communication (CO): ineffective communication between sites, departments, individuals;
- Incompatible Goals (IG): unsuitable situations in which people must choose between optimal working methods on one hand and the pursuit of production, financial, social or individual goals on the other;
- Organization (OR): shortcomings in the organizational structure, organization's philosophy and management strategies.

One mitigation BRF

- Defences (DF): insufficient protection of people, material and environment against the consequences of operational disturbance.

Cambon et al (2006) consider that these factors could be combined with a basic SMS model such as OSHAS 18001.

Also in The Netherlands, a programme of improving worker safety was undertaken by the Ministry of Social Affairs and Employment. Companies that took part in that study focused on improving behaviour. There were 17 companies of which five were successful in significantly reducing accidents over a three-year period. Analysis of the results were undertaken by Hale and Guldenmund (2008). The successful companies showed a combination of a drop in frequency/seriousness of accidents and an increase in the number of reported dangerous situations. Where direct measurement of behaviour was done this also improved. What the successful companies also did was to start, and keep going, the driver for improvement with a motivated coordinator and the support of the directors. Methods were introduced on the work floor to get regular communication with supervisors and thereafter with the line and staff function about safe work methods and work place and any deviations from wishes and agreements. Using multiple interventions, continuous improvement is the focus, and everyone gets training in what it is all about. Performance indicators are also important, plus an overall focus on safety, including procedure improvement, which gets the workforce involved too, and workplace improvement. The authors remark that physical improvements to the work situation are also important, otherwise lasting effects of behaviour change will not be achieved.

From the improvement programmes initiated and studied by the project team, the following important ten tips for improving worker safety on the work floor were identified (Ministry SZW, no date). These are described more fully in Annex 4.

1. Involvement of management is essential.

2. Management standards are employee standards.

3. Find the resistance and eradicate it.

4. Influence safe behaviour.

5. Reward good behaviour.

6. Have employees think for themselves.

7. Resolve safety problems operationally.

8. Learn from each other.

9. Make results transparent.

10. Embed the safety culture in the structure.

Although these results come from studying occupational safety, the general principles, as a set of values, could be seen as just as applicable to process safety in areas requiring behavioural adjustment.

4 Guidance on developing SPIs

4.1 Available guidance

The following guidance was examined:

- American Petroleum Institute (2010) Process Safety Performance Indicators for the Refining and Petrochemical Industries ANSI/API 754;
- Chemical Business Association (CBA and UKWA, 2009) Safety Performance Leading Indicators Guidance for the Chemical Warehouse Sector;
- CEFIC (2011) Responsible care performance reporting;
- Centre for Chemical Process Safety - CCPS (2008, revised 2011). Process safety leading and lagging metrics;
- Centre for Chemical Process Safety - CCPS (2010) Guidelines for Process Safety Metrics;
- Deltalinqs University (2010) DU Toolbox, including key performance indicators;
- Energy Institute (2005) A framework for the use of key performance indicators of major hazards in petroleum refining;
- Energy Institute (2010) Human factors performance indicators for the energy and related process industries;
- EPSC (1996) Safety performance measurement;
- HSE (2006) Developing process safety indicators. A step by step guide for chemical and major hazard industries HSG 254;
- OECD (2008, 2011). Guidance on developing safety performance indicators related to chemical accident prevention, preparedness and response for industry;
- Plastics and Chemicals Industries Association PACIA (2008) Guidance - Process Safety – Developing Key Performance Indicators December 2008.

Short descriptions are available of a sample of these in Annex 2.

4.2 Types of metrics

Indicators of safety are proxies for measures of the effectiveness of risk controls and which are judged to have a relationship with risk based on incident analysis or expert judgement. Ale (2009) says that '…once the entities to be observed have been derived from an analysis of the causal chain, these entities have to be conscientiously observed and monitored, for ever.'

In the guidance, metrics are leading (before the loss of control event) or lagging (unwanted consequence). Leading indicators are primarily related to safety management and risk control systems and whether they are being implemented. Lagging are more related to consequences and severity.

Lagging indicators might include:

- near misses;
- incidents;
- injury types;
- spill quantities;
- causal analyses/statistics;
- low consequence events.

Leading indicators might include:

- reporting ratio of reported deviations (e.g. near misses) to loss events;
- assessments, observations, audits and inspections;
- planned/action items carried out;
- culture questionnaire results.

Stough (2011) made a review of leading indicator research findings amongst a large industry data set in over 100 countries and involving industry leaders such as ExxonMobil, Shell, Total and others for all kinds of unwanted outcome events. Apparently the most effective and accurate leading KPIs are associated with reporting and action items. Over a million data records were accumulated (but not exclusively process safety), of different loss, failure, damage and quality events and with data on assessments and deviations. When subjected to statistical analysis relationships were found which suggested the use of the following leading indicators by top safety performers:

Culture of voluntary event reporting and fixing:

- near miss reporting rate;
- % of all events with actions.

Rate of actions with timely execution

- % of all events with on-time completion;
- all events action initiation rate.

Responsive disciplined leadership (includes supervisors)

- average days to respond to near misses;
- average days to authorise first incident action.

4.3 Nature of guidance

There are many sources of guidance available, most of which centre around the concepts of leading and lagging indicators and although this has given rise to various discussions about where leading ends and lagging begins - a special edition of Safety Science was dedicated to this discussion (Hopkins and Hale, 2009) - most guidance adopts the same general approach.

Some general points about guidance are

- They are primarily for companies, but other parties may also be considered (e.g. OECD 2008).
- Indicators are primarily data driven (bottom-up).
- They all deal with either leading and lagging indicators or just lagging indicators, often adopting the Heinrich triangle concept.

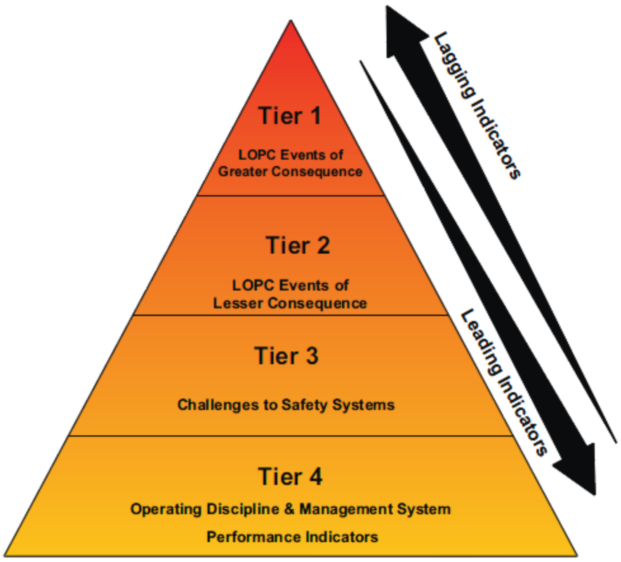


Figure 16 Leading and lagging indicators from ANSI/API ANSI/API Recommended practice 754 (API 2010)

- Most of the guidance documents have no model, unless it is the Swiss cheese.

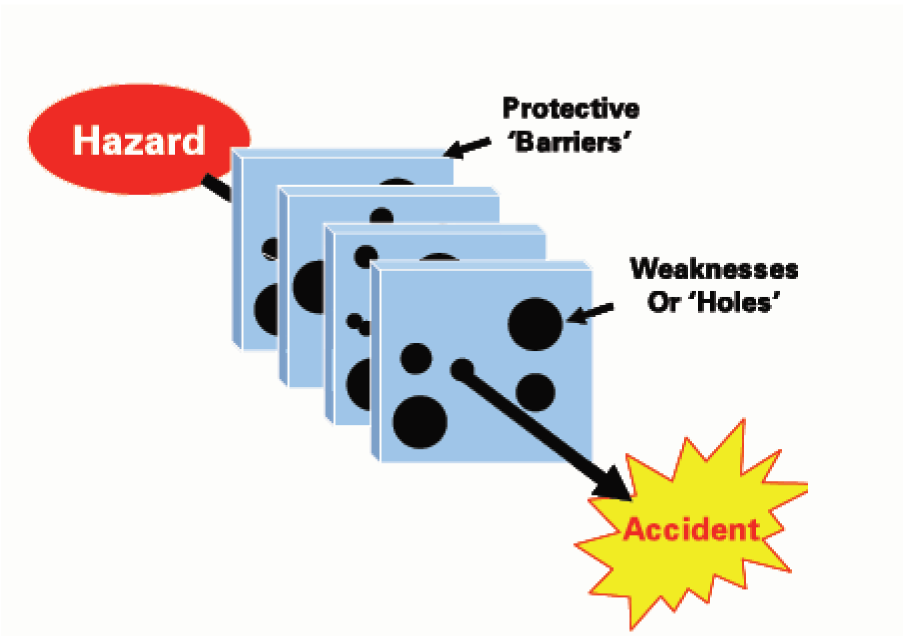


Figure 17 Swiss cheese model as represented in the CCPS guidance (CCPS 2011)

- The guidance documents are primarily thought-up indicators by a particular industry sector or regulator, identifying where indicators should be developed.
- Typical of guidance is to specify both input and output measures of the management process like a percentage relating to how well the activity

itself is performed and one which looks at deviations found in the results of the activity. E.g. % checks performed to schedule and % checks where defects are found (CBA and UKWA 2009, CCPS 2008). The HSE (2006) guidance is different in that it proposes (in its examples) primarily positive input indicators and primarily negative output indicators, which it calls leading and lagging respectively. One can understand the logic of this approach because it provides information on the success or otherwise of the inputs (% good) and whether they do actually achieve the good safety outputs (% bad). CCPS pairs of indicators look similar. This can be called the dual assurance approach.

- Most guidance documents include leading indicators as well as lagging and are based around safety management components or risk control systems. Table 1 gives an example from the set of indicators from Deltalinqs University (2010).

Table 1 KPIs for Safety Management Procedure (SMP) 7 'Procedures for Maintenance and Operations' from the Deltalinqs University (2010) method 7.1 is a lagging indicator.

Key performance indicator	**Explanation**
7.1 Number of SHE incidents with a root cause in Procedures	Information is acquired from incident investigation methods such as TRIPOD and other systems that identify root causes. It concerns the more serious incidents and near misses with a high potential for serious consequences.
7.2 Percentage of actual checked and updated procedures in relation to planning	Measurement includes all procedures that are part of a controlled document system. Checked and updated means also that procedures are again communicated and/or trained.
7.3 Consistent use of procedures: - Number of times procedures not followed and the causes - Perform a Pareto analysis of causes on a yearly basis	Measurement concerns the consistent use of SHE critical procedures (amongst other things the ticking off of procedural steps). Measurement of procedures can also be coupled to safety inspections and observation rounds.

- The Energy Institute (2005) is an exception to the pattern. The link to the management or risk control systems is not systematically defined. This guidance is mainly about the results of incident analysis and has checklists which include a lot of equipment checks.
- All put much more emphasis on what is measured than when and what is followed-up.
- The concept of performance targets (measureable goals) and tolerances (limits for what can and cannot be accepted) for SPIs is generally included.
- There is a move towards benchmarking indicators in some areas (e.g. CCPS, CEFIC) and tailor-made indicators in others (e.g. OECD, HSE, Deltalinqs). Sugden et al (2007) point out that, from the experience in the nuclear industry and offshore industry, intra-industry diversity means that companies have to develop their own indicators – 'a fixed suite of indicators was out of the question'.

5 Evidence of use of leading safety performance indicators

BP on their website www.bp.com claim that their US refineries adopted a common set of leading and lagging process safety indicators that are reported monthly to line management and quarterly to executive management and the board.

'To track our progress in process safety management, we measure lagging indicators that record events that have already occurred, such as oil spills, and leading indicators that focus on the strength of our controls to prevent undesired incidents, such as inspections and tests of safety-critical equipment. A suite of lagging and leading indicators is reported quarterly to the group operations risk committee within the HSE and Operations Integrity Report. We have been working with bodies such as the Center for Chemical Process Safety, the American Petroleum Institute (API) and American National Standards Institute (ANSI) for several years on the development of process safety metrics, definitions and guidance for the downstream part of our business. Additionally, since 2009 we have been collaborating with our industry peers through the International Association of Oil and Gas Producers to adapt this work for the upstream.'

Broadribb et al (2009) report on the use of the new metrics in BP, including the following leading metrics with the adoption of CCPS and API lagging metrics. The approach includes identification of important 'barriers'. The five key barriers identified were:

- equipment overpressure;
- equipment overfill;
- accidental leakage;
- corrosion;
- management of change.

They collect deviation events e.g. as a lagging indicator, the number of high pressure alarms is recognised and as a leading indicator, the number of pressure and level control loops operating outside their normal configuration e.g. the loop is in manual rather than auto, and other situations where the distributed control system is less effective and will not quickly return the process to within its operating envelope. Using such indicators it was discovered, for example, that more alarms were occurring than expected.

Table 2 BP leading process safety metrics (from Broadribb, 2009)

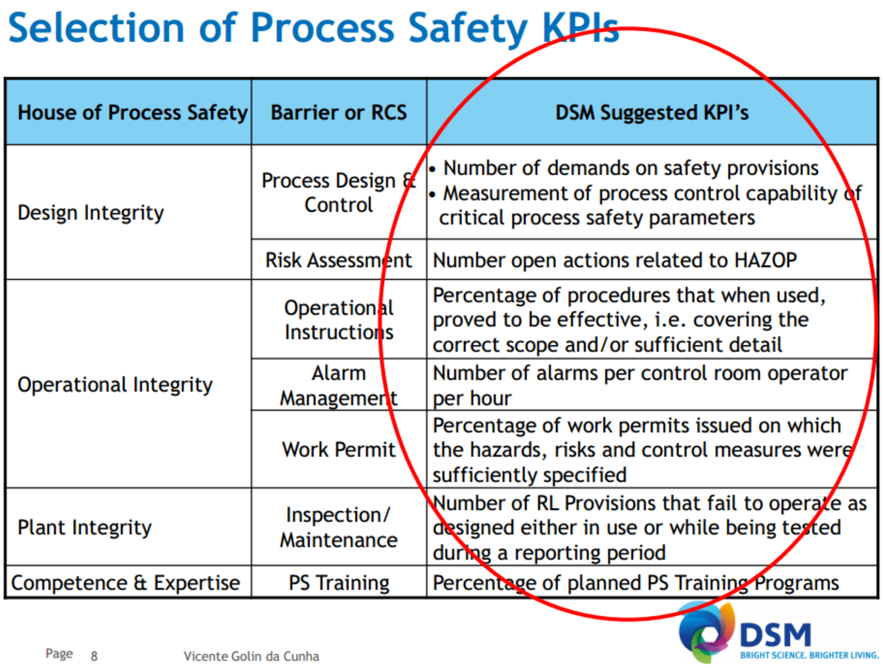
Quarterly Metric	Brief Description
Process HiPo's (2 Levels)	Number of High Potential near-misses that could have resulted in an MIA and were process safety related
MIA & HiPo Lessons Learned Reports Issued	Number of MIA and HiPo investigations completed with lessons learned shared, including number completed within target period of 30 days
Overdue Plant Inspections & Tests	Number & percentage of scheduled safety critical inspections and tests completed / overdue
MAR Assessments Completed	Number & percentage of planned Major Accident Risk Assessments completed and authorized
MAR Action Closures	Percentage progress on closure of actions from Major Accident Risk Assessments
ISO 14001 certification of major sites / operations	Number & percentage of major operations (e.g. refineries) with ISO 14001 certification complete and up-to-date
Safety & Operations Audit Actions	Numbers of actions open, overdue and delinquent from independent corporate audits of management systems including process safety
Number of Approved Audit Action Changes	Number of approved changes to action deadlines from the independent corporate audits of management systems including process safety
Incident Investigation - Action Closure	Tracks change in percentage of actions resulting from MIA or HiPo incident investigations closed on time within the past 4 quarters
Elimination of HTALHC Blow-down stacks	Tracks commitment to take all heavier than air, light hydrocarbon blow-down stacks out of service (i.e. type involved in the Texas City explosion)
Elimination of Occupied Portable Buildings in Red Zones	Tracks commitment to prevent use of portable buildings to accommodate workers within high risk areas within or close to process unit
Implementation of BP standards	Tracks aggregated progress of sites to implement strengthened mandatory BP operating practices, including Integrity Management, Control of Work and Regulatory Compliance
Leadership competence	Ensures that assessment of BP operational management has been assessed at a general level in terms of experience and knowledge

Webb (2009) believes, from experience of a process SPI system piloted at a Basell site, Carrington UK, that good metrics should have the following characteristics:

- Support continual improvement.
- Drive appropriate behaviour.
- Emphasise achievements rather than failures.
- Be precise and accurate.
- Be difficult to manipulate.
- Be owned and accepted by the people involved in related work activities and those using the metrics.
- Be easily understood.
- Be cost-effective in terms of data collection.

The system started from using company lagging indicators (releases, unplanned shutdowns, operation of safety related protection systems) and then built up leading indicators based on brainstorming weaknesses in risk control systems.

Recently a conference on performance indicators was held where industry described leading and lagging indicator systems in use (CEFIC-EPSC, 2012). Examples of practice show that the selection of indicators is small in number.



Selection of Process Safety KPIs

House of Process Safety	Barrier or RCS	DSM Suggested KPI's
Design Integrity	Process Design & Control	• Number of demands on safety provisions • Measurement of process control capability of critical process safety parameters
	Risk Assessment	Number open actions related to HAZOP
Operational Integrity	Operational Instructions	Percentage of procedures that when used, proved to be effective, i.e. covering the correct scope and/or sufficient detail
	Alarm Management	Number of alarms per control room operator per hour
	Work Permit	Percentage of work permits issued on which the hazards, risks and control measures were sufficiently specified
Plant Integrity	Inspection/ Maintenance	Number of RL Provisions that fail to operate as designed either in use or while being tested during a reporting period
Competence & Expertise	PS Training	Percentage of planned PS Training Programs

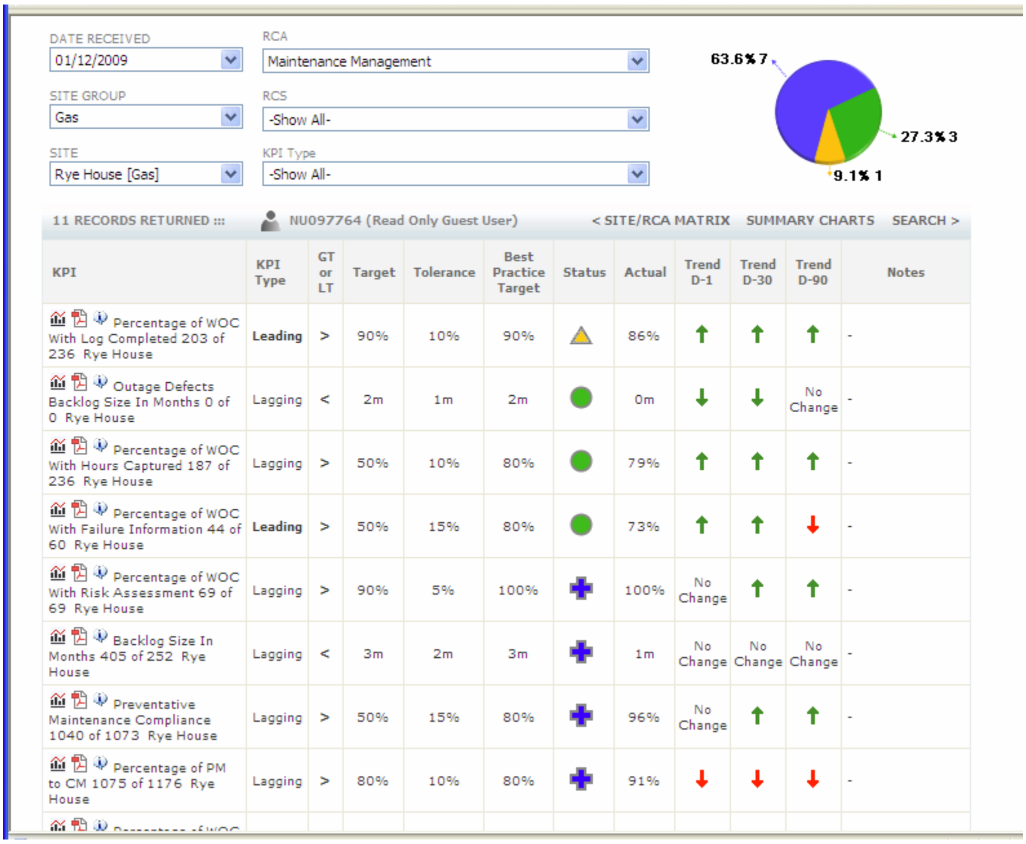
Figure 18 Example of a KPI process safety system limiting KPI to a few factors This is reflecting the current trend in chemical process safety (da Cunha, 2012)

An exception is the Scottish Power approach. Judith Hackett (2011), Chair of the HSE, has highly recommended the work of Scottish Power. Enhanced plant reliability based on the development of performance indicators following the HSE method has led to a reduction in unplanned outages and breakdowns, and a drive to less reactive maintenance has significant cost savings.

'*The system tracks the status and drives improvements just because everyone can see the data,*' according to the programme manager (HSE, 2010), and '*Although we use the same KPIs across the business we set differing targets to reflect the variation in the different age and technology profiles of our sites; this approach makes sure that each site is driving towards realistic performance targets,'* according to the Generation Director.

The system uses handheld data loggers to record performance. Sample screens are shown in Sedgwick and Stewart (2010).

The system is driving down process safety incidents and costs with an increase in plant availability.



KPI	KPI Type	GT or LT	Target	Tolerance	Best Practice Target	Status	Actual	Trend D-1	Trend D-30	Trend D-90	Notes
Percentage of WOC With Log Completed 203 of 236 Rye House	Leading	>	90%	10%	90%		86%				-
Outage Defects Backlog Size In Months 0 of 0 Rye House	Lagging	<	2m	1m	2m		0m			No Change	-
Percentage of WOC With Hours Captured 187 of 236 Rye House	Lagging	>	50%	10%	80%		79%				-
Percentage of WOC With Failure Information 44 of 60 Rye House	Leading	>	50%	15%	80%		73%				-
Percentage of WOC With Risk Assessment 69 of 69 Rye House	Lagging	>	90%	5%	100%		100%	No Change			-
Backlog Size In Months 405 of 252 Rye House	Lagging	<	3m	2m	3m		1m	No Change	No Change	No Change	-
Preventative Maintenance Compliance 1040 of 1073 Rye House	Lagging	>	50%	15%	80%		96%	No Change			-
Percentage of PM to CM 1075 of 1176 Rye House	Lagging	>	80%	10%	80%		91%				-

Figure 19 Example of a KPI Process Safety dashboard of Scottish Power (Sedgwick and Stewart 2010)

Figure 20 Donut charts for reporting leading and lagging indicators (Sedgwick and Stewart 2010)

6 Conclusions

The following are key points emerging for the review:

a. The primary purpose of safety performance indicators is to improve the risk control and safety assurances of a plant rather than for benchmarking purposes.

b. Benchmarking is most likely with a small number of lagging indicators. A tailor-made site-specific set of indicators may use significantly more indicators for status and trending purposes and which may not be suitable for benchmarking because of site specific variability.

c. The idea that smaller incidents predict bigger incidents is both accepted and questioned as a model underpinning performance indicators. The main objectors challenge approaches using linear causal relations or question whether near misses or smaller leak events have the same causes as the big events. The numerical frequency issue is quite important because of relative causes affecting what is focused on at the precursor level. The argument against is that attention may be taken off rarer potentially more catastrophic events. The argument for is that it provides an opportunity to look at underlying weaknesses in safety management practices.

d. Understanding relationships and interactions between different parts of the socio-technical system are important, as well as the relationship with risk (usually the starting point in indicator development). This understanding includes the effect of changes in management input to a process and how that affects the output in terms of the effect on the technical system.

e. A sufficient number of indications are required to be able to measure performance over time (trends), particularly on a yearly basis, but also to give a current snapshot or helicopter view.

f. The safe boundary is specified as tolerances or targets, the tolerances that can be accepted both at the management level, such as actions not closed out and in operating close to the edge of the design envelope such as measured by high alarm frequencies.

g. Findings must be actionable. At best it should be easy to determine what actions are required in relation to the behaviour of the performance indicator.

h. The whole safety performance indicator (SPI) system has to be structured in the organisation and embedded in the culture of the company/site.

i. Evaluating a SPI system will depend on the system having a desired set of characteristics which should include the 20 aspects below.

As a result of the current review, 20 aspects are considered important, but not necessarily complete, for system design and operation of a safety performance indicator system:

1. a link (usually causal) to the major hazard (process) risks, with appropriate coverage and priorities in the (safety) management system;

2. sufficient in number and frequency to be able to identify trends (e.g. quarterly, yearly, three-yearly), including any 'Rasmussen drift' effects towards boundaries of safe operation to allow appropriate recovery in time;
3. tailor-made for the company/site;
4. metrics distinguish between good and bad in the population distribution (this also facilitates benchmarking);
5. consideration of published guidance (HSE, CCPS, OECD, API, Deltalinqs, CEFIC etc.);
6. quantitative measureable indicators associated with defined objectives;
7. precursor (prior to loss/harm) indicators of sufficient scope and sensitivity to give sufficient and timely 'warning' of deviations from safe standards of design and operation;
8. precursor indicators on management system inputs to major hazard risk which control processes and indicators on related outputs of these processes;
9. evaluation of management inputs, outputs and incidents for relationships, interactions, causes and major hazard risk potential;
10. specification of indicator tolerances with justification in safe boundaries of operation and associated with action levels;
11. specification of indicator targets, especially in relation to the objectives of the major accident prevention policy;
12. a selection of KPIs for reporting to the top management;
13. indicators which are actionable, in that there is a connection between the indicator and the actions which should affect it;
14. a reporting culture involving the whole workforce who have responsibilities in the control of major hazards;
15. workforce involvement in indicator development and reporting programmes;
16. a leadership which maintains the reporting culture and which ensures actions are carried out in time;
17. a leadership which positively influences safety culture through interactions with the workforce, safety improvement (programmes), and measuring the effect on safety attitudes and awareness;
18. consideration given to using metrics that could be sensitive to changes in the external system climate (such as economic pressures, takeovers, new knowledge) and their impact on safety at the plant;
19. indicator review and improvement at least on a yearly basis;
20. use of indicators also by external bodies about their own performance, particularly emergency response organisations. This point has not really been elaborated in the review, but it suffices to say that if they are part of the socio-technical safety system affecting plant then perhaps emergency responders should also be part of the measurement system.

j. With regards to the development of indicators by the regulator, a further ten points are considered:

21. Leading KPIs should give signals for concern about future safety.
22. Lagging KPI's should show past performance.
23. KPIs should identify degradation in safety performance as early as possible.
24. KPIs should be designed according to the way they are to be used by the regulator.
25. Consideration should be given as to whether indicators can be used standalone.
26. Aligning action levels with KPI measurement should be possible.
27. KPIs should be clearly defined and unambiguous to ensure accurate communications with stakeholders.
28. KPIs should not be capable of being manipulated.
29. Learning from the use of indicators may require changes in the set of KPIs used or associated action levels over time.
30. Standardisation, e.g. based on number of hours worked, could facilitate comparisons between companies.

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ANNEX 1: Safety management system requirements of the Seveso II Directive

Annex III of the Seveso II Directive (European Council Directive, 1996) states: For the purpose of implementing the operator's major-accident prevention policy and safety management system account shall be taken of the following elements. The requirements laid down in the document referred to in Article 7 should be proportionate to the major-accident hazards presented by the establishment:

(a) The major accident prevention policy should be established in writing and should include the operator's overall aims and principles of action with respect to the control of major-accident hazards.

(b) The safety management system should include the part of the general management system which includes the organizational structure, responsibilities, practices, procedures, processes and resources for determining and implementing the major-accident prevention policy.

c) The following issues shall be addressed by the safety management system:

(i) organisation and personnel — the roles and responsibilities of personnel involved in the management of major hazards at all levels in the organisation. The identification of training needs of such personnel and the provision of the training so identified. The involvement of employees and of subcontracted personnel working in the establishment;

(ii) identification and evaluation of major hazards — adoption and implementation of procedures for systematically identifying major hazards arising from normal and abnormal operation and the assessment of their likelihood and severity;

(iii) operational control — adoption and implementation of procedures and instructions for safe operation, including maintenance, of plant, processes, equipment and temporary stoppages;

(iv) management of change — adoption and implementation of procedures for planning modifications to, or the design of new installations, processes or storage facilities;

(v) planning for emergencies — adoption and implementation of procedures to identify foreseeable emergencies by systematic analysis, to prepare, test and review emergency plans to respond to such emergencies and to provide specific training for the staff concerned. Such training shall be given to all personnel working in the establishment, including relevant subcontracted personnel;

(vi) monitoring performance — adoption and implementation of procedures for the ongoing assessment of compliance with the objectives set by the operator's major-accident prevention policy and safety management system, and the mechanisms for investigation and taking corrective action in case of non-compliance. The procedures should cover the operator's system for reporting major accidents of near misses, particularly those involving failure of protective measures, and their investigation and follow-up on the basis of lessons learnt;

(vii) audit and review — adoption and implementation of procedures for periodic systematic assessment of the major-accident prevention policy and the effectiveness and suitability of the safety management system; the documented review of performance of the policy and safety management system and its updating by senior management.

ANNEX 2: Guidance for developing safety performance indicators

European Process Safety Centre
In the book *Safety Performance Measurement* of the European Process Safety Centre (1996) it is reported that:

'There need to be indicators which give assurance that the absence or reduction of harm or loss is due to a systematic management approach which is aimed at preventing the occurrence of incidents. This contrasts with the reactive management approach, which initiates actions and programmes after undesired events'. p. 3.

Four areas of safety management input were identified:

- plant and equipment, emphasising technical inspections, technical standards, good practice, hazard and risk assessment, condition monitoring, audit to assess deviations in practice from standards and procedures;
- systems and procedures, emphasising operational integrity, compliance audits for measuring the performance of the management system, self-assessment and external assessment, stage of development of SMS, effectiveness of SMS measured against objectives;
- people, emphasising behaviour, behaviour observation, feedback and verification, leadership and commitment, reinforcing policies and goals, involvement, safety culture measurement, interviews, audit, failure profiles;
- output measures, emphasising overall performance measurement, trends, reactive indicators like spills and losses.
-

More recently the European Process Safety Centre developed a guidance leaflet (EPSC, 2012) which was provided at the International Conference on Process Safety Performance Indicators (CEFIC-EPSC, 2012). Some key points of the leaflet are

- Do not try to measure everything.
- Aim for a blend of indicators.
- Express leading indicators positively (100% is desired).
- Legal compliance indicators are not recommended.
- Number of employees and contractor hours can be used as a scaling factor in a reporting period as a normalisation factor.
- Leading indicators originate at plant level where the hazards are.
- Allow time for sustainable improvement actions.
- Engage staff rather than buy commitment through bonus schemes.

CEFIC
The short CEFIC (2011) guidance provides benchmarking indicators for across the industry and are lagging indicators only. Leading indicators are excluded as these are considered to be site specific. Lagging indicators are defined by release thresholds depending on substance and within a specific time period. The number of process safety incidents per one million working hours 'as a first step' is the proposed performance metric. This is presumably to make normalisation easy. A process safety incident directly involves a chemical substance process and results in:

- injury resulting in a Fatality, Hospitalization (>24h) or lost workday of any people on or off site;
- release of energy (e.g. fire, explosion) that causes a damage with direct costs of > € 25,000;
- release of chemical substances due to Loss of Primary Containment (LoPC) above certain thresholds;
- shelter in place (e.g. media release evacuation).

The following Loss of Primary Containment (LoPC) thresholds are suggested:

LoPC > 5 kg:
- Cat 1 + 2 Acute Toxicity;
- Cat 1 Long Term Health Effects: Carcinogenicity (H350), Reproductive toxicity, Germ cell mutagenicity (H340);
- Specific Target Organic Toxicity (STOT) after single exposure and related to H370, category 1.

LoPC > 100 kg:
- all other Global Harmonised System (GHS) classified substances.

LoPC > 2000 kg:
- all other not GHS classified substances (recommended for internal reporting).

Deltalinqs University

The DU Toolbox is provided by Deltalinqs University (2011). The University functions to promote safety amongst member companies in the Rotterdam area. A safety management system comprising 17 safety management procedures (SMPs) is described, based on best practices amongst Seveso and the larger member companies. The key performance indicators (KPIs) are based around these 17 areas, supplying leading and lagging indicators:

1) leadership, commitment and responsibilities of management;
2) risk evaluation and assessment;
3) design and construction of installations;
4) SHE information and documentation;
5) safety and health of personnel;
6) training;
7) procedures for design and operations;
8) work permits;
9) maintenance management;
10) maintenance and management of SHE critical systems;
11) prevention of releases;
12) comply with laws and regulation;
13) management of change;
14) working with third parties (contractors);
15) reporting of incidents, analysis and follow-up;
16) emergency preparedness;
17) management of communication with the public and the regulator.

For each area (SMP) the lagging indicators are the number of incidents and near misses which have an underlying cause in the area and the leading indicators suggest that the metric looks at such as deviations from yearly planning, unavailability of critical equipment, carried out inspections, tests, training, checked and adapted procedures, procedures not followed, out of date, open corrective actions etc. Around three indicator types per areas are given, with an explanation of each. An example for SMP7 Procedures for Maintenance and Operations is given below:

Table 3 KPIs for Safety Management Procedure (SMP) 7 'Procedures for Maintenance and Operations' from the Deltalings University (2011) method

Key performance indicator	Explanation
7.1 Number of SHE incidents with a root cause in procedures	Information is acquired from incident investigation methods such as TRIPOD and other systems that identify root causes. It concerns the more serious incidents and near misses with a high potential for serious consequences.
7.2 Percentage of actual checked and updated procedures in relation to planning	Measurement includes all procedures that are part of a controlled document system. Checked and updated means also that procedures are again communicated and/or trained.
7.3 Consistent use of procedures: - Number of times procedures not followed and the causes - Perform a Pareto analysis of causes on a yearly basis	Measurement concerns the consistent use of SHE critical procedures (amongst other things the ticking off of procedural steps). Measurement of procedures can also be coupled to safety inspections and observation rounds.

The toolbox does not address follow-up to performance reporting or what constitutes an incident in the first place. Incidents are defined as events leading to unwanted SHE events or near misses of such events. The user has freedom to define their own KPI metrics with respect to the recommended measures. It is the task of leadership to ensure that the KPIs are developed and used.

Health and Safety Executive

HSE uses SPIs to mean a small number of selected site specific indicators for monitoring the performance of key risk controls. The HSE (2006) guide was produced jointly with the Chemical Industries Association. It works on the principle of 'dual assurance' that key risk control systems are operating as intended. These are the so-called leading and lagging indicators. For each risk control system:

- The leading indicator identifies failings or 'holes' in vital aspects of the risk control system discovered during routine checks on the operation of a critical activity within the risk control system.
- The lagging indicator reveals failings or 'holes' in that barrier discovered following an incident or adverse event. The incident does not necessarily have to result in injury or environmental damage and can be a near miss, precursor event or undesired outcome attributable to a failing in that risk control system.
- The 'holes' concept is derived from the famous defence-in-depth Swiss cheese model of Reason (1997) and is used as a basis for lining up risk control systems associated with particular risks.

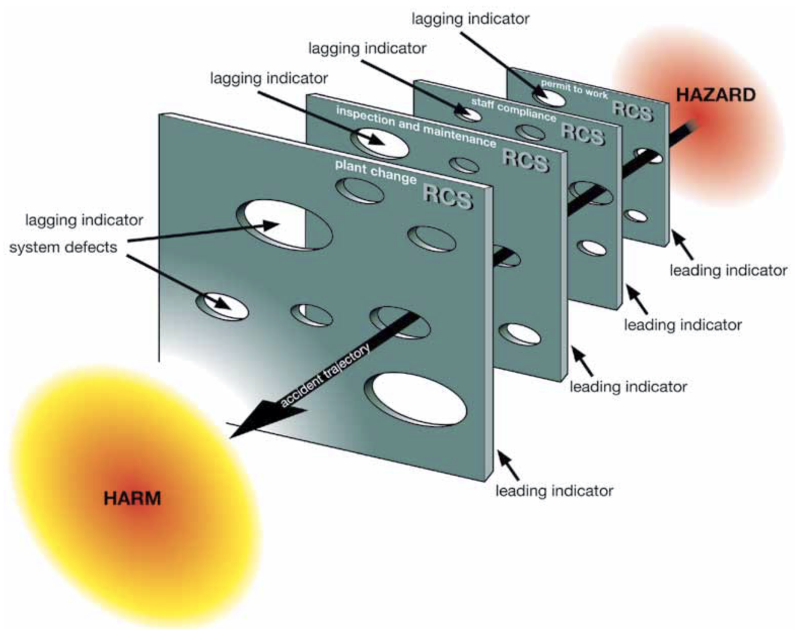

Figure 21 Leading and lagging indicators within the 'Swiss cheese' concept (from HSE 2006)

Like OECD guidance, the tolerance metric is used.

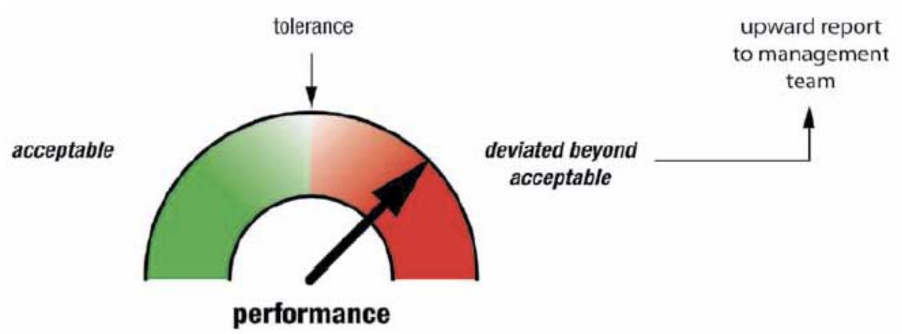

Figure 22 Tolerance Metric (HSE, 2006)

The approach is specified in steps:

Step 1: Establish the organisational arrangements to implement the indicators.
Step 2: Decide on the scope of the measurement system. Consider what can go wrong and where.
Step 3: Identify the risk control systems in place to prevent major accidents. Decide on the outcomes for each and set a lagging indicator.
Step 4: Identify the critical elements of each risk control system, (i.e. those actions or processes which must function correctly to deliver the outcomes) and set leading indicators.
Step 5: Establish the data collection and reporting system.

Step 6: Review.

The indicators are measures of routine safety related activities or measures of failures and are regarded as safety management inputs (leading) or outputs (lagging).

The model is criticised by Hopkins (2009) as inconsistent in its definitions. He criticises the distinction between leading and lagging. 'The relevant issue is not whether the indicator is current or after the fact. The issue is whether, in the relevant time period, there are sufficient instances of the events being counted to be able to talk meaningfully about a rate.' He suggests that the most important point to emerge from the HSE guidance is the need to choose indicators to measure the effectiveness of the controls upon which the risk control system relies.

OECD
OECD (2008) guidance on SPIs was developed by the working group on chemical accidents to help enterprises understand whether risks of chemical accidents are being appropriately managed. HSG 254 (HSE, 2006) was influential in this process.

It is a complement to the OECD (2003) guiding principles. The guidance focuses on the process of establishing an SPI programme rather than specifying the indicators themselves, believing that indicators should be tailor-made for the enterprise. It provides a menu of outcome indicators and activities indicators to help enterprises choose and/or create indicators that are appropriate in light of their specific situation.

'In choosing indicators, enterprises should identify those that could provide the insights needed to understand where they should take action to avoid potential causes of accidents. Therefore, in deciding on priority issues, enterprises should consider an assessment of their risks as well as historical data showing where there have been problems or concerns in the past. They should also take into account other information or suspicions that might suggest a potential problem, for example, experience at similar hazardous installations. In establishing priorities, enterprises should also consider the resources and information available, the corporate safety culture and the local culture.' p. 9.

A metric is defined as a system of measurement used to quantify safety performance for outcome and/or activities indicators.

- Outcome indicators measure whether safety related actions are achieving desired results in lowering the likelihood of an accident occurring and/or less adverse impacts on human health or the environment from an accident (called lagging indicators in other guidance).
- Activity indicators help identify whether the enterprise/organization is taking actions believed to lower risk (called leading indicators in other guidance).
- Descriptive Metrics: illustrate a condition measured at a certain point in time.
- Threshold Metrics: compare data developed using a descriptive metric to one or more specified 'thresholds' or tolerances. The thresholds/tolerances are designed to highlight the need for action to address a critical issue.

- Trended Metrics: compiles data from a descriptive metric and shows the change in the descriptive metric value over time.
- Nested Metrics: two or more of the above types of metrics used to present the same safety-related data for different purposes.

It is considered that in order to identify the issues that would benefit most from SPIs, it is necessary to consider which policies, procedures and practices (including human resources and technical installations) could fail and result in a serious chemical incident. This is the important Step 2 in a seven step programme as shown in Figure 23.

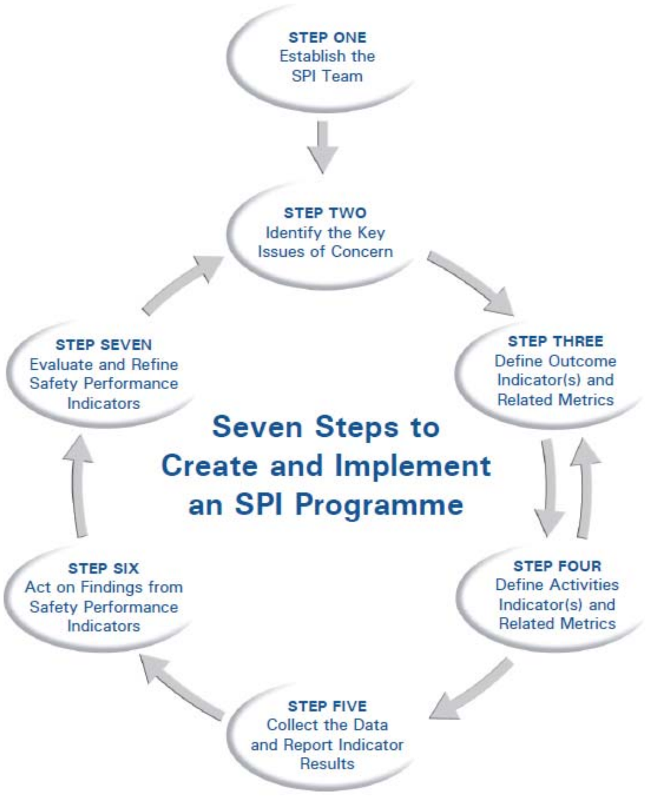

Figure 23 OECD (2008) seven step programme

A menu of possible outcome indicators and activities indicators includes the following headings:

A. Policies, Personnel and General Management of Safety

A.1 Overall Policies;
A.2 Safety Goals and Objectives;
A.3 Safety Leadership;
A.4 Safety Management;
A.5 Personnel;
A.5a Management of Human Resources (including training and education);
A.5b Internal Communication/Information ;
A.5c Working Environment;
A.6 Safety Performance Review and Evaluation.

B. General Procedures

B.1 Hazard Identification and Risk Assessment;
B.2 Documentation;
B.3 Procedures (including work permit systems);
B.4 Management of Change;
B.5 Contractor Safety;
B.6 Product Stewardship.

C. Technical Issues

C.1 Research and Development;
C.2 Design and Engineering;
C.3 Inherently Safer Processes;
C.4 Industry Standards;
C.5 Storage of Hazardous Substances (special considerations);
C.6 Maintaining Integrity/Maintenance.
D. External Cooperation

D.1 Co-operation with Public Authorities;
D.2 Co-operation with the Public and Other Stakeholders (including academia);
D.3 Co-operation with Other Enterprises.

E. Emergency preparedness and response

E.1 Internal (on-site) Preparedness Planning;
E.2 Facilitating External (off-site) Preparedness Planning;
E.3 Co-operation Among Industrial Enterprises.

F. Accident/Near-Miss Reporting and Investigation

F.1 Reporting of Accidents, Near-Misses and Other 'Learning Experiences';
F.2 Investigations;
F.3 Follow-up (including application of lessons learnt and sharing of information).

Centre for Chemical Process Safety (2008, updated 2011)
Updated after the ANSI/API guidance, the CCPS guidance:
'The ultimate goal of the 2006 CCPS project was to develop and then promote the use of common metrics across the industry and around the world. CCPS continues to support that objective, whether via adoption of the ANSI/API RP 754 definitions or via use of this document.'

The model is based on the Heinrich triangle concept and the Swiss cheese model.

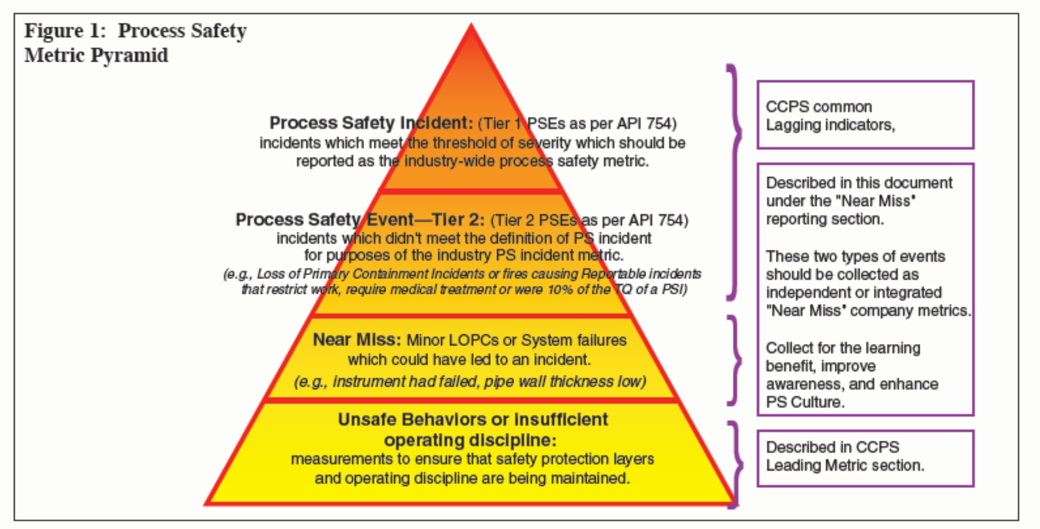

Figure 24 Process Safety Metric Pyramid (CCPS 2008, revised 2011)

CCPS recommended that all companies adopt and implement leading process safety metrics, including a measurement of process safety culture.

A number of potential leading metrics are described indicating the health of what are considered to be important aspects of the safety management system. If measured and monitored, data collected for leading metrics are intended to give early indication of deterioration in the effectiveness of these key safety systems, and enable remedial action to be undertaken to restore the effectiveness of these key barriers, before any loss of containment event takes place.

The safety systems that leading metrics have been developed for are
- maintenance of mechanical integrity;
- action items follow-up;
- management of change;
- process safety training and competency (and training competency assessment).

They suggest companies should only develop metrics for what is important for them for ensuring the safety of their facilities, and should select the most meaningful leading metrics from the examples given for the identified components, and where significant performance improvement potentially exists. These leading process safety metrics were selected, based upon the experience of the organizations represented by the work group, including:
- barriers related to the hazards inherent in their operations;
- barriers related to the critical causal factors or immediate causes of major incidents and high potential near-misses experienced by their operations;
- review of the metrics detailed in the CCPS Risk Based Process Safety book.

CCPS Suggested Leading Indicators:
- Mechanical Integrity
  - Inspections done/Inspections due;
  - Time safety critical equipment in failed state/Total operating time.
- Action Items Follow-up

- o No. of overdue action items/Total action items.
- Management of Change
  - % MOC's satisfying MOC policy;
  - % Start-ups with no safety related problems following a change.
- Operator Competency
  - % operators trained on schedule.
- Challenges to the Safety System
  - Activations of safety systems and relief valves;
  - Deviations outside of operating limits.

Plastics and Chemicals Industries Association (PACIA 2008)
This is guidance is aimed at senior managers and safety professionals who wish to develop performance indicators to provide assurance that process safety risks are adequately controlled. Based primarily on the CCPS system, the following example metrics are given:

Procedures for critical operation and maintenance

% of critical operational and maintenance procedure reviews completed to schedule
% compliance with critical procedures

Hazard Identification

% of risk assessments reviewed to schedule

Risk reduction Action Plan

% of risk assessment corrective actions completed to schedule

Management of Change (MOC)

% of MOC documents compliant with procedure

% of temporary changes overdue

% of MOC physically installed but awaiting completion of documentation

Permit To Work

% of PTW compliant with procedure

Plant Integrity

% of inspections or tests completed to schedule

Critical controls

All critical controls for process safety identified

% of controls inspected to schedule

% of controls outside tolerance (i.e. failure on test or demand)

Incident Investigation

% of overdue incident investigations

No. of repeat incidents occurring

% of follow up corrective actions completed to schedule

Process safety training

Mandatory training completed to schedule

e.g. fire fighting training, PTW authorities, Hazard Id/Risk Assessment training, etc.

Emergency preparedness

No. of emergency exercises/desktop exercises completed to schedule

Emergency plan reviewed to schedule

Energy Institute (2005) A framework for the use of key performance indicators of major hazards in petroleum refining

The objective of this approach appears to be focused on the rejection of proposals put forward by an HSE Pilot project on voluntary reporting of major hazard performance indicators. The approach is dominated by looking at causes of incidents in refineries, although it does not look at underlying causes. The approach rejects the use of potential indicators, what might be called near misses or smaller incidents as not correlating with what are called 'actual' incidents although the comparison process is difficult to follow and requires a much closer analysis. The comparison between different databases, the lack of definitions, dates, double counting (frequencies of causes not frequencies of accidents) and subjective evaluation of the potential for a 'potential' incident to have developed into an 'actual' incident contribute to the difficulties. In addition, searching for any available reports on the original referenced Chemical Engineering database produced no results in Google or Scopus (SciVerse Scopus is the world's largest abstract and citation database of peer-reviewed literature and quality web sources).

Rather than safety performance indicators being linked to the safety management system it mainly focuses at a level of current design conditions, operating and maintenance procedures.

The framework states that KPIs are wanted which:

- provide a measure of annual improvement for individual sites;
- provide meaningful comparisons between sites.

It was also considered necessary to have indicators which are

- of sufficient numbers so that yearly changes would be statistically significant;
- applicable across the refining industry;
- able to be scored (numerical system);
- simple to minimise different interpretation.

The framework suggests that the best way to improve major hazards safety performance is to 'tackle the most frequent causes of actual major hazards incidents...' p. 15. Reference is made to direct causes such as corrosion, leaks from flanges, safety instrumentation failures. The framework specifies that: 'Generating meaningful leading KPIs requires companies to assess whether they have a quality process in operation to manage the above causes'. A list of questions with yes/no answers are suggested (Annex J), for example:

J13 Have the most likely points for corrosion/erosion been identified?
J26 Are the tubes of each pass of a tubular fired heater fitted with at least two skin thermocouples connected to a temperature alarm?
J37 Does operator training cover start-up, shutdown and likely abnormal operations, using process simulators where practicable?

The issue of lagging indicators are addressed insofar as to reject them in favour of leading indicators.

A set of short indicators is also given:

- Poor HAZOP study;
- Corrosion of equipment;
- Equipment or mode of operation modified;
- Safety instrumentation fails;
- Equipment under pressure opened up;
- Materials not to design specification;
- Uncontrolled flow through drain or vent;
- Equipment not gas free;
- Abnormal high temperature;
- Vibration causing fatigue failure or unscrewing;
- Leak from flanged joint or coupling.

American Petroleum Institute

API Recommended Practice 754 (American Petroleum Institute, 2010) was developed to identify leading and lagging process safety performance indicators in the refining and petrochemical industries. The basic principles are the following:

- Indicators should drive process safety performance improvement and learning.
- Indicators should be relatively easy to implement and easily understood by all stakeholders (e.g. workers and the public).
- Indicators should be statistically valid at one or more of the following levels: industry, company and site.
- Statistical validity requires a consistent definition, a minimum data set size, a normalization factor and a relatively consistent reporting pool.
- Indicators should be appropriate for industry, company, or site level benchmarking.

The standard uses the tier approach described earlier in this chapter the Centre for Chemical Process Safety (2008, 2010) and Health and Safety Executive (2006) model also described earlier.

Tier 1 Performance Indicator—Process Safety Event - Higher consequence
Tier 2 Performance Indicator—Process Safety Events – Lesser consequence
Tier 3 Performance Indicators—Challenges to Safety Systems
Tier 4 Performance Indicators—Operating Discipline and Management System Performance

At Tier 4 level the following are considered:

1) Process Hazard Evaluations Completion—Schedule of process area retrospective and revalidation hazard evaluations completed on time by fully qualified teams;
2) Process Safety Action Item Closure—Percentage and/or number of past-due process safety actions. This may include items from incident investigations, hazard evaluations or compliance audits;
3) Training Completed on Schedule—Percentage of process safety required training sessions completed with skills verification;

4) Procedures Current and Accurate—Percentage of process safety required operations and maintenance procedures reviewed or revised as scheduled;
5) Work Permit Compliance—Percentage of sampled work permits that met all requirements. This may include permit to enter, hot work, general work, lockout/tag-out, etc.;
6) Safety Critical Equipment Inspection—Percentage of inspections of safety critical equipment completed on time. This may include pressure vessels, storage tanks, piping systems, pressure relief devices, pumps, instruments, control systems, interlocks and emergency shutdown systems, mitigation systems, and emergency response equipment;
7) Safety Critical Equipment Deficiency Management—Response to safety critical inspection findings (e.g. non-functional PRDs and SISs). This may include proper approvals for continued safe operations, sufficient interim safeguards, and timeliness of repairs, replacement, or rerate;
8) Management of Change (MOC) and Pre Start-up Safety Review (PSSR) Compliance—Percentage of sampled; MOCs and PSSRs that met all requirements and quality standards;
9) Completion of Emergency Response Drills—Percentage of emergency response drills completed as scheduled;
10) Fatigue Risk Management—Key measures of fatigue risk management systems may include: percentage of overtime, number of open shifts, number of extended shifts, number of consecutive shifts worked, number of exceptions, etc.

ANNEX 3: Monitoring system attention points from AVRIM2

AVRIM2 (Bellamy and Brouwer 1999) was originally developed for the Dutch Labour Inspectorate to support auditing activities. Below is the checklist of items for evaluating the formal monitoring component of the safety management system for maintenance.

Example from lifecycle : Maintenance
Component: Formal monitoring systems

<u>Knowledge of maintenance hazards</u>
- regularity of checks of hazard awareness of personnel Communication systems for sharing maintenance hazards concerns and experience between plants and sites.

<u>Standards for maintenance</u>
- routine internal audits and inspections;
- safety review meetings;
- management walk-rounds;
- focussed reviews e.g. on a specific critical maintenance task;
- checks on short-cutting and procedural modifications;
- competences of those with formal monitoring tasks;
- formal complaints procedure.

<u>Control of conflicts between safety and production</u>
- system for monitoring conflicts between safety requirements for maintenance and production/time pressures.

<u>Formal safety review</u>
- formal requirements to check standards of formal safety review;
- spot checks on results of formal safety review;
- formal meetings to review effectiveness of maintenance and inspection;
- system of reviewing maintenance hazards included in internal audits;
- checking system that formal safety review follow-up/actions carried out;
- companies system (audit possibly) for assessing compliance with maintenance human factors policy.

<u>Safe maintenance procedures</u>
- system of procedure review;
- regularity of procedure review;
- spot checks on correct use of safe procedures;
- formal meetings for reviewing concerns over maintenance and inspection;
- system of developing, managing and using procedures reviewed in internal audits;
- monitoring system for inconsistencies between procedure and design or labelling of equipment;
- procedures for checking the consistency of completed work with the job specification/requirements;
- process for checking the integrity of the plant before and after maintenance.

<u>Human Factors in error management</u>
- frequency of safety consultation groups;
- system for checking accuracy and availability of critical displays and controls;
- system for reviewing whether maintenance task demands can still be met;
- record system of maintenance/inspection errors;

- system for evaluating validity of human reliability assessment e.g. in risk analysis;
- check on availability and status of required safety equipment like PPE, gas detectors;
- human factors review included in audit;
- spot checks that there are no temporary modifications.

<u>Manning levels, competence and training</u>

- review of manning, competence and training included in audit;
- spot check system that tasks are carried out by competent personnel;
- review of training content adequacy;
- checks that training schedule is met;
- system of checks on workload and manning levels;
- reporting and follow up of safety training.

<u>Supervision and checking</u>

- system for giving assurance that supervision and checks are carried out where specified;
- system for assessing adequacy of level of supervision and checking.

<u>Capturing operational experience</u>

- system for reporting/ collecting data on near misses;
- system for keeping and searching incident and near miss records;
- formal meetings for reviewing near misses, incidents;
- checks made of adequacy of maintenance task checking, by collating information of the frequency failure of authorised equipment, due to poor repairs.

ANNEX 4: Ten tips to improve safety in the workplace

From Ministry of Social and Affairs and Employment (Ministry SZW, n.d.) the Netherlands the following ten areas were derived from evaluating the effectiveness of safety improvement projects.

Involvement of management is essential
In order to implement a change to the safety culture, all management must support this change –both in words and in deeds – by releasing a budget, being present and setting a good example. As the figurehead of the organisation, the general director in particular plays an important role; the stairway is cleaned from the top down, as it were. If the director makes clear that he feels strongly about safety, all managers and those in charge will follow. Top and other management must demonstrate leadership in order to bring about behavioural change, ultimately resulting in a culture in which safe working methods are is the norm.

Management standards are employees standards
The safety standard observed by management is same standard as must be observed by the entire group. This applies to all layers of management, including top management and the board of directors.
A manager cannot allow himself or herself to be negligent in this regard. He or she is responsible for maintaining this safety standard, not only by demonstrating good safety behaviour, but also by introducing and instructing employees on the shop floor, and by showing why certain working methods are safer. He makes it clear to them that this is in the interests of their health and safety. Finally, it is essential to supervise and talk to employees about any unsafe behaviour. People might have the best intentions, but it is not always easy to replace old habits with new ones.

Find the resistance and eradicate it
At the end of the day, everyone wants to go home healthy. People feel that safety and health are important, yet they do not always work according to this believe. The resistance to doing things right may have different underlying causes. Find the resistance and eradicate it. This gives employees the possibility to change their behaviour and contribute to creating a strong safety culture. It is essential to know what the problem is before it can be resolved. So create a climate in which employees feel comfortable saying what bothers them without fearing repercussions. Moreover, a manager who learns to carefully observe and thoroughly analyse what he sees is often able to identify possible areas of resistance.

Influence safe behaviour
A manager or employee cannot be held responsible for the number of accidents in the company because he is unable to influence this. He can only be held responsible for that which he can influence, namely his own behaviour. A middle manager can be held responsible for conducting observation rounds, holding progress discussions, covering the theme of safety during progression discussions and ensuring a tidy workplace. Behaviour can be changed by influencing intentions while, at the same time, working with stimulus from the surroundings. After all, intentions are quickly forgotten if not supported by the person’s surroundings and can even incite different, usually old, behaviour. To

influence behaviour, managers must be extremely consistent by maintaining set values and standards and monitoring compliance with agreements.

Reward good behaviour
Rewarding desirable safety behaviour can result in a significant decrease in the number of accidents and incidents. Punishing undesirable behaviour only promotes denial and avoidance. Approaching safety from a positive angle results in a ‘no-blame’ culture in which behaviour is discussable. Positive stimulus has a significant effect on people's behaviour and the formation of habits. The greatest effect is achieved when the reward immediately follows an act of good behaviour. There are different ways to reward good behaviour. It is preferable not to use monetary rewards in order to prevent a cessation of positive behaviour once the financial reward is not longer given. An acceptable reward would be a pat on the back or giving an employee or team a special role within the company, such as a coach. The latter is a very powerful means of rewarding good behaviour.

Have employees think for themselves
A project designed to strengthen the company’s safety culture can only be successful if the entire workplace is involved. Have employees help come up with solutions and personally contribute to carrying out those solutions. This will make employees feel more involved – and involvement leads to a better safety culture and higher productivity. Do not tell employees what they are doing wrong, but rather ask questions about the safety of their actions. What risks are they aware of? How can they reduce those risks? This type of approach teaches employees to think for themselves about their own safety. It also makes them feel they are being taken more seriously and gives them a sense of responsibility for their own actions. By having employees indicate what can go wrong, what the consequences could be, what they can do to prevent the problem and making agreements on future working methods, the desired behaviour will occur naturally, thereby reducing the chance of new, dangerous situations.

Solve safety problems operationally
In order to structurally improve a company’s safety culture, it is necessary for employees and their immediate supervisors to be personally responsible for remedying their own unsafe situations. The safety department can play a facilitating role in this. Only when a situation surpasses the department or an additional budget is needed is the safety problem taken to a higher level. By placing responsibility as low as possible, safety becomes the responsibility of the entire organization. Risk-related knowledge and experience is the responsibility of the employees on the shop floor. By making safety issues a personal and joint responsibility, people will come up with challenging solutions. Managers activate their employees to identify unsafe situations, take action personally as much as possible, and draw up reports. They then make sure that everyone adheres to the agreements made.

Learn from each other
Why should everyone have to reinvent the wheel and make the same mistakes? Learning from each other’s mistakes not only helps to prevent mistakes but also to make safety a topic of discussion and increase safety awareness. It is absolutely necessary to report accidents, incidents and dangerous situations in order to make improvements. Dealing quickly with the matter and informing the notifier is essential to maintaining a sense of urgency of safety. It is better not

to talk of 'mistakes', as this entails placing blame and, after all, accidents often have multiple causes. ‘Lessons from the past’ is a better term. Viewing every accidents and incidents as a learning opportunity creates an open culture in which mistakes are allowed, provided they can be learned from. In a condemning and disciplinary culture, people start safeguarding themselves and passing the blame. It is only in an open culture in which people learn from the past that safety can be improved.

Make results transparent

Results can provide stimulation to further improve safety. To determine whether results have been achieved, they must be measured. And, in order to measure them, performance indicators must first be established. Once the results have been measured, they are communicated to the organization in order to motivate employees to continue making efforts to improve safety. If the results are only available in thick reports filled with numbers, the information will not be accessible for everyone. So present the numbers visually in charts, thereby making them immediately clear to all employees. After all, a picture is worth a thousand words. There always be employees who do not like numbers or charts. They, and all other employees for that matter, can be motivated to make further safety improvements by communicating the successes of the safety project by means of posters, flyers, and the staff magazine and during progress discussions.

Embed the safety culture in a structure

During a safety project, the change in behaviour achieved can result in a long term change in culture. To ensure that the change is a structural one, it is embedded in the structure of the company. Structure means the presence of a set working methods based on business processes and supported by procedures. Structure offers regularity, repetition, agreements, allocation of responsibility, testing, evaluation, and communication. There can be no cultural change without structure. A few examples of structure are making the safety theme a permanent agenda item during progress discussions and board meetings, assigning responsibility for safety in the line organisation and pursuing a reward policy for safe working methods. Systematically observing employees and talking about acting safely also gives structure to the safety culture.

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