

## DEVELOPMENT OF A PROCESS SAFETY CLIMATE TOOL<sup>1,†</sup>

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Process safety involves the prevention of leaks, spills, equipment malfunction, over-pressures, over-temperatures, corrosion, metal fatigue and other similar conditions (Baker, 2007). Typical process safety incidents involve the escape of toxic substances and the release of flammable material which may or may not result in fires or explosions (Hopkins, 2008).

The term 'safety climate' describes employees' perceptions about risk and safety, providing a 'snapshot' of the current state of safety (Mearns and Flin, 1999). Climate tools can serve as useful tools in understanding occupational behaviour in an organisation (Zohar, 1980).

The BP U.S. Refineries Independent Safety Review Panel designed a process safety tool as a 'one off' to review safety culture/climate on process safety at BP US refineries. However there are no validated tools to review process safety culture/climate. The aim of this research was to develop a validated Process Safety Climate Tool that will assess perceptions towards process safety, to pilot and refine the tool, and evaluate the tool for measures of homogeneity, reliability and validity.

To date, the development of the tool has involved compilation of an evidence base to support the inclusion of scales within the tool and completion of two stages of piloting. Work on the third stage of piloting is underway and plans for the final stage have been formulated. This paper discusses the first two stages of piloting of the tool and summarises an evidence base to support the inclusion of the following scales in the tool: training effectiveness, staff competence, management support and commitment, communication during shift changeover, reporting and investigating, maintenance of equipment, procedures, competence of contractors, alarm management, resources, permit to work system, management of change and ageing plant. Current pilot work on the third and final stage of piloting and validation are also summarised.

### INTRODUCTION

The process safety discipline is concerned with controlling materials or fuels which will burn or explode when exposed to oxygen and a source of ignition (HSE, 2003a). It is also concerned with the safe processing of toxic materials and those which can undergo runaway chemical reaction. In particular it involves, the prevention of leaks, spills, equipment malfunction, over-pressures, over-temperatures, corrosion, metal fatigue and other similar conditions (Baker et al., 2007).

The term 'safety climate' describes employees' perceptions, attitudes, and beliefs about risk and safety, typically measured by questionnaire surveys and providing a 'snapshot' of the current state of safety (Mearns and Flin, 1999). Climate tools can, when used and validated correctly, serve as useful tools in understanding occupational behaviour in an organisation (Zohar, 1980).

The BP U.S. Refineries Independent Safety Review Panel designed a process safety culture/climate tool as a 'one off' to review the 'process safety climate' at BP US refineries (Baker et al., 2007). However there are no validated tools to review process safety climate. The aim of this research was to develop a validated Process Safety

Climate Tool, to pilot and refine the tool, and evaluate the tool for measures of homogeneity, reliability and validity.

The purpose of a Process Safety Climate tool is to identify workers' perceptions about organisational practices with regard to process safety. It is intended that the tool will be used across an organisations' workforce from frontline operators to management. Results gained from the tool could be used as a starting point for discussions between different levels and/or sites within an organisation to identify the reasons underlying the perceptions of workers within a particular site/level of that organisation. Action plans could then be developed outlining interventions to be taken on any issues of concern.

The Process Safety Climate Tool is part of a suite of tools in development at the Health and Safety Laboratory. The Health and Safety Laboratory's Safety Climate Tool (SCT) has recently been updated and revised so as to improve its reliability and validity as a psychometric instrument (Sugden et al., 2008). The revised SCT consists of 40 statements, comprised of the following eight coherent factors: (i) Organisational commitment to safety; (ii) Health and Safety orientated behaviours; (iii) Health and safety trust; (iv) Usability of procedures; (v) Engagement in health and safety; (vi) Peer group attitude to health and safety; (vii) Resources for health and safety and (viii) Accident and near miss reporting. It was considered that the process safety industry may require a climate tool with

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greater specificity to process safety than that offered by the SCT so as to gain an insight into workers' perceptions specifically related to process safety.

**METHOD**

This section summarises the method used to explore the tool content, the piloting work that has been completed to date and plans for future piloting and validation work (Figure 1).

**EXPLORATION OF TOOL CONTENT**

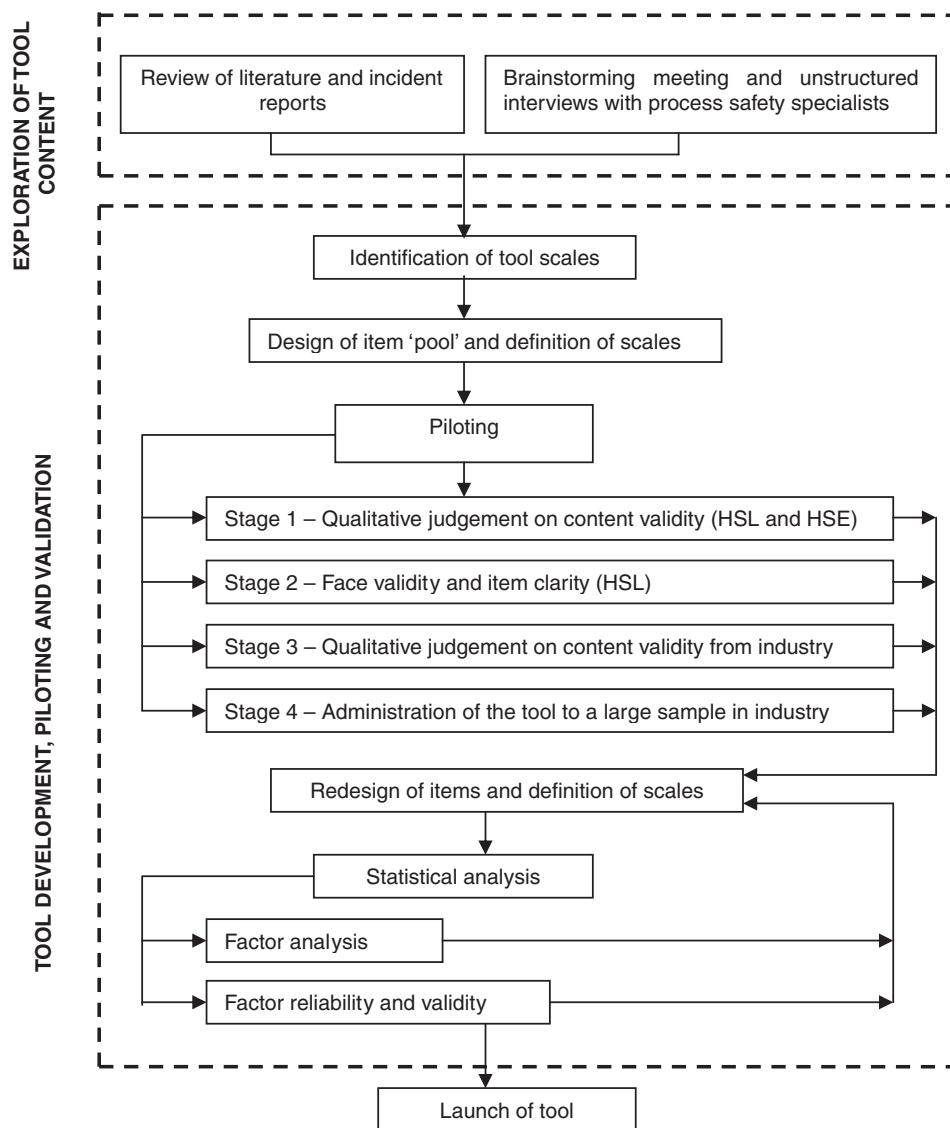
The exploratory stage involved reviewing literature relating to process safety incidents, a brainstorming meeting and unstructured interviews with process safety specialists.

This provided an evidence base for the inclusion of scales within the tool.

So as to maintain consistency with the format of the Health and Safety Laboratory's Safety Climate Tool (SCT), a Likert-type rating scale is used. In this scale, the respondent is asked to rate on five-point scale how much they agree or disagree with the statement (1 – Strongly agree; 2 – Agree; 3 – Neither agree nor disagree; 4 – Disagree; 5 – Strongly disagree).

**TOOL DEVELOPMENT, PILOTING AND VALIDATION**

From the exploratory stage, nine scales were considered important to include in the tool – training and competence,



**Figure 1.** Overview of process safety climate tool development method

reporting, maintenance and equipment, usability of procedures and alarm handling, worker support, confidence in management, communication during shift changeover, permit to work system and management of change.

Initially, a total of 64 statements was developed to capture the nine process safety scales.

#### Piloting

Piloting involved four stages, two stages within HSL and two stages within industry.

*Stage one:* At stage one, content validation of the tool was conducted with qualitative judgements by 6 process safety specialists within HSL and HSE to ascertain expert evaluation of the relevance of the chosen scales. In particular, this process ascertained the extent to which the tool captured all relevant process safety dimensions. Following this, 'ageing plant' and 'contractors' were added as scales.

Further revision of the items and scale definition resulted in the addition of two other scales and 19 statements to make an item 'pool' of 83 statements with 13 scales. In revising the statements, particular attention was paid to avoid producing double-barrelled items, that is, items that convey two or more ideas so that endorsement of the statement might refer to one or both ideas. The majority of scales also contained at least one negatively worded statement in order to avoid agreement bias (DeVellis, 1991). The revised scales were:

- training effectiveness;
- alarm management;
- permit to work system;
- maintenance of equipment;
- management of change;
- reporting and investigating;
- resources;
- communication during shift changeover;
- staff competence;
- competence of contractors;
- usability of procedures;
- management support and commitment;
- ageing plant.

*Stage two:* At stage two, a pilot on 8 individuals within HSL was conducted. The aim of this stage of piloting was to check the face validity of the tool and the clarity of the individual statements. Respondents were given a list of all 83 items randomly ordered with a definition of each scale and were required to categorise each item into a scale. As the process safety climate tool consisted of various scales measuring different constructs, it was important that individuals could determine which statements corresponded to which scale. A total of 11 items were discarded due to ambiguous wording and poor face validity. Following these two piloting stages, 72 items were retained and 2 items were added on the 'ageing plant' scale resulting in a tool with 74 items.

*Stage three:* At the third stage of piloting, a focus group was held at a major pharmaceutical company with 12 workers ranging from frontline operators to safety

managers. The aim of this stage of piloting was to test the content validity with qualitative judgement from industry, check the relevance and understanding of terminology with particular reference to the terms 'process safety', 'managers', 'supervisors', and obtain feedback on the length of the tool. Feedback from industry suggested that it was important to define the terms 'process safety' and 'startup' for respondents and to reduce the length of the tool by reducing the number of items per factor. A total of six items were removed based on their similarity to other items. The tool was reduced from 74 to 68 items.

Further piloting at this stage is planned. This will involve semi-structured interviews with workers in the chemical industry to further address content validity, use of relevant terminology and item clarity.

*Stage four:* The final stage of piloting will involve administration of the tool to a substantial sample (ideally 250 respondents) in order that the 'best' items can be selected by statistical means. Exploratory factor analysis and factor reliability analysis will be conducted at this stage, the aim of which will be to identify the underlying factor structure of the tool and test its reliability.

The use of a five-point rating scale will be reconsidered at this stage depending on respondents' use of the neutral response ('Neither agree nor disagree') – respondents may over-rely on this response rather than committing themselves to an opinion (Breakwell et al., 1995).

#### EVIDENCE BASE FOR TOOL CONTENT

The evidence base for the chosen scales in the Process Safety Climate tool is summarised in this section (Table 1).

#### TRAINING EFFECTIVENESS

A lack of training effectiveness has been identified as a contributing factor to the cause of several process safety accidents. In many cases, the training provided to process safety workers has not been an accurate reflection of the process safety risks on the job. For example, the real cause of the Esso Gas Plant Explosion in Longford, Australia (1988), was, as stated by the Royal Commission (set up to investigate the accident) found to be 'inadequate knowledge and training of the operators' (Hopkins, 2000). Their training did not question their overall understanding of the plant, it just questioned whether they could repeat back what their assessors had told them.

In an investigation of the BP Texas City refinery accident (2005). The BP U.S. Refineries Independent Safety Review Panel found that process safety education and training needs to be more rigorous, comprehensive and integrated (Baker et al., 2007).

Inadequate operator training was identified as a contribution to the cause of the Three Mile Island incident (1979) where there was a release of radioactive gas. In this incident the operators were unable to diagnose or respond properly to an unplanned automatic shutdown of a nuclear reactor. Inadequate emergency response training

**Table 1.** Summary of evidence base for scales to include in a process safety climate tool

No.	Scales	Issues recognised as contributing to the cause of process safety incidents	Incident	Reference
1	Training effectiveness	Inadequate training singled out as a basis for claim that Esso had violated the Occupational Health and Safety Act	Esso gas plant explosion at Longford, Victoria, Australia (1988)	Hopkins (2000)
		The Baker Panel found that process safety education and training needs to be more rigorous, comprehensive and integrated	BP Texas City refinery (2005)	Baker et al. (2007)
		Inadequate operator training identified as contribution to cause of accident	Three Mile Island (1979)	HSE (1999)
2	Alarm management	BP did not have adequate arrangements for alarm handling	BP Grangemouth Scotland (2000)	HSE (2003b)
		It became normal to operate the plant in alarm	Esso gas plant explosion at Longford, Victoria, Australia (1988)	Hopkins (2000)
3	Permit to work system	The permit to work system was not practiced sufficiently at shift changeover	Piper Alpha explosion in North Sea (1988)	HSE (1999)
		The principle contractor did not fully comply with the terms of the excavation permit	Natural gas pipeline puncture, San Francisco (1981)	HSE (2009a)
4	Maintenance of equipment	No formal system of maintenance of components	Associated Octel Company Ltd (1994)	HSE (1996)
		Poor maintenance procedures – fire detection and fire fighting equipment has fallen into disrepair	Piper Alpha explosion in North Sea (1988)	HSE (1999)
5	Management of change	Modifications had not been fully assessed	Texaco Refinery, Milford Haven (1994)	HSE (2009d)
		A plant modification occurred without the a full assessment of the potential consequences	Flixborough (1974)	HSE (2009b)
		No management of change procedure carried out for design and implementation of a water injection point	Conoco Oil Refinery, Humberside (2001)	HSE (2005)

6	Reporting and investigating	BP sometimes failed to address promptly and track to completion process safety deficiencies identified during incident investigations – Serious process upsets were almost never reported – Failure to investigate the cold temperature incident which occurred a month prior to the accident	BP Texas City refinery (2005)  Esso gas plant explosion at Longford, Victoria, Australia (1988)	Baker et al. (2007)  Hopkins (2000)
7	Resources	An absence of engineers on site at Longford cascaded down to cause the incorrect bypass valve operation  “BP did not always ensure that it provided the resources required for strong process safety performance”	Esso gas plant explosion at Longford, Victoria, Australia (1988) BP Texas City refinery (2005)	Hopkins (2000)  Baker et al. (2007)
8	Communication during shift changeover	Communication between shifts was less than adequate	Esso gas plant explosion at Longford, Victoria, Australia (1988)	Hopkins (2000)
9/10	Staff competence and competence of contractors	Fire resulted from a lack of co-ordination between shifts BP were recommended to develop a system to ensure all workers including contractors possessed an appropriate level of process safety knowledge and expertise	BP Texas City refinery (2005) BP Texas City refinery (2005)	Mogford (2005) Baker et al. (2007)
11	Usability of procedures	Lack of thorough and complete procedures to deal with process safety issues	Irving Oil Refinery (1998)	WHSCC (1999)
12	Management support and commitment	‘Management at Esso had not demonstrated an uncompromising commitment to identify and control every hazard’.	Esso gas plant explosion at Longford, Victoria, Australia (1988)	Hopkins (2000)
13	Ageing plant	A review of offshore hydrocarbon release incidents concluded that older platforms experienced the most release incidents	—	McGillivray and Hare (2008)

proved to be one of the root causes of the accident (World Nuclear Association, 2009).

#### ALARM MANAGEMENT

Some process safety accidents have involved a lack of effectiveness in the handling and management of alarm systems. For example, at the Esso Gas Plant in Longford, a culture developed over time where it became normal to operate the plant in alarm. But as Hopkins (2000) commented: 'this culture was a natural and necessary adaptation to the otherwise impossible alarm overload situation which the operators faced.'

At BP Grangemouth, Scotland (2000) three incidents occurred which had the potential to cause fatal injury and environmental impact. There was clear evidence that the operators experienced significant alarm flooding during the incident (HSE, 2003). An investigation found that BP did not have adequate arrangements for alarm handling.

It appears that the handling of alarms is particularly susceptible to 'normalisation of deviance' – a phenomenon that describes what happens when there is a knowing episodic or routine deviance from systems in operation (Jones et al., 2005).

#### PERMIT TO WORK SYSTEM

A permit to work system is a formal written system used to control certain types of work which are identified as potentially hazardous. It is also a means of communication between site management, plant supervisors and operators and those who carry out the work (International Association of Oil and Gas Producers, 1993). The importance of effective permit to work systems has been illustrated in a number of accidents.

The permit to work system was identified as a root cause to the Piper Alpha accident (1988) where 167 workers died after a major explosion on an offshore platform. The permit to work system had become too relaxed – employees relied on too many informal communications (Fire and Blast Information Group, 2009).

In a natural gas pipeline puncture in San Francisco (1981), failure to implement the permit to work system was identified as a probable cause of the incident – the principle contractor did not fully comply with the terms of the excavation permit (HSE, 2009a).

#### MAINTENANCE OF EQUIPMENT

The frequency, prioritisation and standard of equipment maintenance have been identified as contributing to the causes of several process safety accidents. In the Piper Alpha disaster and the Esso fire on its Tuna platform at Bass Strait, fire fighting equipment had been allowed to fall into partial disrepair and not work properly (Hopkins, 2000).

One of the failings identified in an investigation of a chemical release and fire at the Associated Octel

Company Ltd (1994) was that there was no formal maintenance and fault reporting of the components.

#### MANAGEMENT OF CHANGE

Process safety may be compromised when changes to a plant are managed ineffectively. At the Nypro chemical plant at Flixborough (1974), 28 workers were killed and 36 injured when the site was severely damaged by a large explosion. An investigation of the incident found that a plant modification was made without a full assessment of the potential consequences – this was a root cause of the accident (HSE, 2009b).

In an investigation of a fire and explosion at the Conoco Oil Refinery in Humberside (2001), no management of change procedure was conducted when a water injection point was installed. The investigation found that had such an assessment been carried out the corrosion risk that the injection point introduced for pipework could have been identified.

An explosion and fire at the Texaco Refinery in Milford Haven (1994) was partially caused because the plant was modified without a full assessment of the consequences of that modification (HSE, 2009d).

The US Chemical Safety and Hazard Investigation Board (CSB) has focused on the need to manage process changes in the chemical industry by highlighting two incidents where ineffective management of change procedures contributed to injuries and fatalities (CSB, 2001).

#### REPORTING AND INVESTIGATING

The importance of reporting and investigating process safety incidents and near misses has been identified as key in numerous process safety accident investigations. In the Esso gas explosion at Longford, serious process upsets such as leaks and unexpectedly cold temperatures almost never were reported and therefore failed to trigger any accident investigation (Hopkins, 2000). A cold temperature incident which occurred a month prior to the accident was not investigated.

The BP U.S. Refineries Independent Safety Review Panel found that certain BP employees and contractors tended to believe that in general, workers did not bother to report minor process-related incidents, accidents or near misses (Baker et al., 2007).

#### RESOURCES

The lack of available resources and expertise to support and promote process safety has been identified as contributing to the cause of several process safety accidents.

The BP U.S. Refineries Independent Safety Review Panel found that BP had not always ensured that it provided the resources required for strong process safety performance (Baker et al., 2007). The Panel found that BP did not have a designated high-ranking leader for process safety dedicated to its refining business. Furthermore, BP did not always



ensure that its refineries had adequate capabilities and expertise in place.

In the Longford gas explosion, the absence of engineers on site resulted in an incorrect bypass valve operation which started the accident sequence. This absence of engineers on site occurred because of cost-cutting practices by Esso (Hopkins, 2000).

#### COMMUNICATION DURING SHIFT CHANGEOVER

Problems with communication between shifts has led to major accidents and incidents. Shift handover has been considered a particular area of risk when plant maintenance continues over a shift change, when handovers are between experienced and inexperienced staff or during any deviations from normal working (HSE, 2009c).

A report on the Texas City accident outlined how inadequate communication between shifts contributed to causing the accident (Mogford, 2005). The day shift supervisor arrived late for his shift and did not receive any handover information from the night shift supervisor and the duration and quality of pass down information between the respective operators was inadequate.

In the Longford gas explosion, operators and their supervisors were unaware how workers on previous shifts had been dealing with a continuing problem and therefore 'adjusted the valve without reference to the previous shift – in fact one operator described it as a tug of war between two supervisors on different shifts, one wanted it open and the other closed' (Hopkins, 2000).

#### COMPETENCE OF STAFF AND CONTRACTORS

The ability of staff and contractors to deal with process safety issues and the on-site knowledge of contractors is an issue which has arisen in some process safety accident investigations.

The BP U.S. Refineries Independent Safety Review Panel found that BP had a number of deficiencies in the process safety knowledge and competence of personnel and contractors at BP's U.S. refineries. (Baker et al., 2007).

#### USABILITY OF PROCEDURES

Unusable procedures have been identified as contributing to the cause of some process safety accidents. For example, an accident investigation of an explosion and fire at the Irving Oil Refinery, Saint John, New Brunswick, revealed that procedures were incomplete and lacking in detail – there was no documentation outlining information on shut down when hot spots were detected (WHSCC, 1999).

#### MANAGEMENT SUPPORT AND COMMITMENT

The support and commitment of management to keep the workplace safe from process safety accidents may be demonstrated by a management mindset where every major hazard is identified and controlled (Hopkins, 2000).

Furthermore an organisation truly committed to improving their safety performance will avoid excessive focus on production rates or meeting schedules (Olive et al., 2006).

In the Longford gas explosion, the Royal Commission found that management had not demonstrated 'uncompromising commitment to identify and control every hazard at Longford. ... there was a deficiency in the safety culture of management' (Hopkins, 2000).

#### AGEING PLANT

A review of offshore hydrocarbon release incidents between 2001–08 by the Health and Safety Laboratory concluded that ageing was an important factor and that older platforms, aged 20 years or more, experienced the most release incidents (McGillivray & Hare 2008). Ageing was also highlighted in a review of the KP3 programme of offshore inspections focused on asset integrity (HSE, 2008).

The ageing and deterioration of pressure systems is a particular process safety issue highlighted by Wintle et al. (2006).

#### SUMMARY AND CONCLUSIONS

A Process Safety Climate Tool is undergoing development at the Health and Safety Laboratory (HSL). The development of the tool has involved a review of literature and process safety incident reports, consultation with process safety specialists and initial stages of piloting both within HSL, HSE and industry. Training effectiveness, communication during shift changeover, effectiveness of permit to work systems, competence of contractors, management of changes are some of the topics identified as important to include in such a tool. Future work on the tool is planned and will include further content validation of the tool from the process safety industry, administration of the tool to a large sample within industry and statistical analysis of the results from industry so as to draw out the underlying factor structure of the tool and test its reliability.

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