

Improving resilience to major safety events by analysing case studies

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Executive summary: Development of a potentially widely applicable ‘tool’ to address sometimes neglected ‘organisational and cultural’ precursors to major safety-related ‘events’ is described. Twelve ‘events’ across several industries were studied, and detailed ‘expectations of good practice’ developed. Associated ‘penetrating diagnostic questions’ were also then developed to enable the identification of potential operational vulnerabilities, and a ‘systems approach’ is outlined (which also addresses behavioural factors) to facilitate the design of effective interventions.

Tags: Ramsgate walkway collapse, Heathrow Express tunnel collapse, Longford Gas Plant explosion, Tokai-mura criticality accident, Davis-Besse nuclear reactor incident, Columbia shuttle disaster, Paks nuclear plant fuel accident, Texas City refinery accident, Buncefield fuel storage explosion, Nimrod aircraft crash

Section 1: Background and introduction

Events such as a space shuttle disaster, oil refinery accident and the collapse of a pedestrian walkway may appear to have little in common. Such events have occurred in different industrial settings, involved very different engineering failures, and have happened in different operational contexts. However, analysis of the findings from the investigations that took place following twelve disasters that occurred across a wide range of ‘high hazard’ industries, reveal significant similarities in their deeper-lying organisational and cultural accident precursors.

An important conclusion is that if defences can be developed to remove or mitigate these

vulnerabilities, they should enhance organisational resilience to accidents across a very wide range of industrial settings. Effective use of this learning could reduce the occurrence of major events which have, in some cases, cost many lives and led to significant environmental damage – as well as financial loss, reputational damage and impacts on infrastructure.

It is important that greater awareness and understanding of organisational and cultural precursors in the causation of major events and their similarities is fostered among relevant stakeholders, including policy makers, corporate leaders, regulatory bodies and other safety professionals. This paper aims to help achieve this and outlines how, following encouraging foundation research (1,2) and more recent work (3) funded by the UK Energy Institute (EI), an approach is being developed which offers the prospect of identifying and then more effectively addressing these precursors to failure which should be of value to both operational organisations and their regulatory bodies.

The analysis is based upon the major events listed in **Table 1**. These events were chosen following discussions with relevant

industry sectors about key sources of potential learning, taking into account the depth of investigations and the extent to which they identified and considered organisational and cultural deficiencies. The analysis of the case studies is intended to provide a contribution to learning and not criticism of the organisations involved.

Two further events (the Deepwater Horizon accident in the Gulf of Mexico in 2010, and the Fukushima nuclear event in Japan in 2011, have been the subject of preliminary study and many of the organisational and cultural precursors were found to be similar to those in the events above.

Following most of the events, considerable efforts were made by some organisations and regulatory bodies to apply the learning, but this was typically restricted to the specific industry sector directly involved. Furthermore, findings were often addressed on a fragmented, one-by-one basis without considering the potential systemic ‘knock-on’ effects which arise in a complex system. Major events continue to occur with, for example, a very high number of large losses in the energy industry reported since 2017 (4).

Table 1 – case study major events and key investigation references

Ramsgate – walkway collapse, UK 1994	Health and Safety Executive, 2000a, ‘Walkway Collapse at Port Ramsgate: A Report on the Investigation’.
Heathrow Express – NATM tunnel collapse, UK 1994	Health and Safety Executive, 2000b, ‘Collapse of NATM Tunnels at Heathrow Airport: A Report on the Investigation’.
Longford – gas plant explosion, Australia, 1998	Royal Commission, 1999, ‘The Esso Longford Gas Plant Accident: Report of the Longford Royal Commission’ and, ‘State Coroner Victoria Inquest into the Deaths of (named individuals) and the Fire at Longford Gas Plant Number 1’.
Tokai-mura – JCO criticality accident, Japan, 1999	IAEA, 1999, ‘Report on the Preliminary Fact-Finding Mission Following the Accident at the Nuclear Fuel Processing Facility in Tokai-mura, Japan’, Vienna, Austria.
Hatfield – railway accident, UK 2000	Office of Rail Regulation, 2006, ‘Train Derailment at Hatfield: A Final Report by the Independent Investigation Board’.
Davis-Besse – nuclear reactor incident, USA, 2002	US Nuclear Regulatory Commission, 2002, ‘Davis-Besse Reactor Vessel Head Degradation Lessons-Learned Task Force Report’.
Columbia – shuttle disaster, USA, 2003	Columbia Accident Investigation Board, 2003, ‘Columbia Accident Investigation Board Report’, Washington D.C.
Paks – nuclear plant fuel accident, Hungary, 2003	IAEA, 2003, ‘Report of the Expert Mission Conducted Under the IAEA Technical Co-operation Project’, HUN/9/022.
Texas City – refinery accident, USA 2005	Chemical Safety Hazards Investigation Board, 2007, ‘Investigation Report: Refinery Explosion and Fire’, Baker et al, 2007, ‘BP U.S. Refineries Independent Safety Review Panel’, and BP interim ‘Fatal Accident Investigation Report’, May 2005.
Thorp – reprocessing incident, UK 2005	Health and Safety Executive, 2005, ‘Report of the Investigation into the Leak of Dissolver Product Liquor at the Thermal Oxide Reprocessing Plant (THORP), Sellafield’.
Buncefield – fuel storage explosion, UK 2005	Buncefield Major Incident Investigation Board, 2008, ‘The Buncefield Incident, 11 December 2005 – The Final Report of the Major Incident Investigation Board’.
Nimrod – aircraft crash, Afghanistan, 2006	Haddon-Cave QC, 2009, ‘The Nimrod Review – An Independent Review into the Broader Issues Surrounding the Loss of the RAF Nimrod MR2 Aircraft XV230 in Afghanistan in 2006’, Published. by HMSO.

The present research has been taken forward (1,3) in three iterative steps:

Step 1 involved synthesising findings from the twelve events to form a basis for producing a set of initial organisational ‘expectations’ of good practice specifically aimed at promoting higher resilience to failure. These have been presented in the form of statements against which organisations should be able to benchmark their equivalent requirements and should enable potential ‘gaps’ (potential vulnerabilities) to be identified. If organisations do not currently have such statements, those developed provide a possible template.

Step 2 relates to work recently carried out, to generate from the expectations, sets of ‘penetrating diagnostic questions’ as part of the work funded by the UK Energy Institute (to be published). These are designed to help duty-holders determine the extent to which expectations are being met in practice in their organisation. It is vital to assess the strength of this link between ‘aspiration and reality’ – the need for intentions to be ‘embedded in the bloodstream’ of the organisation. Successful prototype work with Centrica plc on this topic (5) was carried out to test the approach.

Step 3 involves work which is currently underway. When

expectations are found not to be realised in practice, organisations need to design effective interventions to address the vulnerabilities identified. It is important that planned interventions do not produce unanticipated and undesirable secondary knock-on effects (such as suppression of reporting, or over bureaucratisation of procedural requirements) and an approach is being developed which should minimise this. Importantly, this will also incorporate ‘behavioural’ and socio-technical elements.

Some of the key benefits of the approach include:

- a) A means of achieving a

systematic risk assessment of the sometimes neglected organisational and cultural precursors to failure complementing well-established tools (such as Probabilistic Risk Assessments and Hazops) which enable engineering vulnerabilities to be assessed;

- b) The potential to improve safety in processes involving complex interactions between people, processes and plants across a wide range of industry sectors – enabling and encouraging wider learning;
- c) An approach which should be practical in its application and raise awareness of ‘operational reality’ at all organisational levels through the application of the ‘penetrating diagnostic questions’ and to address them through team collaboration;
- d) A process which should be widely applicable and robust, yet sufficiently flexible and manageable to meet the needs of organisations across the spectrum of capability and organisational maturity. It should enable either analysis of specific areas of concern, or a review across all areas to be carried out, and;
- e) It should reduce the tendency to employ a ‘piecemeal’ approach to designing interventions to reduce vulnerability to events. It enables potential responses to be designed holistically as part of a systems approach, ‘rehearsed’ and analysed with the involvement of those involved in the change – enabling potential ‘behavioural’ factors to be recognised and addressed.

Section 2: Analysis and insights

2.1 Event findings and the choice of ‘themes’

Findings from the review of the twelve events have been

categorised under ten broad and often inter-related ‘themes’ and sets of expectations developed within each. **Figure 1** illustrates the relationship between the themes in an organisational setting. However, it is important to note that in order to draw out the systems implications and the potential complexity involved, it is necessary to develop a more detailed ‘causal understanding’ (see Section 2.2).

Table 2 attempts to provide an indicative overview of the extent to which elements of each theme were identified in the findings from each of the twelve events. It shows that a high proportion of the investigations identified factors within all themes. It is a matter of judgement as to the degree of importance attached to each entry in the table, but some indication of this has also been given based on the respective investigation reports.

A very brief outline of the themes is presented here, but a full discussion of each of these and their basis can be found in reference 3.

a) *Business environment*

What has been referred to as the ‘business environment’ (e.g., the need to complete a project to a very tight schedule or the impact of major organisational change on operations) was present and led to unintended consequences to varying degrees in all of the events studied. Under such circumstances, achieving greater resilience requires leadership awareness of potential impacts on safety, reinforced by a rigorous management of change process that identifies and effectively mitigates the potential impact of proposed changes on safety. This needs to be independent and effective, or there is a danger that decisions may simply be ‘rubber stamped’.

b) *Leadership*

It is vital that competent, well-informed senior leaders ‘set the tone at the top’ and that this is

reinforced by actions and visible commitment. As depicted in **Figure 1**, the role of leaders is primarily to develop organisational strategy, establish requirements and provide oversight; whilst that of operational management is to ensure full understanding and effective implementation and monitoring. At all levels of leadership, a vital objective is to promote attitudes and behaviours, provide resources conducive to maintaining high standards and to achieve the motivation and involvement of all staff to seek continuous improvement.

c) *Safety culture*

All of the events studied exhibited shortfalls in safety culture.

Examples include:

- A lack of commitment and operational awareness among leaders;
- Failure to learn from experience;
- A tendency towards ‘operational drift’ where poor practices become the norm;
- The absence of a sufficiently questioning attitude and ‘precautionary’ approach to emerging risks and rigour in addressing them;
- Failure to involve the workforce in identifying and implementing improvements.

d) *Safety Management System (SMS)*

Good safety performance requires the presence of an effective SMS that sets out the required approach to all important operational matters – including defined performance standards, making accountabilities clear and providing the workforce with understandable and practicable procedures to enable risks to be effectively controlled. In **Figure 1**, some themes have been grouped under the general heading of the SMS as these must be supported by clear organisational systems to provide a basis for

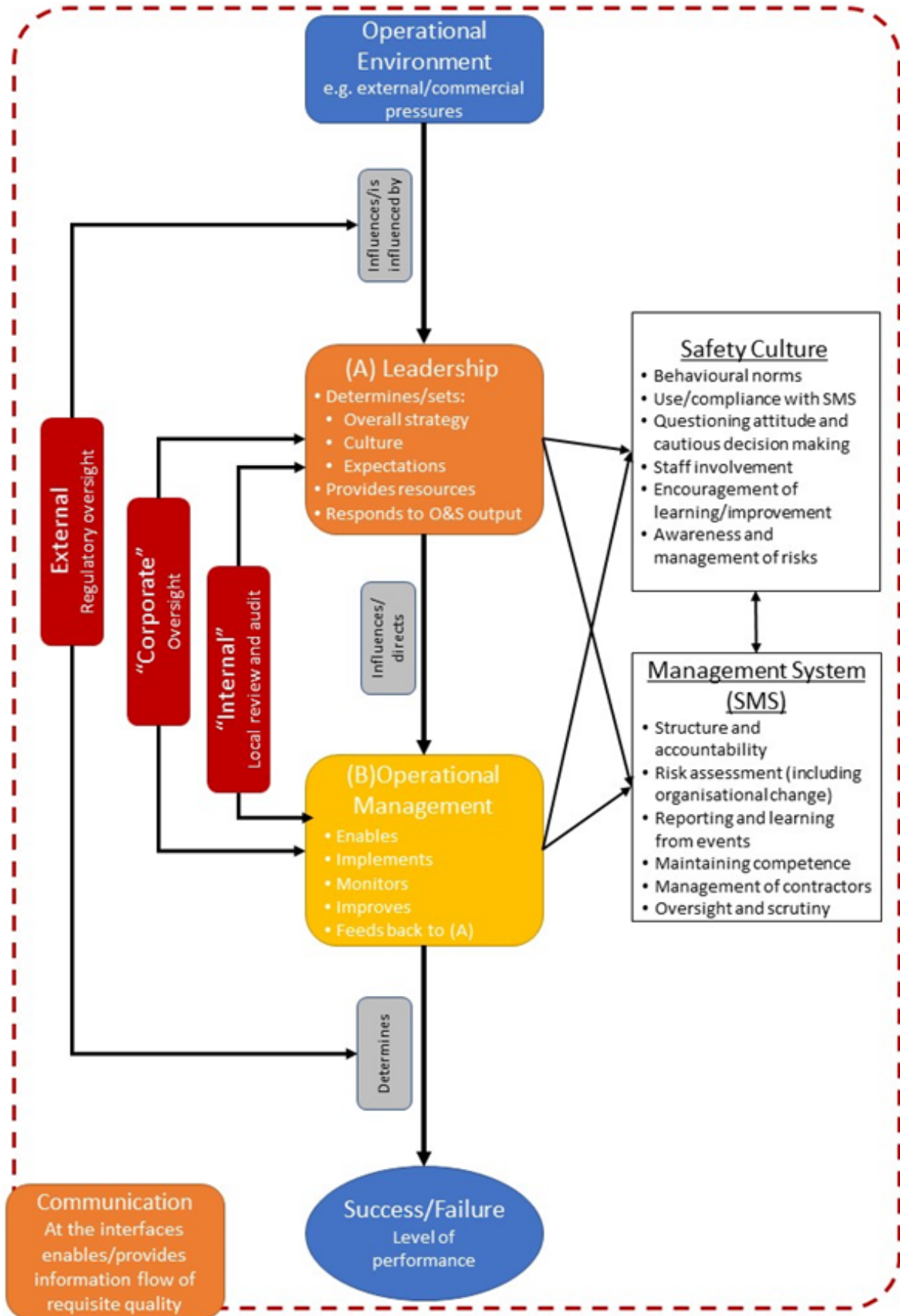


Figure 1 - the relationship between the themes in an organisational setting

Table 2 – indicative overview of the extent to which elements of each theme were identified in the findings from each of the twelve events

Event	Themes									
	Leadership	Safety Culture	Business Environment	Comms	SMS	Risk Assessment	Reporting / Learning Organisation	Competence	Contractor Management	Oversight and Scrutiny
Longford	**	**	*	**	**	**	**	**	X	**
Texas City	**	**	**	**	**	**	**	**	X	**
Buncefield	**	**	**	**	**	**	**	**	**	**
Tokai-mura	**	**	**	**	**	**	*	**	X	**
Davis Besse	**	**	**	*	**	**	**	*	X	**
Paks	**	**	**	*	**	**	*	*	**	**
Thorp	**	**	*	*	**	**	**	**	X	**
Ramsgate	**	**	**	**	**	**	*	**	**	**
Heathrow	**	**	**	**	**	**	**	**	**	**
Hatfield	**	**	**	**	**	**	**	**	**	**
Columbia	**	**	**	**	*	**	**	*	**	**
Nimrod	**	**	**	**	**	**	**	**	**	**

Notes:

** Aspects relating to these ‘themes’ appeared to be significant precursors to the event.

* Contributory factors mentioned or strongly implied in relevant investigation reports.

x Not apparently applicable to the event.

effective implementation. However, they are important topics in their own right, that require in-depth consideration and have therefore been identified as separate themes.

e) Risk assessment and management

Shortcomings identified in assessing and managing risks ranged from failing to take a ‘holistic’ view of risks to deficiencies in ‘day-to-day’ operational risk control. In the latter case, there was often a lack of awareness and/or competence, and sometimes a failure to recognise the need to continuously monitor and seek expert advice when necessary. This was found to be particularly important for new plant, processes or systems and during recognised higher risk phases of work – such as start-ups.

f) Reporting and learning

A ‘learning organisation’ first needs effective reporting of precursors to failure based on a well-understood and accepted ‘just’ system. Leaders and managers need to make it clear through their response and resulting actions that feedback from staff and wider learning from events is highly valued. Underpinning this process is the need for organisational arrangements to ensure that effective learning is developed and disseminated to those who can benefit, in an accessible form which recognises the context of the potential area of application. It is very important that learning is made available wherever it may have relevance and that effectiveness in its use is assessed.

g) Competence

Shortcomings were also found

to have arisen, at least in part, by failure to provide systems to ensure personnel competence and effective associated training at many levels in the organisations involved. In addition to competent and up-to-date coverage of technical matters, there were often shortcomings in ensuring that organisational, cultural and ‘people issues’ received adequate emphasis and, importantly, that training fully reflected operational reality. Maintaining competence within relevant functions during organisational change, ensuring continued understanding and compliance with changes in procedures and maintaining a capability to detect emerging risks, were also identified in several events as being particularly important.

h) Contractors

Not all of the events studied

involved contractors. However, where they did, deficiencies at the interface between the duty-holder and contractors were often very significant. These included:

- Poor communication and project control;
- A lack of clarity about operational procedures between organisations;
- Contractual arrangements which resulted in failures to report deficiencies, and
- A failure of the client to retain the motivation and capacity to understand and scrutinise contractor work (i.e., failure to act as an ‘intelligent customer’).

i) Communication

Failures of communication were identified across a wide range of organisational interfaces in the events studied and because of its all-pervading importance, it is represented separately in **Figure 1**. Failures ranged from ineffective engagement by leaders to obtain sufficient understanding of ‘operational reality’ with breakdowns in communication both up and down the management chain, to failures of communication

at important interfaces such as that between client and contractor, and within and between teams. There were many examples of deficiencies at shift hand-over, and between operators and support functions. In some cases, communication was inhibited by over-complex or bureaucratic organisational arrangements.

j) Oversight and Scrutiny (O and S)

Shortcomings in O and S ranged from a lack of recognition that operational monitoring and audit requires effective organisational arrangements and a willingness to challenge existing, and sometimes well-established, practices to the need for the wider organisation to maintain an effective process for ‘independent’ oversight (usually by a dedicated corporate safety function). Having such safety processes enables senior leaders to maintain a stronger awareness of emerging risks and for them to use the results, together with analysis of trends and open feedback through the management chain, to obtain a regular overview of safety performance, and to take appropriate action to prioritise and address identified deficiencies.

The ten themes identified here align with many of the factors in the initial University of York Safer Complex Systems (SCS) Framework Report (6) and, as concluded in Section 3 below, use of the findings from this study may provide potential input and help to ‘operationalise’ the Framework.

2.2 Expectations and question sets

The expectations that have been developed are presented in full in reference 3 for each of the ten themes, along with an associated discussion and commentary. Their coverage and potential use are illustrated here by considering the theme of ‘reporting and learning’.

Expectations have been developed from each of these points. For example, the first two points in **Table 3** led to the following:

- a) “There should be a systematic and effective process for the reporting of ‘events’, near-hits and non-conformance with the SMS which are relevant to process safety as an input to a wider operational experience (OE) programme. This should also apply to any contracting organisations. The reporting

Table 3. Major topics covered in the expectations of good practice relating to ‘reporting and learning’

Ensuring a process for effective reporting
The need for a ‘just’ reporting culture
Obtaining the views of staff – including from team reviews
Using all relevant sources of data for developing learning
Ensuring a systematic process for investigation and follow-up
Achieving a well-resourced process for the review and dissemination of learning
Keeping learning ‘alive’ and in the ‘corporate memory’
Incorporating learning into training
Ensuring effective follow-up actions and prioritising them
Maintaining learning during organisational change
Promoting leadership awareness of key learning
Use of event reporting as a potential key performance indicator (KPI)
Use of events to reinforce safety culture and to make the message ‘realistic’ to the workforce

process should be kept as straightforward as possible to ensure uptake.”

- b) ‘Reporting should take place within a ‘just’ culture and should also be actively encouraged by management at all levels, even when the input may not provide ‘welcome’ news. Feedback should be given to those who report in order to reinforce commitment. It should be made clear that failure to report is unacceptable. Anonymity should be respected.’

Following the development of expectations under each theme, sets of ‘penetrating diagnostic questions’ have been developed based on the expectations. These will enable leaders, function heads and those involved more directly with operations to contribute to developing a critical perspective on resilience to failure and obtain a deeper understanding, whilst promoting a questioning approach as required in a strong safety culture. The question sets seek to identify the extent to which the expectations are embedded in organisational practice and include the need to examine examples of how the expectations are applied in practice.

They are designed to enable a flexible approach in identifying and

prioritising areas for improvement. They can be applied either for all themes to obtain an overview, or in selected areas where concerns may exist. To enable this, each theme and associated questions have been made ‘self-standing’; even though this results in some overlap in content. It is also anticipated that the expectations may evolve as a ‘living’ document, by incorporating findings from future events if these provide new insights.

2.3 Developing effective interventions

This section outlines the development of a modelling approach designed to enable duty-holders to develop effective improvement interventions. It takes account of the potentially complex interplay between engineered systems, structural, organisational, behavioural and cultural elements. Because of this complexity, unanticipated consequences of interventions are an important issue. The approach outlined below should help to minimise these and facilitate the development of more effective performance indicators.

A simple example, again based on ‘reporting and learning’, illustrates the concept. A technique known as Causal Loop Modelling (CLM) is used to

depict the interactions between causal factors and the potential consequences of intended changes. It has the capacity to go beyond characterising simple linear causality to capture less immediately obvious, subtle, emergent or ‘hidden’ effects.

Figure 2 illustrates through a simple example how the approach can be used to analyse the possible consequences of actions intended to improve learning by increasing the number of ‘events’ being reported. The scenario considered is one where leaders recognise and promote the need to improve reporting and, following agreement with staff and their representatives, set in motion a programme to achieve this.

The arrows in Figure 2 represent causality. An ‘S’ means a similar change is caused. An ‘O’ means an opposite change is caused. The right-hand loop shows that more reporting leads to more investigations and more corrective actions. Unless carefully controlled, prioritised and resourced, this may lead to a significant increase in workload and, in this scenario, the number of visible improvements and completed actions decrease because insufficient resources have been put in place to address the issues.

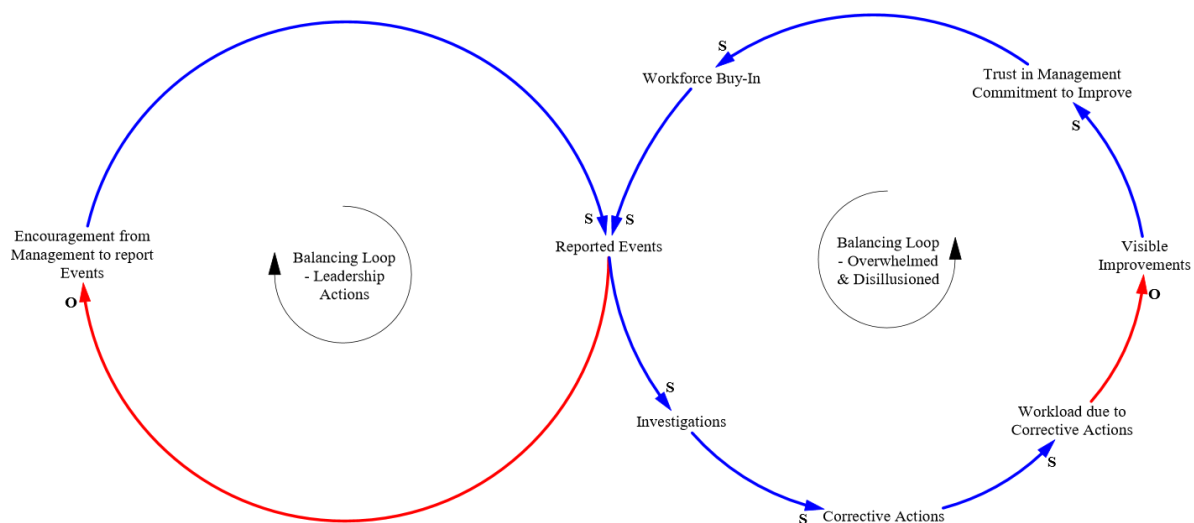


Figure 2 – Causal loop diagram presenting a simple example of how the approach can be used to analyse the possible consequences of actions intended to improve learning by increasing the number of ‘events’ being reported

A consequence is that staff see their best efforts to report leading to further actions on them and/or little material improvement. This understandably produces disillusion and cynicism within the workforce, which will then tend to reduce staff engagement and result in a lower level of reporting. More corrosively, its legacy may blunt the impact of future (different) initiatives and interventions. Meanwhile, leaders, having made a highly visible commitment, are still encouraging more reporting. This can lead to a situation where the workforce progressively loses trust in the ability of its leaders to understand operational ‘reality’.

This example, although very simple, illustrates how a potentially worthwhile initiative might leave the organisation worse off than before it was launched. It is this capacity, to recognise potential pitfalls and perverse consequences at the design stage of interventions, that CLM is designed to address.

It also illustrates the importance of developing more effective performance indicators as a result of the modelling. Instead of a simple performance indicator, based on the number of events reported, other measures dealing

with response and visible improvement would be important indicators.

In reference 3, more detailed examples are considered relating to a) contractor and supply chain management, b) safety culture and oversight, and c) incentives and performance indicators. The value of team working in constructing models is also discussed.

The example in **Figure 2** also illustrates how cognitive, behavioural and cultural factors can affect potential improvement activities within a complex system – in this case, degraded workforce commitment to safety because of a lack of visible response to their efforts and a growing dislocation between leadership aspirations and operational reality. In the events studied, a wide range of behavioural factors were identified as important contributors to failure and examples are given in **Table 4**.

Causal loop diagrams are now being developed to demonstrate how more effective interventions can be achieved across a sample of ‘common’ or ‘archetypal’ failure modes from the case study events. The modelling will (perhaps for the first time) include the potential behavioural responses which

could undermine the success of proposed interventions.

In essence, the technique (or ‘tool’) will provide a risk assessment of the potential for vulnerabilities in the design and delivery of interventions.

Section 3: Discussion and transferrable learnings

By studying twelve major events across a range of high hazard industries, it has been possible to highlight the importance of organisational and cultural precursors. Identifying and addressing these important precursors offers a powerful way to minimise future events – including serious accidents, such as some of those studied. The events exhibited a high degree of commonality with respect to precursors to failure and findings have been synthesised and classified under ten themes, which may be of value in assessments and event investigations.

Many organisations have documented standards of good practice or ‘expectations’ which set out requirements for operations. The results of this analysis should enable them to ‘benchmark’ these against a ‘model’ set of expectations based on the findings from a wide range of actual events.

Table 4. Some examples of identified undesirable cognitive and behavioural issues

Development of shared ‘mindsets’
‘Conditioning’ by past success
‘Normalisation’ of deviance
Lack of a questioning attitude
‘Casual compliance’ with procedures
Over-simplification and a failure to consider unintended consequences
Attitudes and behaviours driven by a commercial ‘agenda’
Development of organisational complacency and ‘drift’
A ‘disconnect’ between workforce and leadership expectations
Loss of understanding of operational ‘reality’ by leaders
Unintended reactions to ‘incentives’

Sets of penetrating questions have recently been developed based on the expectations. It is envisaged that these should provide organisations with a practical means to assess the degree to which 'operational reality matches aspiration' and to identify where they may be most vulnerable. Application involves a flexible, team-based approach that can either cover all ten themes collectively or could be applied to particular areas where concerns exist. The approach should be of value to organisations across industry sectors and at different levels of capability and organisational maturity.

In the complex, interactive, socio-technical systems involved, developing effective improvement interventions is not straightforward. Making what might appear to be a simple improvement can produce unintended consequences unless the systems implications of the proposed change are carefully analysed and, importantly, behavioural factors which may adversely affect uptake are fully recognised and assessed. The use of causal loop modelling provides a valuable technique for assessing the potential impact of proposed interventions.

The ten themes and many of the associated findings underpinning the 'expectations' presented in this study appear to align strongly with those identified as important factors developed to 'build a more resilient future' in the wide-ranging SCS Framework (6). These are set out and discussed considering design and operation-time controls and exacerbating factors and the various layers of these (governance, management and task/technical). A possible area for further research would be to map the findings from the present study onto those in the framework and identify any new factors. The present study provides a potential systematic and practical approach to developing

greater resilience in 'process safety' which might be considered in the further development of the SCS Framework and the 'common language' that it seeks to introduce.

Application of the present approach to other areas (such as healthcare and governmental preparedness) by examining its potential application to other case studies examined in the Engineering X project could be the subject of further research.

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Acknowledgements

This work was supported by a grant from the Safer Complex Systems mission of Engineering X, an international collaboration founded by the Royal Academy of Engineering (the Academy) and Lloyd's Register Foundation (LRF). The opinions expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Academy or LRF. The authors wish to acknowledge the support received from industry (particularly BNFL and Centrica) and regulatory bodies (ONR/NII) in the earlier phases of this work. We are particularly grateful for the recent support and funding from the UK Energy Institute and for agreement to include in this paper, findings and figures from the most recent ongoing research and an associated publication (3). Valuable comments have been received from two Safer Complex Systems mission 'mentors' and three independent technical reviewers.

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