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Understanding organisational and cultural precursors to events

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Reviewing the collective findings from investigations into a range of major events in high-hazard industries has led to the conclusion that there is a need to develop greater resilience to the organisational and cultural causes of these events. This requires more rigorous methods for identifying disaster precursors and for supporting intervention design. A study of the organisational and cultural precursors relating to 12 major events across several industries revealed shared precursors in areas such as leadership, operational attitudes and behaviours, communication, risk analysis, learning and oversight and scrutiny. This has enabled statements of good practice to be developed, together with question sets that can be used by regulators and the industry to profile organisational risk management resilience and thereby drive organisational learning. The research shows that the processes of incubation and evolution of disaster events can be complex and exercising control therefore requires development of more sophisticated 'tools' than are currently available. It has revealed repeating patterns of failure and the importance of psychological and behavioural factors which have led to poor decision-making. Causal loop modelling is being used to capture these patterns to facilitate the design of more informed interventions. Emerging issues and new approaches being developed are discussed and examples given.

1. Introduction

Serious accidents (and near-hits) still occur 'out of the blue' in all high-hazard industries and, in some cases, occur in organisations with an excellent industrial safety record. Major transport accidents, civil engineering project disasters, petrochemical industry events such as the Buncefield explosion and Gulf of Mexico accident and nuclear accidents such as that in Fukushima all illustrate the potential for major loss of life, environmental damage and impact on the industry in terms of production, collateral losses, company value and reputation. They can also have a significant impact on the integrity of national infrastructure.

The capacity to identify frailties in maintaining risk control in complex sociotechnical systems is fundamental to maximising resilience. Increasing engineered complexity, technical specialisation, fragmented contractual arrangements and other factors conspire to make it increasingly difficult for individuals and organisations to recognise weaknesses in risk control. Often, problems arise because the array of salient variables outstrips human cognitive capacity to comprehend the complexity of interactions by using current approaches. This has highlighted a need for effective decision-support tools.

2. Research background

The analysis reported here draws on important early works on developing the conceptual framework of complex accidents, aimed at obtaining an understanding of the underlying causes of accidents, carried out by such authors as Turner and Pidgeon (1997), Pidgeon *et al*. (1991), Reason (1997) and Toft and Reynolds (1994).

Other accident models have explored the complex sociotechnical issues involved. Perrow's (1984) normal accident theory, with its concept of coupling and complexity, presented an argument for the need for a greater understanding of the inherent interdependence within the systems being modelled. 'Systems' models and tools have been developed to address this (at least partially) by Rasmussen (1997), Hollnagel and Goteman (2004), Leveson (2004), Léger *et al*. (2009) and others.

In this context, Reason's Swiss cheese model (SCM) has exercised considerable influence. In this approach, weaknesses in all relevant factors potentially leading to an event are modelled as 'holes' in defences arising from risk-control procedural oversights, failures in engineered systems or the wider cultural issues which facilitate or allow these holes to develop.

The SCM is seen largely by those who advocate systems-based approaches (e.g. Hollnagel and Goteman (2004), Leveson (2012)) as reductionist, linear and focused on specific failures rather than emergent system-level behaviours. This focus can be at the expense of understanding more complex accident development processes involved, particularly in situations where an event arises at the system level without any specific 'failures' at lower levels. Such failures can occur due to the structure of the system itself

(Marais *et al*., 2006; Senge, 1990). Reason *et al*. (2006) argued that the actual theory underlying the model better reflects the complexity of reality than the common 'Swiss cheese' visual metaphor may suggest.

Reason (1997) also gave a simple and compelling presentation of the importance of some of the 'deeper' issues leading to what he termed 'organisational accidents'. This involves the important concept of incubation (see also Turner and Pidgeon (1997)) or 'latent pathogens'.

This paper considers what further should be done to provide the industry and regulators with practical tools, building on some of the mentioned approaches, to identify and apply remedial measures to address organisational and cultural event precursors.

3. Previous research at the Safety Systems Research Centre

Previous work at Bristol University, initiated by British Nuclear Fuels and funded by the UK Nuclear Installations Inspectorate (now the Office for Nuclear Regulation), studied the organisational and cultural precursors that underlie the more easily identifiable causes of engineering disasters (Taylor *et al*., 2015). This drew on the findings of an earlier industry study (Taylor and Rycraft, 2004).

Twelve major events were studied. These were

(*a*) Port of Ramsgate walkway collapse (UK, September 1994)
(*b*) Heathrow Express new Austrian tunnelling method (NATM) tunnel collapse during construction (UK, October 1994)
(*c*) Longford gas plant explosion (Australia, September 1998)
(*d*) Tokaimura criticality accident (Japan, September 1999)
(*e*) Hatfield railway accident (UK, October 2000)
(*f*) Davis–Besse nuclear reactor pressure vessel corrosion event (USA, February 2002)
(*g*) Loss of the *Columbia* shuttle (USA, February 2003)
(*h*) Paks nuclear plant fuel-cleaning event (Hungary, April 2003)
(*i*) Texas City oil refinery explosion (USA, March 2005)
(*j*) Loss of containment incident at the Sellafield Thermal Oxide Reprocessing Plant (UK, 2005)
(*k*) Nimrod air crash (Afghanistan, 2006)
(*l*) Buncefield oil storage depot explosion (UK, 2005).

The published investigation reports on these events on which the studies were based (references to the relevant reports and the methodology used are given by Taylor *et al*. (2015)) repeatedly reached conclusions which showed that failures were attributable to very similar organisational and cultural weaknesses, suggesting that if defences could be developed, they would have wide applicability.

Organisational and cultural findings contributing to the events were then assembled and initially grouped under eight generic 'themes' or 'categories'

(*a*) leadership issues
(*b*) operational attitudes and behaviours (local operational 'culture')
(*c*) impact of the business environment (often commercial and budgetary pressures)
(*d*) oversight and scrutiny (O&S)
(*e*) competence and training (at all levels)
(*f*) risk assessment and risk management application (also at all levels)
(*g*) organisational learning
(*h*) communication issues.

From these findings, sets of 'expectations' were developed as statements of good practice in the form of high-level strategic requirements, which, if recognised and implemented, should enable organisations to build stronger defences against the reoccurrence of similar failures.

It is important, however, that duty-holders and regulators are able to assess not only whether the salience of such event precursors has been recognised in organisational requirements/policies, but also that they have been 'absorbed into the bloodstream' of the organisation. Thus, the next vital step is to ensure that actions and practices are demonstrably in place to ensure that they are carried over effectively into operational practice at all levels from the boardroom to the shop floor. To this end, the expectations were developed into sets of draft 'penetrating' questions which actively explore whether 'reality aligns with expectation'. Such question sets may provide a valuable tool for scrutinising existing defences and, in particular, assessing whether these offer an acceptable degree of resilience to the organisational and cultural precursors to events. The question sets can be used collectively to provide an overview of current organisational capability or to explore particular areas of potential concern.

4. Modelling the overall system

The analysis of events also enables a broader picture of the resilience of the system involved to be developed. One possible approach is set out in Figure 1. It starts from the judgement that a primary issue in all of the events studied is a shortfall/failure in leadership. Effective leadership provides three essential requirements in minimising the risk of organisational accidents. The first of these is setting the values and expectations for 'process safety'; the second is ensuring that there is an effective safety management system for process safety (SMS), supported by sufficient resources and with clearly defined accountabilities; and the third relates to setting and being seen to commit to attitudes and behaviours which provide a basis for the effective use of the management system. In this paper, the industry context of all of these events is referred to as process safety – this is normally used to refer to chemical or petrochemical industries, but it is used here to refer to any industry process that relies for safety on effectively managing the interaction between engineered systems, processes and people in a complex setting.

The way in which leaders make decisions and the culture which they set within the organisation is often bounded by the commercial

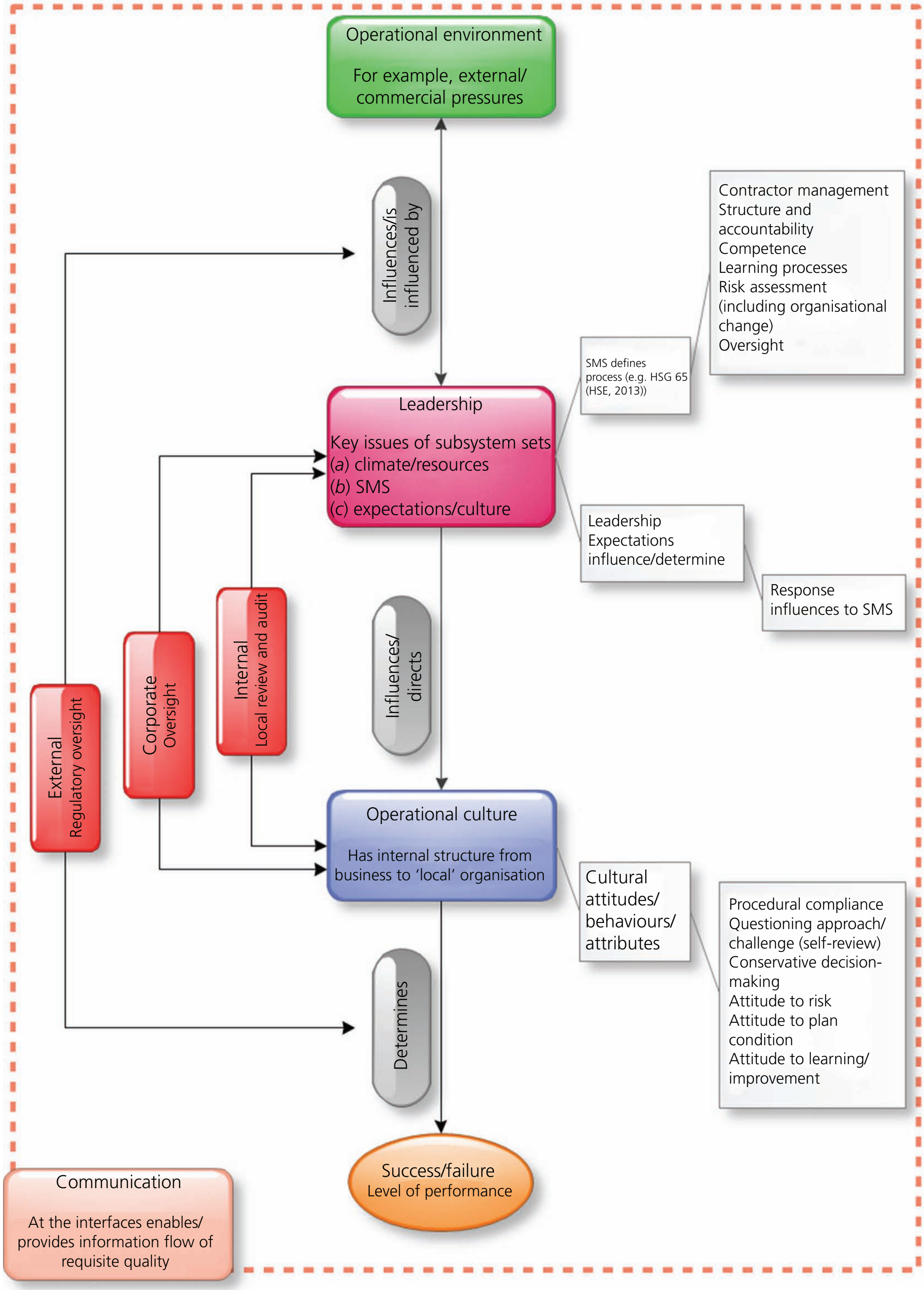

Figure 1. Flow chart of activities/processes related to areas of potential vulnerability within an organisation

and 'political' environment in which the organisation operates. In nearly all of the events studied, a significant precursor to the event appeared to relate to the actual or perceived pressures on the organisation. Leaders can still be effective, and safe operations achieved, in the light of such pressures, but what the authors have called the 'operational environment' seems to be an important factor which can dispose an organisation towards decision-making which does not take sufficient account of safety risks.

The third major box in Figure 1 is labelled ‘operational culture’. This is strongly influenced by the ‘tone from the top’. It includes the way that the workforce commits to procedures, a questioning attitude, willingness to make rigorous and prudent decisions and the general way in which the management chain prioritises and reacts to learning opportunities.

Although there is clearly much overlap, these cultural attributes have been separated from the issues which are listed on the right-hand part of the figure. Issues such as assuring competence, a process for risk management and management of organisational change are requirements of the SMS (see, for example, IAEA (2009) and HSE (2013)). However, their effectiveness is determined both by leadership expectations and by the operational culture.

Finally, what has been termed O&S provides a mechanism, if effective, by which shortfalls in the mentioned areas can be put right. Not only does it enable organisational learning, providing opportunities for continuous improvement, but it is also a ‘long stop’ with the ability to spot and remedy deficiencies before they lead to significant events.

Communication failure has also been identified as an important factor in nearly all of the events studied. Almost every accident investigation concludes that at some stage communication broke down. This can occur in a wide variety of ways, including a failure by leaders to be clear about requirements for a strong safety culture backed by demonstration of their own commitment, breakdown in communication between work groups such as between client and contractor or between engineering and operations functions and at a working level in ensuring the adequacy of risk assessments and handover procedures. Effective communication provides an essential ingredient in the effectiveness of all of these. It pervades the whole process map.

5. Issues which need to be addressed

There are four key areas which the authors believe need to be explored in greater depth if sustainable progress is to be made in developing greater resilience to the ‘causes’ of major events. In particular, there is a need to develop ‘practical tools’ based on deeper understanding and modelling that unpack and bring transparency to areas of organisational vulnerability that are masked by the increasing complexity of engineered systems. This needs to take account of the interplay among structural, cognitive, social and behavioural elements to enable the industry to identify and develop sufficiently sophisticated risk controls. This requires the use of a systems approach (e.g. Senge (1990), Blockley and Godfrey (2017)) to take account of the interactive nature of the issues identified.

Four key questions have been identified from the research which the authors believe need to be addressed further to achieve the objective of developing greater resilience to the causes of major events. These are the following.

(*a*) Can usable, effective, reliable ‘tools’ be developed, akin to techniques such as fault trees and probabilistic risk assessment (PRA), which would enable organisational and cultural vulnerabilities to be identified in a systematic way based on learning from the collective findings of failure-event analyses such as those described earlier?
(*b*) In studying the development of organisational failure, repeating patterns of failure emerge. Can ways be found to enable the industry and regulatory bodies to identify incubating contributors to failure such that their development can be identified at an early stage and appropriate mitigation action be taken?
(*c*) Almost all of the events embodied elements that were related to psychological factors which led to flawed decision-making – for example, leadership style, incomplete or flawed mental models, cognitive bias and group process effects such as social conformity and groupthink. Can these recognised phenomena be integrated into failure models?
(*d*) Having identified vulnerabilities, can tools be developed to enable modelling of alternative intervention strategies to inform and support decision-making by using a systems approach to take account of the complexity and interactive effects involved?

5.1 Assessing vulnerability

Hierarchical process modelling (HPM) provides a detailed understanding of the ‘top’ process (i.e. the highest-level process that defines the purpose of a given activity) in terms of the factors that lead to the success of that process. The hierarchy elaborates these factors in increasing levels of detail. It can improve transparency by enabling stakeholders to ‘walk through the model’ and understand how lower-level processes affect the performance of higher-level processes. It thus introduces a systematic approach to the analysis of the issues and the opportunity to prioritise them much in the same way that PRA achieves this in a more conventional engineering context. The output from HPM can be potentially valuable if it is used as a systematic method for identifying areas of vulnerability and consequent priorities for improvement.

As an illustration of the approach, in an earlier publication (Taylor *et al*., 2015), a prototype hierarchy was developed for ‘organisational learning’. Here, as a further example, aspects of O&S are considered further.

When failures occur in organisational processes and/or as a result of a weak organisational culture, this can be put right before a major failure occurs by oversight systems designed to alert different layers of the organisation to the deficiencies. Thus, audit and management review through the responsible line management function is one safeguard; audit and scrutiny by a broader business function is another and higher-level corporate oversight is the third. Each of these has a different focus. Thus, line management audit and review processes are likely to be most effective at detecting more detailed shortfalls in procedures and compliance with them, while the higher-level processes should give a broader perspective, enabling cultural and organisational issues to be identified against a broad base of comparison and with the potential benefit of greater independence. However, information and data become more 'rolled up' in progressing up the organisation. This gives rise to the risk of fostering superficiality, unless there is a strong questioning approach and a constructive 'tension' set up between those parts of the organisation operating at the 'sharp end' and those whose responsibility it is to inform and provide reassurance to company boards and executive committees. Beyond this, for 'high-hazard' industries in many countries, there will be a regulatory body providing a range of oversight processes from monitoring to in-depth scrutiny. Failures in oversight were (perhaps unsurprisingly) a common feature of all of the events studied. The following specific issues were among those identified.

- There was a failure to have in place a system such as that outlined earlier. In some cases there was only a conventional audit process – often solely within the line and consequently lacking clear independence. In some cases oversight appeared generally weak – it did not appear to look beyond paper systems and failed to identify failures to comply and deficiencies in the underlying safety culture.
- Oversight processes were sometimes ineffective because they were either poorly resourced or because reports and feedback were not given sufficient weight and/or were not the subject of sufficient questioning by the recipients of the reports. This was sometimes reinforced by a 'good-news culture' in which 'unwelcome' findings were not highlighted or acted on.
- In some cases, information being fed to senior leaders was aggregated such that weaknesses relating to particular plants or functions could not easily be identified and addressed. On occasions, there was also a failure to prioritise actions and then to check that actions had been carried out and had achieved the desired outcome.
- Early warning of emerging issues can most effectively be identified in the oversight process if key measures and issues are integrated. Thus, it is not sufficient just to rely on performance indicators. An effective system uses these together with audit findings, event reports and senior leaders questioning safety performance systematically to the same depth and intensity to which financial and project-related programmes would normally be scrutinised.
- Safety departments, which might be expected to provide independent authoritative advice, were not sufficiently resourced or competent and/or did not have sufficient authority to stop potentially unsafe operations.
- In several of the events studied, organisations had once been strong performers with a good reputation, but this had gradually eroded without the organisation being aware of this. This 'organisational drift' is thus often an important precursor to organisational accidents.
- Failure to detect weaknesses in process safety performance not only arose from the factors described above, but also from the lack of suitable safety metrics. In some cases overreliance was placed on metrics relating to industrial safety (e.g. 'slips, trips and falls'). In nearly all cases, suitable metrics relating to process safety were not available or contained only lagging indicators.
- There was evidence in many cases that leaders were unaware of the risks associated with the reality of the safety shortcomings at plant level. Findings were not always questioned – in some cases probably because of the lack of expertise at this level about the process safety issues involved and in others because it appeared that the needs of the broader business agenda did not align or sit comfortably with the information being made available through the oversight processes.

Some features of O&S are shown in an illustrative HPM in Figure 2. This starts with the 'key issue' of the effectiveness of organisational O&S in terms of the required layered, hierarchical process. It then moves to the effectiveness of the scrutiny exercised by the operational function directly responsible (which in some organisations may also involve a business function with its own requirements), a corporate safety department independent of the 'line' and reporting at executive team/board level and the regulatory body. In this illustrative example, the next 'layer' tracks from the corporate process to five lower-level processes. The first of these relates to the focus and attention given by the top leadership team; the second to their awareness and understanding of the risks that are being addressed; the third to the role and effectiveness of the corporate safety function; the fourth to the various sources of information and data made available to the top leadership team in order to enable their decision-making; and the final box to the input and value that is made as a result of a strong relationship with the regulatory body.

In a full HPM, each of the five subprocesses would be followed through to the relevant detailed penetrating questions as described earlier. Draft versions of these were identified from the authors' research into the 12 events studied and examples are given by Taylor *et al*. (2015).

5.2 Patterns of organisational failure

As noted previously, earlier research at the University of Bristol Safety Systems Research Centre also identified repeating dynamic patterns of system failure in many of the events studied. Understanding the detailed phenomena underlying these patterns may provide an effective means of increasing resilience to these repeating failure modes. In this respect, techniques such as system dynamics (SD) have already proved very promising in the authors' initial studies.

For example, starting with a prototype expert workshop and a further analysis of the events in which repeated patterns of failures in contractor management were exhibited (seven of the 12 events), key strategic issues have been recognised and 'mapped' and the complexities and interactive nature of these have been identified and considered (Taylor *et al*., 2016). An example is

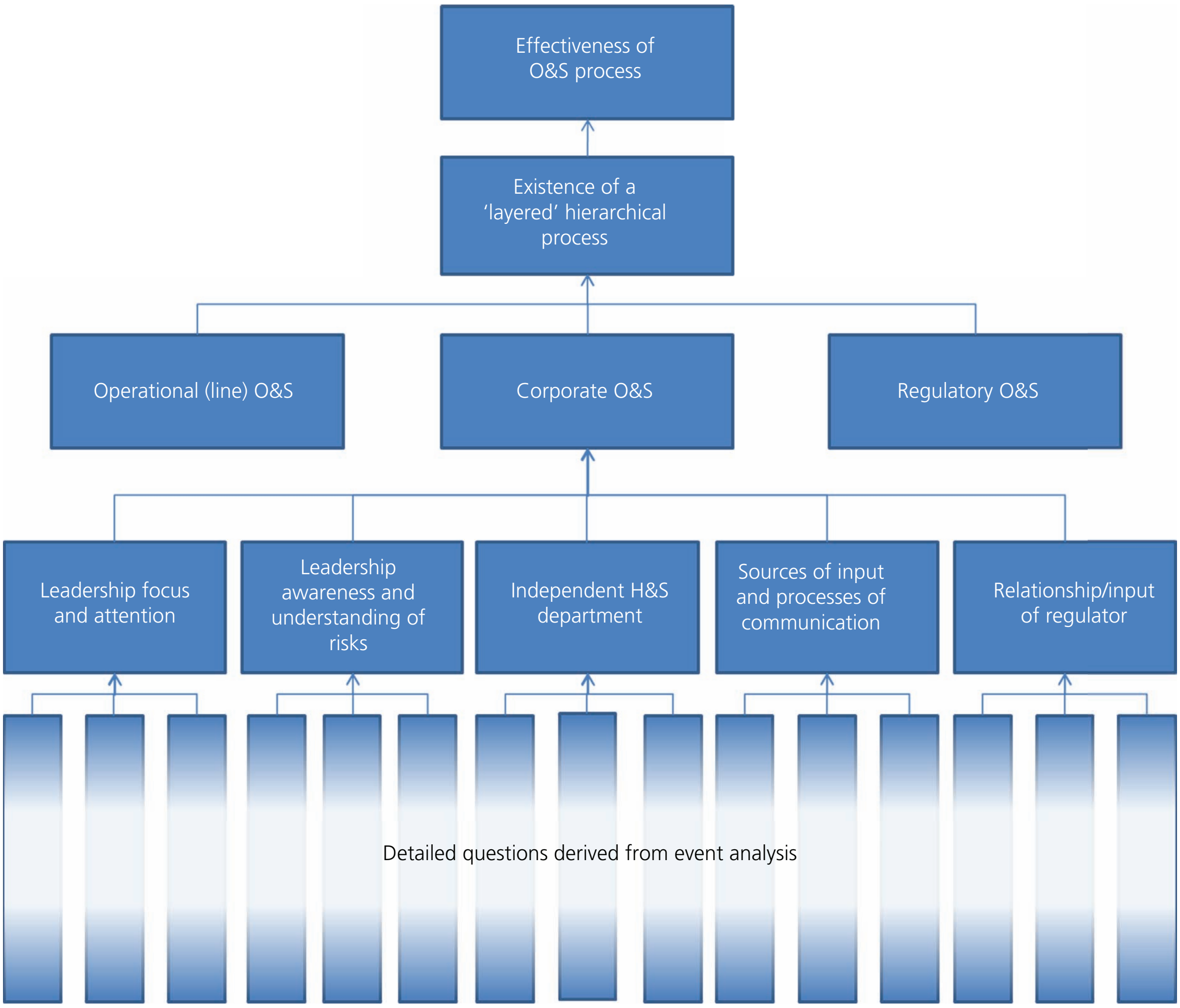

Figure 2. Outline HPM addressing effectiveness of O&S. H&S, health and safety

presented in Section 5.4. This research shows the importance of highlighting interdependencies and the impact of time lags within systems as vulnerabilities incubate.

Another example of such a repeated pattern of failure which was identified in almost all of the events studied involved a disconnect between knowledge and aspirations of those at senior management levels and those planning and carrying out operations. Usually, there are at least four links in the chain between the most senior organisational levels, where decisions will be made about major changes and the appetite for risk, through business group senior management, plant or project management and engineers and supervisors at the plant level, to those carrying out day-to-day operations. In the events studied, there was frequently a failure to ensure that effective information flows up and down the chain, and sometimes unintended 'messages' arose from a failure to consider ambiguity and possible incorrect interpretation. For example, tensions have arisen because of the need to maintain safety standards and at the same time to pursue productivity and cost objectives. Where this becomes part of custom and practice, it can be manifested as organisational 'drift' and normalisation of non-standard practice. The absence of 'bad news' can also give rise to unjustifiable complacency, characterised by a good-news culture. Within such a culture, the reality of plant safety is neither always appreciated nor addressed at more senior levels. The underlying drivers for this have been shown in the authors' initial research to be interdependent, dynamic and complex. To understand these drivers requires not only an appreciation of the interaction between relevant dormant precursors, but also an understanding of the psychological 'influences' which lead to the attitudes and behaviours that become embedded in the system if not adequately challenged.

Other patterns of failure that have been identified as potential priorities relate to

- failure to follow procedural requirements when these do not align with perceptions of individual and organisational needs

- failures in management of organisational change processes which, while often based on strong procedural requirements, often do not encourage the open discussion of important vulnerabilities such as the impact of commercial priorities
- a continuing inability to learn from experience even where there is a strong commitment to do so.

5.3 Psychological factors in decision-making

A defining feature of modern large-scale industrial systems and processes is ever-increasing complexity (Glendon *et al*., 2016). Recognising the potential for system failure, and attempting to engineer ways to mitigate this, pivots on the expertise and conceptual insight of designers, installers, operators and risk managers. Despite the development of monitoring systems, fault trees, risk assessment and other decision-support tools, the issue of complexity is challenging insofar as the limitations of human cognitive capacity represent a barrier to recognising potential pathways to failure. This situation is compounded by the increasing specialisation and bureaucratisation of expertise, such that knowledge becomes bounded and compartmentalised (Rasmussen, 1997).

A widely recognised cognitive strategy for dealing with complexity, particularly for time-sensitive decisions (e.g. in emergency situations, during process disruptions), or simply because it is quicker and easier, is to draw from a library of tried-and-tested solutions. This might involve extrapolating from ‘recognised’ patterns, or selecting a smaller number of what are deemed to be key variables, the interactions between which can be more readily comprehended (Rundmo, 1992). Much of this processing can be characterised as inferential sense-making based on pattern recognition, referenced to a mental model of how salient features are believed to interact (Doyle and Ford, 1998). Most of the time, such strategies serve well – indeed pattern recognition and heuristics are an essential features of how human beings operate. However, they can prove problematic where important features go unrecognised or are underplayed – for example, where recourse to old tried-and-tested solutions omits to take account of unique features of an otherwise familiar presenting issue.

Even where more systematic strategies are adopted, much rests on the accuracy, completeness and sophistication of the mental models of the decision maker(s). From the perspective of organisational resilience, it is important to be able to recognise where knowledge gaps and misunderstandings proliferate and the circumstances that might give rise to them. This is particularly important where personnel have limited conceptual knowledge or understanding of the systems that they are working with. Resilient risk management systems take account of and mitigate knowledge gaps, traits and decision biases (Cox *et al*., 2003; Woods, 2003).

However, there is need to consider variables beyond the cognitive traits and capacities. Workplace decisions are made in a specific sociopolitical context, where cognitive elements tend to be moderated and/or mediated by social, structural and technical elements. These include awareness (and intuitions) relating to corporate/managerial priorities, implications for career prospects, systems of reward, social approval or disapproval of peers or superiors and pressing operational demands (Weyman *et al*., 2006; Zohar, 2002). It is important to recognise and take account of how such features of workplace climate play a role in defining the decision makers’ choice architecture. Other, more subtle influences on choice architecture include informal social influence; custom and practice; social norms and related variables that come to define workplace safety culture. Their relative salience can also be variable within a single organisation – for example, between different functions, departments or work teams (Meams *et al*., 1998).

The use of safety culture/climate surveys and similar methods means that many organisations have the capacity to become aware of weaknesses in this area. However, most struggle with crafting effective solutions. The capacity to recognise the importance of safety climate on risk management performance is not matched by the capacity to find effective, durable ways to mitigate undesirable effects on culture and behaviour (Weyman, 2012).

However, undesirable features attributable to group process effects are not limited to the shop floor. While many senior managers conclude that ‘there is something wrong with *their* (employee) safety culture’, many are reluctant to take on board fully their own role in framing the prevailing safety climate (Gadd and Collins, 2002). Similarly, they are vulnerable to overlooking how group processes can negatively impact on their own decision-making.

The evidence on group process effects in collective decision-making highlights both a tendency towards more extreme options (risky shift and group polarisation) giving rise to excessive risk seeking or excessive risk aversion and moderation effects. The amassed findings point to the conclusion that contextual components – for example, senior management style, political expediency of achieving consensus and magnitude of the consequence of undesired outcomes – can play a key role (Woods, 2006). Indeed, while group members sharing a common worldview/mental model can represent a strength, this is moderated by the risk of sponsoring groupthink. This is particularly relevant where dissident voices are absent or suppressed, such that system weaknesses and vulnerabilities are underarticulated, unrecognised or simply ignored.

The literature on these and related decision-making phenomena is extensive and is at a fairly mature level. However, to date, there have been few attempts at its integration with engineering-derived models of system failure or resilience modelling. There are a number of fundamental challenges to achieving this, not least with respect to the characterisation of cause–effect relationships.

What is envisaged is a contribution to failure resilience modelling that is not unreasonably deterministic (as the underpinning behavioural science precludes this), but is enhanced through taking account of behavioural components in the representation of 'alternative futures' – that is, possible/foreseeable outcomes arising from alternative configurations of features of the sociotechnical systems under consideration.

Borrowing terminology from the public policy behaviour change domain, the contribution of the output from the envisaged resilience verification/enhancement models is perhaps usefully conceptualised as a nudge function (i.e. nudging organisations to consider the impact of identified threats to maintaining effective risk control). Essentially this is envisaged as operating as an internal challenge function, to support learning in high-reliability organisations (Argyris and Schön, 1996; Leveson *et al*., 2009; Weick *et al*., 1999).

5.4 Developing effective interventions

The effectiveness of interventions can be improved by developing a sufficient shared understanding of the problem being addressed. This helps ensure that any recommendations are grounded in a robust understanding of the mechanisms generating the problem situation and that those who are expected to implement them understand why they are important. This can be challenging when the problem exhibits significant complexity. Problem-structuring methods, informed by systems theory, offer a means of dealing with this complexity. One such method is the use of causal loop diagrams (CLDs). Such diagrams can be developed collaboratively by those involved as a means to illuminate the mechanisms underlying the problem to be addressed. These models can then be used as the basis for quantitative SD models, developing equations that reflect the nature of the causal relationships. These can be simulated and used to develop confidence in the models, or to perform analysis on the merits and risks of potential corrective actions.

CLDs are visual models consisting of two components: named variables and directional arrows representing the causal influence that they have on one another. Variables can influence each other in one of two ways: first, one variable may have a positive relationship with another in the sense that any change in one variable causes a similar change in another. In other words, if an increase in variable *A* causes an increase in variable *B*, they have a positive causal relationship. This is visually represented by an arrow from variable *A* to variable *B* with a '+' sign at the head. This positive relationship can also mean that a decrease in variable *A* would cause a decrease in variable *B*. The second type of causal relationship is an inverse or negative relationship (i.e. a change in variable *A* causes an inverse change in variable *B*). This is represented by an arrow from variable *A* to variable *B* with a '−' sign at the head.

When combined, these two types of causal connection can form feedback loops between the variables. Some feedback loops reinforce growth or decline of the variables; others work to balance changes. The diagram in Figure 3 is extracted from a larger model constructed by experts from a range of process safety industries in a workshop facilitated by one of the authors of

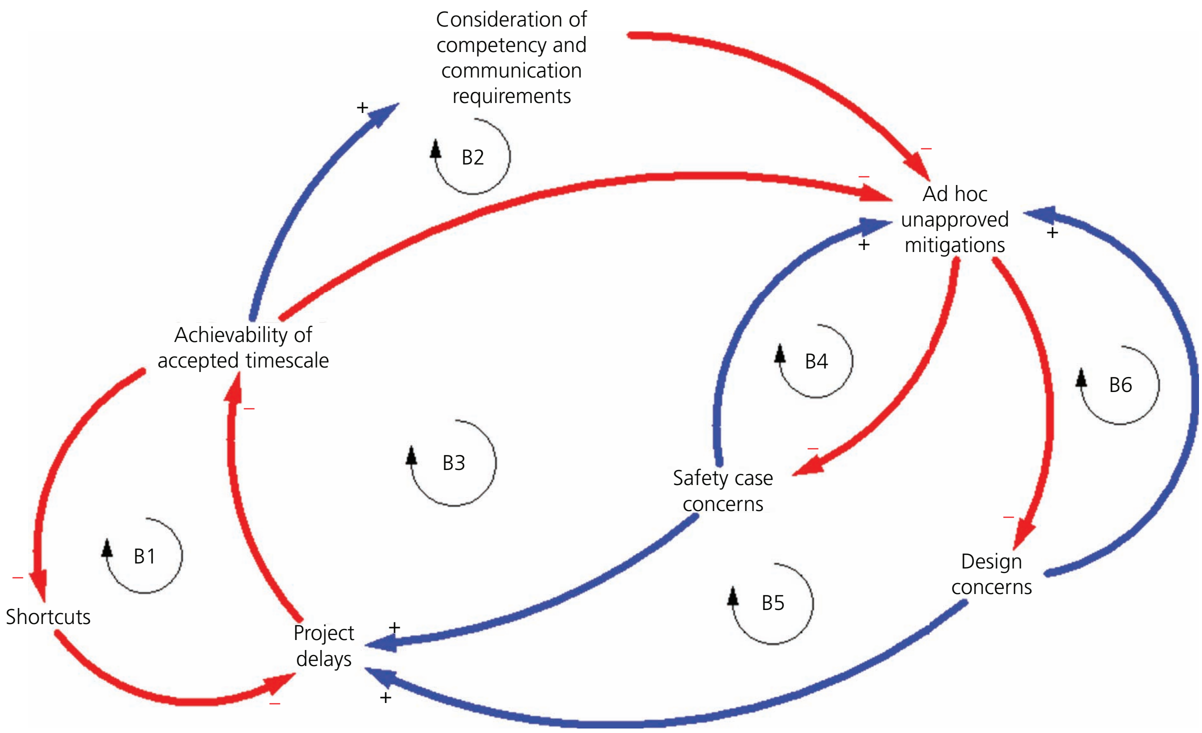

Figure 3. Example of CLD

this paper. It shows six feedback loops relating to 'ad hoc unapproved mitigations' to undesirable situations. This has been identified, for example, as an important failure mechanism in some contractual arrangements where the contractor is under pressure to complete work to time and cost even when there are emerging problems that need to be addressed. As an extract, it is presented only to demonstrate the use of CLDs in this context, rather than to provide comprehensive coverage of the insights or issues that it contains. One of the strengths of this approach is that it makes assumptions about the relationships between variables explicit such that they can then be critiqued and potentially mitigated by others.

The feedback loop labelled B1 can be read as follows: if project delays increase, they cause the achievability of accepted timescale to change in the opposite direction – that is, the achievability of accepted timescale decreases. A decrease in the achievability of accepted timescale in turn causes the number of shortcuts taken to increase and this causes project delays to decrease. Hence, a balancing loop is formed that attempts to counteract any delays. If any of the three variables in this loop begin to change, then the structure of the loop will work against the change.

Similar balancing feedback dynamics play out in the other loops through ad hoc unapproved mitigations. For example B2 'says' that an increase in safety case concerns could cause project delays to increase; this in turn reduces the achievability of the accepted timescale; this reduction in the achievability of the accepted timescale causes an increase in ad hoc unapproved mitigations in order to address the safety case concerns, therefore reducing them.

Through collaboratively constructing these diagrams, it is possible to gain an insight into the nature of the system, design meaningful interventions to counter unwanted feedback loops and communicate motivation to those involved in the problem situation. In some situations, it also allows more effective performance indicators to be agreed.

6. Conclusions

Major events in high-hazard industries have revealed strikingly similar organisational and cultural precursors when studied collectively. These 'common findings' have been brought together and expectations and question sets have been developed that should enable duty holders and regulators to explore potential vulnerabilities more effectively. This is important because although much progress has been made in addressing vulnerability arising from engineering and human failure, systematic approaches to addressing these 'deeper-lying' precursors to events have not generally been available.

The authors' research has not only enabled initial steps to be taken, but has also pointed to the need to develop new approaches and associated tools if the often incubating, organisational and cultural precursors are to be identified and steps taken to apply effective interventions. These are as follows.

- A more systematic approach to their early identification should be developed. Here, HPM provides the basis for an effective tool which is in some ways analogous with quantitative risk assessment techniques used in the identification of engineering vulnerabilities.
- Collective analysis of events shows that patterns of failure frequently occur. Some of these have been identified from the authors' studies. This demonstrates the need for a systems approach to address the interactive and connected nature of many of the identified precursors.
- Such a systems approach needs to be underwritten by a better understanding of the behavioural and psychological influences on decision-making. If effective interventions are to be designed to increase resilience to the causes of major events, it is important that learning from the social sciences is used to inform thinking.
- In addressing the identified issues, the use of causal loops and SD shows promise of providing a usable and relatively simple approach which would allow effective interventions and associated performance indicators to be developed collaboratively to take account of the complexity and the psychological factors involved.

Further research might be profitably aimed at developing new techniques to address the identified issues and at developing new tools and approaches which could be made available to high-hazard industries and their regulatory bodies to address these and to provide more effective oversight. The learning from the collective study of major safety-related events may also apply to other examples of organisational failure (e.g. financial, healthcare). They may also provide an improved basis for event investigation.

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