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Examining the asymptote in safety progress: a literature review

Sidney Dekker[a,b*] and Corrie Pitzer[c]

[a]*Griffith University, Australia;* [b]*The University of Queensland, Australia;* [c]*Safemap International, Canada*

Many industries are confronted by plateauing safety performance as measured by the absence of negative events – particularly lower-consequence incidents or injuries. At the same time, these industries are sometimes surprised by large fatal accidents that seem to have no connection with their understanding of the risks they faced; or with how they were measuring safety. This article reviews the safety literature to examine how both these surprises and the asymptote are linked to the very structures and practices organizations have in place to manage safety. The article finds that safety practices associated with compliance, control and quantification could be partly responsible. These can create a sense of invulnerability through safety performance close to zero; organizational resources can get deflected into unproductive or counterproductive initiatives; obsolete practices for keeping human performance within a pre-specified bandwidth are sustained; and accountability relationships can encourage suppression of the 'bad news' necessary to learn and improve.

Keywords: asymptote; safety bureaucracy; vision zero; behavioral safety; resilience; accidents

1. Introduction

Many industries are confronted by plateauing safety performance as measured by the absence of negative events – particularly lower-consequence incidents or injuries.[1] At the same time, these industries are sometimes surprised by large fatal accidents that seem to have no connection with their understanding of the risks they faced; or with how they were measuring safety. Thus, 'surprising' accidents have occurred in organizations with apparently stellar safety records.[2] Could both these surprises and the asymptote be linked to the very structures and practices organizations have in place to manage their safety? This article reviews the available safety literature for a possible answer.

The idea that the very structures and processes which are meant to improve safety actually do the opposite is not new in safety research. Protective structures, or defenses, have long been known to create new kinds of vulnerabilities because of their unexpected interactions and couplings. Barry Turner, back in 1978, traced how accidents and disasters are administrative or bureaucratic in origin; that the very processes intended to help forestall risk actually contribute to letting risk grow and leaving it unrecognized because of some very familiar and normal processes of organizational life [3]: 'disasters arise from an interaction between the human and organizational arrangements of the socio-technical systems set up to manage complex and ill-structured risk problems.'[4] The notion that this holds for how organizations tend to assure safety bureaucratically has received particular attention in light of recent large-scale disasters and accidents.[5]

The problems created by bureaucratically managing organizational safety through the prevention or suppression of low-impact, higher-frequency injuries (or to extrapolate process safety from personal safety) have been documented previously. Recent research has begun to examine the limited effectiveness of other safety management practices and the validity of the assumptions on which they are founded as well. Some cherished safety programs do not actually yield much.[6] Low-yield initiatives turned out to include safety orientations, written safety policies, recordkeeping, incident investigations and emergency response planning. Of the investments that were seen to have a safety return, upper management support, subcontractor selection and management and employee involvement in safety and work evaluation generated the most. Job hazard analyses, worksite inspections and safety meetings ranked halfway. Hallowell and Gambatese [6] did not explicitly study the reasons for such lack of (or differences in) safety yield, but Besnard and Hollnagel [7] noted how industrial safety management practices are driven by persistent 'myths.' These include that (a) human error is the major cause of disasters, (b) compliance is key for safety, (c) better barriers create greater safety, (d) root causes can be found and explain why accidents happen, (e) accident investigation is the rational activity that does just that and (f) safety has organizations' highest priority. Such myths both permeate and are expressed by safety management

*Corresponding author. Email:s.dekker@griffith.edu.au

practices, policies and structures. They make a safety organization and the safety profession part of the problem of stalled progress.

Bureaucracy, of course, has been known since Max Weber in the 19th century to produce secondary effects that run counter to the organization's objectives – precisely because of a bureaucracy's focus on rationality, hierarchy, quantification, formalized rules, divisions of labor and bureaucratic accountability.[8] It is through these structures and processes that inadvertent risk secrecy can develop; that information is not passed across or up or down; that organization members might be incentivized for suppressing 'bad news' and showing low numbers of negative events; and that preoccupation with process and compliance with paperwork becomes a stand-in for real risk assessment. In certain cases, such activities can emerge as anti-tasks which make non-random use of organized systems of protection.[4] The vulnerability to serious failure becomes concealed in the very systems of protection (e.g., loss prevention systems, safety management systems) that are supposed to collect, count, tabulate and highlight risk. This happens not only because of the sheer bureaucratic workload created by such systems, although that certainly plays a role. In 2008, for instance, 2 years before the Macondo well blowout, BP warned that it had 'too many risk processes' which had become 'too complicated and cumbersome to effectively manage.'[9] What also seems to happen is that years with supposed 'incident-free' performance can engender a collective sense of invulnerability, where a warning of an incomprehensible and unimaginable event cannot be seen, because it cannot be believed.[10] The question asked of the safety literature in this article is how current safety practices, processes and structures that are intended to forestall risk and assure safety actually contribute to the growth of vulnerability to larger failures, while stalling progress in safety of lower-consequence events – through various secondary effects associated with bureaucracy and normal organizational processes.

2. Method

This article examines how current safety practices associated with bureaucratic concerns around process, compliance, control and quantification could be partly responsible for both the plateau and the occasional large surprise. It reviews existing literature for assumptions about proportional relationships and causal similarity between incidents and accidents, linear causation, the existence of one best method and value of compliance and consistency, and ideas about operators' 'unsafe acts' as a final weak link in otherwise well-defended systems. The article has selected these aspects of the literature in particular because the research base suggests that such assumptions and practices in an industry can create a sense of invulnerability because of quantified safety performance close to zero. It has also examined the literature for suggestions that organizational resources can get deflected into unproductive or counterproductive initiatives; that obsolete practices associated with keeping human performance within a pre-specified bandwidth can be kept in place; and that accountability within and between organizations can encourage the suppression of the kind of 'bad news' necessary to learn and improve.

3. Results

3.1. Linear causation and complexity

Linear causation, or the notion that an effect is the proportional, direct result of a preceding cause, has been popular in safety thinking since the 1930s. This idea is grounded in Newtonian thinking,[5] where each effect is assumed to have an identifiable cause – a popular notion still seen as consistent with nature, commonsense and science. A most persistent idea (or indeed myth) is that there are common causes to incidents and accidents (this idea is maintained in chain-of-events, defenses-in-depth and Swiss-cheese models), and that serious injuries, accidents and fatalities can be avoided by reducing or avoiding minor incidents and safety events. The empirical basis of surprising accidents (e.g., the Macondo blowout which caused 11 fatalities after 6 years of supposed incident-free and injury-free performance) drastically belies this myth. But more systematic studies do as well. A study of Finnish construction and manufacturing from 1977 to 1991, e.g., showed a strong correlation between incident rate and fatalities, but reversed ($r = -.82$, $p < .001$). In other words, the fewer incidents a construction site reported, the higher its fatality rate.[11] The same effect has been observed in the aviation industry, where passengers' mortality risk goes up when they board airlines that report fewer incidents.[12] In other words, the equivalent-cause assumption between incidents and accidents (and the suggestion that we can prevent accidents by focusing on incidents) has no empirical support, or at least a very troubled empirical basis.[13]

Also, because of the idea of linearity in causation, and because of outcome and hindsight biases, people involved in, or responsible for, safety outcomes easily overestimate how well they could have predicted events that have now indeed occurred (e.g., 'this was an accident waiting to happen' [9]). Researchers get caught in these *post-hoc* biases as well. Commenting on what he saw as failures of foresight by visiting VIPs to the Deepwater Horizon rig hours before the Macondo disaster, Hopkins judged that:

> Something was going seriously wrong before their eyes, but because of the constraints they had imposed on themselves, they turned away and investigated no further. Not only was an opportunity lost to do some informal auditing, but so too was an opportunity lost to avoid disaster. Apart from the reduced pressure test, there was a second missed opportunity to avoid disaster that afternoon . . . for observers to know whether the outflow matched the inflow.[14]

Such *post-hoc* biases to our own understanding of predictability and preventability tend to imbue subsequent interventions with overconfidence. Following Newtonian logic, we suggest componential solutions (taking out one of the causal links in the chain, e.g., by inserting an enhanced procedure or removing a fallible human operator). We subsequently wonder why these interventions are not having the sought-after effects, and we once again tend to blame individual components (e.g., non-compliant human operators) for their failure. Such interventions thus tend to retain the *status quo*.

According to the Newtonian image of the world, the future of any part of it can be predicted with certainty if its state at any time was known in detail. Following this logic, if we fail to foresee harm, we tend to blame a lack of effort or intelligence (something that is often asserted in the aftermath of an incident, injury or accident). Thus, organizations invest in enhancing their safety intelligence, with some now sitting on vast numbers of incident reports (which often remain open) or the products of other forms of surveillance (e.g., monitoring systems in vehicles and control rooms). The governance challenges are significant, not just with respect to data integrity but also to the analytic yield. Safety work can become coincident with ever greater data gathering; the tragedy being under-analysis. This produces interventions that are known to retain the *status quo*: behavioral controls, re-education and safety policies.[15]

3.2. Compliance and consistency

The confidence that compliance with existing written guidance (rules, procedures, checklists, standards) is essential for safety has arisen in part from the Tayloristic management movement of the early 20th century.[16] Reducing work to its most basic components and assuring compliance with the one best method for achieving its results (managed by imposing a layer of front-line supervisors) was thought to guarantee consistency, efficiency, predictability, quality and indeed safety. Tayloristic thinking, in caricature, suggests that managers, engineers and planners are smart and workers are dumb. Such thinking shows up frequently in contemporary research, for instance when it rhetorically asks:

> ... whether it is reasonable that safety-relevant decision-making by front line workers or operators be based primarily on their own risk-assessments? For a number of reasons, the answer is: No. In the first place, workers may not fully understand the hazards and the controls that have been put in place to deal with those hazards.[17] Q9

Tayloristic thinking, however, gets faithfully and uncritically reproduced in research on safety and safety culture – and many industries follow suit. According to these ideas, people are the problem that needs to be controlled through stricter compliance. Those who made the rules figured it all out, and those who are employed to follow them should not stray from the script:

> It is now generally acknowledged that individual human frailties ... lie behind the majority of the remaining accidents. Although many of these have been anticipated in safety rules, prescriptive procedures and management treatises, *people don't always do what they are supposed to do*. Some employees have negative attitudes to safety which adversely affect their behaviours. This undermines the system of multiple defences that an organisation constructs and maintains to guard against injury to its workers and damage to its property.[18,original emphasis] Q10

Interestingly, such insights are rarely based on empirical evidence, but seem supported more by dogma and belief. The assertion that most accident reports contain evidence of non-compliance with written guidance can of course not count as evidence. Not only is this no more than the attribution of a particular set of analysts; it is also trivial. Non-accidents are preceded by non-compliance too – the 'messy interior' of any organization always features a gap between how work is imagined and how work is performed. Calling that gap a 'violation' or 'non-compliance' is a moral judgment which obscures the adaptations and resilience necessary to get real work done under resource constraints and goal conflicts. Yet current practices, beliefs and vocabularies associated with compliance and consistency help maintain the *status quo*.

In contrast to the moral judgment and safety dogma that underlies calls for consistency and compliance, empirical research shows the importance of diversity and adaptation:

> ... studies of work practices have often highlighted the improvisational nature of actions at the sharp-end where physical, social and temporal constraints force individuals to depart from prescribed procedures by making local adjustments and improvisations.[19] Q11

Procedures and other written guidance are a resource to inform situated actions, among other resources.[20] The sequential nature of procedures is often mismatched to task demands.[21] Procedures do not specify all circumstances in which they fit, and cannot dictate their own application. Applying procedures and following rules successfully across complex, dynamic situations can be a substantive and skillful cognitive activity. Safety results from people being skillful at judging when (and when not) and how to adapt written guidance to local circumstances:

> Regardless of how carefully an activity may be prepared, it is impossible in practice to describe a situation in every little detail. The original plan, such as it is, must therefore be adjusted to fit the action as it takes place.[19] Q12

Consistency, then, is not the only point for creating safety in complex dynamic operating worlds. Strict compliance with procedures has even been known to lead to fatalities in some cases.[22,23] The focus on compliance and consistency mismatches actual ways in which safety and risk get created throughout organizational hierarchies.[24] Field studies of safety-critical work show expert judgment, rather, as key [25–27] and affirm that imposing limits on such expertise, e.g., through buggy training and preparation or compliance demands, adds to risk.[28]

Careful ethnographic study of safety-critical activities has even revealed the dichotomy between planned (compliant) and adapted (non-compliant) work to be spurious [19] or at least heavily situation dependent.[29] During a planned non-productive outage at a nuclear power plant, it became clear that merely describing actions as planned and compliant or as improvised and non-compliant oversimplifies the subtleties and complexities of maintaining control. What matters, indeed, is maintaining control through subtle human judgment and expertise. Recent ethnographic research in safety-critical industries has affirmed that 'compliance with a pre-defined envelope underestimates the direct contribution to safety from operational managers based on their professional judgment [and] by experienced operating personnel when abnormal situations arise.'[30] Q13

3.3. Risk control

The growth of complexity in many industries has outpaced our understanding of how complex systems work and fail, and how we can best regulate them.[5] In many cases, our technologies have got ahead of our theories. We are able to build things – deep-sea oil rigs, collaterized debt obligations – whose properties we understand, certify and monitor in isolation. But in competitive, regulated settings, their connections with other systems tend to proliferate, their interactions and interdependencies multiply, and their complexities mushroom. The design and operation of modern safety-critical technologies are both configured in expansive webs of contractors and subcontractors, who are themselves at the receiving end of transferred risks from clients, who establish thin-margined contracts and who demand high-quality safety systems and 'zero' negative outcomes. Moreover, they are cross-regulated by a number of agencies that hold them accountable for variety of performance indicators and measures. In such configurations, the construction of risk by any agency or participant depends on where in the web they are, what they bring and what they see:

> Risk, perhaps most simply defined as the probability of a bad outcome, does not exist in an objective space as an unchangeable feature of the physical world. Rather, risk is a construct which we, with our bounded human imaginations, overlay on the world around us. In order to decide what is the 'risk' of a given negative event, [we] have to make a host of simplifying assumptions about the context in which it arises. The kind of imagination we bring to this activity, moreover, depends on our objectives, values, training and experience. The risks we control therefore do not exist in reality but only in an artificial micro-world of our own creation.[31] Q14

This is what complexity does: what any participant in her or his part of a complex system sees and has access to is unique from that position, and cannot be reduced to that of any other. Risk may seem to exist in the part of the system that this participant directly interacts with. But the further away one moves from that position, the more it may slide out of view, to be replaced by other constructions of what is risky which make sense from that perspective. Hence the notion of 'objective' risk becomes problematic. The idea of risk 'control' does too. The deep interconnections that spread across a complex system, many of them unknown because of the sheer size and computational demands their understanding would impose, create a unique control problem.[32] Indeed, in a complex system, any participant's action tends to control very little, even though that action can influence almost everything.

This does not stop organizations from attempting to stabilize parts of a complex, dynamic system through process, paperwork and protocol. Risk is seen as under control (or at least it is known where it is not completely under control) when such exercises reach their logical endpoint: the completed audit, the safety case, the probability calculation. Many of these, however, result in what are known as 'fantasy documents.'[33] These are pieces of paperwork that force a particular dynamic of the complex system into congealed stability. They tend to be underspecified relative to the situation or work they represent, and can quickly devolve into obsolescence or tick-box exercises (e.g., safety orientation, emergency response planning). Such 'risk control' sometimes seems to have drifted toward managing the organization's liabilities if something was to go wrong – more than preventing that something goes wrong.

3.4. 'Human error'

The plateauing of safety performance across many industries has coincided with a resurgence of behavioral safety interventions. These interventions (e.g., 'behavior modification') target the worker and their 'errors' and 'violations,' not the working conditions.[34] This contrasts with the essence of human factors, which since the 1940s has argued that safety enhancements cannot be based on asking who is responsible for errors, but only on asking what is responsible. Worker error is a post-hoc attribution which we give to assessments and actions that are, on closer scrutiny, locally rational and systematically connected to people's tools and tasks.[35] The focus on behavioral safety reverses this. It turns back a remarkable post-Heinrich emancipation that swept industry around the middle of the 20th century, when:

> experts moved away from a focus on the careless or cursed individual who caused accidents. Instead, they now concentrated, to an extent that is remarkable, on devising technologies that would prevent damage no matter how wrongheaded the actions of an individual person.[36] Q15

Heinrich, whose *post-hoc* actuarial work yielded the idea that 88% of accidents are caused by worker 'unsafe acts,' has long been kept alive in safety thinking. 'Unsafe acts' (a Heinrich concept from the 1930s), e.g., are an integral part in epidemiological accidents models. 'Latent pathogens' are activated by the unsafe acts of frontline personnel, which push a system through the last barriers into breakdown. 'Human errors,' or the unsafe acts of sharp-end operators, are believed to be the final frontier, and eliminating them is an intervention that strengthens this final barrier.[37] This focus on the individual worker as the moral and practical agent for the creation of safety has been linked to the rise of neoliberal discourses of self-regulation in western countries where:

> workplace safety is undergoing a process of 'responsibilization' as governments reconfigure their role in directions consonant with now dominant mantras of neo-liberal policy. Workers are assigned ever greater responsibility for their own safety at work and are held accountable, judged, and sanctioned through this lens.[38]

Q16

Notwithstanding its intentions, much of the safety culture literature fits hands-in-glove with this trend of devolution, self-regulation and responsibilization. Safety culture, after all, is most frequently operationalized in terms of the attitudes and behaviors of individual actors (those accessible through behavior modification).[39] These are often the lowest-level actors, with the least authority in the organizational hierarchy. Such individuals are called to be responsible for safe behavior, which is then assumed to 'trickle up' and constitute organizational safety. This too, helps maintain the *status quo*, which tends to see individual actors as the cause of safety trouble. Error is the target. It suggests that better control (keeping their behavior within a prescribed bandwidth) is a strong investment in safety.

Contrasting insights about the role of the human in creating safety actually predate Heinrich by decades. Ernst Mach observed in 1905 how human error is the other side of human expertise, which only the outcome can tell apart.[35] Indeed, people's work evolves to cope with the inevitable hazards, complexities, gaps, trade-offs and dilemmas which the organization (and the nature of their work) helps create. Human expertise is deemed increasingly critical for the assurance of safety in complex, dynamic domains. In fact, not deferring to judgment and expertise is seen as a major safety shortcoming. Prior to the Texas City refinery explosion in 2005, for example, BP had eliminated several thousand US jobs and outsourced refining technology work. Many experienced engineers left.[40]

Similarly, with the appointment of Sean O'Keefe (Deputy Director of the White House Office of Management and Budget) to lead NASA, the new Bush administration signaled that the focus should be on management and finances.[41] NASA had already vastly reduced its in-house safety-related technical expertise in the 1990s. NASA's Apollo-era research and development culture once prized deference to the technical expertise of its working engineers. This had become overridden by bureaucratic accountability – managing upwards with an allegiance to protocol and procedure. Contributing to the Columbia accident was that 'managers failed to avail themselves of the wide range of expertise and opinion necessary.' Their management techniques 'kept at bay both engineering concerns and dissenting views, and ultimately helped create "blind spots" that prevented them from seeing the danger the foam strike posed.'[41] In the wake of the Columbia accident, Q17 NASA was told it needed 'to restore deference to technical experts, empower engineers to get resources they need, and allow safety concerns to be freely aired.'[41] The two Space Shuttle accidents – Challenger in 1986 and Q18 Columbia in 2003 – have led to calls for organizations to take engineering and operational expertise more seriously.

This has become well established in research on high-reliability organizations and resilience. The pursuit of resilience demands an embrace of variability rather than consistency in human performance.[42] Without an acceptance of variability, there is no space for the kind of dissent many in NASA wished had been given wider airing. It is a basic necessity to match the variability and unpredictability in the domain in which people work.

3.5. *Quantification*

The idea of constant improvement is deeply embedded in the zero-visions of many industries. The drive to quantify safety performance can actually mean being really creative with numbers, and with the policies and practices that incentivize a particular kind of reporting. The US Government Accountability Office (GAO) recently studied these issues in the USA and asked whether some safety incentive programs and other workplace safety policies may actually discourage workers' reporting of injuries and illnesses.[43] It found that:

> Little research exists on the effect of workplace safety incentive programs and other workplace safety policies on workers' reporting of injuries and illnesses, but several experts identified a link between certain types of programs and policies and reporting. Researchers distinguish between rate-based safety incentive programs, which reward workers for achieving low rates of reported injuries or illnesses, and behavior-based programs, which reward workers for certain behaviors. Experts and industry officials suggest that rate-based programs may discourage reporting of injuries and illnesses and reported that certain workplace polices, such as post-incident drug and alcohol testing, may discourage workers from reporting injuries and illnesses. Researchers and workplace safety experts also noted that how safety is managed in the workplace, including employer practices such as fostering open communication about safety issues, may encourage reporting of injuries and illnesses. [43,p.2]

Quantification of safety performance, combined with certain incentive structures, can lead to a suppression of evidence about incidents, injuries or other safety issues.[34] Beyond these, little is actually known about the sorts of activities and mechanisms that lie underneath the reductions in harm that committed companies have witnessed, and not much research has been conducted into this.[44] A recent survey of 16,000 workers across different industries revealed widespread cynicism about zero vision.[45] With a focus on a quantified dependent variable – injury and incident statistics that determine how bonuses are paid, contracts are awarded and promotions are earned – manipulation of that dependent variable (after all, a variable that literally depends on a lot of things not under one's control) becomes a logical response. Injury discipline policies, safety incentive programs, post-injury drug testing, observation and prevention of 'unsafe acts' are the more obvious measures; flying the dead bodies of deceased workers from one country to another (the contractor's home country) is an extreme one.

The suppression that results from quantification of personal injury statistics can have nefarious effects for process safety [2] as well as fatality risk. These are strong suggestions, then, that quantification of injury and incident data tends to maintain the *status quo*. It is hard for an organization to break through the asymptote in safety improvement if its very safety practices, policies and measurements encourage the suppression of the kind of bad news necessary to learn and improve. Such news is not necessarily quantitative or even quantifiable, but rather qualitative – the sorts of stories of successes, of coping and occasional failures that can only really be told, listened to and learned from, not pressed into numeric categories.

3.6. Invulnerability

Quantification of safety data may suggest, to important stakeholders in the organization, that risk is under control. They might believe they have a great safety culture, because they have the numbers to show it.[9] The literature on accidents and disasters, however, offers no solace; it offers no justification for a sense of invulnerability. Perrow, for example, suggested that accident risk is a structural property of the systems we operate.[10] The extent of their interactive complexity and coupling is directly related to the possibility of accident. The only way to achieve a zero vision, for Perrow, is to dismantle the system, to not use it altogether. Increasingly coupled and complex systems like military operations, spaceflight and air traffic control have all produced surprising, hard-to-predict Perrowian system accidents since 1984, as has the Fukushima nuclear power plant.[46]

Other accident literature is also generally pessimistic about our ability to be completely safe. Man-made disaster theory, e.g., has concluded that 'despite the best intentions of all involved, the objective of safely operating technological systems could be subverted by some very familiar and "normal" processes of organizational life.'[4] No
Q19
matter what vision managers, directors, workers or other organization members commit to, there will always to be erroneous assumptions and misunderstandings, rigidities of human belief and perception, disregard of complaints or warning signals from outsiders and a reluctance to imagine worst outcomes. These are the normal products of bureaucratically organizing work.[3] Vaughan's analysis of the 1986 Space Shuttle Challenger launch decision reified what is known as the banality-of-accidents thesis. Similar to man-made disaster theory, it says that the potential for having an accident grows as a by-product of doing business under normal pressures of resource scarcity and competition.[47] Continued success in doing business that way:

> . . . breeds confidence and fantasy. When an organization succeeds, its managers usually attribute success to themselves or at least to their organization, rather than to luck. The organization's members grow more confident of their own abilities, of their manager's skills, and of their organization's existing programs and procedures. They trust the procedures to keep them apprised of developing problems, in the belief that these procedures focus on the most important events and ignore the least significant ones.[48] Q20

Recent disasters occurred in 'high performing' organizations with – if not a strong focus on safety – a strong focus on low numbers of negatives. This includes companies such as BP, suffering disasters at their Texas Refinery in 2005 with 15 deaths, and the Macondo blowout with 11 deaths, the West Fertilizer Company in 2013 with 15 deaths, or the Montreal, Maine and Atlantic Railway company in Quebec, Canada, whose railcars derailed in Lac Megantic and killed 47 people. All of these companies reported high levels of safety performance (as measured by the absence of injury and incident) and many people in them would seem to have had confidence in their safety systems prior to these events.[2,40] Weick and Sutcliffe echoed this:

> Success narrows perceptions, changes attitudes, reinforces a single way of doing business, breeds overconfidence in the adequacy of current practices, and reduces the acceptance of opposing points of view.[49] Q21

4. Discussion and conclusion

These results suggest that safety practices associated with compliance, control and quantification could be partly responsible for the inability of many industries to break through their recent asymptote in safety improvement. Assumptions about linear causation, about the value of consistency and about operators' 'unsafe acts' as the final weak link in otherwise well-defended systems tend to lock into place these and other practices. The reasons why this then contributes to the plateau in safety improvement could include the following:

- The (officially and bureaucratically legitimated) illusion of risk being known and kept under control, communicated to upper management by way of numbers, targets and bullet lists, creating a sense of invulnerability.[50]

- The deflection of organizational resources into unproductive or counterproductive safety activities (e.g., associated with investigating everything because everything is assumed to be preventable).[51]
- The sustaining of obsolete practices and policies intended to keep human performance within a prespecified bandwidth, which run counter to people's mandate and ability to adapt so as to cope with the dynamics and complexity of actual work.[52]
- The suppression of 'bad news' that results from a focus on quantification and 'looking good' because of how the organization is held accountable for its safety performance.

Safety practices based on these ideas are not sustained because of their inherent truth value or practical yield. Indeed, the results suggest that there is an increasing amount of evidence that they offer neither. It is more likely that they are kept alive through social processes of:

- consensus authority – everybody is doing it so everybody is doing it; and
- bureaucratic enterpreneurialism – demands for more administrative work arise from existing administrative work, ensuring business continuity for an organization's bureaucratic functions.

Of course, whether (or the extent to which) some of the safety practices examined still contribute to safety performance improvement depends on the existing safety level of the industry,[51] and on the kind of safety that needs to be managed (e.g., personal versus process safety). Also, whether efforts to reduce uncertainty have any effect depends on the stability and predictability of particular 'islands' of practice, even within larger settings that are noisy, messy and unpredictable. The pre-surgical checklist, e.g., is credited with improving patient safety. It has in many cases been successful in part because it is introduced into such an 'island' of relative calm and stability before surgery starts.[53] Where that does not work, of course, efforts to cope with uncertainty, by enhancing flexibility, resilience and localized expertise, will have more effect.[29]

5. Implications for industry

Many industries are dogged by plateauing safety performance as measured by the absence of (low-consequence) negative events (e.g., incidents, injuries). At the same time, these industries are sometimes surprised by large fatal accidents that seem to have no connection with their understanding of the risks they faced. In this article we have examined the extent to which current safety practices associated with compliance, control and quantification could be partly responsible for both the plateau and the occasional large surprise. Recent theorizing in safety, such as resilience engineering [52] and high-reliability theory, suggests organizations remain sensitive to the possibility of failure; and recommends that they stay curious, open-minded, complexly sensitized, inviting of doubt and ambivalent toward the past.[54] Such organizations are described as skeptical, wary and suspicious of quiet periods. Resilience engineering [52] has offered specifications for how to stay sensitive to the possibility of failure:

- Monitoring of safety monitoring (or meta-monitoring). Does the organization invest in an awareness of the models of risk it embodies in its safety strategies and risk countermeasures? Is it interested to find out how it may have been ill-calibrated all along, and does it acknowledge that it needs to monitor how it actually monitors safety? This is important if the organization wants to avoid stale coping mechanisms, misplaced confidence in how it regulates or checks safety, and does not want to miss new possible pathways to failure.[55]
- Do not take past success as guarantee of future safety. Does the organization see continued operational success as a guarantee of future safety, as an indication that hazards are not present or that countermeasures in place suffice? In this case, its ability to deal with unexpected events may be hampered. In complex, dynamic systems, past success is no guarantee of continued safety.
- Resist distancing through differencing. In this process, organizational members look at other failures and other organizations as not relevant to them and their situation. They discard other events because they appear to be dissimilar or distant. But just because the organization or section has different technical problems, different managers or different histories, or can claim to already have addressed a particular safety concern revealed by the event, does not mean that they are immune to the problem. Seemingly divergent events can represent similar underlying patterns in the drift towards hazard.
- Resist fragmented problem-solving. To what extent are problem-solving activities disjointed across organizational departments, sections or subcontractors, as discontinuities and internal handovers of tasks? With information incomplete, disjointed and patchy, nobody has the big picture, and nobody may be able to recognize the gradual erosion of safety constraints on the design and operation of the original system that move an organization closer to the edge of failure.
- Knowing the gap between work-as-imagined and work-as-done. One marker of resilience is the distance between operations as management imagines they go on and how they actually go on. A large

distance indicates that organizational leadership may be ill-calibrated to the challenges and risks encountered in real operations. Also, they may miss how safety is created as people conduct daily work.

- Keeping the discussion about risk alive even (or especially) when everything looks safe. One way is to see whether activities associated with recalibrating models of safety and risk are going on at all. This typically involves stakeholders discussing risk even when everything looks safe. Indeed, if discussions about risk are going on even in the absence of obvious threats to safety, an organization could get some confidence that it is investing in an analysis, and possibly in a critique and subsequent update, of its models of risk.
- Having a person or function within the system with the authority, credibility and resources to go against common interpretations and decisions about safety and risk. Historically, ‘whistleblowers’ may come from lower ranks where the amount of knowledge about the extent of the problem is not matched by the authority or resources to do something about it or have the system change course. An organization shows a level of maturity if it succeeds in building in this function at meaningful organizational levels.[56]
- The ability and extent of bringing in fresh perspectives. Organizations that apply fresh perspectives (e.g., people from another backgrounds, diverse viewpoints) generate more hypotheses, cover more contingencies, openly debate rationales for decision-making and reveal hidden assumptions.[35,49]

Disclosure statement

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