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Abstract

Both academics and practitioners have recently discovered resilience as a core topic of interest. Resilience is widely viewed as a potential solution to the challenges posed by crises and disasters. The promise of resilience is an organization or society that absorbs shocks and 'bounces back' after a disturbance. While the idea of resilience is increasingly popular, empirical research on resilient organizations is actually quite rare. This article explores whether a relation exists between organizational characteristics, processes and resilience. Building on the insights of high reliability theory and crisis research, it probes this relation in two organizations that experienced deep crises: the California Independent System Operator (CAISO) and National Aeronautics and Space Agency (NASA).

Key Words

Resilience, high reliability organizations, crisis management, CAISO, NASA

THE RESILIENT ORGANIZATION

A critical appraisal

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THE RISE OF RESILIENCE

In recent years, the management of crises and disasters has become a key topic of concern for both practitioners and academics. Public and private organizations routinely prepare for a wide variety of adverse events. Academics, in turn, study the causes and dynamics of these threats, map patterns of organizational response and offer prescriptions (Weick and Sutcliffe, 2001; Boin *et al.*, 2005; Drennan and McConnell, 2007).

One of the dominant normative ideal-types that has recently emerged in this field of study is the resilient organization (Weick and Sutcliffe, 2001; Sutcliffe and Vogus, 2003; Sheffi, 2005; Hollnagel *et al.*, 2006; Flynn, 2008; Cascio, 2009; Christianson *et al.*, 2009; Comfort *et al.*, 2010; Välikangas, 2010). Long a dominant concept in the field of ecology, the idea of resilience is catching on in the fields of crisis management and organization studies.

The idea of resilience offers the promise of an intuitively plausible, attractive and seemingly attainable strategy to prepare for and deal with various types of adversity. The literature suggests that a resilient organization will maintain a high level of performance even when environmental pressures mount, threats arise and uncertainties deepen. In the face of unexpected adversity, the resilient organization is said to 'bounce back' quickly, without much effort (cf. Wildavsky, 1988). If disruptions are both inevitable and surprising, as the literature tells us, investing in resilience promises to be a more effective strategy than allocating scarce resources aimed at controlling the environment and defending against specific risks (Wildavsky, 1988).

The resilient organization is also quite remarkable from a theoretical perspective. The organizational literature typically identifies external shocks as potentially existential threats to an organization's health. The same literature predicts that organizations will find it hard to cope with such shocks. So here comes the resilient organization, which absorbs unexpected shocks and somehow emerges from crises without lasting damage. The resilient organization thus presents researchers with an enigma, as it 'works in practice but not in theory' (cf. LaPorte and Consolini, 1991).

While the idea of resilience is increasingly popular, empirical research on resilient organizations is actually quite rare. Much of the literature on resilience is prescriptive and normative; it spurs people to recognize impending dangers, learn on the spot, work in joint teams and high spirits, improvise their way around excruciating setbacks and emerge from crises stronger and better (e.g. Weick and Sutcliffe, 2001; Hamel and Valikangas, 2003). But it is not quite clear how these skills can be built into an organization and its employees. In fact, we do not really know what causes resilience or how it is achieved. Is it the result of designed processes or perhaps the outcome of improvisation and luck?

In examining the relation between organizational *processes* and the *outcome* of resilience, we encounter two problems. First, it is not clear what resilience is, exactly. Second, it is hard to recognize resilience in action. We do not know resilience when we see it – rather, we assume it must have been there if an organization survives a crisis or disaster. If it ends

badly, the organization obviously was not resilient. If we want to study organizational resilience without conflating process and outcome, we must address these problems.

In this article, we explore whether a relation exists between organizational characteristics, processes and resilience. We make an explicit connection with the literatures on crisis management and so-called 'high reliability organizations' (HROs). We then use two well-known cases to probe the relation between organizational characteristics, the process of adversity management and the resilience: The California Independent System Operator (CAISO), which managed to keep the lights when the electricity market imploded in the summer of 2000, and the National Aeronautics and Space Agency (NASA), which suffered two Space Shuttle disasters.

RESILIENCE IN THEORY: TWO MODELS

There are many definitions of resilience to be found in a wide variety of academic fields including psychology, sociology, ecology, organization theory, public administration and political science.[1] These definitions pertain to different levels of analysis, ranging from the individual to the global level. In this article, we are primarily interested to understand resilience at the level of the organization.

Two elements typically return in definitions of resilience: (1) after a surprising danger manifests itself (2) the organization manages to restore order – i.e. bounces back to an acceptable state of normality (cf. Wildavsky, 1988: 77). The first element is conceptualized fairly consistently across the different definitions of resilience. It emphasizes that the disturbance 'fall[s] outside of the set of disturbances the system is designed to handle' (Woods and Hollnagel, 2006: 3). Standard operating procedures, in other words, will not suffice.

The second element leaves more room for diverging conceptualizations. Definitions vary along two dimensions. Some definitions simply focus on returning to a prior order, while other definitions refer to the capacity to emerge stronger from a crisis (Sullivan-Taylor and Wilson, 2009). The latter type infuses resilience with the idea of learning. Then there is the time dimension: does the 'bouncing back' occur early on in the crisis process (thus preventing further escalation) or does it occur after the crisis (building the city up after the earthquake)?

This leads to two very different models of resilience. The first type is *precursor* resilience, which we can define as the 'ability to accommodate change without catastrophic failure, or a capacity to absorb shocks gracefully' (Foster, 1993: 36). This is the type of resilience that prevents budding problems from escalating into a full-blown crisis or breakdown. A second type can be referred to as *recovery* resilience, which can be defined as 'the ability to respond to singular or unique events' (Kendra and Wachtendorf, 2003: 42), bouncing back to a state of normalcy. This is the type of resilience that we can witness: the organization or city that miraculously arises from the ashes of crisis or disaster (Vale and Campanella, 2005).

In the literature, many processes and structures are casually associated with resilience. Resilient organizations 'keep errors small and improvise workarounds that keep the system functioning' (Weick and Sutcliffe, 2001: 14). They possess 'an impressive capacity to grasp crisis dynamics… They resist tendencies to adopt and cling to an interpretation based on limited information and hasty analysis. They force themselves to continuously probe their situational assessments… [They] have created a culture of awareness… They expect crisis to happen. They look for them because employees know that they are expected to do that – even when it comes at the cost of task efficiency' (Boin *et al.*, 2005: 36–37; cf. Weick and Sutcliffe, 2001: 14). Hamel and Välikangas (2003: 54) write that in a resilient organization 'revolutionary change happens in lightning-quick evolutionary steps – with no calamitous surprises, no convulsive reorganizations, no colossal write-offs and no indiscriminate, across-the-board layoffs'. Kendra and Wachtendorf (2003: 42) speak of 'redundancy, the capacity for resourcefulness, effective communication and the capacity for self-organization in the face of extreme demands'.

The dearth of empirical data makes it hard if not impossible to relate with any type of certainty organizational characteristics and processes to resilient performance. We seek to address this lacuna. To facilitate empirical research, we need a theoretical framework that proposes precise relations between organizational attributes and processes, and specific types of resilience.

Studying resilience in practice

In this article, we are primarily interested to study what we defined above as precursor resilience: a resilient organization absorbs shocks and prevents emerging problems from escalating into full-blown crises. The research into so-called HROs provides us with a starting point for theorizing on conditions for precursor resilience (Weick and Sutcliffe, 2001; Sullivan-Taylor and Wilson, 2009: 253).

High reliability theory (HRT) began with a small group of researchers studying a distinct and special class of organizations – those charged with the management of hazardous but essential technical systems (LaPorte and Consolini, 1991; Roberts, 1993; Schulman, 1993; Rochlin, 1996, 2011). Failure in these organizations could mean the loss of critical societal functions and could cause severe damage, threatening thousands of lives. The term 'high reliability organization' was coined to denote those organizations that successfully avoid such failure while providing operational capabilities under a wide range of environmental conditions.

High reliability theorists set out to investigate the secret of HRO success (Bourrier, 2011; Rochlin, 2011). They engaged in individual case studies of nuclear aircraft carriers, nuclear power plants and air traffic control centres. Two important (if preliminary) findings surfaced.

First, they discovered that HROs share similar and rather distinctive features. The most important are:

- high technical competence throughout the organization;
- a clear awareness of core events that must be precluded from happening;
- an elaborate and evolving set of procedures and practices, which are directed towards avoiding disastrous events from happening;
- a formal structure of roles, responsibilities and reporting relationships that can be transformed under emergency conditions into a decentralized, team-based approach to problem-solving;
- a 'culture of reliability' that distributes and instills the values of care and caution, respect for procedures, attentiveness and individual responsibility for the promotion of safety throughout the organization.

A second finding relates to the *process* of reliability maintenance. The researchers found that once a threat to safety emerges, however faint or distant, an HRO immediately 'reorders' and reorganizes to deal with that threat (LaPorte, 1996). This reordering involves a combination of rapid decentralization and facilitated improvisation. However, very little is known how, exactly, this process unfolds and how it relates to constant performance under pressure and, by implication, precursor resilience.

The HRO framework thus offers a fairly precise (if only hypothetical) relation between organizational characteristics and precursor resilience. The crisis management literature offers additional insights with regard to the conditions for a rapid and effective response in the face of unexpected threats.

First, organizations need capacity to arrive at an authoritative definition of the situation. The coordination of an improvised response network requires that all participants are 'on the same page'. This, in turn, demands a form of dynamic sensemaking: information must be collected, commissioned, analysed and shared in real time (Weick and Sutcliffe, 2001). It is no exaggeration to state that this is one of the biggest challenges that crisis managers encounter.

Second, crisis management scholars put a premium on the ability to improvise. Whereas HRT scholars view improvisation as 'the last 5%' only to be used when all else fails, crisis management scholars view it as an integral building block for an effective response. Plans and procedures cannot prescribe what an organization must do to address a major crisis (Clarke, 1999). In crisis, an organization must rally its resources and partners in creative ways to produce an urgent response to a unique problem.

Two empirical case studies revisited

To further explore if, and how, organizational characteristics and processes can be related to precursor resilience, we selected two organizations that have been extremely well studied and can be expected to have had at least the potential to be resilient.

The first organization demonstrated resilience in the face of unprecedented challenges. The CAISO is the focal organization for electricity transmission in California. The electricity crisis of 2000–2001 posed a major and unanticipated crisis for the CAISO. Much of the institutional design broke down – including the means with which to secure the reliable provision of electricity. Yet, the CAISO kept the lights on in California (Roe and Schulman, 2008).

The second organization is NASA, which suffered two major disasters in 17 years. This organization possessed many (but not all) of the 'right characteristics' for an HRO (cf. Boin and Schulman, 2008) and is known for its ability to manage crises ('Houston, we have a problem'). We will revisit NASA and consider why these organizational capacities were not enough to prevent two Shuttle disasters.

KEEPING THE LIGHTS ON IN CALIFORNIA: FROM CHAOS TO RESILIENCE

In 1996, California restructured its system of electricity generation, transmission and distribution. The state moved from a system of large integrated utilities that owned and operated the generation facilities, the transmission lines and the distribution and billing systems, and set retail prices under a cost-based regulatory system, to a market-based system consisting of independent generators who sell their power on wholesale markets to distributors, who then sell it to retail customers. The transmission lines were placed under the control of a new organization, CAISO, which assumed responsibility for managing a new state-wide high-voltage electrical grid.

The new system worked fairly well for the first few years. Then disturbances began to emerge and the system entered a period now known as the California electricity crisis of 2000–2001 (Roe *et al.*, 2003; Roe and Schulman, 2008). The CAISO faced unanticipated volatility in the scheduling of electricity transmission. The scheduling is supposed to happen months, weeks, days or at least hours in advance, so that there is time to coordinate the complicated schedules and cope with congestion in the network. Real-time 'imbalance markets' were designed to take care of the last per cent or so of total load.[2] During this crisis, reality looked quite different:

> We had days where the load [was] forecasted to be 42,000 MW, but our scheduled resources in the morning were 32,000 MW, leaving us 10,000 MW short that day. How do we deal with this? 99% of the planning has to be done prior to real time. Real time is only to react to what you missed. Real time is not 'I'm short 10,000 MW in the day ahead and I'm not doing anything.' Most of the time things did come together, but at a very high price.

At one point, the markets stopped functioning altogether. 'I was here, working as a new gen dispatcher, when I saw the market collapse. From one day to the other, there were no more bids coming [into the real-time imbalance market]', said a member of the California Energy Resources Scheduling purchasing team.[3] The CAISO did operate

closer to the edge of failure than ever before – where failure means uncontrolled blackouts or, worse, grid collapse.[4]

Yet, CAISO somehow managed to keep the lights on. Notwithstanding the popular view of rolling blackouts sweeping across California during its electricity crisis, in aggregate terms – both in hours and megawatts (MW) – blackouts were minimal and comparable to previous years (Roe *et al.*, 2003).

CAISO: Characteristics of a resilient organization?

Drawing from extensive, long-term research on CAISO (Roe and Schulman, 2008), we can establish that this organization possessed the characteristics deduced from HRT:

High technical competence

The operational core of the organization consisted of approximately fifteen operators in the central control room in Folsom. Their key competence is to maintain peak load operations under time pressure. Rather than formal education, their background was dominated by operational experience, either in the electricity system or in similar environments, such as air traffic control. Extensive in-house training programmes prepared them for the job of real-time operations. Around this control room, the organization had wrapped, physically as well as organizationally, various staff units that focused on analytical competence, as witnessed by a high concentration of PhDs among its members. (The number of employees in these units was multiple times the number of control room staff.)

A clear awareness of core events that must be precluded from happening

It was both widely understood and formalized (in so-called Control Performance Standards) that the reliable delivery of electricity was a core value in CAISO. Failure to meet reliability standards, such as always maintaining a 7-per cent operating reserve, was sanctioned by the North American Electricity Council, an industry body that enforced the self-regulation of grid operators. Operators are under no illusion that they are in control; they understand how vulnerable the grid is, how limited the options are and how precarious the balance is; they keep communications lines open to monitor the state of the network and they are busily engaged in developing options and strategies to deal with disturbances.

An elaborate set of procedures and practices directed towards avoiding these events

CAISO was a highly formalized organization. The complexity of electricity provision through a market-based system requires extensive rules, regulations and procedures.

A formal structure that can be transformed under conditions of emergency into a decentralized, team-based approach to problem-solving

During the crisis, CAISO demonstrated that it could depart from its formal structure. As formal role descriptions no longer sufficed, operators had to reinvent new procedures and new lines of cooperation (for instance, with planners and analysts who also stepped outside their role descriptions). Interdisciplinary teamwork replaced hierarchical practices dominant in 'normal' times.

A 'culture of reliability'

Long-term research (Roe and Schulman, 2008) describes the strong organizational culture in CAISO. This culture emphasized the importance of the reliability value (described above) – it can also be seen as a source of stress for operators (who felt compelled to solve emerging crises through constant trial and error).

The process of resilience: Managing crisis in the control room

Scheduling transmission for a large, complex transmission grid is very difficult and highly risky, e.g. because congestion can overload paths and trigger cascading failures. In 2001, the markets that were designed to coordinate supply and demand stopped functioning, almost overnight. Strategic behaviour on the part of the generators caused them to withhold generation capacity in order to artificially raise prices. The most dramatic effect was that a large part of the load – approximately 10,000 MW out of a peak load of 40,000 MW – was not scheduled beforehand, but ended up in the real-time market. To schedule this amount under such intense time pressure is a recipe for blackouts.

The control room played an important role in CAISO's efforts to maintain reliability. The need to balance load and generation along with meeting other regulatory parameters is the key requirement of the CAISO control room operators. All kinds of telemetry measurements come back to the control room in real time. The Automatic Generation Control system connects the CAISO generation dispatcher directly to privately held generators; the Automatic Dispatch System connects the dispatcher directly to the bidder of electricity and the dynamic scheduling system in the CAISO connects to out-of-state generators.

CAISO survived this challenge through a number of adaptations that enabled them to rely heavily on real-time operations to ensure grid and service reliability. One such adaptation was to pull the wrap-around units into the control room and involve them in supporting real-time operations. Models, which were initially developed to do contingency planning for outages, were adapted to provide immediate feedback on real-time events, thereby helping the operators to quickly assess different options to deal with disturbances.

In addition, CAISO mobilized informal networks to coordinate supply and demand. Under dire conditions, operators contacted generators off the record – because it was illegal to have such contacts – and told them the truth about those conditions, motivating them to no longer withhold generation capacity, but to put it into the market – albeit at outrageous prices. They thus leveraged the interdependencies in the system, pointing out the threat of immediate massive cascading failure. They explained how other players, such as adjacent transmission grid operators, would also be greatly affected by such events, which made them offer generation capacity that they initially reserved for their own needs.

These adaptations enabled CAISO to pull the needed resources together at the last minute. Yet, CAISO also faced a series of problems during this crisis: reliability standard violations, computer failures, software disasters, data problems, late submissions by security coordinators, not enough bids in the beep stack, ignoring dispatch orders and shedding load.

In summary, improvisation in the control room proved crucially important in managing this emerging crisis. A combination of effective sense-making and decentralized decision-making enabled operators to make the right calls at the right moment.

What we describe in terms of real-time improvisation, operators described in terms of luck. They experienced real-time confusion and incomprehension and felt they somehow escaped from disaster. In recounting one bad day that turned out good, a shift manager in CAISO's control room described how 'just by sheer stroke of luck I had made a voltage change at that time and caught what happened'. But the holes were plugged and the lights stayed on.[5]

ONE ORGANIZATION, TWO TRAGEDIES: THE DEMISE OF SPACE SHUTTLES *CHALLENGER* AND *COLUMBIA*

On 28 January 1986, the Space Shuttle *Challenger* exploded within 2 minutes of its launch. On 1 February 2003, the *Columbia* Space Shuttle disintegrated during the final stages of its return flight to earth. High-level commissions investigated the causes of these disasters. Both Commissions – the Presidential Commission on the Space Shuttle Challenger Accident (1986) and Columbia Accident Investigation Board (CAIB) (2003) – criticized the safety organization and culture of the NASA. Both commissions discovered that NASA engineers had voiced concerns, which, if heeded, could have prevented the *Challenger* and *Columbia* disasters.

On the eve of the *Challenger* launch, Thiokol engineers had raised doubts with regard to the safety of the O-rings in cold weather (Vaughan, 1996).[6] The engineers suspected that the O-rings might not seal well in cold weather, which would pose a dangerous situation. After several phone conferences between the Thiokol team and the NASA managers, both groups finally agreed that there was no conclusive evidence to suggest that the Shuttle should not be launched. During the launch, the O-rings failed to seal.

The following explosion tore the *Challenger* apart. All astronauts on board of the Shuttle died.

The foam (and the associated tile) problem, which would ultimately cause the demise of *Columbia*, had a similar history. It was considered a dangerous problem in the early days of the shuttle programme. After well over a hundred flights, the NASA engineers thought that they understood the problem and deemed the risk acceptable. When NASA studied the tape of *Columbia's* launch (a standard procedure), it was noticed that a piece of ice knocked off some of the tiles (which protect the shuttle from re-entry heat). After extensive discussions between engineers and managers, it was decided that the risk of the observed tile damage was acceptably low. Upon re-entering Earth's atmosphere, the *Columbia* disintegrated over the skies of Texas.

NASA: A resilient organization?

NASA has been subjected to a tremendous amount of study.[7] Judging from these studies, there is a remarkable sense of agreement among observers with regard to NASA's organizational characteristics and core processes, which makes it possible for us to describe the organization in terms of HRO characteristics (Boin and Schulman, 2008).

High technical competence

NASA is home to the proverbial 'rocket scientist'. The core challenge for NASA has always been to match external demands (high expectations, insufficient budgets and tight schedules) with engineering brilliance. To save costs and to keep with the schedule ('before the decade is over'), NASA adopted a philosophy of calculated risk that was supported by the technique of systems engineering (Johnson, 2002). This philosophy demanded an unwavering commitment to 'sound engineering' principles and generated a powerful culture around expertise. Discussions are held on the basis of engineering logic; every flight risk and anomaly is assessed against the laws of physics and engineering (there is no room for 'gut feeling' or 'observations').[8]

A clear awareness of core events that must be precluded from happening

The people in NASA were intensely aware of the negative consequences that disasters in human spaceflight would cause to the programme. Many of the NASA engineers who worked on the Shuttles knew the astronauts (Vaughan, 1996); most would be aware of the negative consequences of media and political attention following a disaster.

An elaborate set of procedures and practices directed towards avoiding disastrous events from happening

Through what is called the acceptable risk process, NASA seeks to identify to establish whether engineers from the involved centres and contractors agree that 'the shuttle is ready to fly and to fly safely' (Vaughan, 1996: 82). If an identified hazard cannot be eliminated before launch time, NASA has to determine whether such a hazard qualifies as an 'acceptable risk'. Each mission is followed by a mission evaluation report, which identifies anomalies that occurred during flight (Vaughan, 1996). These anomalies have to be dealt with ('closed') before the next flight can take place. Each shuttle flight is preceded by a so-called flight readiness review (FRR). This formal review procedure is a bottom-up process designed to identify risks and bring them to the attention of the higher management levels. Because it is impossible and undesirable that top-level administrators review all possible risks and anomalies, the FRR aims to filter out the critical anomalies for senior management review.

A formal structure that can be transformed under crisis conditions into a decentralized, team-based approach to problem-solving

To invent the technology that would bring humans to the Moon and back, NASA created interdisciplinary teams and centres with high degrees of autonomy (Murray and Cox, 1989). The flexibility and resourcefulness of NASA was best demonstrated during the near-disaster that occurred when the *Apollo 13* experienced an explosion in space. The different engineering disciplines were represented in the Houston centre. The adherence of procedures enabled the engineers to figure out what had happened and what was possible. Yet, it was the capacity to be flexible and to *depart* from enshrined rules that gave rise to the level of improvisation that in the end saved the day (and the crew). It is not clear whether this characteristic was still present before and during the shuttle disasters.

A 'culture of reliability'

Time-proven safety mechanisms had become institutionalized in its organizational culture. If engineers provide an acceptable 'engineering rationale' that explains why a risk should be accepted (rather than redesigning the parts that posed the risk), the hazard is officially classified as an acceptable risk and the shuttle is launched. If that does not happen, the launch will be delayed (NASA has a history of launch delays).

The process of resilience: A failure of sense-making?

NASA abided by its safety system (the risk procedure and the FRR), but the processes in place did not stop the disasters from happening. In the absence of a disaster, these processes would have been quite remarkable for their thoroughness, commitment to

safety and ability to deal with surprises. The failure to read the signals of impending disaster appears to be related to a crucial vulnerability in NASA's safety system, which remained unidentified and unaddressed in the wake of *Challenger*: the inability to deal with emerging uncertainties that could not be resolved through the normal 'sound engineering' discussion method. In other words, NASA had no proper procedures that would allow the organization to identify signals of doubts, coming from respected engineers, which were not substantiated by engineering data (see also Dunbar and Garud, 2005).

Revisiting *Challenger*

The infamous O-rings that caused the failure of the *Challenger* shuttle had been repeatedly subjected to the acceptable risk procedure (Vaughan, 1996). In the mid-1970s (well before the first shuttle flight), doubts arose with regard to the effectiveness of the O-rings. NASA would only fly the shuttle if Thiokol (the contractor that had designed the O-rings) could provide an acceptable rationale that convinced NASA that the O-rings were safe.[9] After years of extensive discussion, testing, more debate and more worst-case testing, engineers at Marshall and Thiokol finally and 'unanimously agreed that, although the joint performance deviated from design expectations, it was an acceptable risk' (Vaughan, 1996: 104).

On 12 April 1981, the first Space shuttle flight took place. The inspection upon return showed no anomalies; the O-rings had performed according to the prediction. The rationale for accepting this acceptable risk was confirmed by experience – a most important argument in NASA's engineering culture, which held that 'a design is a hypothesis to be tested' (Vaughan, 1996: 109).

When Thiokol engineers discovered the first in-flight anomaly – motor gases had eroded 0.053" of a primary O-ring – they established the cause of the problem, designed a solution, which was then extensively tested. No erosion occurred on subsequent flights, which convinced the engineers that they had solved the problem. This would happen again and again: a problem would be found, analysed and fixed. The shuttle would fly and return safely. The institutionalized procedures seemed to prove their worth over and over again.

Before the fateful flight of *Challenger*, a few Thiokol engineers *suspected* that the predicted cold January weather (abnormally cold for Florida) could pose a problem to the O-rings. They were unable, however, to provide a compelling rationale for their intuition. In their rush to produce one on the eve of the launch, the Thiokol engineers committed the ultimate sin of presenting a *flawed* rationale to the NASA engineers. The NASA people – who had always been considered the more conservative group – were 'appalled' with the line of argumentation coming from Utah. The Thiokol engineers realized their mistakes and ended up voting for launching even though their worries remained. This is how a Thiokol engineer and a NASA engineer described what happened (Vaughan, 1996: 302, 307):

> I don't believe they did a real convincing job of presenting their data […] The Thiokol guys even had a chart in there that says temperature of the O-ring is not the only parameter controlling blow-by. In other words, they're not coming in with a real firm statement. They're saying there's other factors. They did have a lot of conflicting data in there. (Marshall's Ben Powers who agreed with the Thiokol recommendation)

> I recognized that it was not a strong technical position [to recommend against launching], but yes, I basically supported that position. I had become very concerned during the presentation, however, when one of the [Thiokol] people seemed to indicate […] that he had forgotten or didn't know about one of the recent warm temperature firings that also had a problem […] And so it began, to my way of thinking, to really weaken our conclusions and recommendations. And I was already wishy-washy. And that one [chart] really hit me home when I began to think, gosh, you haven't really thought this out as thoroughly as you should have. (Thiokol's Bill Macbeth)

The analysis suggests that NASA's safety structure trumped sense-making capacities. NASA culture had no room for arguments that violate basic engineering logic. It could not handle 'feelings' or 'doubts' that were not supported by hard data. This was the entrenched norm that everybody in NASA knew and abided by – this was the way it had been done during the *Apollo* years.

In hindsight, it is easy to argue – as the Rogers commission did – that the doubts of respected engineers should suffice to snuff out the problem, to experiment and test, until safety can be proven. During the *Apollo* years, however, NASA had learned that this does not work with engineers: they will tinker, test and experiment forever (for they know that they can never prove the safety of an experimental space craft). The system in place had served NASA well: no astronauts had been lost in space until the *Challenger* explosion.

The *Columbia* disaster revisited

This tension between structure and sense-making played a crucial role in the demise of shuttle *Columbia*. The foam-caused damage to *Columbia* was not discovered until day 2 of the trip after the Intercenter Photo Working Group studied the film of the launch. The Photo Group formed a Debris Assessment Team (DAT), which was to consider whether the damage would pose a safety issue. Moreover, the photo material showing the foam hit was widely disseminated throughout NASA and its contractors by email. Both the media and the astronauts on board of *Columbia* knew of the problem.

Initial assessments did not provide any cause for alarm and 'may have contributed to a mindset that [the foam hit] was not a concern' (CAIB, 2003: 141). Mission Control was under the impression that the foam strike fell within the experience base and waited for additional information to emerge from the DAT (CAIB, 2003: 146). This impression was confirmed by an email of Calvin Schomburg – whom Shuttle

programme managers considered an expert on the matter – stating that the hit 'should not be a problem' (CAIB, 2003: 149). Boeing used a software tool ('Crater') to assess potential damage. The analysis did not give rise to concern.[10]

On Day 9 of the flight, the DAT presented its findings to a representative of Mission Control. The DAT engineers 'ultimately concluded that their analysis, limited as it was, did not show that a safety-of-flight issue existed' (CAIB, 2003: 160). As a senior engineer wrote to his colleagues 2 days later: 'I believe we left [the shuttle manager] with the impression that engineering assessments and cases were all finished and we could state with finality no safety-of-flight issues or questions remaining' (CAIB, 2003: 163). The CAIB pointed out that many uncertainties were noted in this presentation, but, as we have seen above, NASA culture did not allow for 'feelings' and 'observations'.

The many empirical accounts of NASA's culture all emphasize a deep commitment to the safety of astronauts. The process to detect emerging problems is transparent, smart and solidly based on engineering knowledge. In the months and weeks leading up to both shuttle disasters, this process played out in a neat and orderly fashion. Clearly, NASA had a safety structure in place that resembled the building blocks of an HRO.

A critical problem was NASA's inability to deviate from entrenched safety processes, which prevented an accurate assessment of the impending threats to the safety of the doomed shuttles. In addition, once the threat to *Columbia* was recognized, it proved hard to improvise or design a 'work around'. Intriguingly, it appears that NASA was hemmed in by the very processes and structures that had long been considered pillars of a vaunted safety culture.

DISCUSSION: RETHINKING RESILIENCE

This article explores the organizational antecedents of *precursor resilience*: the capacity to absorb an emerging crisis while maintaining a high level of performance. Other forms of resilience – notably *recovery resilience* – will likely require different strategies, structures and practices (and a different research agenda).[11]

We revisited two organizations that tried to be – indeed had to be – resilient. It is, of course, impossible to deduce any sort of generalized relation between organizational processes and resilience based on two case studies. Moreover, the cases differed with regard to the types of hazard they faced; the meaning and consequences of organizational failure; the character of political-administrative oversight and the organizational processes that are initiated in the face of impending crises. In revisiting CAISO and NASA, we were particularly interested in the differing organizational responses.

The case comparison brought us at least one intriguing insight: adherence to well-structured safety processes is not sufficient for precursor resilience. The seemingly chaotic processes of decentralized improvisation and sense-making play an important role. This can produce internal tensions, as principles of crisis management (such as improvisation) do not always sit well with principles of HROs (as espoused in the 'high reliability' literature).

Both reliability and crisis management impose very different demands on an organization. Reliability must be exhibited continuously. Organizational structures and processes must be designed to facilitate it. Crisis management is typically used quite rarely (bringing the proverbial 'last 5%') and requires different types of training, preparation, facilitation and perhaps leadership. An organization that wants to be resilient must traverse simplistic distinctions between 'anticipation' and 'trial-and-error learning'. It must somehow create a highly structured environment in which various response modes can coexist (cf. Moynihan, 2012). We stand only at the beginning of the research that may tell us how that can be done.

The case studies bring to the fore several questions that may guide that research. For instance, we should study whether different forms of resilience require different skills, structures or processes. Another question, largely ignored in this article, pertains to the type of external relations that may facilitate or inhibit organizational resilience.

Future research should also consider the price of resilience. The literature on resilient organizations sketches an overwhelmingly positive image of resilience and rarely includes any discussion of the *costs* of resilience. This is awkward, to say the least, as resilience is often described in terms of redundancy and slack. But redundancy, as Schulman (1993: 353) reminds us, 'reeks of inefficiency' and usually comes at a cost.

Resilience will likely become increasingly important in the face of new threats. If we could design organizations to absorb small disturbances and shocks, surely the world would be a safer place. Recipes for resilience, however, are built on a rather weak empirical and theoretical basis. This article suggests that we should be careful to prescribe resilience before we develop a stronger grasp on the relation between organizational characteristics, processes and outcomes. Much more research is needed before prescriptions for resilience can be administered.

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NOTES

1 For an extensive literature overview, see De Bruijne *et al.* (2010).

2 'Load' is the demand for electricity and 'generation' is the electricity to meet that load, both of which must be balanced within mandated periods of time, or otherwise service delivery is interrupted as the grid fails.

3 See Mensah-Bonsu and Oren (2001) for a detailed analysis of the causes of this crisis.

4 In thirty-eight instances, CAISO operated with 1.5 per cent or less operating reserves. The regulatory standard was to have at least 7 per cent.

5 Within the organization, the crisis exerted a price on the part of the operators in terms of burnouts and divorce, according to Jim McIntosh, then the CAISO's director of grid operations. CAISO later faced a court case because of the excessive overtime demands that its employees had been subjected to during that period.

6 An O-ring is a commonly used seal in machine design. In the shuttle, O-rings were used to prevent gases from escaping from the Solid Rocket Booster.
7 A few selected sources include Murray and Cox (1989), Vaughan (1996) and Logsdon (1999).
8 In the words of one famous NASA character ('Mad' Don Arabian): 'If anybody does anything technically that's not according to physics, that's bullshitting about something, I will forever be death upon them' (Murray and Cox, 1989: 361).
9 Ironically, Thiokol engineers complained about the overly conservative design mentality of the involved engineers. As one Thiokol engineer explained his objections against the continuous prodding of NASA: 'You take the worst, worst, worst, worst, worst case and that's what you have to design for. And that's not practical [...] All those worsts were put together, and [Marshall] said you've got to design so that you can withstand all of that [...] and you just can't do that or else you couldn't put the part together' (Vaughan, 1996: 99).
10 The CAIB discovered that the CRATER software was, in effect, not designed to perform this type of analysis nor were the Boeing engineers performing the analysis sufficiently qualified.
11 For instance, a focus on recovery resilience might well benefit from a study of emergency management structures in the US such as the Incident Command System (ICS) and the National Incident Management System (NIMS), which appear much less relevant for our study of precursor resilience (see also Boin, 2010).

REFERENCES

Boin, A. (2010) 'Designing Resilience: Leadership Challenges in Complex Administrative Systems' in L. K. Comfort, A. Boin and C. Demchak (eds) *Designing Resilience: Preparing for Extreme Events* 129–141, Pittsburgh, PA: Pittsburgh University Press.

Boin, A. and Schulman, P. (2008) Assessing NASA's Safety Culture: The Limits and Possibilities of High-Reliability Theory. *Public Administration Review*, 68:6 pp1050–62.

Boin, A., 't Hart, P., Stern, E. and Sundelius, B. (2005) *The Politics of Crisis Management: Public Leadership Under Pressure*, Cambridge: Cambridge University Press.

Bourrier, M. (2011) The Legacy of the High Reliability Organization Project. *Journal of Contingencies and Crisis Management*, 19:1 pp9–13.

Cascio, J. (2009) The Next Big Thing: Resilience. *Foreign Policy*, 8:3 May/June.

Christianson, M. K., Farkas, M. T., Sutcliffe, K. M. and Weick, K. E. (2009) Learning Through Rare Events: Significant Interruptions at the Baltimore & Ohio Railroad Museum. *Organization Science*, 20:5 pp846–60.

Clarke, L. (1999) *Mission Improbable: Using Fantasy Documents to Tame Disaster*, Chicago, IL: University of Chicago Press.

Columbia Accident Investigation Board (CAIB) (2003) *Columbia Accident Investigation Report*, Burlington, ON: Apogee Books.

Comfort, L. K., Boin, R. A. and Demchak, C. (eds) (2010) *Designing Resilience: Preparing for Extreme Events*, Pittsburgh, PA: Pittsburgh University Press.

De Bruijne, M., Boin, R. A. and van Eeten, M. (2010) 'Resilience: Exploring the Concept and Its Meanings' in L. K. Comfort, A. Boin and C. C. Demchak (eds) *Designing Resilience: Preparing for Extreme Events* 13–32, Pittsburgh, PA: University of Pittsburgh Press.

Drennan, L. and McConnell, A. (2007) *Risk and Crisis Management in the Public Sector*, Abingdon: Routledge.

Dunbar, R. and Garud, R. (2005) 'Data Indeterminacy: One NASA, Two Modes' in W. H. Starbuck and M. Farjoun (eds) *Organization at the Limit: Lessons From the Columbia Accident* 202–19, Malden, MA: Blackwell.

Flynn, S. E. (2008) America the Resilient: Defying Terrorism and Mitigating Natural Disasters. *Foreign Affairs*, 87:2 pp2–8.

Foster, H. (1993) 'Resilience Theory and System Evaluation' in J. A. Wise, V. D. Hopkin and P. Stager (eds) *Verification and Validation of Complex Systems: Human Factor Issues* 35–60, NATO Advanced Science Institutes, Series F: Computer and Systems Sciences, Vol. 110, New York: Springer.

Hamel, G. and Välikangas, L. (2003) The Quest for Resilience. *Harvard Business Review*, 81:9 pp52–63.

Hollnagel, E., Woods, D. D. and Leveson, N. (eds) (2006) *Resilience Engineering – Concepts and Precepts*, London: Ashgate Publishing.

Johnson, S. B. (2002) *The Secret of Apollo: Systems Management in American and European Space Programs*, Baltimore, MD: Johns Hopkins University Press.

Kendra, J. and Wachtendorf, T. (2003) Elements of Resilience After the World Trade Center Disaster: Reconstituting New York City's Emergency Operations Center. *Disasters*, 27:1 pp37–53.

LaPorte, T. R. (1996) Unlikely, Demanding and at Risk. *Journal of Contingencies and Crisis Management*, 4:2 pp60–71.

LaPorte, T. R. and Consolini, P. M. (1991) Working in Practice but Not in Theory: Theoretical Challenges of 'High-Reliability Organizations.' *Journal of Public Administration Research and Theory*, 1:1 pp19–48.

Logsdon, J. M. (ed.).1999. *Managing the Moon Program: Lessons Learned from Project Apollo*. Monographs in Aerospace History 14, Washington, DC: National Aeronautics and Space Administration.

Mensah-Bonsu, C. and Oren, S. (2001) *California Electricity Market Crisis: Causes, Remedies and Prevention*, Folsom, CA: CAISO.

Moynihan, D. P. (2012) A Theory of Culture-Switching: Leadership and Red Tape During Hurricane Katrina. *Public Administration*, 90:4 pp851–68.

Murray, C. and Cox, C. B. (1989) *Apollo: The Race to the Moon*, New York: Simon & Schuster.

Presidential Commission on the Space Shuttle Challenger Accident. (1986) *Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident*. Washington, DC: Government Printing Office.

Roberts, K. H. (ed.) (1993) *New Challenges to Understanding Organizations*, New York: Macmillan.

Rochlin, G. I. (1996) Reliable Organizations: Present Research and Future Directions. *Journal of Contingencies and Crisis Management*, 4:2 pp55–9.

Rochlin, G. I. (2011) How to Hunt a Very Reliable Organization. *Journal of Contingencies and Crisis Management*, 19:1 pp14–20.

Roe, E. M. and Schulman, P. (2008) *High Reliability Management: Operating on the Edge*, Stanford, CA: Stanford Business Books.

Roe, E. M., Schulman, P., van Eeten, M. J. G. and de Bruijne, M. L. C. (2003) *Real-Time Reliability: Provision of Electricity Under Adverse Performance Conditions Arising from California's Electricity Restructuring and Crisis*, A Report Prepared for the California Energy Commission, Lawrence Berkeley National Laboratory, and the Electrical Power Research Institute, San Francisco, CA: Energy Commission.

Schulman, P. (1993) The Negotiated Order of Organizational Reliability. *Administration & Society*, 25:353 p372.

Sheffi, Y. (2005) *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage*, Cambridge, MA: The MIT Press.

Sullivan-Taylor, B. and Wilson, D. C. (2009) Managing the Threat of Terrorism in British Travel and Leisure Organizations. *Organization Studies*, 30:2–3 pp251–76.

Sutcliffe, K. M. and Vogus, T. J. (2003) 'Organizing for Resilience' in K. S. Cameron, J. E. Dutton and R. E. Quinn (eds) *Positive Organizational Scholarship* 94–110, San Francisco, CA: Berrett-Koehler Publishers.

Vale, L. J. and Campanella, T. J. (2005) *The Resilient City: How Modern Cities Recover From Disaster*, Oxford: Oxford University Press.

Välikangas, L. (2010) *The Resilient Organization: How Adaptive Cultures Thrive Even When Strategy Fails*, New York: McGraw-Hill.

Vaughan, D. (1996) *The Challenger Launch Decision: Risky Technology, Culture and Deviance at NASA*, Chicago: University of Chicago Press.

Weick, K. E. and Sutcliffe, K. M. (2001) *Managing the Unexpected*, San Francisco, CA: Jossey Bass.

Wildavsky, A. (1988) *Searching for Safety*, New Brunswick, NJ: Transaction Books.

Woods, D. D. and Hollnagel, E. (2006) *Joint Cognitive Systems: Patterns in Cognitive Systems Engineering*, Boca Raton, FL: Taylor and Francis.