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SPECIAL ISSUE
The Organization's Response to Ambiguous Information
Guest Editors: Daved van Stralen & Warren Watson

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Ambiguity

When you have an event, you can intervene in the wrong moment and cause catastrophic failure. By the time you see the problem, the catastrophic event has occurred.

Michael Gallo, Kelly Space & Technology, Inc., on high energy testing

Ambiguity may lead us to construct a world that, while supported by evidence, is not true. This is the danger of ambiguity – we select evidence and interpretations for their plausibility, but later events show we were wrong. After an unwanted result, ambiguity allows us to select interpretations to blame people, accept the inevitability of failure or announce this result as success. Carroll (1995) describes this as 'root cause seduction'. These inconsistencies among self-perception, perception and sensemaking are the essence of ambiguity.

In Gallo's scenario, intervening at the right moment may prevent catastrophe, while intervening at the wrong moment causes catastrophic failure. Here, we cannot be uncertain, or even aware, about the right moment, as it has passed before we can take the correct action. We can, rather, search for context and give value to what is known in an effort to identify early heralds of failure. The right moment is ambiguous. The observer can respond to an anomaly by collecting more information and be wrong before error can be identified. Or the observer can respond to an anomaly by giving meaning to existing information to better interpret observations. Information describes the circumstance, while meaning reflects context and the value of information. Context and value influence the success or failure of ambiguous situations, a pragmatic, rather than philosophical or theoretical, distinction.

We must distinguish between uncertainty and ambiguity in a radically distinct way. Information, as data or description, lessens uncertainty, a word stemming from *cert* (sure or decided). Ambiguity, from *ambigere* (to go around, *ambi* both + *igere* drive, lead or act), describes information that contains more than one meaning. The distinction between uncertainty and ambiguity is critical

Warren E. Watson, PhD, Regents Professor of Management, University of North Texas, Denton, TX, participated in the development of this special issue from the beginning. His unexpected death in July 2014 prevented him from carrying this to completion. His participation and guidance are felt throughout this work.

to those who work in hazardous situations. Uncertainty compels the search for information, ambiguity the search for meaning.

Uncertainty–certainty is binary, our information is right or not right, there is a correct answer. Information has fidelity to reality. Our goal becomes one of finding this correct answer and achieving fidelity. Ambiguity, on the other hand, is multifaceted and describes multiple, reasonable explanations of events; multiple, likely predictions; or multiple responses to a single intervention. Ambiguity has limited fidelity to the situation, particularly when the situation is in flux or a dynamic state.

Ambiguity is, to some degree, uncertainty with a time dimension. When taken as a single moment in time, it is possible to reduce a situation towards the spectrum of certainty and uncertainty. Ambiguity develops when we add the element of time – the addition of a past creates multiple ways the situation developed; the addition of a future creates multiple possible developments; the addition of only one intervention, added to the complexity of the situation, creates multiple possible responses. In this definition, adding the element of time makes ambiguity a special case of uncertainty.

More information does not resolve ambiguity, as the relevance of information may change with a different past or future. We want to learn about causation within the event, something we cannot observe without experimentation. Operators experiment through engagement of the situation, observing responsiveness to their actions. Action by short feedback loops generates information while also giving it meaning from context and causation, even as it changes the situation. Compare this to observation, where information collected as the situation changes becomes almost immediately outdated. Information generated by action, along with knowledge and experience, allows the operator to give meaning to the situation. Operators can better resolve ambiguity through engagement, as discussed in papers of this special issue, or passively, with the passage of time.

In preparation for the Eighth International High Reliability Organizing Conference, hosted by the University of North Texas, Fort Worth, March 2014, I considered bringing experts together to discuss how organizations respond to uncertainty. Marc Otten (ContainR Media, Amsterdam, the Netherlands) suggested asking the question, 'How do organizations respond to ambiguous information?' He recommended this because

organizations can respond to uncertainty with increased information and evaluation but the same response to ambiguity will not be effective. This special issue of the *Journal of Contingencies and Crisis Management* arises from that conference session.

Ambiguous information occurs within stochastic processes or dynamic states. Uncertainty is the result of stochastic processes, but during the process, we see ambiguity. The difficulty lies in giving meaning to information when there is uncertainty of 'before, now, and future'. Because the interpretation of information during dynamic situations depends on events that have happened or will happen, collecting more information to reduce uncertainty does not relieve ambiguity.

Wolfberg (2006) describes this dilemma as puzzle-solving vs. mystery-solving. There is only one right answer in puzzle-solving and the puzzle has its own internal logic. Collecting puzzle pieces leads to a solution. Mystery-solving accepts the multifaceted nature of events and, while Wolfberg refers to this as uncertainty, the concept of ambiguity I use here better fits his description of how mystery-solving opens up a universe of possibilities. This occurs when the operator engages the situation.

How the organization responds to ambiguous information may predict resilience and adaptability to a greater extent than the organization's response to uncertainty. The organization can reduce uncertainty through systems for collecting and better understanding information. Ambiguity, on the other hand, occurs in dynamic, real-time interactions and responds to using tacit knowledge with shared sensemaking, use of local and general context, the flow of information and migration of authority. The detailed intimacy of an organization's reliable response to ambiguous information may be inaccessible to observers and, possibly, even to executives within the organization.

The silent danger of ambiguity comes from our failure to consider multiple paths and trajectories or the denial of ambiguity itself. With only one path to the event and one trajectory away from it, one can easily search for information that supports decisions made (confirmation bias) and, as events progress, memory triggers will readily occur to bias decision-making towards easily recalled information (availability heuristic). In a dynamic state, this rapidly increases the vulnerability of the operator and the system.

This sense of vulnerability drives the search for early heralds of problems and threats while also informing the decision-making that increases information (information entropy and certainty). The multiple possible meanings in ambiguous events hinder us from easily reducing the situation to a few simple components. By accepting ambiguity, operators also accept the possibility of diverse responses to their interventions and remain watchful for interventions that make the

problem worse. Operators must remain engaged with the situation, as multifaceted events will change even as the operators grasp the structure of the problem. By making choices, operators develop local information in context; this local expertise can influence decisions others will make. Response to the inherent vulnerability that comes from ambiguous information drives resilience and reliability when the organization is faced with unexpected crisis or catastrophic situations.

These responses by individuals and the organization reflect the five principles of High Reliability described by Weick and Sutcliffe (2011): pre-occupation with failure, reluctance to simplify, sensitivity to operations, commitment to resilience and deference to expertise in respective order of the above paragraph. The organization's response to ambiguity may also reflect its level of High Reliability.

Three forms of uncertainty are in common use: dictionary definitions, Werner Heisenberg's famous Uncertainty Principle and Claude Shannon's Information Entropy. Dictionary definitions derive from the Latin root *cert* for sure, settled or decided and relate to confidence vs. doubt, accuracy and precision, and unknown or unpredictable states. These definitions do not incorporate the dynamics inherent in the definition of ambiguity.

Heisenberg, using wave mechanics, found an uncertainty relation between the position and momentum (mass × velocity) of a subatomic particle. Increasingly precise measurement of one decreases the precision of the other. This uncertainty affects causality and prediction of the particle's behaviour. Uncertainty principles result from wave mechanics and oscillation in linear time-variant systems (as their name implies, they vary or oscillate in a linear manner over time). Collecting information over one dimension relies on the other, affecting precision in that measurement, somewhat analogous to our macro experience in crisis management.

In crisis management, the relation between events (position) and time (momentum) interferes with precise evaluation of an event. At a specific time, the precision of information for that moment is low or we can have a greater precision of information about the event but obtained over a longer time interval. Therefore, in crisis management, we can know *what* is happening but not *when* it happened, or we can know *when* it happened but not fully *what* happened. This is most obvious when the trajectory of events accelerates or changes direction. This change moves the uncertainty of events into ambiguity.

Shannon (1948) identified information entropy from the mathematics he used to solve the fundamental problem of communication – transmitting information in a reliable manner between transmitter (encoder) and receiver (decoder). To evaluate information in a

mathematical formula he used base 2 ('certainty' vs. 'uncertainty') and introduced the concept of 'bit.' ['If the base 2 is used the resulting units may be called binary digits, or more briefly *bits*, a word suggested by Tukey. A device with two stable positions, such as a relay or a flip-flop circuit, can store one bit of information' (Shannon, 1948).] The equation he found is the same equation used for thermodynamic entropy, the measure of randomness vs. order in a thermodynamic system. Thermodynamic entropy increases as energy dissipates and randomness increases. Information entropy, a variable of state for information scientists, also increases as information is corrupted, as measured from certainty (order) towards uncertainty (randomness).

Entropy, for thermodynamics and information, is a state measure on the spectrum between certainty and uncertainty. In Information Theory, entropy increases with random sources (uncertainty). For Shannon, the act of choosing between messages creates information. Certainty is having only one message possible, no choice and predictability. Because of this, certainty carries no information, creating an apparent paradox: uncertainty is information. We can resolve this paradox if we follow Shannon's approach – making a choice from randomness creates information and communication is the act of resolving this uncertainty. Because of the large number of choices, the unexpected event has high information entropy. We gain information by making choices when we engage the unexpected.

Physicists and chemists study the change of entropy in the system because it is the change in entropy that drives reactions. While information scientists study entropy as a single variable, in crisis management we can study the change in information entropy as people make choices over time to resolve uncertainty and ambiguity. Making choices creates information. Just as the change in thermodynamic entropy drives physical processes, the change in information entropy, giving meaning to randomness and uncertainty by choices, increases information. Ambiguity, when it drives engagement, can create reliable crisis management.

In these three forms of uncertainty, the dictionary form describes states where information can decide the situation. Heisenberg's Uncertainty Principle refers to knowledge of either place or movement but never both and the inability to know causation and prediction. It approaches ambiguity when we focus on momentum and prediction. Shannon's Information Entropy describes how choice creates information. For pragmatic purposes, however, we face situations with multiple reasons for causation, multiple predictions and multiple responses following each intervention. Uncertainty, as a static state, is amenable to the collection of information. Ambiguity, as the temporal quality of uncertainty, has multiple possible causes, multiple possible futures and multiple possible responses to each intervention.

Ambiguity creates the possibility for divergent views on how best to act. Individuals select different interpretations or some people see ambiguity where others see single causation or a predictable trajectory. Focus on the most frightening possibility in these discrepancies makes possible the use of fear to motivate others; focus on the most benign possibility or denial of alternative views, leads to dangerous complacency. Ambiguity, and the sense of vulnerability it creates, may drive safety and reliability or create fear and panic. Ambiguity can also lead to serious, intractable problems.

Operators who accept ambiguity and Wolfberg's mystery-solving are more likely to entertain doubt while expressing less confidence that they are right. They may actually be more accurate with predictions than those who deny uncertainty and ambiguity. Ambiguity deniers tend to reduce the problem to some core theoretical theme with which they feel comfortable, giving them exceptional confidence in the accuracy of their predictions (Watts & Brennan, 2011). The crowd is more likely to follow the reductionist, ambiguity denier who expresses great confidence than the operator who accepts ambiguity and the doubt that accompanies it.

A group may reduce the ambiguous situation to one explanation through which all perception is filtered. When the group's beliefs co-opt newer members, not only does groupthink develop but this shared belief becomes a self-fulfilling prophecy through enactment (Weick, 1979). Enactment prevents individuals from acting on their sensemaking to engage the situation. The group will ostracize the individual who acts contrary to the groupthink, creating stagnation in the presence of ambiguity.

Rule-based decision-making relies on recognition of the situation and categorization together with rules for actions (Rasmussen & Lind, 1982). For such a rule-based system to work, a certain level of fidelity must exist between the chosen category and reality. In states of uncertainty, one can collect more information to support the chosen category. Ambiguity in causation, however, clouds where to look to relieve the uncertainty, ambiguity in prediction clouds how to prepare for the outcome, and ambiguity of response to actions clouds the ability to learn from the choices made.

When the rule does not perform well, enactment and cognitive dissonance may drive the individual, supportive colleagues and organizations to continue using the rule despite its failure. Reason (1990) described this as the 'strong-but-wrong' rule. The application of discrete concepts to ambiguous situations is problematic, much as the difficulties that exist between discrete concepts and continuous perceptions (Weick, 2011).

Ambiguity prevents us from making a direct link between our actions and results. We cannot fully attribute success to a specific intervention, a problem that hinders learning. In the same way, we may continue to

fail without being able to identify the cause of our failure or the flaw in our reasoning.

When people identify themselves as highly expert and experienced, they risk the effects of cognitive dissonance – the painful inconsistency that forms between reality and the person's self perception. The logical response, in their mind, is to believe their own perception over reality (Tavris & Aronson, 2008). The nature of ambiguity enables the individual to select information supporting their perception while furthering their identity. Cognitive dissonance, reinforced by ambiguity, makes some people resistant to reality.

The dynamic, multifaceted event, rich with paradoxical meanings, contributes to errors and disagreement, confounding efforts to explain the cause of actions. In the causation–action–justification linkage, causation is hidden and justification is suspect. Ambiguity allows the selection of information that, retrospectively, supports a particular view and we can see how easy it is to commit an error, criticize others or blame the individual. This is related to the availability heuristic and confirmation bias, along with individual prejudices and attitudes.

Another way to use ambiguity in a positive sense is to assume 'People in these situations do the right thing; they do what I would do.' This drives us to look at the circumstances from the individual's perspective with the goal of understanding what would cause the person to act in the manner they did. This begins a search for signals and meaning from the environment that would drive specific actions, opening up new possibilities of understanding.

The papers in this Special Issue can be assembled and considered in multiple ways. At the risk of oversimplifying, I have placed them in an order that emphasizes a discussion of ambiguity followed by responses to ambiguity and finally the role of organizations in handling ambiguity.

My co-author (Thomas A. Mercer, RAdm, USN, retired) and I write about ambiguity as experienced while creating new programmes (van Stralen & Mercer, 2015). RAdm Mercer describes his experience assuming command of the US Navy aircraft carrier Carl Vinson with the ambiguity of a novel communication system. Karlene Roberts, from the University of California, Berkeley, studied his command philosophy and the crew's performance in her work on High Reliability Organizing (Rochlin, LaPorte, & Roberts, 1987) and my experience in a paediatric intensive care unit (Roberts, Madsen, Desai, & van Stralen, 2005). Our article describes the effect ambiguity has, at the levels of the individual and leader, on creation of our respective programs.

John Carroll (2015) focuses on functional types of ambiguity and their effect on safety. *Fundamental ambiguity* is experienced as the lack of categories; *causal ambiguity* is from cause–effect relationships; and *role ambiguity* of who is accountable. This is what people face when they stand alone at the beginning of a crisis and to what the organization responds. Weak signals of unsafe practices tend to be ambiguous and easy to ignore. As in Wolfberg's mystery-solving and full spectrum analysis, we do not know what information may be relevant. Carroll describes the effect of information entropy on bad news as it is reframed to become less threatening and also less meaningful and less urgent. More successful strategies involve seeking multiple perspective and *innovative suggestions*, which contributes to *learning by doing*.

Bea (2015) creates a typology of ambiguity and uncertainty for assessment and management. He identifies ambiguity inherent to the system, Intrinsic Uncertainty, comprising a natural part of the environment or the result of analytical modelling. Ambiguities from outside the environment, Extrinsic Uncertainty, arise from human and organizational test performance or the development and utilization of information. Engineering approaches do not address extrinsic uncertainties where high reliability leadership and management have greater importance. Proactive management requires anticipation and a robust system that can tolerate the damage and defects of the adverse effects from extrinsic uncertainties. Reactive assessment management relies on the premise that systems can fill in the goals to minimize consequences of failures. Engagement, a necessary component of working with ambiguity, occurs through interactive assessment and management functions, a form of real-time crisis management. Because ambiguity cannot be reduced to zero, the management of ambiguity is a continuous process, a constant struggle to make sense of what is happening to a complex system.

Barton et al. (2015) studied how wildland firefighters reduce ambiguity with improved sensemaking and leadership. This is enabled by a two pronged set of practices enacted by leaders and frontline workers that includes actively searching for discrepancies and actively seeking diverse perspectives. Wildland fire culture accepts real-time experimentation and improvisation. The authors' use of Bertrand Russell's concept of 'Knowledge by acquaintance and knowledge by description' to explain leadership in dynamic states is of good use and long overdue for complex organizations that rely on highly experienced personnel. The closer one comes to the event, the greater the influence of ambiguity. The authors' clear explanation of anomalizing and proactive leader sensemaking can easily translate to other industries.

Flin and Fruhen (2015) defined ambiguity more broadly to encompass vague probabilities and lack of clarity. They focus on senior managers and ambiguous threat with problem solving as a management behaviour. Flin and Fruhen's description of problem solving as

a behavior is similar to the principle of engagement and Wolfberg's mystery-solving and full spectrum analysis. This correlates closely to emergency responders who routinely encounter novel situations, which may explain the insightful conclusion that, with problem-solving strategies, managers 'gain a closer estimate of the risks they are dealing with'. This point will benefit any discussion of how to create a safety culture. The concept that calm is a source of chronic unease in operators is very real, not because operators want to act, but because the calm may be due to missing an early herald of failure. Chronic unease in managers influences how they react with subordinates, but it also presents the opportunity to model behaviour and thinking for ambiguity. Conflicted decision-making, from Janis and Mann, is a most useful explanation of the response to uncertainty and ambiguity under stress, including many of my experiences that became an integral part of what I taught for emergency management.

Meshkati and Khashe (2015) used the US Airways Hudson River landing and the Fukushima Daini Nuclear Power Station earthquake response to show how ambiguity can act as a source of resilience through improvisation. In each of these situations the operators remained engaged to enact a response that lessened the damage that could have occurred. To do this, people had to move from routine operations to non-routine, emergency operations quickly and with minimal discussion among themselves. Using Rasmussen's skill-based, role-based, and knowledge-based framework, they demonstrate that independent, thinking people are the last line of defense in a high risk, ambiguous situation.

Woods et al. (2015) discussed how organization managers discount safety metrics and information when faced with uncertainty and ambiguity. With several real-life examples, they show that the deficit in ability for an organization to assess incoming evidence of vulnerability can be measured. Their Q4-Balance framework provides the analytic individual basis to assess balance and imbalance across the four classes that are formed. *Safety energy* comes from this framework; it looks at how the organization consumes its 'energy', which is expertise, time and networking activities for safety personnel. Safety energy is a dynamic quantity expanding or contracting in the face of the organization's reaction to ever-changing goals and conditions of operation.

Vidal (2015) approaches ambiguity from the three stances of Thorngate (1976): simplicity, generality and accuracy. We can have any two but not all three. Vidal explains our choices with metaphors of the engineer, the craftsman and the gardener. The engineer metaphor (simple and accurate, local therefore not general) underscores our discussion of uncertainty with use of delegation of authority, protocol, and collection of facts. The craftsman (simple and general, ambiguous therefore not accurate) aims for causation and uses creativity

to shape the world. The gardener (general and accurate, complex therefore not simple) can only respond to a limited number of things, 'a figure who takes action on the little things under his control, without expecting to control nature, and who contemplates the beauty of a world within his comprehension'.

Weick (2015) embraces ambiguity, describing that even to reduce ambiguity you must initially increase it. Ambiguity becomes a moving target and acceptance of avid unity as an expected part of the everyday marks an increase in understanding from the level of the superficially simple and uncertain to the complex and ambiguous. But it is through the engagement of the complex and ambiguous that we organize. Information entropy is deeply embedded in his article as the active engagement of ambiguity to create understanding, organization, and communication similar to Shannon's statement that when we make choices in uncertainty we create information. Weick describes how we manage ambiguity through experience. This is similar to 'You become part of the problem', a phrase used to describe our experience as rescue ambulance paramedics in an area of high crime gang activity. We could only solve the problem by entering the crowd, but by entering the crowd we might need rescue ourselves as we change the immediate environment.

Mentioned in several of the articles were the early herald and anomaly, the presence of a time course, the need for engagement or interaction, the need for creativity and improvisation, and the importance of leadership.

Anomalies, small deviations, early warnings, minor perturbations and weak signals are signs that the system is not working well and bring attention to events that, if not engaged, can enlarge to cause major disruptions. Anomalies as indicators 'have the potential to trigger re-evaluation and re-conceptualization about changing risks before serious incidents or accidents occur' (Woods et al). 'Among these emerging disconnects and contradictions lurk the weak signals, the cues indicating a hazardous condition where additional scrutiny is now merited' (Flin & Fruhen). Ambiguity and background noise make it easy to ignore these signs (Barton et al., 2015; Carroll, 2015; Flin & Fruhen, 2015; Meshkati & Khashe, 2015; van Stralen & Mercer, 2015; Woods et al., 2015).

Shannon's formulation of information entropy finds information in uncertainty and that we gain information by the choices we make. Ambiguity, discrepancy and the creation of discrepancy force us to make choices, creating information

From our authors, discrepancy identifies the small deviation that may enlarge. Every experience creates discrepancies and, when we pay more attention to the seemingly subtle and insignificant, we experience more ambiguity (Weick, 2015). Discrepancy can come from

people with different experiences or from people with the same experience but difference sensemaking. Within 'these emerging disconnects and contradictions lurk the weak signals, the cues indicating hazardous condition where additional scrutiny is now merited' (Flin & Fruhen, 2015).

Barton et al. call the active search for discrepancy and outliers anomalizing. The leader can then reflect on the harsh realities of multiple viewpoints (Carroll, 1995, 2015; Barton et al., 2015; Bea, 2015; Flin & Fruhen, 2015; Weick, 2015).

Organizations that operate effectively will simultaneously engage different parts of the system to maintain balance (Barton et al., 2015). Carroll (2015) describes this eloquently as 'acting into an ambiguous situation', capturing our feeling, as rescue ambulance men, when we approached a hostile crowd. People are involved in dynamic and continuous interaction to prevent failure and hazard; touching the boundary of loss of control is necessary during a crisis (Meshkati & Khashe, 2015). In this manner, several groups of heroic people engaged the crisis of an airplane landing on the river and a nuclear power plant severely damaged by an earthquake and tsunami. Interactive approaches, interactive assessment and management of ambiguity, is performed during the operations conducted (Bea, 2015). Safety energy reflects the resources devoted to safety-oriented indicators for proactive safety management; the purpose of proactive safety metrics is for engagement (Woods et al., 2015). The Fog of War can only be managed by engagement (van Stralen & Mercer, 2015).

Weick describes how high reliability organizations increased ambiguity in the initial phase of engagement. 'To grasp ambiguity is to comprehend it adequately.' We experience ambiguity and we do this through engagement, always substituting, always interrupted, and always relational. To manage ambiguity we experience ambiguity and even that experience, because we see it new, allows us to see new things. Innovative suggestions and learning-by-doing are significant contributors to success in ambiguous states (Carroll, 1995, 2015).

Ambiguity can enable collective action by numbing potential conflicts of interest; it can trigger exploration and learning. In the gardener's stance, Vidal (2015) evocatively describes engagement with the Gardener's Stance; 'take action on the little things under his control, without expecting to control nature, and who contemplates the beauty of a world beyond his comprehension' (Carroll, 1995, 2015; Barton et al., 2015; Bea, 2015; Meshkati & Khashe, 2015; van Stralen & Mercer, 2015; Vidal, 2015; Weick, 2015; Woods et al., 2015).

Ambiguity, by several authors, unfolds over time and with it the context changes, which changes the meaning of observations and experience. As an unfolding

sequence of events, ambiguity threatens safety and reliability. Reactive management approaches, the premise that systems can fail, seek to learn from near misses (Bea, 2015), events easily missed or disregarded in real time. Safety energy is a dynamic quantity that contracts or expands in the face of the organization's reaction to ever-changing goals and conditions of operation (Barton et al., 2015; van Stralen & Mercer, 2015; Weick, 2015; Woods et al., 2015).

The principle that organizations use creativity, improvisation and innovation as a response to ambiguity, surprised me the most about this project. Vidal (2015) describes the basis of innovation, 'Organizations are better prepared when their reservoir of ideas and actions is large enough, so that people can choose those that help them make sense of the situation at hand and recombine behaviours to improvise ad-hoc solutions'. Meshkati and Khashe (2015) write, 'Improvisation is considered as an engine of resiliency, improvisation in safety critical situation, which inhabits ambiguous information, could result in either mitigation or prevention of catastrophic system failures'. In the heroic response to the nuclear power station damaged by an earthquake and tsunami, they add that, 'The improvised acts of the nuclear shutdown are too numerous to mention'. From Weick, 'Interruptions and improvisations seem to go together . . . one possibility of how organizations react to ambiguity'. Flin and Fruhen (2015) write, 'The ability to imagine negative consequences is requisite imagination. This is captured as flexible thinking' (Carroll, 1995, 2015; Flin & Fruhen, 2015; Meshkati & Khashe, 2015; van Stralen & Mercer, 2015; Vidal, 2015; Weick, 2015; Woods et al., 2015).

The authors who discussed leadership commonly described elements of a bottom-up approach or, at the least, transformative and supportive leaders at the top. Weick (2015) discusses the 'group writ small', which I think is critical as it describes the dynamics of a bottom-up approach. It supports the idea that safety and reliability are self-organizing responding to local context. 'Empowering expert people closest to a problem and shifting leadership to people who have the answer to the problem at hand' (Meshkati & Khashe, 2015) is central to success.

Leadership in ambiguity also has a top-down element. Vidal urges caution with the Engineer's Stance of leadership – 'when lessons learned by organizations translate into the refinement of procedures, protocols, and the proliferation of rules'. 'Managing uncertainty by an inflation of rules is typical of the engineer's stance.' Rather, successful leaders seek out diverse perspectives and discrepancy (Barton et al., 2015), engage diverse participants from inside and outside the organization to provide multiple perspectives and innovative suggestions that contribute to learning-by-doing (Carroll, 1995, 2015), and a shuffling of power and influence to

those who can make sense of the ambiguous situation. Only the Captain of the ship could say no, giving a bias for action to make the system work (van Stralen & Mercer, 2015). A deeper understanding of 'only the Captain can say no' is the Captain sees a larger picture of the events (Mercer, pers. commun.). Carroll describes the CNO who reversed the firings of two contract workers who voiced safety concerns. The CNO saw the larger picture and, by acting into ambiguity, increased not only safety in the program but transformed leadership in the ranks of management.

Bea described the importance of corporate leadership: when the leaders who developed the programme retired, 'the pipes started leaking again.' (Barton et al., 2015; Carroll, 1995, 2015; Meshkati & Khashe, 2015; van Stralen & Mercer, 2015; Vidal, 2015; Weick, 2015).

When we assume uncertainty, we assume we have missed information, that there is a correct hypothesis and outcome, and more information will bring us closer to reality. When we accept ambiguity, we accept that there are multiple interpretations, that system trajectories and our conclusions will change, and that perceptions have limited fidelity to reality.

How an organization responds to ambiguity is how the organization maintains productivity, quality, resilience and safety in a changing, hostile and ambiguous environment.

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References

Barton, M., Sutcliffe, K.M., Vogus, T. and DeWitt, T. (2015), 'Performing under Uncertainty: Contextualized Engagement and Wildland Firefighting', *Journal of Contingencies and Crisis Management*, Volume 23, Number 2, pp. 74–83.

Bea, B. (2015), 'Learning about Ambiguity', *Journal of Contingencies and Crisis Management*, Volume 23, Number 2, pp. 66–73.

Carroll, J.S. (1995), 'Incident Reviews in High-Hazard Industries: Sensemaking and Learning under Ambiguity and Accountability', *Industrial and Environmental Crisis Quarterly*, Volume 9, pp. 175–197.

Carroll, J.S. (2015), 'Making Sense of Ambiguity through Dialogue and Collaborative Action', *Journal of Contingencies and Crisis Management*, Volume 23, Number 2, pp. 59–65.

Flin, R. and Fruhen, L. (2015), 'Managing Safety: Ambiguous Information and Chronic Unease', *Journal of Contingencies and Crisis Management*, Volume 23, Number 2, pp. 84–89.

Meshkati, N. and Khashe, Y. (2015), 'Operators' Improvisation in Complex Technological Systems: Successfully Tackling Ambiguity, Enhancing Resiliency and the Last Resort to Averting Disaster', *Journal of Contingencies and Crisis Management*, Volume 23, Number 2, pp. 90–96.

Rasmussen, J. and Lind, M. (1982), A model of human decision making in complex systems and its use for design of system control strategies, Presented at the American Control Conference, Arlington, VA, USA.

Reason, J. (1990), *Human Error*, Cambridge University Press, Cambridge, UK.

Roberts, K.H., Madsen, P., Desai, V. and van Stralen, D. (2005), 'A Case of the Birth and Death of a High Reliability Healthcare Organisation', *Quality and Safety in Health Care*, Volume 14, Number 3, pp. 216–220.

Rochlin, G.I., LaPorte, T.R. and Roberts, K.H. (1987), 'The Self-Designing High-Reliability Organization: Aircraft Carrier Flight Operations at Sea', *Naval War College Review*, Volume 40, Number 4, pp. 76–90.

Shannon, C.E. (1948), 'A mathematical Theory of Communication', *Bell System Technical Journal*, Volume 27, Number 3, pp. 379–423.

Tavris, C. and Aronson, E. (2008), *Mistakes Were Made (But Not by Me): Why We Justify Foolish Beliefs, Bad Decisions, and Hurtful Acts*, Houghton Mifflin Harcourt, Orlando, Florida, USA.

Thorngate, W. (1976), 'Possible Limits on a Science of Social Behavior', in Strickland, J.H., Aboud, F.E. and Gergen, K.J. (eds), *Social Psychology in Transition*, Plenum, New York, pp. 121–139.

van Stralen, D. and Mercer, T.A. (2015), 'Ambiguity in the Operator's Sense', *Journal of Contingencies and Crisis Management*, Volume 23, Number 2, pp. 54–58.

Vidal, R. (2015), 'Managing Uncertainty: The Engineer, the Craftsman, and the Gardener', *Journal of Contingencies and Crisis Management*, Volume 23, Number 2, pp. 106–116.

Watts, C. and Brennan, J.E. (2011), 'Capturing the Potential of Outlier Ideas in the Intelligence Community', *Studies in Intelligence*, Volume 55, Number 4, pp. 1–10.

Weick, K.E. and Sutcliffe, K. (2011), *Managing the Unexpected: Resilient Performance in an Age of Uncertainty*, John Wiley & Sons, San Francisco, CA, USA.

Weick, K.E. (1979), 'Enactment and Organizing Chapter 6', in *The Social Psychology of Organizing, Topics in Social Psychology Series*, (Vol. 2), Random House, New York.

Weick, K.E. (2011), 'Organizing for Transient Reliability: The Production of Dynamic Non-Events', *Journal of contingencies and crisis management*, Volume 19, Number 1, pp. 21–27.

Weick, K.E. (2015), 'Ambiguity as Grasp: The Re-Working of Sense', *Journal of Contingencies and Crisis Management*, Volume 23, Number 2, pp. 117–123.

Wolfberg, A. (2006), 'Full-Spectrum Analysis: A New Way of Thinking for a New World', *Military Review*, Volume 86, Number 4, pp. 35–42.

Woods, D., Herrera, I., Branlatt, M. and Woltjet, R. (2015), 'Where Is the Organization Looking in Order to Be Proactive about Safety? A Framework for Reviewing Whether It Is Mostly Looking Back, Also Looking Forward, or Simply Looking Away', *Journal of Contingencies and Crisis Management*, Volume 23, Number 2, pp. 97–105.

Ambiguity in the Operator's Sense

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Ambiguity is a central problem for operators working in dynamic, high-risk environments. Operators must decide on a course of action before knowing with certainty how the system will respond. Though ambiguity is expected, how it presents is unexpected. We reduce ambiguity when we can give meaning to information and events through use of context, responsiveness of the system, and when we can view events from a higher level. Preparation and training for routine operations helps identify potential ambiguities before events begin. The experienced operator engages the situation relying on real-time experience to learn what works through action, thus further reducing ambiguity.

1. Introduction

Events and probabilities continuously change to create stochastic situations. This is the world of operational military and public safety (fire suppression, law enforcement and emergency medical services) where uncertainty and ambiguity are viewed as one and the same, a dualism. The unknown history, incomplete knowledge of the incident, multiple possible futures and solutions, and uncertain responsiveness to actions in time creates inherent ambiguity. Operations, then, identify characteristics and properties of the situation while maintaining an agile response. Experienced operators do not distinguish between observation and engagement.

In a time-compressed situation, two people, or an individual, will interpret the same evidence in different ways with different alternatives. One of the most serious effects of ambiguity is loss of decisiveness from failure to choose between alternatives. Resolution of ambiguity in high-risk situations must be resolved in a highly reliable manner.

Operators learn how to engage ambiguity through anecdotes and stories, some of which were learned, literally, in blood. These stories carry an underlying principle with the purpose to educate others, differentiating them from 'war stories', which do not necessarily have the purpose of education.

2. Ambiguity is present in routine operations

The third Nimitz class aircraft carrier, USS Carl Vinson (CVN 70) was commissioned in March 1982 and departed from Norfolk, Virginia, on its first extended deployment in March 1983. During this first year, the ship and its airwing team were formed with intensive air operations and refresher training at sea, culminating in the initial Operational Readiness Inspection. In the past, a full 2 years had been available for this process prior to the first deployment. The timelines were compressed because the Carl Vinson was destined to be the first new aircraft carrier homeported on the west coast in over 20 years, and the Pacific Fleet supply chain

provided all the operational funding and aircraft and ship logistic support. An air wing homeported in California composed of nine squadrons and over eighty aircraft was embarked for work-ups within a week after commissioning.

To facilitate internal communications and the information display throughout the ship prior to the development of the Internet, e-mail or the Global Positioning System, the first captain acquired and installed in the ship prototypes of several high-tech systems. Even the ether net cabling throughout the ship was not part of the original construction contract. The ship's crew installed this during the first 4 months after commissioning. The major new technology components of the system included an early Wang e-mail system available throughout the ship, a multicoloured moving map display system connected to the ships Inertial Navigation System with monitors at the key ship and aircraft control stations and squadron ready rooms, a high-speed online printer to replace numerous mimeograph machine's and a rudimentary artificial intelligence system to help with the decision processes, aircraft fuel state and priority for landing during air operations in bad weather.

The ambiguity created by limited knowledge of the system capabilities, training in their use, maintenance of the equipment with no established schools for operators or maintenance personnel, and the continuing writing of software, and development of standardized display formats throughout the ship, was a constant challenge. Also, the small special-purpose computers were not hardened or built for the harsh shipboard environment and frequently failed.

The captain and several specifically selected and trained 'believers', as a collateral duty to their normal jobs, directed the entire effort, engaged problems as they presented themselves, regrouped, deferred to technical expertise wherever it existed, and continued to motivate the department heads to use and recognize the future value of such systems. All were encouraged to work with their counterparts to correct a deficiency, but if unable, to push the problem up the line for resolution. Only the captain could say 'no'. Methods were developed to make sense out of the frequent ambiguities presented, to affect a solution and communicate up the chain to the accountable person.

Command was by 'negation' only, that is, higher authority would only intercede if he did not agree with the decisions or if there were resource constraints that he must resolve between two lower agencies. This is the norm in the Combined Warfare Concept. Each individual warfare commander and responsible agency makes the decisions for which he is responsible and requests and controls the necessary resources to accomplish their mission.

This approach gives the higher authority the freedom to see the larger view of events and how individual agencies interact with others. When ambiguity presents itself as a threat, leaders of the local responsible unit may cone attention to events. At the local level, ambiguity may confuse the leader, while at the larger level, the commander may not experience this confusion either from experience or the ability to see the larger view. This larger view allows the commander to observe what is working and how and when to bring assistance.

At the end of the cruise, Carl Vinson was welcomed to the San Francisco Bay area with its professional reputation for mission accomplishment enhanced and its accident-free safety record over its first 3 years in commission intact. Rochlin, et al., 1987, later studied the Carl Vinson at the beginning of the University of California, Berkeley, High Reliability Organization Study Group.

3. Ambiguity is expected; how it presents is unexpected

Ambiguity in wartime is often described as the 'Fog of War' because no matter how good your pre-war planning and the intelligence assessment may be, until the battle is joined, there is really no way of knowing how the enemy will react to the situation and which forces they will be able to bring to bear to counter the forces and tactics that you have devised. Preliminary plans rarely survive the first engagement.

When the United States entered the Vietnam War in 1964, aircrews faced the most sophisticated combined air defence systems in history. While the air-to-air threat was formidable both during the Korean and Vietnam Wars, the combined air defences of SAMs (surface-to-air missiles) and large- and small-calibre anti-aircraft (AAA) guns had not been encountered before. There was a lack of intelligence of where the SAM sites and large-calibre gun emplacements were located and how they would be deployed with numerous aircraft from both sides in the same airspace. Because of this ambiguity, many of the squadrons and airwings that were led by Korean War veterans initially went in low and fast. But they were vulnerable to barrage fire from small arms and light AAA. Single-engine attack jets do not have the power, when carrying heavy bomb loads, to gain sufficient altitude for a high-angle bombing run. They were often slow and vulnerable to SAMs at the height of their roll-in. Conversely, those squadrons that went in high all the way were vulnerable to SAMs and large-calibre AAA throughout their entire overland approach to the target. It took several months of trying different tactics and communicating the results between the various aircraft carriers and their airwings, to resolve the ambiguities and trade-offs. As the air war progressed, new sensors and anti-radar weapon

systems were rapidly added to the mix and more powerful and stealthy twin-engine attack aircraft came on line. Graduate training in tactics for the junior squadron weapons training officers (responsible for training the rest of the squadron) was commenced at 'Strike U' similar to 'Top Gun' for the advanced training of fighter pilots in air-to-air tactics at 'Top Gun', which more people are familiar with because of the popular movie of the same name. This evolution was a lesson of 'learning what works through action' and evaluating the enemy response throughout the ongoing events.

Even simple principles, with non-linear interaction, create complex incidents having novel properties that appear unexpectedly. With uncertainty, we collect facts and learn about the circumstances; with ambiguity, 'facts' have multiple possible meanings or may change while we collect them. Ambiguity is the temporal correlate of uncertainty. We cannot, however, predict the trajectories or properties these complex interactions produce, a source of ambiguity, nor the response to our actions.

Acceptance of ambiguity reduces vulnerability to the system and crewmembers. The interaction between the team and problem creates ambiguity, making the direction of events more uncertain. There is continuous action-response cycling within the system that can reach an unpredictable rate of change; events can accelerate without warning because of hidden properties within the system and limits in the capabilities of the individual or team effect responses. The goal is to work for the best outcome while preparing for the worst.

In South Los Angeles, during the early 1970s, several rival street gangs, the Crips and Pirus (later called the Bloods) formed. Two-man fire department rescue ambulance crews, responding to violent incidents without law enforcement, would encounter gang members or possible gang members. An adolescent male would wear particular clothing styles to show gang membership or for protection from attack, the sense of identity, camouflage or a sense of belonging to the neighbourhood. If the medics misunderstood the reason for the clothing choice, they could mistake a gang member for a non-member or vice versa, leading to antagonism and possible attack either way. What worked on the previous incident may start a fight in the current incident. In these situations, facts were of little help. Interaction with the individual and bystanders, closely observing nuanced responses and subtle identification of attitudes, reduced ambiguity. This type of sensitive interaction would build rapport with either faction.

4. Ambiguity and context

Context can reduce ambiguity by providing meaning and value to information. In an evolving problem, context refers to past, present, future and trajectory. To the operator, facts are less important in dynamic risky situations than responsiveness, something that can only be obtained through interaction with the situation. Any action can create desired or undesired consequences. To the operator, ambiguity is the standard operating situation and direct engagement the response.

In fire rescue ambulance responses, people may withhold embarrassing or incriminating information necessary for medical care. How closely people stood to each other, whether they spoke freely or looked to someone before or after they answered provided information necessary to decipher if an injury was accidental or intentional. Out of place items, such as a kitchen knife out of the kitchen, a lamp on the floor conveyed information, and type and placement of family photos all carried infomration. Most important was any household item that could be used as a weapon.

Medical treatment *before* making a diagnosis creates context and produces a more accurate medical diagnosis. A medical treatment can make a person better, worse or unchanged. Failure to respond, and its ambiguity, is most difficult to interpret, as it generates no information. In one case, failure of a child to respond to breathing treatments frustrated a physician, who believed he was treating asthma. He transferred care to a pulmonologist who diagnosed bronchomalacia, a weakening of the airway cartilage with airway to collapse during breathing that mimics asthma. When a treatment causes deterioration, loss of this context can lead to incorrect diagnosis. In several cases of children transferred for heart transplant, the physicians were treating the side effects of medications that led to further side effects. The physicians treated their treatment. Adjusting the medications revealed that the drugs themselves caused the heart problem and the heart transplants were not necessary.

5. Bringing control to ambiguity

Ambiguity is the basic, underlying problem that operators address in high reliability operations. Operations bring control to fluid events while developing information about the system. This occurs through interaction with the situation, focusing on response to interventions. This focus has a dual purpose, learn the new direction of events and to evaluate the response through the ongoing event. Always, there is acceptance that an action can produce several results, some favourable and some harmful, or the action may produce nothing.

The inexperienced operator may consider situations as uncertain and amenable to solution if only sufficient information could be found, risking confirmation bias. This operator moves away from ambiguity and its greater fidelity to the problem, ignoring developing, contradicting events and information. Lost is the search

for vulnerabilities and gaps in knowledge. New or weak signals are interpreted as noise. The high reliability operator appreciates weak signals as early heralds of evolving vulnerability while expecting, seeking and recognizing ambiguity within the noise of events.

While the inexperienced operator 'finds' meaning in the incident, the experienced operator uses experience to 'give' meaning to the incident. This is meaning in the context of the situation and surrounding environment from training and experience, both recent and repeated experience. The availability bias, where the most easily recalled experience influences perception and cognition, heavily influences and can mislead the sense of context. This bias also comes from dangerous experiences or from signals carrying greater salience for conscious or unconscious reasons. Refusal to simplify, one of the principles of HROs (Weick & Sutcliffe, 2011), makes visible ambiguity to help identify multiple possible causes of the event, various meanings and different futures.

Accepting situations as uncertain vs. ambiguous has significant ramifications. The primary distinction is whether one observes or engages the situation, as uncertainty is amenable to observation and collection of information while ambiguity is not. Ambiguity requires entry into the problem space and interaction with the environment. The individual, engaged with the problem, becomes part of the problem through this interaction causing the need for support and safety. This interactive sensemaking, real-time operant learning, forms the basis of Bea's concept of 'Interactive real-time risk assessment and management' (Bea, 2008).

Natural disaster prediction and response are replete with ambiguity. The eruption of Mt. Pinatubo in the Philippines, June 1991, gave little warning of severity, location and extent of damage. Clark Air Base, 8 miles east of the mountain, was evacuated 2 days before the first minor eruption, which did no significant damage (the ash cloud went to 80,000 feet, but blew west out to sea). Then on the second eruption, 3 days later, the mountain blew its top (1,600 feet was lost forming a crater over a mile wide). The winds from a passing tropical storm brought 10 inches of heavy wet ash to the US Naval Facility at Subic Bay, 23 miles south of Mt. Pinatubo, which had been considered a safe haven from the effects of the eruption for the 13,000 Clark Air Base personnel who had been evacuated to Subic. They were living with the Subic families awaiting air transportation to leave the Philippines. The ash fall completely destroyed over 200 corrugated metal buildings, interrupted the power and water supply, and severely damaged the runway at Cubi Point Naval Air Station. The 20,000 Navy and Air Force dependents then had to be evacuated by Navy ship to Cebu, 300 miles south where they could be airlifted back to the United States.

Multiple trips by two aircraft carriers and a large amphibious ship completed the evacuation to Cebu within a week after the eruption, and the Navy and Marine Corps personnel remaining at Subic set about to clear the ash from buildings, runways and roads; restore utility services; build many temporary warehouse and shop buildings; and return the base the full operational capability within 3 months.

Many unique lessons were learned in providing essential services to the evacuees and accomplishing the subsequent clean-up of the base. While there is much experience with dry volcanic ash, there was little with wet ash. At Subic, surrounded by jungle in a typhoon-prone area, the trees were cut back from the above ground power lines. The conductivity of the ash, however, required climbing all power poles on the base to wipe down the insulators and all wires and transformers had to be washed before power could be restored.

There was little history of flying helicopters and fixed-wing aircraft in ash-filled skies, but air search and rescue in isolated areas near Mt. Pinatubo was essential. Helicopter flights were accomplished under careful supervision and frequent material inspections from day 1 of the recovery, followed by fixed-wing aircraft 3 days later after a portion of the runway was cleared. Any damage to the aircraft (minimal) was documented and became part of the bank of knowledge of the hazards of flying through a volcanic ash cloud. International air control authorities subsequently utilized this information after volcanic eruptions in Iceland and Japan.

The eruption response and recovery effort was led by numerous individuals, often isolated and out of touch with their normal leadership chain, with a bias for action to try something and learn what would work in these unusual circumstances.

Even personnel with previous experience in disaster relief operations had never seen anything like this. All of nature seemed out of kilter, with the sky filled with ash, pitch-black for 24 hours, winds up to 45 knots with heavy rain, and frequent earthquakes rolling across the countryside, fortunately only to magnitude 5 on the Richter scale. Travel around the base was impossible. They used their training and previous experience to form teams and accomplish what they could in assessing the risk and managing their situation, often being the only source of support and encouragement to the refugees from the storm scattered throughout the base.

6. Preparation and training for ambiguity

While planning is difficult in ambiguous situations, training for ambiguity is not. Injuries to the crew and damage to equipment is inevitable working in high-hazard environments. Keeping them minimal is central to effective

operations. Good leaders develop safety through good procedures and a demanding training environment. These operators viewed everything – safety, reliability and mission performance – through the concept of operations and action.

These experts achieved good safety records through high-tempo professional operations vice an inordinate emphasis on safety rules and procedures *per se*. Certainly, one can achieve an excellent aviation safety record by never operating in unusual weather, night or high threat conditions (ambiguous situations), but operational readiness and confidence of the crew members in their ability to accomplish their mission under any circumstances will suffer.

Experienced operators start work before the incident through standardized training, procedures, policy and operations to the greatest extent possible, then practice them daily for familiarity and compliance throughout the organization. On a US Navy aircraft carrier, every attempt is made to reduce the ambiguity and uncertainty in daily ship and aircraft operations. This is accomplished through training in peacetime at the same tempo and demanding conditions that will be required during combat operations. For flight operations, rendezvous and refuelling altitudes over the ship are standardized, and any anomaly encountered in the air is handled in accordance with standardized procedures to the greatest extent possible. Potential ambiguities specific to the mission are briefed before each flight and any uncertainties encountered in air operations are thoroughly debriefed, not only among the aircrews experiencing the anomaly, but also to all aircrews of the airwing.

In healthcare, particularly emergency or critical care, physicians may have to treat the patient's medical condition before making the diagnosis. Teaching students to use 'response to therapy' as a guide during an emergency may not be recalled in the heat of the moment. But when the student routinely gives information as 'cause-and-effect', this thinking and communication becomes routine during a crisis. For example, it is standard to include the amount of oxygen in the blood as part of the patient description and the amount of oxygen administered as part of the treatment. Describing them together (e.g., 50% oxygen giving 90% oxygen saturation) reduces the possibility of ambiguous information during an emergency.

Other sources of ambiguity occur with airborne aircraft or ship problems. At the first reported indications of aircraft malfunctions, before the incident can be clarified, the ship or airwing team goes into action to consider all options, considering whether the aircraft can wait for the next normal recovery cycle or if is necessary to move aircraft out of the landing area and effect an early recovery of the stricken airplane.

Circumstances will change as information is collected, accelerating decision loops. In such developing situations, decisions are made and changed as clarity comes to the situation. In these high-tempo operations, one comes to 'expect the unexpected' and engage it.

7. Conclusion

Operators and leaders in high-hazard environments experience ambiguity as uncertainty within the context of time – everything has a past, present and future. Safety comes through good operations; and good operations can only come about through safety. They train repeatedly to make responses reflexive, but reflexive by choice, that is, under pressure in ambiguous states, they have a bias to act but they act because they choose to, not because they have to. They immediately engage the problem with methods that generate information while bringing control to the situation.

References

Bea, R. (2008), 'Managing the Unpredictable', *Mechanical Engineering*, Volume 130, Number 3, pp. 27–31.

Rochlin, G.I., La Porte, T.R. and Roberts, K.H. (1987), 'The Self-Designing High-Reliability Organization: Aircraft Carrier Flight Operations at Sea', *Naval War College Review*, Volume 40, Number 4, pp. 76–90.

Weick, K.E. and Sutcliffe, K.M. (2011), *Managing the Unexpected: Resilient Performance in an Age of Uncertainty*, Vol. 8, John Wiley & Sons, San Francisco, CA, USA.

Making Sense of Ambiguity through Dialogue and Collaborative Action

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This paper outlines the importance of ambiguity in organizations that manage hazardous operations in a rapidly changing environment. Three kinds of ambiguity are described: fundamental ambiguity in categories and labels for understanding what is happening; causal ambiguity for understanding cause–effect relationships that enable explanation, prediction, and intervention; and role ambiguity of agreeing on responsibilities. Examples of successful and unsuccessful ways that organizations deal with ambiguity are drawn from several industries. Although the most typical response is to avoid ambiguity or to seek a false clarity from confident leaders, more successful strategies engage diverse participants from inside and outside the organization to provide multiple perspectives and innovative suggestions that contribute to learning-by-doing.

1. Introduction

Organizations that face significant safety hazards are challenged to operate with high reliability (LaPorte & Consolini, 1991; Weick & Sutcliffe, 2007), especially when the risks are born by high-status stakeholders (Perrow, 1984). Hence, airlines and nuclear power plants are consistently put forward as models of high reliability. Yet these organizations, along with all modern organizations, face growing complexity, and a dynamic environment of constant change in technology, local and global competition, human resource availability, and public expectations. Complexity and change bring uncertainty and, even more importantly, ambiguity. Part of what makes a crisis (such as a major accident or disaster) so challenging is that it represents a 'fundamental surprise' (Lanir, 1986) or sudden recognition that accepted meanings do not fit the situation. In this paper, I first define ambiguity, distinguish it from uncertainty, and articulate three types of ambiguity with particular relevance for high-hazard or high-reliability organizations. Then, I illustrate the role of ambiguity in several real-world examples and finally draw implications for research and management of ambiguity.

2. Definitions and types of ambiguity

Ambiguity and uncertainty have many meanings in science and everyday language. For this paper, I take a dictionary definition of ambiguity as 'something that does not have a single clear meaning' (www.merriam-webster.com/dictionary/ambiguity). A situation may be ambiguous because there are multiple possible meanings or because there is no clear meaning at all. For most people, ambiguity is an uncomfortable state of mind (Ellsberg, 1961), although reactions to ambiguity vary across people and can be measured as tolerance for ambiguity (Budner, 1962; Lauriola, Levin & Hart, 2007). Similarly, I define uncertainty as 'something that is doubtful or unknown' (www.merriam-webster.com/dictionary/uncertainty). Uncertainty is typically thought of as lack of information about whether something is true or false, as in assigning probabilities to events (i.e., if an event has a probability near 0% or 100%, there is little uncertainty, but if the probability is near 50%, there is a great deal of uncertainty). Psychological reactions to uncertainty are labeled risk attitudes, risk tolerance, or risk aversion (MacCrimmon & Wehrung, 1986; Weber, Blais & Betz, 2002), including the idea that risk seekers may find

enjoymentor business opportunities in uncertain situations that others avoid.

Although scholars could reasonably debate over whether ambiguity is a subcategory of uncertainty or uncertainty is a subcategory of ambiguity, in this paper, I will consider ambiguity as the more general and more psychological concept, which serves as a frame for uncertainty (March & Olsen, 1976; Weick, 1979). We typically think of uncertainty as arising from the world or the limited information we have available about the world. For example, with more information, we can make more accurate (less uncertain) predictions. But if ambiguity is an inability to identify, classify, or understand an event, then we do not even know what information may be relevant or how to assign probabilities to undefined events.[1]

To illustrate ambiguity and uncertainty in practical use, consider nuclear power plants that routinely assess the risks associated with various accidents. For the most part, the accident pathways or failure modes are known and the probabilities are assessed through some combination of experience and expert judgment. There is some uncertainty around those probability assessments that arises from variation in expert opinion, misestimation in extrapolating from one context to another, natural variability in every piece of equipment and the exact way it has been operated over time, and so forth. But these uncertainties are familiar and they can be estimated and combined; the rest is just math.

However, the calculated accident probabilities hold only when the plant is operated within its design envelope (cf. Bedford & Cooke, 2001), which is essentially a collection of assumptions positing that the plant is designed, built, and operated as intended. Yet accident investigations typically reveal that a trigger event (such as a human error) occurred in a context of plant defects, some known, some unknown; these defects combined with the trigger event to become a full-blown accident. In essence, there is not only uncertainty in the risk calculations, but also ambiguity in that some unknown number and type of things will be left out of the calculations. Inserting a generic 'fudge factor' or 'engineering margin' helps protect against ambiguity, but no one really knows whether the margin is adequate or not. Over time, with operating experience (especially when it can be shared across plants), we come to learn about what was not in the original calculations (e.g., the rush to consider tidal waves following the Fukushima disaster) and hence reduce ambiguity (and uncertainty); however, at the same time, plants are continually changing in equipment and operating practices, and also responding to cost pressures, regulatory dictates, loss of expertise with retirement, and so forth, which increase ambiguity. We have no easy way to measure, calculate, or understand whether the plant is now safer

or less safe, with more or less uncertainty or ambiguity than before.

It may be useful to distinguish a few types or areas of organizational ambiguity. Although there may be many ways to distinguish types of ambiguity, I have articulated three kinds that seem particularly important and relevant to organizations (not simply to individual behavior). These types of ambiguity will be further explicated in the examples presented in the succeeding text. First, *fundamental ambiguity* is experienced when we lack categories for understanding our reality, or come to appreciate or fear that our current categories are lacking (cf. 'equivocality' in Weick, 1979). Without labels or categories, we cannot even formulate a useful question beyond the most generic 'What's going on?' Second, we experience *causal ambiguity* when we have an understanding of categories, but we struggle to sort them into causal relationships (cf. ambiguity of means and ends in March et al., 1976). In hindsight, it is easy to assign causality to accidents, such as identifying a human error or a misleading procedure, yet a list of root causes and contributing causes rarely provides a satisfactory understanding or an effective plan for improvement. We are far from having a complete understanding of the causes of accidents and therefore face considerable ambiguity in managing operational safety. Third, the concept of *role ambiguity* (Kahn, Wolfe, Quinn, Snoek, & Rosenthal, 1964; cf. authority ambiguity in March et al., 1976) captures the challenge of who is accountable for what aspects of safety and which stakeholders are or should be involved in any changes. Role ambiguity is related to goal ambiguity (cf. March et al., 1976) in that different stakeholders often advocate different organizational goals (e.g., shareholder vs. stakeholder value); this tension is rarely resolved through purely logical argument. I will not consider goal ambiguity as a separate type in this paper as it seems to overlap with other types, but it is certainly one (of many) that could be added.

3. Ambiguity at Millstone Nuclear Power Station

Northeast Utilities (NU), the largest electric utility company in New England, faced a crisis in the late 1990s (Carroll & Hatakenaka, 2001). All three units at the Millstone Nuclear Power Station were shutdown and the US Nuclear Regulatory Commission (NRC) required a wide range of actions before they would allow the units to restart. Among those requirements was an unprecedented order requiring Millstone to demonstrate a 'safety conscious work environment' (SCWE) as a condition of restart. However, this label had never been used before, in any industry. The NRC provided little guidance regarding what would constitute a SCWE, how to produce it, or how to know

whether Millstone had succeeded in creating it. Instead, the NRC Order required Millstone to hire an independent third-party consultant to certify that the organization had achieved a healthy SCWE. The entire nuclear power industry watched the situation (and some actively participated by lending help) with concern that they could face future regulatory requirements of a similar nature. This is a large-scale example of a regulatory tactic (more generally, specifying customer requirements) known as 'bring me a rock'. The regulator requires something ambiguous; the plant produces something, the regulator says, 'that's not it' until eventually the regulator says, 'that's what I want'.

In the case of Millstone, NU initially moved ahead in predictable ways. They hired a new Chief Nuclear Officer (CNO) from another utility, who made several moves to restructure Millstone and shift the culture. He held an all-hands meeting at Millstone to articulate his values of 'two-way communication' and 'doing the right thing'. He reshuffled the senior management team, demoting some of them, and bringing in a retired US Navy Admiral to head Millstone. A SCWE team was formed with the Vice President (VP) of Operations in charge and the Employee Concerns Program (ECP) was reenergized with a new Director who had worked previously for the Admiral. An external consulting group was hired to fulfill the SCWE certification process; they were sufficiently independent of NU to be acceptable to the NRC. They developed a definition of SCWE, as the ability of workers to raise[2] safety and quality issues without fear of harassment, intimidation, retaliation, or discrimination, and the ability of managers to respond appropriately to those concerns.

But several months into the change initiative, with enormous amounts of money being spent to upgrade the units and change the culture, it was evident that progress was much slower than hoped. Although there were some signs of change, the company was bleeding red as they not only invested in change but also had to buy electricity from other utilities to supply their customers while Millstone was shutdown. No one knew what to do to speed things up or whether momentum would build somehow.

Then they got lucky, but not in the ways we might predict. The old habits and thought patterns surfaced very visibly and, paradoxically, offered an opportunity to accelerate the change process *if* management responded in new ways. For example, after two contract workers had raised safety and quality concerns, their manager fired them for doing poor quality work; senior Millstone managers then approved the firing. The Director of ECP immediately intervened (those who make safety allegations are legally protected from retaliation) and the CNO reversed the firing decision pending an investigation. Within days, the investigation revealed that the workers had been correct about their allegations and there had been no grounds to fire them.

This was a transformative event for many managers who had not accepted that anything was wrong at Millstone, including the VP of Operations who was in charge of the SCWE effort yet admitted he had been 'going through the motions'; they had blamed their shutdown on the NRC and denied the need to change. Because the CNO responded well to this event (and there were other events in the same time period), there was an opportunity to hear multiple viewpoints and reflect on some harsh realities. This led to more engagement and energy, and the creation of specific processes, teams, meetings, and measures to assess and enhance SCWE.

Many organizations receive 'weak signals' that their practices are unsafe, or that their intended improvements are not working, yet these signals are typically ambiguous and easy to ignore. Managers and subject matter experts have been successful in the past; they are reluctant to admit (even to themselves) that their success is transitory, their status provisional, and their ways of thinking limited to one perspective among many. Bad news does not travel easily upward in organizations and fundamental ambiguity allows the news to be reframed in ways that are less threatening but also less meaningful and less urgent. With causal ambiguity, even if we accept that change is needed, it is easy to blame someone (e.g., contractor management fired the contractors and misled us about the firing, so there is nothing we have to do about our safety and management practices) and therefore keep the problem from affecting most of the organization. With role ambiguity, it is not clear who is responsible for learning and change, so problems fall between the cracks and nothing becomes actionable.

At Millstone, a deeper understanding of SCWE and how to create and measure it developed over months and years, driven by broad engagement of employees from top to bottom as well as external assistance. There was widespread recognition that NU could go bankrupt or close its nuclear power plants if change was not accomplished and demonstrated to the regulator. NU's Chief Executive Officer (CEO) participated regularly in role-plays in management training. Regular meetings of cross-department management teams monitored conflict areas on a daily basis and developed understanding and action possibilities. Individual contributors added innovations and ideas that were welcomed as positive contributions. The third-party consultant became a true partner, helping to craft ideas and plans and providing advice and coaching to managers. These conversations and activities reduced ambiguity, in the sense that participants had more clarity about what to measure and analyse, how to address causes and implement change, and who needed to be involved. In about 2 years, NU

was able to restart the newest and largest unit, a year later the next unit, and the oldest and smallest was decommissioned. The plant was later sold to another utility for a remarkably high price and is still in operation.

4. Ambiguity around the meaning of 'safety culture'?

In an analogous way to the ambiguity around Millstone's SCWE, entire industries have faced the question of 'What is safety culture?' The label was created in the 1980s by the International Atomic Energy Agency in Vienna during their investigation of the Chernobyl accident (see review in Guldenmund, 2000). Again, the label was created to fill a gap – something had gone wrong at Chernobyl that was more than a technical issue and more than human error. Instead, there seemed to be an inexplicable disregard for the fundamental principles of safety management. Test engineers, overriding the operators, shut off safety systems and deliberately placed the power levels at a point where the reactor was known to have a design problem that made it hard to control. Lacking a way to understand why this had happened, the report called it a failure of safety culture.

Over time, multiple definitions arose to articulate the concept of safety culture, i.e., to create shared meaning around this ambiguous concept. Almost concurrently, the concept of 'safety climate' also had been circulating through the research literature (e.g., Guldenmund, 2000; Zohar, 2010). It is generally agreed that a safety climate is the workers' *perceptions* of the priority given to safety. Safety culture is a much broader (and more ambiguous) term, encompassing espoused values, beliefs, practices, and underlying assumptions (e.g., Reason, 1997; Schein, 2009, 2013a). Because safety climate is built around a relatively clear concept, including a simple quantitative measurement technique based upon employee surveys, it holds a competitive advantage with managers looking for action opportunities and measurable and timely results. If an organization improves its safety climate score from 3.8 to 4.0 in the past 2 years, and then compares those scores favourably against other organizations in its industry, there is a clear story to tell to bosses, regulators, the press, and other stakeholders. The results are very persuasive, even if the climate survey does not fully capture the concept of culture. In comparison, a 'real' culture assessment is hard to specify, and probably involves lengthy qualitative data collection and subjective analysis by consultants or (gasp!) academics, with results that may be too late or too confusing to be useful. No wonder climate surveys became widespread in aviation, health care, nuclear power, and other industries, where they are often called safety culture surveys.

Consider the recently formed Bureau of Safety and Environmental Enforcement (BSEE) that exercises regulatory authority over US offshore oil and natural gas. Born in the wake of the 2010 Gulf oil spill, with blame shared among the oil company, the contractors, and the now-defunct government regulator, BSEE has developed its policy documents to include discussion of safety culture. One key draft document stated that leaders and individuals 'emphasize safety over competing goals'. Later on the same page, safety culture was described as 'appreciation for the importance of safety ... for its integration and balance with competing performance objectives' (BSEE, 2012). But what does this mean? How are we to understand whether safety is an *overriding* goal or to be *balanced* with other goals? Such ambiguity or equivocality may be resolved by articulating the policy further or by an evolutionary process as people inside and outside BSEE wait to see what happens when decisions are made and things go wrong, when people get blamed or promoted. However, this ambiguity may remain if decisions provide no clear pattern and if key leaders and respected experts differ among themselves as they jockey for influence. In the case of BSEE, the current safety policy document has moderated the ambiguity by defining safety culture as 'values and behaviors ... that reflect a commitment to conduct business in a manner that protects people and the environment' while also emphasizing 'integration into performance objectives to achieve optimal protection and production' (http://www.bsee.gov/Safety/Safety-Culture-Policy).

At a nuclear fuel manufacturing plant, a safety culture survey has recently been administered twice, a year apart. The survey measures multiple aspects of safety culture, with most items taken from a survey developed by the Institute of Nuclear Power Operators (INPO); the INPO survey in turn derives from work in several industries by Reason (1997), Weick and Sutcliffe (2007) and others. Following the first survey, which revealed some lower scores on safety culture dimensions, the plant organized four teams to initiate improvement efforts. In the second survey, plant managers were expecting to see some positive impact of their efforts. Instead, the results were very similar to the prior year, even slightly worse.

In particular, the dimension of 'respect' (i.e., people treat each other with respect, especially across hierarchical levels and departments) was somewhat lower, which surprised those who expected that the efforts of the 'Respect' team would produce improvements. An explanation surfaced that the company had shifted their health insurance to the plan of their corporate parent in the weeks just prior to the survey administration. There had been many reports of people going to their doctors with their old insurance cards and being told they were not covered anymore, or had less coverage than before,

and there were other inconveniences and confusions during the transition. Managers believed that workers might have answered the respect questions in this context, feeling that they had not been treated very respectfully during this transition. Of course, the connection between insurance coverage and safety is indirect at best. But this story illustrates the ambiguity in understanding what scores on a safety culture survey mean, what has influenced those scores, what initiatives are likely to improve those scores, and who should be participating in and managing these initiatives.

The safety culture survey, by itself, does not reduce ambiguity. A common failure mode is to use the readily measurable scores as a substitute for inquiry (Schein, 2013b), based on the simplifying assumption that there are additive cause–effect relationships. In short, we can make an improvement here and an improvement there, and on average the culture will improve (just as higher scores on some climate questions will result in a higher average climate score). Instead, the plant used a series of focus group interviews following the survey to discuss the results and to get specific examples and details of what the responses meant to workers, supervisors, and managers. Then, diverse teams could begin to assemble ideas about how to intervene and how to know whether progress was being made. This is a process of *acting into* an ambiguous situation (or enacting, Weick, 1979): elevating a concern to receive attention, making resources available, and taking steps to gather information and engage broad participation in sensemaking and change initiatives. Thus, the survey was a starting point and a legitimation of the conversations and activities that flowed from a commitment to self-study and improvement (Carroll, 1998).

5. The ambiguities of incident investigations

Root cause analysis (RCA) is the label placed on a family of techniques for investigating incidents, accidents, problems, and so forth (e.g., van Vuuren, Shea, & van der Schaaf, 1997). Every industry uses some form of incident investigation, which can vary from one person spending a half hour reviewing documents to a multidiscipline team taking weeks or months to investigate and issue a report. There are famous reports on Piper Alpha, Clapham Junction, Herald of Free Enterprise, Three Mile Island, Challenger, Texas City, and so forth that have had tremendous impact on their industry and even across industries.

The intent of RCA is to reduce causal ambiguity, i.e., to identify the causes of an accident or incident so that steps can be taken to manage risk and improve performance. However, the very label suggests that there is a single 'root' cause that can be identified. In the extreme, I visited one nuclear power plant that had a database of

RCA investigations that required the report writer to enter a single root cause code in the database; the database was constructed with space for only one root cause. I have called this 'root cause seduction' (Carroll, 1995) because of the very human desire to find the root cause so we can fix the problem and turn our attention to other matters. Once the root cause is identified, ambiguity seems to dissolve away – the organization takes steps to discipline or train the humans who made errors, write more procedures, replace bad equipment, or whatever the investigation has targeted as the source of the problem. This avoidance of ambiguity is especially acute among managers and engineers, who (forgive my gross generalization) like having answers to problems. Even those who enjoy ambiguity often have a boss who wants answers (now!) and therefore end up avoiding and minimizing ambiguity. In contrast, academic researchers prefer questions that require more data gathering and analysis and become uncomfortable at the idea that a problem is solved or a theory is complete. No wonder managers and academics often struggle to work together.

Interestingly, RCA investigations that go more deeply into causes typically find that equipment problems and human error are only the tip of the iceberg. Underlying issues around training, hiring, long-standing design flaws and backlogs of work, availability of resources, work practices, management priorities, and so forth begin to surface. And then the role ambiguity also surfaces: just who is responsible for these problems and who is responsible for making it better? It is easy and comforting to blame someone at the 'sharp end' (Reason, 1990) who had their hands on the equipment and made a mistake, but whom do we blame for cutting training budgets or delaying maintenance? Blaming the people above you in the organization can be a career-ending mistake. Blaming the competitive environment, the pressures from Wall Street to produce earnings, the chronic task overload, or the lack of safety culture seem equally futile. Managers fear that blaming 'the system' will reduce accountability and make the organization less manageable.

6. Lessons for managing ambiguity and closing remarks

Most people, including managers, shy away from ambiguity and uncertainty. The prospect of losses loom larger than equivalent gains, and ambiguity is experienced as a loss of control (Slovic, 1987). We know that people are willing to take 1,000 times the risk for activities that they perceive as being within their control (e.g., driving a car, skiing) in comparison with those they perceive they cannot control (e.g., flying in a commercial airplane). Hence, the public demand for safety from aviation accidents, nuclear accidents, and so forth. And,

not surprisingly, the very human desire to believe that high-hazard industries are under control: after all, we have safety equipment, quality assurance, external audits, safety culture assessments, and no disaster since the current plant manager has been in charge. And, oh yeah, that accident that happened in another plant, it could never happen here.

The typical response to ambiguity, as illustrated in the examples earlier, is avoidance. People look for ready answers, including at-hand fixes such as training, blaming the individual at the sharp end, or writing more detailed procedures. Managers look to experts and consultants to provide a recipe for improvement, or to confident-appearing CEOs (or former Admirals) who seem to have the answers, or at least the 'right stuff'. But we do not avoid ambiguity solely as individuals; in organizations, we avoid ambiguity *together* by constructing socially acceptable shared meanings and explanations that give us great comfort, even if they are not valid. When events give us an opportunity to challenge old ways of thinking, to embrace ambiguity and work together to find new meanings, will we be ready and willing? (Or, even better, can we proactively seek out ambiguity before events make it painfully obvious?)

In all the cases presented in this paper, initial ideas about problems and solutions were useless or wrong; ambiguity had to be accepted and addressed collectively, with new information emerging from feedback over time. At Millstone, a new CNO brought the right values and a genuine desire to engage with others, but that was too little to push the transformation against deep resistance. And, in a sense, the resistance was well-grounded, as he and others did not know how to change the organization – even the regulator did not know what it wanted and sought to learn from Millstone's evolution. It was the CNO's acknowledgement of management mistakes and openness to ideas from multiple participants that facilitated the transformation. With safety culture efforts, the desire to monitor and manage by the survey scores is the most visible and *least important* part of culture change. Instead, the driving force is the conversations and engagement of broad participation in acknowledging ambiguity, striving to understand the organization, and generating innovative ways forward, with continual discussion to learn from these efforts. In RCA, the misleading search for the 'root cause' can inhibit progress. Instead, it is the process of convening to investigate and learn, and then to discuss ways to improve, that offers the true benefit in terms of sensemaking and building trustful relationships across pieces of the organization.

As Weick (1979) pointed out, maintaining or even increasing diversity of thought is costly and uncomfortable in the near term, but better in the long run. It is another case of what is known in systems thinking as 'worse before better'. Weick uses the term 'equivocal-

ity' rather than ambiguity. It is an evocative term because it suggests 'equal voices' or multiple participants conversing with mutual interest and respect for diverse viewpoints. The ability to hold conflicting ideas in a conversation or in one's mind is important to managing ambiguity. That includes the ability to take action without assuming that the action is correct. There will be feedback to test the assumptions underlying the action plan, so assumptions must be held lightly in order to be testable and changeable. This requires cognitive flexibility, faith in the process over time, and willingness to work with others who bring diverse viewpoints.

I would be remiss without noting that ambiguity is also a fruitful research topic. There is much to be learned from both laboratory and field about how individuals and groups deal with ambiguity and deepen their understanding of concepts, causes, and responsibilities. The world of practice sometimes leads the world of theory, but it is desirable for practitioners and researchers to learn from and with each other. That relationship is inherently ambiguous and conflicted because the parties are driven by different timeframes and goals and work with different concepts and frameworks. But that very ambiguity opens possibilities if the participants are genuinely curious and willing to learn.

Acknowledgements

Notes

1. Many academic traditions seek out ambiguity and then create new meanings, which initially increases ambiguity, but has the potential to decrease ambiguity if these meanings create more comprehensive and useful concepts.
2. Karl Weick notes that 'raise' is itself an ambiguous term, used at Millstone for their SCWE definition, and now embodied in NRC policy guidance documents. I would add that 'ability' is being used here to imply willingness, beyond simply skills and knowledge.

References

Bedford, T. and Cooke, R. (2001), *Probabilistic Risk Analysis: Foundations and Methods*, Cambridge University Press, New York.

Budner, S. (1962), 'Intolerance of Ambiguity as a Personality Variable', *Journal of Personality*, Volume 30, Number 1, pp. 29–50.

Bureau of Safety and Environmental Enforcement (2012), Draft Safety Culture Policy Statement: Request for Public Comments. Docket ID: BSEE-2012-0017.

Carroll, J.S. (1995), 'Incident Reviews in High-Hazard Industries: Sensemaking and Learning Under Ambiguity and Accountability', *Industrial and Environmental Crisis Quarterly*, Volume 9, pp. 175–197.

Carroll, J.S. (1998), 'Safety Culture as an Ongoing Process: Culture Surveys as Opportunities for Inquiry and Change', *Work and Stress*, Volume 12, pp. 272–284.

Carroll, J.S. and Hatakenaka, S. (2001), 'Driving Organizational Change in the Midst of Crisis', *Sloan Management Review*, Volume 42, pp. 70–79.

Ellsberg, D. (1961), 'Risk, Ambiguity, and the Savage Axioms', *The Quarterly Journal of Economics*, Volume 75, Number 4, pp. 643–669.

Guldenmund, F.W. (2000), 'The Nature of Safety Culture: A Review of Theory and Research', *Safety Science*, Volume 34, pp. 215–257.

Kahn, R.L., Wolfe, D.M., Quinn, R.P., Snoek, J.D. and Rosenthal, R.A. (1964), *Occupational Stress: Studies in Role Conflict and Ambiguity*, Wiley, New York.

Lanir, Z. (1986), *Fundamental Surprise*, Decision Research, Eugene, Oregon.

LaPorte, T. and Consolini, P.M. (1991), 'Working in Practice but not in Theory: Theoretical Challenge of High Reliability', *Journal of Public Administration Research and Theory*, Volume 1, pp. 19–47.

Lauriola, M., Levin, I.P. and Hart, S.S. (2007), 'Common and Distinct Factors in Decision Making Under Ambiguity and Risk: A Psychometric Study of Individual Differences', *Organizational Behavior and Human Decision Processes*, Volume 104, Number 2, pp. 130–149.

MacCrimmon, K.R. and Wehrung, D.A. (1986), *Taking Risks: The Management of Uncertainty*, Free Press, New York.

March, J.G. and Olsen, J.P. (1976), 'Organizational Choice under Ambiguity', in March, J.G. and Olsen, J.P. (eds), *Ambiguity and Choice in Organizations*, Universitetsforlaget, Bergen, pp. 10–23.

Perrow, C. (1984), *Normal Accidents*, Basic Books, New York.

Reason, J. (1990), *Human Error*, Cambridge University, Cambridge, UK.

Reason, J. (1997), *Managing the Risks of Organizational Accidents*, Ashgate, Brookfield.

Schein, E.H. (2009), *The Corporate Culture Survival Guide* (Revised), John Wiley, San Francisco.

Schein, E.H. (2013a), 'The Culture Factor in Safety Culture', in Grote, G. and Carroll, J. (eds), *Safety Management in Context: Cross-Industry Learning for Theory and Practice*, Swiss Re Centre for Global Dialogue, Zurich, Switzerland.

Schein, E.H. (2013b), *Humble Inquiry: The Gentle Art of Asking Instead of Telling*, Berrett-Koehler, San Francisco.

Slovic, P. (1987), 'The Perception of Risk', *Science*, Volume 236, pp. 280–285.

van Vuuren, W., Shea, C.E. and van der Schaaf, T.W. (1997), *The Development of an Incident Analysis Tool for the Medical Field*, Eindhoven University of Technology, Eindhoven.

Weber, E.U., Blais, A. and Betz, N.E. (2002), 'A Domain-Specific Risk-Attitude Scale: Measuring Risk Perceptions and Risk Behaviors', *Journal of Behavioral Decision Making*, Volume 15, Number 4, pp. 263–290.

Weick, K.E. (1979), *The Social Psychology of Organizing*, Addison-Wesley, Reading.

Weick, K.E. and Sutcliffe, K.M. (2007), *Managing the Unexpected: Resilient Performance in an Age of Uncertainty*, (2nd edn), Jossey-Bass, San Francisco.

Zohar, D. (2010), 'Thirty Years of Safety Climate Research: Reflections and Future Directions', *Accident Analysis and Prevention*, Volume 42, pp. 1517–1522.

Learning About Ambiguity

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This paper proposes a classification system for definition, analysis and management of the primary ambiguities influencing the performance of engineered systems. One category of ambiguities (Intrinsic) is addressed with 'hardware and structure' approach that is intended to develop and maintain 'robust' damage and defect-tolerant systems. The other category of ambiguities (Extrinsic) is addressed with 'human and organizational' approach intended to develop and maintain high reliability organizations having high reliability management with high reliability systems. Proactive (performed before activities are conducted), Reactive (performed after activities are conducted) and Interactive (performed while activities are conducted) risk management approaches and strategies are described to help develop and maintain systems having desirable performance characteristics, including acceptable 'safety'. Results from a study of seven organizations that worked for more than 10 years to implement these approaches and strategies to assess and manage ambiguities are summarized.

1. Introduction

As a young engineer, I did not receive training in how to understand, evaluate and manage different types of ambiguities; to understand and successfully cope with the uncertainties influencing how different types of systems were engineered, constructed, operated and maintained. Frequently, factors-of-safety (FoS; ratio of capacity to demand) appeared magically in the engineering processes. Safety of the systems engineers designed was discussed; it was emphasized that engineers should hold public safety as a priority, but there was no instruction in how to determine if a system was safe or not safe. In many cases, it was assumed that something was safe if it was designed according to some generally accepted engineering code or guideline.

2. Types of uncertainties

I have learned that there are different types of ambiguities – things that are doubtful or uncertain. These different types of ambiguities must be assessed and managed in different ways. There is not a 'one size fits all' approach to either characterize or manage uncertainties.

To provide organization and structure for classification, description and analyses of the different types of ambiguities, they have been organized here into two fundamental categories (Table 1): (1) Intrinsic – belonging to the essential nature, and (2) Extrinsic – what comes from outside of something.

There are two types of Intrinsic uncertainties: Type 1 – natural, inherent, information (data) insensitive, and Type 2 – analytical modelling (qualitative and quantitative), parametric, state, information sensitive. Knowledge and data can be used effectively to reduce Type 2 uncertainties. Other means like FoS can be used to cope with Type 1 uncertainties.

There are two types of Extrinsic uncertainties: Type 3 – human and organizational task performance, and Type 4 – human and organizational information development and utilization. Results from Extrinsic uncertainties frequently are identified as 'human errors'. Experience has amply demonstrated that such errors are results from human and organizational processes and are not the 'root causes' of accidents and failures (Dekker, 2006; Reason, 1990; Woods, 1990). Human errors are results, not causes.

Type 4 uncertainties have been divided into two subcategories: (1) Unknown Knowables – 'Predictable Surprises' (Bazerman & Watkins, 2004) or 'Black Swans' (Taleb, 2007), and (2) Unknown Unknowables (Bea, 2002) – not predictable or knowable before something is done. In the case of Unknown Knowables,

Table 1. Classification of Sources of Uncertainties

Intrinsic	Extrinsic
Type 1 – Natural, inherent, information insensitive	Type 3 – Task performance
Type 2 – Analytical, information sensitive	Type 4 – Knowledge development (a) Unknown Knowables (b) Unknown Unknowables

the knowledge exists but has not been properly accessed, analyzed and understood. In the case of Unknown Unknowables, the knowledge does not exist and the uncertainties and their effects are not predictable. In this case, the knowledge must be developed at different times and ways during the life of a system, properly analyzed, and appropriate actions taken to understand these uncertainties to enable preservation of the operational integrity of a system. Recognition of and preparation for Unknown Unknowable uncertainties makes it clear that processes to understand and manage uncertainties performed before a system exists and is operated can and never will be complete. Developing safe and reliable systems is a continuing 'improvement' process to properly recognize and defend systems for ambiguities.

3. Management of uncertainties

A primary method to manage Type 1 uncertainties is with FoS incorporated into the different parts of a system. The FoS is the ratio of the element or system (assembly of elements) Capacity (force and displacement resistance) to the Demand (forces and displacements) imposed on or induced in the element or system. The Capacity (demand resistance) can be increased and/or the Demand decreased. Often, the element or system is deemed to be 'Safe' if the Capacity exceeds the Demand and 'Not Safe' if vice versa. Greater Type 1 uncertainties require larger FoS.

Frequently, the 'design Demand' conditions and FoS can be found in engineering codes and guidelines. In most cases, these design conditions and FoS have been developed by professional engineering societies. In these cases, there has been sufficient 'good experience' with certain types of systems so the design conditions and FoS can be developed from system performance 'hindcasts' (backward-looking analyses). The difficulties with this approach develop when the systems are modified or used in conditions that have not been included in the referenced 'good experience'. This difficulty becomes even more important when ageing systems need to be addressed together with the ageing processes, which leads to greater Type 1 and Type 2 uncertainties. Additional challenges develop when the

potential consequences of failures have increased as a result of changes in the natural or 'social' environments in which the systems exist. What was deemed Safe for the original environments can no longer be deemed for the changed environments.

A very important part of management of Intrinsic uncertainties is properly addressing Type 2 uncertainties. These uncertainties are 'information sensitive'. Reliable data and information on the performance of elements and systems when they are subjected to intense Demands (e.g., load testing) can provide vital information needed to validate and calibrate analytical models. These data-based validation processes can provide information that can be used to better define Type 2 uncertainties. Investments in gathering and analyzing data can be shown to pay substantial economic rewards. Explicit treatment of Type 2 uncertainties leads directly to rejection of unproven invalidated analytical models. This is an important wake up call for many who may not be taught to question the validity of the analytical models they use in their work; particularly, when these analytical models are embedded in complex computer programs.

Extrinsic uncertainties can be addressed with leadership and management developed by high reliability organizations (HROs) (Weick & Sutcliffe, 2007) with high reliability management (Roe & Schulman, 2008) that develop high reliability systems (HRS) (Bea, 2002).

Three interrelated and interactive approaches are used by HROs to continually assess and manage Extrinsic uncertainties: (1) proactive management performed before activities are conducted, (2) interactive management conducted during activities, and (3) reactive management conducted after activities are concluded.

Each of these approaches is based on three primary strategies: (1) reduce the uncertainties, (2) reduce the effects of uncertainties, and (3) increase the proper detection, analysis and correction of the adverse effects of uncertainties.

These three approaches and strategies are intended to develop effective 'barriers' to continually assess land manage system risks – barriers to maintain 'acceptable' likelihoods and consequences of failures.

Application of these HRO system management approaches is very dependent on the time and other resources available for their development, validation and implementation. If there is a lot of time and other resources available (days, months), then the goal can be to develop approaches that can result in optimized solutions. If time is very limited (seconds, minutes, hours), then the goal is to implement approaches and mobilize resources that can result in survival – non-failure conditions. This is crisis management (Bea, 2008). Systems need to be prepared with people and system 'supports' that enable proper management of both types of situations.

Engineering approaches typically do not explicitly address Extrinsic uncertainties. Often, engineering approaches are premised on 'effective' assessment and management of Extrinsic uncertainties using 'specified' Quality Assurance and Control (QA/QC) and 'good' HRO leadership and management processes. Omission of explicit analysis of and provisions to cope with Extrinsic uncertainties is one of the primary reasons why traditional engineering approaches can result in significant underestimates of the likelihoods and consequences of major system failures and in overly optimistic evaluations of the 'safety' of such systems. Similarly, neglect of explicit consideration of Extrinsic uncertainties can lead to root cause analyses that do not properly address the true root causes because they focus on 'what broke'. Rarely are specified QA/QC and good management processes perfect. Consequently, they can produce predictable and unpredictable undesirable outcomes.

Of major importance is the definition and characterization of the particular 'system' that is being considered. Systems are comprised of seven primary parts: (1) operating groups with daily responsibilities for the functionality and performance of the system, (2) organizations that determine the means, methods and resources used by the operating groups, (3) hardware utilized by the operating groups and organizations, (4) structures that provide the support and protection for the operators and operations, (5) procedures and processes (formal, informal) used by the operators, (6) environments in which the operations are conducted (external, internal, social), and (7) the interfaces among the foregoing. These components are highly interrelated, interconnected and interdependent. Systems are highly dynamic and organic – adaptive. Systems are not uniform, homogeneous and static or unchanging.

These characteristics pose special challenges for assessment and management of ambiguity. Assessment and management of ambiguity is never complete, never perfect and often not appreciated until it fails. These characteristics also pose special challenges for engineers and engineering. Engineers typically address some parts of systems – often, the hardware and structure components – sometimes the procedure components (e.g., computer programs). The behaviour and performance of the entire system is rarely adequately understood or addressed by engineers and engineering. Engineers are typically taught to decompose a system into its parts and focus on the parts. The vast majority of engineering analytical models are 'static', not dynamic and organic – changing and adaptive to the multiple environments in which real systems exist.

Proactive management is intended to prepare systems so they are ready and able to cope with the hazards and threats they will face during their lives – to reduce the likelihoods and consequences of major

system failures so the associated risks (combinations of likelihoods and consequences of failures) are maintained to be tolerable and acceptable. A key part of this work is to eliminate the potential for Unknown Knowables and to learn all that can be learnt about the constitution and performance of a particular system.

Another key part of this work is to acknowledge and prepare for Unknown Unknowables. For many, if not most engineers, this is a foreign concept because the majority of engineering work is focused on predictability – knowability. Effective management of Unknown Unknowables requires two basic things: (1) people supports and (2) system supports. Such management supports needs to be provided for the system operators who have daily responsibilities for the safety of the system.

People support strategies include such things as selecting personnel well suited to address unknown unknowable ambiguities, and then training them so they possess the required skills and knowledge to properly understand the ambiguities and implement corrective actions to mitigate their negative effects. Training needs to encompass normal daily situations, unusual situations and 'unbelievable' unusual situations that require development of innovative methods that can return the system to a safe state. Retraining is important to maintain skills and achieve vigilance. The cognitive skills developed for management of unknown unknowable ambiguities degrade rapidly if they are not maintained and used.

Unknown Unknowables management teams should be developed that have the requisite variety to manage the crisis and have developed teamwork processes so the necessary awareness, skills and knowledge are mobilized when they are needed. Auditing, training and re-training are needed to help maintain and hone skills, improve knowledge and maintain readiness. Unknown Unknowables management teams need to be trained in 'divide and conquer' strategies that preserve situational awareness through organization of strategic and tactical commands and utilization of 'expert task performance' (specialists) teams. Unknown Unknowables management teams need to be provided with practical and adaptable strategies and plans that can serve as useful 'templates' in helping manage each unique situation. These templates help reduce the amount and intensity of cognitive processing that is required to manage the situation.

System support includes factors such as improved maintenance of the necessary critical equipment and procedures so they are workable and available as an unknown unknowable development unfolds. Data systems and communications systems are needed to provide and maintain accurate, relevant and timely information in 'chunks' that can be recognized, evaluated and managed. Adequate safe haven and life saving measures

need to be provided to allow Unknown Unknowables management teams to face and manage the developments, and if necessary, escape. Hardware and structure systems need to be provided to slow escalation of the developments, and re-stabilize the system. Safety system automation needs to be provided for the tasks people are not well suited to perform in emergency situations.

Another key part of Proactive management is to develop systems that are Robust – damage and defect tolerant of the adverse effects from Extrinsic uncertainties. These are not 'minimum' initial cost systems. These are not hemophiliac systems that when scratched, bleed to death and fail. These are 'hell for stout' systems designed to help people succeed in their operations.

Robust systems can safely tolerate the effects of large defects and damage developed by Extrinsic uncertainties. Experience has shown that robust systems result from a combination of four essential things (Bea, 2002): (1) excess capacity to withstand system demands, (2) proper configuration so there are alternative ways to handle the system demands, (3) very high ductility or 'stretchability' so that the system can tolerate excess demands without loosing capacity, and (4) appropriate 'associations or correlations' – high and positive for 'series – weak link' system components and low for 'parallel' element components in which all of the elements must fail before there is failure. These robustness guidelines apply to all of the important parts of a system, particularly the human and organizational components. Since explicit assessment and management of Extrinsic uncertainties is traditionally not included in engineering, it is easy to understand how non-robust, first cost minimized hardware and structure systems often are developed by engineers.

Reactive assessment and management of ambiguity is intended to prepare systems to cope with failures – to reduce and control the short and long-term consequences associated with failures. Reactive management is based on the premise that systems can fail and that the goal is to make the failures have minimum consequences. System Reactive management also is intended to develop deep understanding of the lessons taught by near misses and system failures and then use this knowledge to help further defend or protect the system. Organizations that have good Reactive management are rapidly learning and highly adaptive organizations. They make the right decisions at the right times in the right ways.

Interactive assessment and management of ambiguity is performed during the operations conducted during the life of system; from the time the system is conceived until it is decommissioned. Interactive management frequently takes the form of QA/QC processes. Interactive management also frequently takes the form of crisis

management and provides mechanisms that allow the effects of unknown unknowable uncertainties to be properly detected, analyzed and managed. In this way, potential failures and hazards that are not foreseen or predicted can be managed to prevent major system failures. The people and system supports previously discussed provide the essential elements needed for successful Interactive assessment and management of uncertainty. Interactive assessment and management of ambiguity explicitly acknowledges the limitations in predictability of the performance of systems and prepares systems including the system operators to successfully cope with these ambiguities. These processes require significant investments to provide adequate people and system 'supports', resources and protections. Properly preparing to manage unknown unknowable uncertainties is not quick, easy or free. Proper preparations are essential to develop and maintain the performance of a system when faced with unpredictable – unknowable hazards and threats.

4. Risk assessment

Risk is characterized as the likelihood of 'failure' (undesirable performance) of an element or system (comprised of elements) and the consequences that result from such failures (Figure 1). Consequences of failure can be expressed using different metrics such as monetary, productivity, injuries to people and the environment. The 'risk space' is divided into two quadrants identified as 'Safe' and 'Not Safe'. The Safe quadrant contains combinations of likelihoods and consequences of failures that are 'acceptable' or 'tolerable'. The 'Not Safe' quadrant contains combinations of likelihoods and consequences not acceptable or tolerable.

Figure 1. Example risk space identifying Safe and Not Safe risks based on the annual likelihoods of failure including Type 1–Type 4 uncertainties and the consequences of failure measured in 2010 US dollars.

Often, risk is expressed as the product of the likelihood and consequences of failure. This expression of risk can be interpreted as the 'expected' (or best estimate) of the risk if the expected values of the likelihood and consequences of failure are used. Because there are significant uncertainties associated with assessments of both the likelihoods and the consequences of failures, there are important uncertainties associated with risk assessments. This additional uncertainty dimension of results from risk assessments can have important effects on development of decisions about what constitutes tolerable or acceptable risks.

Earlier, the concept of the engineering FoS and the assumption that an element or system was safe if the FoS was greater than unity were introduced. This is the traditional engineering definition of what constitutes something that is safe. But, there is a major problem with this definition when it is recognized that both the element and the system Capacity and Demand are uncertain and that these uncertainties can change substantially during the life of the element or system.

Typically, engineers are not taught how to determine the safety or 'Reliability' (likelihood of developing desirable system performance) of the things they engineer. Historically, FoS have been developed primarily based on experience. Typically, FoS are focused on the elements that comprise systems, not on the performance of the entire system. If an element or system worked well when it was put into place and operated, then it was replicated. If there were failures, then the FoS would be increased. If there deficiencies in QA/QC or management, then improvements to correct the deficiencies would be made. This 'try, try again' experience-based process characterized much of engineering until late in the 20th century.

It was not until potentially very hazardous or potentially 'high risk' systems (e.g., commercial nuclear power generation, commercial aviation) were engineered that the experience-based process was modified so the performance characteristics of such systems could be assessed before new systems were put into operation. A variety of experimental and analytical processes were developed to help address the performance characteristics of these high-risk systems before they were put into operation. An example of this progress is commercial aviation, particularly associated with commercial jet-powered aviation transportation. Formal ways were developed to quantitatively evaluate safety, reliability and potential risks associated with these complex systems – including both hardware and human parts. These quantitative processes were used to help define systems that had desirable performance characteristics before the systems were put into operation. Prototype experimental testing methods were used to validate that these proposed systems could produce desirable performance characteristics – including potential risks and safety characteristics.

A special challenge develops when it is realized that safety is not an absolute term; safety is relative. Formally, safety can be defined as 'freedom from undue exposure to injury and harm'. This definition is premised on an important concept: high potential consequence of failure systems requires maintenance of low likelihoods of major failures (Figure 1).

Experience with determining the 'acceptable' or 'tolerable' risks associated with engineered systems has demonstrated that such determinations should develop from structured collaborations of concerned and knowledgeable representatives from four groups (Wenk, 1995): (1) the affected publics, (2) commerce and industry, (3) the responsible government agencies, and (4) representatives of the affected environments. There are 'first-principles' methods and 'practical considerations' that should be used to develop definitions of the desirable safety of systems. Examples of first-principle approaches include cost–benefit analyses, historic experience with comparable systems and current 'standards-of-practice'. Insurance and legal requirements – precedents are examples of practical considerations. These approaches have been used to determine the locations of the two diagonal lines in the example shown in Figure 1 that identify risks that are 'As Low As Reasonably Practicable' (International Standards Organization, 2009).

Engineers can provide important insights and information for the collaborative analyses. Engineers should not by themselves be expected to provide adequate definitions or characterizations of the acceptable or desirable safety of systems. Most engineers are taught to keep the safety of the public paramount in their work, but most engineers are not taught about how to realistically determine what constitutes system safety; they need information and direction provided by the four groups and support from the management of organizations for which they work. They need special training and experience in how to quantitatively assess safety, reliability and risk using valid and validated analytical models that address both Intrinsic and Extrinsic uncertainties.

Because of the uncertainties associated with systems that operate in hazardous environments, the concept of the likelihood or probability or failure has been introduced. The uncertainties associated with performance of complex systems can be analytically determined to define the likelihood of failure and the uncertainties associated with this likelihood. If only Intrinsic uncertainties are included in analyses to determine the probabilities of failure of a given system, then it is easy to understand why these analyses typically result in significant underestimates of the actual probabilities of failure.

Given that the risk assessment processes explicitly address Extrinsic uncertainties, then there are two major additions to the determination of the probability of failure. Both additions require characterizations of the Type 3 and Type 4 uncertainties. The additions also require characterizations of the robustness or damage and defect tolerance of the system to Type 3 and Type 4 uncertainties (Bea, Mitroff, Farber, Foster, & Roberts, 2009).

Comparison of analyses of system failures that have included only Type 1 and Type 2 uncertainties with historic data on comparable system failures has shown that such analyses underestimate the likelihood of failure by a factor of 10 or more. Extrinsic uncertainties dominate causation of most major system failures and disasters. It is only when the Type 3 and Type 4 uncertainties are included that the likelihoods of system failures agree reasonably well with those from 'history' – actuarial statistics.

Assessment of the potential consequences associated with failures of systems is another very important part of risk assessment. Experience with risk assessments has clearly shown one consistent trend when the consequences assessed for a given system's failure are compared with the actual consequences associated with failure of the system; they are consistently significantly underestimated. While immediate 'on site' consequences might be reasonably estimated, the long-term 'on-site' and 'off-site' consequences are dramatically underestimated. The long-term 'off-site' consequences frequently are underestimated by factors exceeding 100. Persistent and pervasive failures to accurately estimate long-term environmental, property, quality of life and productivity impacts are generally responsible for these important underestimates.

When it is recognized that Extrinsic uncertainties are omitted frequently in development of assessments of the likelihood of system failures combined with a general tendency to dramatically underestimate the consequences of system failures, it is easy to understand why we are so frequently 'surprised' in the aftermath of large disasters. Many such failures often are attributed to 'organizational' disasters (Reason, 1997).

Further, it is easy to understand why we frequently make the wrong corrections to systems following disasters. Deficiencies in the assessments of Type 1 and Type 2 uncertainties are 'blamed' for the failures when the Type 3 and Type 4 uncertainties have dominated causation of the system failures. The organizations responsible for causation of the disasters often prevent or inhibit identification of the Type 3 and Type 4 uncertainties. They encourage blame for the system failure be placed on the people at the 'pointed end' of the disaster causation spear. As a result, frequently we end up fixing the wrong problems in the wrong ways.

5. Reducing ambiguity and its effects

In cases involving complex systems that operate in hazardous environments, ambiguity cannot be reduced to zero – certainty. There will always be ambiguity and there will always be the risks associated with ambiguity.

However, thanks to several thousand years of experience and knowledge gained from attempts by humans to assess and manage ambiguity, we have learnt that there are ways that ambiguity can be effectively managed. The adage is 'manage or be managed'. There is an important corollary to this adage: 'you can only properly manage what you can properly measure'.

We have learnt that the different types of ambiguity must be properly recognized and quantified (measured) so they can be properly managed. This management includes planning, organizing, leading and controlling to assure that desirable performance is realized from the systems we create. This management must be initiated when a system is conceived and designed, continued when it is constructed – manufactured and put into operation, extended when it is maintained and adapted to changing conditions, and finally concluded when the system is decommissioned. The management of ambiguity is a continuous process – never ending and should be always improving and vigilant. It is a constant struggle to 'make sense' of what is happening to a complex system and then to take effective steps to react and properly adapt to the constantly changing environments in which real systems exist.

As a part of the research and practice experience upon which this paper is based, there was a phase of the work in which seven organizations participated in efforts to improve their capabilities to properly assess and manage ambiguity. This work continued for more than 10 years (Bea, 2002).

At the end of the study period, two of the seven organizations 'succeeded' in their efforts to develop and operate systems that developed acceptable and desirable performance characteristics. As evidenced by the outcomes from this experience, failure of organization efforts to develop HROs with HRSs was more frequent than success.

The characteristics that defined 'success' were defined by the organizations. These characteristics included the following attributes – the HRSs had: (1) acceptable and desirable serviceability (fitness for purpose), (2) safety (freedom from undue exposure to injury and harm), (3) compatibility (met commercial, regulatory and environmental requirements), and (4) durability (freedom from unexpected and undesirable degradation in the system performance capabilities). These systems possessed desirable resilience (ability to rapidly recover functionality following disruptions) and sustainability (ability to maintain functionality without

undue impacts on future resources). The combination of these characteristics was termed 'System Quality'.

It is important to note that safety is a system attribute that is included as one of the attributes that a system should possess. Safety is not a separate or stand-alone attribute. A basic goal is to preserve acceptable balances between the Production developed by a system and the Protections required to properly sustain the Production. What frequently are conflicting goals in the quest for System Quality (e.g., between commercial compatibility – profitability and safety) are made explicit so the people responsible for the creation, management and operations of the system can rationally address these conflicting goals to preserve acceptable System Quality. When properly developed and maintained, such systems have proven that development and maintenance of acceptable safety is good business.

A 'case based' study of the seven organizations identified 5 C's that were required for the organization to realize success: (1) Cognizance, (2) Capabilities, (3) Culture, (4) Commitment, and (5) Counting. All of the 5 C's had to be operationally effective to realize success. If one or more was deficient, then failure to achieve the desired results was the result.

Cognizance was a realistic, clear recognition of the hazards and threats that their systems faced and posed; valid assessments of the likelihoods and consequences associated with major system failures. Capabilities were the human, organizational, leadership and monetary resources required to develop and maintain HROs that created and maintained HRSs. Most important were the knowledgeable, experienced and properly motivated and supported human resources. Culture was organizational and operating group cultures (shared beliefs, values, feelings, artefacts) fostering HROs with HRSs possessing balanced Production and Protection – Quality performance characteristics. Commitment was 'top down' and 'bottom up' continuous effective sustained support provided by the organization management and leadership (including regulators) and operating groups to develop and maintain HROs with HRSs.

Counting was a surprise result from this study. Counting included development of quantitative measurement methods and metrics that could be used to monetarily value and measure the results from corporate financial and human resource investments required to develop and maintain HROs with HRSs. Monetary cost–benefit analysis processes were developed that enabled recognition of the long-term benefits of short-term investments required to achieve acceptable HROs with HRSs. The monetary benefits from major failures that did not occur were recognized and measured. The processes demonstrated that development and maintenance of HROs with HRSs was good business. Corporate internal and public external 'report cards' were developed to communicate what had been achieved by these efforts. This Counting provided key ways to help maintain the means and methods required to achieve and sustain balanced system Production and Protection.

After the study was completed, several years later the two organizations that had succeeded in developing and maintaining the 5 C's reverted back to their previous 'states' – the corporate leadership that established the HROs and HRSs retired. As one employee put it: 'the pipes started leaking again'. Then there was a rash of major system failures. Following these failures, the organizations went back to work to re-establish the 5 C's.

6. Reflections

During the past 25 years, the writer has served as a principal investigator charged with helping determine the 'root causes' of several major system failures and disasters. These failures include the Piper Alpha oil and gas production platform in the North Sea, the grounding of the Exxon Valdez tankship, the crash of the NASA Columbia shuttle, the flooding of the Greater New Orleans area following Hurricanes Katrina and Rita, the San Bruno, California gas pipeline explosion, and the BP Deepwater Horizon Macondo well blowout offshore the coast of Louisiana.

The writer makes an important distinction between the work as a primary investigator of major failures (total of more than 30) and the work to study – perform research on such failures (total of more than 600). Work as a primary investigator has involved extensive 'boots on the ground' long-term exposure to the complex systems that were involved in major failures – disasters. These investigations consumed thousands of hours and involved personal discussions with many of the people directly involved in development of the failures. This 'boots on the ground' investigation experience consistently has provided 'deeper' insights into how and why these disasters happen.

The primary motivation for my work as an investigator has been to learn why the extensive body of knowledge – experience and knowledge about how to prevent major failures was not utilized or if it was utilized, why the technology was not effective at preventing the major failure – disaster.

The writer summarized what he learnt as a simple mathematical expression: $A + B = C$. A are the important hazard and threat environments in which complex systems exist. B are human and organizational deficiencies and defects including hubris, arrogance, greed, complacency, ignorance and indolence that can degrade the acceptable performance of complex systems. C are major system failures and disasters that happen sooner or later.

The A + B = C equation makes it clear that the primary obstacles to develop and maintain HROs and HRSs are human and organizational defects and deficiencies. If these defects and deficiencies can be effectively ameliorated, then there is a high likelihood of developing and maintaining systems that are able to operate successfully in a world that is ambiguous and risky. These are systems whose responsible organizations understand and effectively manage the inevitable ambiguities that systems experience.

Another, and perhaps more helpful way to summarize what has been learnt from investigations of major system failures and disasters is recognition that all of these failures and disasters resulted when there were important defects and deficiencies in one or more of the 5 C's. Most of the time, there were important defects and deficiencies in ALL 5 of the C's. This helps explain why recoveries from major system disasters are so difficult. It takes a lot of time and other resources (human, monetary, technology) to be able to achieve and maintain success in effectively dealing with ambiguity to prevent major system disasters.

References

Bazerman, M.H. and Watkins, M.D. (2004), *Predictable Surprises*, Harvard Business School Press, Boston, MA.

Bea, R.G. (2002), 'Human and Organizational Factors in Design and Operation of Deepwater Structures,' Proceedings Offshore Technology Conference, Society of Petroleum Engineers, OTC 14293, Richardson, TX.

Bea, R.G. (2008), 'Managing the Unpredictable,' Engineering Management, American Society of Mechanical Engineers, New York, NY.

Bea, R.G., Mitroff, I., Farber, D., Foster, H. and Roberts, K.H. (2009), *A New Approach to Risk: The Implications of E3*, Vol. 11, *Risk Management*, Palgrave Macmillan, New York, NY, pp. 30–43.

Dekker, S. (2006), *The Field Guide to Understanding Human Error*, Ashgate Publishing Co., Burlington, VT.

International Standards Organization (2009), *International Standard, Risk assessment – Risk management techniques*, IEC ISO 31010, Paris, France.

Reason, J. (1990), *Human Error*, Cambridge University Press, Cambridge, UK.

Reason, J. (1997), *Managing the Risks of Organizational Accidents*, Ashgate Publishing Co., Brookfield, VT.

Roe, E. and Schulman, P.R. (2008), *High Reliability Management*, Stanford Business Books, Stanford, CA.

Taleb, N.N. (2007), *The Black Swan*, Random House Publishing Group, New York, NY.

Weick, K.E. and Sutcliffe, K.M. (2007), *Managing the Unexpected*, John Wiley & Sons, Inc./Josey Bass Publishers, San Francisco, CA.

Wenk, E. Jr. (1995), *Making Waves*, University of Illinois Press, Urbana, IL.

Woods, D. (1990), 'Risk and Human Performance: Measuring the Potential for Disaster', in *Reliability Engineering and System Safety*, Vol. 29, Elsevier Science Publishers Ltd., UK.

Performing Under Uncertainty: Contextualized Engagement in Wildland Firefighting

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In this paper, we propose that performance under uncertainty and ambiguity is enabled by a two-pronged set of practices enacted by leaders and frontline workers. These contextualized practices fuel performance by enabling teams and organizations to both discern, interpret and make sense of important discrepancies as situations unfold (what we refer to as anomalizing), and to develop a richer understanding of a situation (what we call proactive leader sensemaking). Together, these situation-specific practices contextualize engagement and promote capabilities to contingently tailor actions to unfolding conditions. We test our hypotheses using data gathered from a sample of wildland firefighters and find strong support for our theorizing. We also identify a set of additional group and situational conditions that provide a more nuanced understanding of factors that contribute to reliable performance under dynamic uncertainty. Together, the findings provide quantitative evidence for the micro-foundations of effective performance in uncertain contexts.

1. Introduction

Almost all theories of organization highlight the necessity for organizations to adapt in the face of uncertainty (e.g., Burns & Stalker, 1961; Perrow, 1967; Thompson, 1967). Uncertainty, often experienced as a sense of doubt or inadequate understanding that arises from the ambiguity or equivocality of inputs (Lipshitz & Strauss, 1997), can confuse or delay actions. In high-risk settings, this can have large and deadly consequences.

Uncertainty shapes the extent to which work behaviours and task requirements can be formalized rather than left to emerge through adaptive and proactive behaviours. In certain contexts, work activities can be accomplished through the use of systematic, routine, rational, bureaucratic procedures, whereas uncertain conditions require more flexible, experimental and improvisational approaches. Bureaucratic routines can be both efficient and effective under conditions of relative certainty. Uncertainty, however, requires alternative, interpersonal, high bandwidth coordinating mechanisms (Gittell, 2002). Moreover, when contextual uncertainty is exceptionally high and one cannot imagine or anticipate action interdependencies and contingencies, organizations and their members may face uncertainty not only about future realities, but also

uncertainty about the current state of events. Dynamic and complex situations often create a state of equivocality or ambiguity – in which data are unclear and subject to multiple interpretations (Weick, 2001). The uncertainty challenge in such environments is one of sensemaking. That is, organizations need to develop interactive practices and processes that enable ways of thinking and acting to make sense of the ambiguity and facilitate swift, coordinated action. In this paper, we explore the dual process of how leaders help shape the context and model how to make sense in such circumstances through proactive sensemaking as well as how those on the frontline actually attend to weak signals through processes of anomalizing (Weick & Sutcliffe, 2006).

Our theorizing builds from research exploring the dynamics of high reliability organizing (Roberts, 1990; Vogus & Sutcliffe, 2007a; Weick, Sutcliffe, & Obstfeld, 1999) as well as studies of extreme actions teams (e.g., Klein, Ziegert, Knight, & Xiao, 2006) and fast response organizations (Faraj & Xiao, 2006). High reliability organizations (HROs) strive to continuously manage ambiguity, complexity and fluctuations by sustaining attention or watchfulness. HROs are adaptive organizational forms for uncertain and ambiguous environments (Weick et al., 1999, 82). They have unique capabilities to dynamically organize, which enables organizational actors both to make sense of uncertainty and ambiguity as events unfold and to flexibly respond.

Research over the past decade (see Vogus et al., 2007a; Vogus & Sutcliffe, 2007b; Vogus & Welbourne, 2003; Roe & Schulman, 2008; Madsen, Desai, Roberts, & Wong, 2006; Roberts, Madsen, Desai, & Van Stralen, 2005) has examined the broad organizing principles through which reliable performance in uncertain and ambiguous contexts is achieved. But, much less is known about the micro-level behaviours that underlie dynamic and adaptive organizing. Our goal in this paper is to remedy this gap and particularly attend to micro-level adaptive and proactive behaviours that facilitate coordination and reliable performance when uncertainty is high. We propose that the foundation of dynamic and adaptive organizing (which ultimately results in better performance) stems from the contextualized engagement of actors at multiple organizational levels (Faraj et al., 2006). Specifically, we hypothesize that effective performance is enabled when frontline employees actively strive to capture discriminatory contextual details and build coherent interpretations of them (anomalizing), and, when leaders proactively exhibit behaviours aimed at comprehensive and continuous sensemaking (proactive leader sensemaking). We test our hypotheses in the context of wildland firefighting, a context in which surprises can be deadly, and making adjustments to ongoing action before they can turn into a tragic flaw (Perin, 2005) is critical.

2. Conceptual framework and hypotheses

2.1. Foundations of high performance under uncertainty

Performance in uncertain contexts is a situation-specific accomplishment that involves managing contradictions and interruptions (Barton & Sutcliffe, 2009; Christianson, Farkas, Sutcliffe, & Weick, 2009; Weick, 2011; Weick et al., 1999). Organizations that strive for highly reliable performance provide a template for understanding how this is accomplished. HROs face special problems of learning and acting in the face of ambiguity because of risky technologies or work processes that are not fully comprehended and continuous exposure to dynamic contingencies. The patterns of organizing visible in HROs, serve to 'induce a rich awareness of discriminatory detail and a capacity for action' (Weick et al., 1999, p. 88). Mindful infrastructures (Weick et al., 1999) guard against misspecifying, misestimating and misunderstanding things (Schulman, 2004; Vogus et al., 2007b). That is, by increasing an organization-wide sense of vulnerability, mindful infrastructures mitigate production pressures that can otherwise exacerbate the tendency to normalize or overlook discrepancies signalling that things are unraveling. Thus, HROs can quickly discover, make sense of and correct minor perturbations that can build and cause major disruptions.

There is growing evidence of the salutary effects of these broad patterns of mindful organizing on reliable performance (e.g., Bigley & Roberts, 2001; Madsen et al., 2006; Rerup, 2009; Roberts et al., 2005; Vogus et al., 2007a, 2007b). For example, Vogus et al. (2007a, 2007b) studied the relationship between mindful organizing practices and the commission of medication errors in hospital nursing units finding that fewer medication errors occurred over the subsequent 6 months on units with higher levels of mindful organizing. These studies provide a strong foundation, but lack a detailed examination of the micro-level behaviours by which leaders and frontline employees process organizational conditions under uncertainty. We develop how leaders and frontline employees do this in the following section.

2.2. Processes of contextualized engagement

Managing uncertainty and ambiguity requires attention and alertness, but it also requires discernment, understanding what emerging cues signify, interpreting changes in those cues and determining how behaviours can be adjusted in response. Discernment, in part, means that people appreciate the meaning or significance of data elements (Klein, Pliske, Crandall, & Woods, 2005, p. 20). But, the meaning of data changes as context changes, which means that 'important signals'

change as the details of the current situation change (Sutcliffe & Weick, 2008).

Organizations that operate effectively under uncertainty balance these adjustments by simultaneously engaging different parts of the system (Klein et al., 2006; Weick, 2011). By dynamically blending actions of supervisors and frontline staff, HROs continuously adjust to create a more coherent understanding of what they face and a more composite response (Barton et al., 2009; Roe et al., 2008; Weick, 2011). This requires contextualized behaviours at both levels. The frontline has access to concrete situational details, what Baron and Misovich (1999) call knowledge by acquaintance, whereas leadership has knowledge by description, which fuels broader understanding and action options (Weick, 2011, p. 23). Description is essential for sensemaking and organizing, but acquaintance is critical for successfully navigating ambiguity and dynamism. The implication is that to manage and respond to highly dynamic and uncertain contexts, organizations must have processes in place that interrupt the momentum of ongoing events, thereby providing space and means for renewed awareness and sensemaking (Barton et al., 2009). Such processes presumably enable organizations to interrupt current frames and to notice, interpret and coordinate around new or different conditions *as they unfold*. In the following paragraphs, we develop hypotheses regarding both aspects of this dual process – frontline employee anomalizing and proactive leader sensemaking.

2.2.1. Anomalizing
Previous research suggests that untoward events and crises are often foreshadowed by small discrepancies and anomalies that signal that events are not unfolding as planned (e.g., Turner, 1976). Such *anomalies* are critical signals that the system is breaking down (Rerup, 2009; Sutcliffe & Christianson, 2011; Weick & Sutcliffe, 2007). Yet, particularly, when there are performance and production pressures, there is a tendency to ignore or normalize such signals (Starbuck & Farjoun, 2005; Vaughan, 1996). Consequently, to perform effectively under uncertainty requires organizational members to be vigilant to anomalies and treat them as critical indicators of potential, emergent problems, rather than as normal. We use the term anomalizing to mean taking proactive steps to become alert to discrepancies, to understand them more completely, and to be less encumbered by history (Sutcliffe et al., 2011; Weick et al., 2007). In other words, anomalizing involves both noticing discrepancies and perturbations as well as actively working to understand them without simplifying them into familiar categories. The more people hold on to differences, nuances, discrepancies and outliers, the more slowly they normalize the details and the more nuanced and fine-grained an understanding they

can create. More detailed understanding of anomalies also enables discrepant events to be acted upon more precisely and swiftly, before becoming unmanageable.

Anomalizing, however, is not just a passive process. Anomalies can be created as well as noticed. For example, Barton et al. (2009) found that frontline firefighters created anomalies by collecting diverse perspectives on a fire in two ways. First, by taking a different perspective (e.g., by moving from the ground to elevation), firefighters deliberately created more than one interpretation of ongoing events – a kind of discrepancy that prompted a review of current assumptions and actions. Second, firefighters also sought out different perspectives by engaging with others who had different expertise or levels of experience. These actions contribute to more effective performance under uncertainty by creating a more accurate and complete picture of unfolding conditions. This consistent and disciplined revising of one's understanding means that surprises like those that overwhelmed firefighters at Mann Gulch (Weick, 1993), South Canyon (Weick, 1995) and Cerro Grande (Weick et al., 2007) are less likely to occur and, if they do, be managed more swiftly. Therefore, we hypothesize that when frontline employees (e.g., firefighters) in uncertain contexts avoid the tendency to normalize by deliberately seeking, encouraging, and welcoming the noticing and discernment of anomalies, they will perform better.

Hypothesis 1: Anomalizing will be positively associated with organizational performance.

2.2.2. Proactive leader sensemaking
Anomalizing is an active approach to managing uncertain contexts. As such, it can be facilitated or hindered by other organizational factors. In particular, leaders play a critical role in creating and maintaining a context for anomalizing. Through their behaviour, leaders communicate to group members fundamental assumptions about the situation and the appropriate processes for managing it. Specifically, leaders are in a position to frame the situation *as* uncertain and dynamic, and thus worthy of greater vigilance and exploration. Their behaviour also models the accepted approaches to managing such situations. Thus, when leaders proactively inquire and seek to make sense of potential problems, differences of perspective or other discrepancies, they send two messages. First, by proactively directing attention to sensemaking leaders signal that there is no one right answer or perspective on the situation. By encouraging divergent thinking, the leader presents the situation *as* uncertain – as something still to be understood.

Second, by seeking out diverse perspectives and encouraging people to bring up problems or different viewpoints, leaders model how such ambiguity is to be managed. By encouraging group members to share with

the leader (not just among themselves), the leader not only signals the importance of voice, but also forces him/herself to be constantly faced with the question 'what's the story now?' Research shows that frontline employees often notice anomalies and discrepancies and have divergent perspectives, but they often fail to voice their concerns to others (e.g., Barton et al., 2009; Blatt, Christianson, Sutcliffe, & Rosenthal, 2006; Weick et al., 2007). Voice by itself is important in uncertain environments particularly for surfacing discrepant cues. But, a secondary benefit of 'voice' is that it triggers the integration of information and renewed sensemaking in leaders. Consequently, it enables more effective action taking. If group members only tell each other and it never gets to leaders and other decision makers, these people in power are unable to use the data in their own sensemaking. For example, Weick (2011, p. 22) describes how Paul Gleason, a renowned fire superintendent, privileged sensemaking practices over decision-making practices. As Gleason explained, he wanted to create a dynamic, flexible context to enable all to be able to cope with a changing fire environment (Weick, 2011, p. 22). This line of thinking leads us to hypothesize that proactive leader sensemaking in uncertain contexts is positively associated with performance.

Hypothesis 2: Proactive leader sensemaking will be positively associated with performance.

2.3. Contextual and organizational factors

Within an inherently uncertain context, like wildland firefighting, organizational actors may experience additional sources of uncertainty that particularly affect the complexity and ambiguity of unfolding events and might influence their behaviour and performance. Three sources of such uncertainty are noteworthy: goal clarity (Locke, Saari, Shaw, & Latham, 1981), group familiarity (e.g., Goodman & Leyden, 1991), and task interdependence (Murphy & Jackson, 1999). Although we consider these sources of uncertainty as boundary conditions and include them as control variables, we theorize about them to build a more nuanced understanding of factors that affect the management of uncertainty and unfolding events.

Even when the environment overall is uncertain, in any given situation organizations vary with respect to the clarity of their immediate goals. Goal clarity is critical to coordinating in times of uncertainty because goals direct and focus attention and action (Locke et al., 1981). Moreover, goals are a target against which to measure and make sense of current performance. In the absence of clear goals, organizational actors may struggle to analyse progress with the result that coordination and predictability likely suffer.

Individuals in general and wildland firefighters specifically have to work together to accomplish the goals of the organization. The effectiveness of these collectives depends, in large part, on their ability to coordinate and leverage the knowledge and expertise of their members (Faraj & Sproull, 2000; Rulke & Galaskiewicz, 2000). When group members know one another well, they are better able to anticipate each other's actions, communicate the nature of the task, and make use of the skills and expertise on their team. However, when group members do not know one another, uncertainty increases as the unfamiliarity introduces an additional source of ambiguity and unpredictability.

Finally, task interdependence – the extent to which individuals or units depend on each other to accomplish their tasks – varies according to the structure of the organization and the nature of the task (Thompson, 1967). Task interdependence affects performance under uncertainty by adding complexity to unfolding events, increasing the need for coordination and creating additional uncertainty as a result.

3. Method

3.1. Research context

We studied wildland firefighting – an uncertain context in which attention to discriminatory detail is essential to performance. Wildland firefighting involves a range of fire management efforts, including extinguishing unwanted wildfires (suppression), purposefully setting controlled fires to burn off hazardous fuels such as excess undergrowth (prescribed fires) and overseeing, but not interfering with naturally occurring wildfires, also as a means of reducing hazardous fuels (wildland fire use). These three types of efforts are overseen by a team of individuals structured within a formal hierarchy, called an incident command system.

An incident commander (IC; or a 'Burn Boss' in the case of prescribed fires) generally leads the incident command team and has full responsibility for managing the fire response. In larger fires, individuals responsible for planning, operations, finance, logistics and safety assist the IC, whereas in smaller fires, the IC handles all of these functions. In addition, there are unit-level leaders responsible for a specific group, such as an engine crew or ground crew. These unit leaders report to the head of operations (and ultimately to the IC). In larger fires, additional levels of oversight may be added. For example, crew bosses will report to division supervisors who in turn report to the head of operations.

Wildland firefighting is a highly uncertain context, as fires move rapidly and unpredictably, their behaviour and intensity varying with rapidly changing wind, weather and fuel conditions. In addition, a huge variety of human resources (including fire analysts, smoke jumpers, frontline fighters, safety and public relations officers) and physical resources (from shovels to aircraft) must be distributed, coordinated and effectively

utilized. In addition to environmental uncertainty, teams and units experience varying amounts of goal clarity and familiarity (e.g., units comprised of individuals from different states with little to no knowledge of one another's capabilities).

3.2. Data collection and sample

The primary data used to test our hypotheses were gathered from a sample of wildland firefighters who were involved in US fire management 'on the ground'. The management of fire involves many people in a wide variety of organizations, a large number of whom provide critical infrastructure, planning and support but do not physically become involved in a fire incident on the ground. Much of the work of fire management occurs long before any flames are seen. However, since we were interested in the ongoing action of managing a fire on the ground under uncertain and changing conditions, we chose to focus exclusively on the activities of people who are called upon to physically manage or suppress a fire. The survey population included permanent seasonal and full-time employees filling primary fire positions (including fire, fuels, dispatch and fire aviation) in the USDA Forest Service (USFS) and US DOI Bureau of Land Management (BLM) and National Park Service (NPS). Because sampling was necessarily conducted using day job positions, but the research questions relate to incident positions, we defined our initial sampling frame by agency and day job, then coded responses for analysis based on the incident position respondents provided as part of the survey.

3.3. Procedure

We collected the data using a telephone survey. We drew a stratified random sample of administrative units from complete lists of USFS Forests, BLM State Offices and NPS Parks with fire programs to reflect the relative proportions of federal fire personnel. Proportions were based on a target of 700 surveys: 400 USFS employee respondents (57%), 200 BLM respondents (29%) and 100 NPS respondents (14%). Major units (such as parks, national forests, state offices) were randomly selected, and where multiple subunits occurred for a given major unit (such as multiple ranger districts on a national forest), these were again randomly sampled and complete telephone lists of permanent fire employees (full-time and seasonal) were obtained for the head office and selected local unit. Individual respondents were randomly selected from these lists to reflect the relative proportions of fire personnel in each administrative level: 57% of surveys from ground-level, 29% from mid-level and 14% from upper level positions.

The survey was administered by telephone by the University of Montana's Bureau of Business and Eco-

nomic Research. After asking for basic demographic data, we asked respondents to think back to their most recent fire event. The dates of these events ranged from the day of the interview to 6 months earlier; most occurred within 2 or 3 months of the interview. Respondents provided basic data about the fire event, the size of the fire and the location. They were then asked to respond to a series of questions about their experiences on the fire, using Likert-type scales. For questions relating to a respondent's perceptions about his or her work crew, respondents were asked to 'consider the people with whom you interacted most frequently (e.g., your unit)' and to answer the questions as they related to this particular group.

We obtained usable data from 518 out of 700 respondents, with a response rate of 74%. Thirty-seven per cent of respondents worked for the US Park Service, 24% worked for the BLM and 39% worked for the USFS. Seventy-nine per cent of respondents were male, the average age was 41 years (ranging between 22 and 65) and average experience in fire management was 16 years (ranging from 1 to 45).

3.4. Analyses

We created indices to assess the key variables. Measures of all variables were constructed by taking the average of survey items rated on a 5-point Likert-type scale. Performance was measured using four items (Cronbach's alpha = .62, sample item 'Overall, how well did you feel this fire was managed'). It is important to note that respondents acted as key informants rating overall performance on the fire, not their own performance on the fire (Glick, Huber, Miller, Doty, & Sutcliffe, 1990). Proactive leader sensemaking was measured using eight items (Cronbach's alpha = .89, sample item 'My boss encouraged people to bring up potential problems'). Anomalizing was measured using five items (Cronbach's alpha = .78, sample item 'We actively looked for instances of small things going wrong to try to learn what was happening'). Please see Appendix for full list of proactive leader sensemaking and anomalizing items. Given that these measures as well as some of our control variables were newly developed for this study, we conducted exploratory factor analysis with oblique rotation and found that all items cleanly loaded onto the appropriate factor with no cross-loadings higher than .3.

In our analyses, we also controlled for the internal sources of uncertainty described earlier as well as individual, crew and fire characteristics likely to influence performance. We controlled for the survey respondent's years of experience in fire management as well as their gender (1 = male, 0 = female). Because of the skewed nature of this measure, we took the natural logarithm. We controlled for the familiarity among

members of the firefighting crew using two survey items (Cronbach's alpha = .84, sample item 'How well did you know the skills and abilities of this group?'), used three items to measure the clarity of their goals (Cronbach's alpha = .78, sample item 'Our mission and objectives for each day were clear throughout the day'), and three items to assess their level of task interdependence (Cronbach's alpha = .68, sample item 'The way each person performed their work had a significant impact on how others were able to perform their work'). We also used a series of dummy variables to control for the survey respondent's role (categories included 'command and general staff', 'ground supervisor', 'ground individual' and 'support'. 'Command and general' staff was the omitted category) and the fire type (e.g., wildland, prescribed or suppression) with wildland as the omitted category.

4. Results

Table 1 displays descriptive statistics as well as correlations among all the variables in the study. Most notably, and as expected, anomalizing and proactive leader sensemaking were highly correlated ($r = .55$). However, the exploratory factor analysis suggests that these are actually distinct constructs. In addition, we also examined variance inflation factors and found that they were all less than 2.5 further suggesting that multicollinearity is not a problem (Chatterjee & Price, 1991).

We tested our hypotheses using hierarchical ordinary least squares regression (see Table 2). We first entered the control variables and found that crews with higher levels of familiarity with each other ($\beta = .06$, $p < .001$) and greater goal clarity ($\beta = .43$, $p < .001$) were associated with more positive assessments of performance. We also found that supervisors ($\beta = -.15$, $p < .01$) and firefighters on the ground ($\beta = -.21$, $p < .05$) assessed performance less positively than commanders, a finding consistent with other research suggesting that top leaders in contrast to frontline workers often have a more positive view of performance. The regressions analyses provide support for Hypothesis 1. Anomalizing was positively associated with performance when entered alone ($\beta = .17$, $p < .001$, model 2) or with proactive leader sensemaking ($\beta = .09$, $p < .05$, model 4). Supporting Hypothesis 2, we found that proactive leader sensemaking was positively associated with performance when entered alone ($\beta = .20$, $p < .001$, model 3) or with anomalizing ($\beta = .16$, $p < .001$, model 4). Taken together, this constitutes strong support for our hypotheses and provides evidence for specific behaviours of crew members and leaders consistent with those espoused by HROs contributing to performance across different types of fires.

In our theorizing about the three internal sources of uncertainty (goal clarity, group familiarity and task

Table 1. Descriptive Statistics and Correlations

Variable	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12
Group performance	4.08	.61												
Anomalizing	4.10	.60	.28***											
Proactive sensemaking	4.03	.63	.30***	.52***										
Experience	16.01	9.14	.16***	.06	-.01									
Gender	.79	.41	-.05	.05	-.02	.08								
Familiarity	3.76	1.29	.26***	.06	.07	.04	-.02							
Goal clarity	4.59	.66	.54***	.26***	.24***	.11**	-.05	.20***						
Task interdependence	4.37	.54	.07	.32***	.30***	.02	.03	.11*	.07					
Prescribed fire	.11	.31	.14**	.01	-.04	-.06	.01	.13**	.12**	-.02				
Suppression fire	.76	.43	-.14**	-.02	.01	.02	-.00	-.11*	-.11*	.04	-.61***			
Support	.18	.38	.12**	-.11*	.02	.01	-.27***	.07	.06	.06	-.10*	.01		
Supervisor	.45	.50	-.19***	.04	.00	-.11*	.10*	-.24***	-.12**	-.01	.05	.02	-.55***	
Firefighter	.11	.31	-.12**	-.06	.04	-.30***	.04	.15**	-.12**	-.02	-.02	.05	-.21***	-.31***

$n = 518$.
***$p < .001$, **$p < .01$, *$p < .05$.

Table 2. Ordinary Least Squares Regression of Group Performance

	Model 1	Model 2	Model 3	Model 4
Experience	.06	.06	.06	.06
	(.04)	(.04)	(.04)	(.04)
Gender	−.02	−.02	−.01	−.02
	(.06)	(.06)	(.06)	(.06)
Familiarity	.06***	.06***	.06***	.06***
	(.02)	(.02)	(.02)	(.02)
Goal clarity	.43***	.39***	.38***	.37***
	(.04)	(.04)	(.04)	(.04)
Task interdependence	.02	−.03	−.04	−.06
	(.04)	(.04)	(.04)	(.04)
Prescribed fire	.11	.12	.14	.14
	(.09)	(.09)	(.09)	(.09)
Suppression fire	−.05	−.05	−.05	−.04
	(.07)	(.06)	(.06)	(.06)
Supervisor	−.13*	−.13*	−.16**	−.15**
	(.06)	(.07)	(.06)	(.06)
Firefighter	−.18*	−.17	−.23**	−.21*
	(.07)	(.09)	(.09)	(.09)
Support	.04	.08	.03	.06
	(.07)	(.07)	(.07)	(.07)
Anomalizing		.17***		.09*
		(.04)		(.04)
Proactive sensemaking			.20***	.16***
			(.04)	(.04)
Constant	1.72***	1.44***	1.42***	1.33***
	(.27)	(.27)	(.26)	(.27)
F	26.43***	26.41***	28.00***	26.18***
R^2	.33	.35	.36	.37
ΔR^2		.02	.03	.04

$n = 518$.
***$p < .001$, **$p < .01$, *$p < .05$.

interdependence), we asserted that the effects would be direct. And as stated above, the findings indeed showed that familiarity and goal clarity positively influence performance. But a question arises as to whether these factors might also play moderating roles. Thus, we conducted post hoc analyses to ascertain the validity of this line of thinking. We found modest support for interaction effects between goal clarity and proactive leader sensemaking ($\beta = -.06$, $p < .05$) and goal clarity and anomalizing ($\beta = -.08$, $p < .05$). In both cases, goal clarity attenuated the relationships between proactive leader sensemaking, anomalizing and performance. To further investigate the significant interaction effects, we followed Aiken and West (1991) and plotted the significant interactions at +/−SD. The relationships between proactive leader sensemaking and group performance and anomalizing and group performance are stronger when goal clarity is low. This suggests that proactive leader sensemaking and anomalizing may be especially critical to performance when goal clarity is low. However, this conclusion should be taken with great caution as the magnitude of the interaction effects on group performance was extremely small. We found

no support for other interactions with familiarity and task interdependence.

5. Discussion

Almost 50 years ago, C. West Churchman voiced a sentiment in the preface to *The Systems Approach* (1968, p. xi), which remains relevant both theoretically as well as practically. 'The systems in which we live are far too complicated as yet for our intellectual powers and technology to understand.' If we take seriously Churchman's sentiments, that people and organizations live and act in complex, volatile, uncertain and ambiguous situations, which they cannot or do not understand perfectly (Winner, 1975, p. 69), understanding what enables capabilities for reliable performance under uncertainty is critical. Our findings show that within the firefighting contexts studied here, dual sets of behaviors enacted by leaders and frontline workers are integral to effective performance under uncertainty. Controlling for goal clarity and group familiarity, higher performance occurred when leaders and firefighters on the frontline deeply engaged in their contexts and directed their

behaviours towards proactively searching for and making sense of potential trouble spots.

The findings contribute to the literature in several ways. First, and perhaps most importantly, our findings provide strong support for the importance of particular leadership behaviours in enabling performance under trying conditions. Although there exist myriad case studies showing the criticality of leader behaviours in enabling reliable performance in dynamic conditions (e.g., Bigley et al., 2001; Klein et al., 2006), large-sample quantitative studies are rare. Similarly, few studies have directly examined the micro-behaviours by which front-line employees surface discrepant cues (see Barton et al., 2009; Christianson et al., 2009; Gittell, 2002 for notable exceptions).

Second, and relatedly, the findings reaffirm the importance of active sensemaking processes – both to becoming aware of details, and also to understanding what those details mean. The dangers of normalizing (and conversely the benefits of anomalizing) have taken centre stage since Vaughan's (1996) reanalysis of the 1986 Challenger space shuttle disaster. But to our knowledge, these ideas have received little further empirical scrutiny. Indeed, our findings show the benefits of proactively seeking to become alert to details and avoiding oversimplifying them into familiar events. Moreover, the act of looking for anomalies may actually serve to trigger sensemaking (anomalizing and sensemaking are positively associated). Anomalies provide informational value (e.g., this part of the system may be failing), and they also create an occasion for sensemaking (Jett & George, 2003; Weick, 1995). This represents a rethinking of sensemaking as we find evidence that the discrepancies triggering further sensemaking are not external events, but rather often created by organizational actors as a means of effectively navigating an uncertain context.

Third, our findings illustrate how organizations can create a break in the momentum of action – momentum, which otherwise may prevent renewed sensemaking. This suggests that the very act of looking for anomalies may be critical to the management of uncertainty – not just because it provides important information – but because the act of looking disrupts the momentum of ongoing events, triggers doubt and motivates renewed efforts to make sense. Initial sensing processes are important, but a growing stream of work suggests that organizations and their members often fail to effectively manage unexpected surprises (recognize and readjust or reorient in dynamic situations) because the uninterrupted momentum of previous decisions and ongoing actions hinders sensemaking (Barton et al., 2009). Critically, if conditions change but sensemaking is not renewed, interpretations of the emerging situation are not updated and organizations are apt to remain embedded in ineffective or inappropriate frameworks.

As a result, they are ill-equipped to adjust and respond to changing conditions.

Finally, our findings suggest some of the micro-processes that likely underlie organizational resilience. Resilience refers to the 'ability to absorb strain and preserve (or improve) functioning despite the presence of adversity . . . [and] to recover or bounce back from untoward events' (Sutcliffe & Vogus, 2003, p. 96). Enacting resilience involves engaging with the reality of difficult situations and actively searching for and reporting errors or other unexpected problems (Watts-Perotti & Woods, 2009; Weick et al., 2007) rather than avoiding or merely surviving adversity. Resilience also entails cultivating and using resources (e.g., emotional, social, technical, capital) flexibly to enact new, adaptive responses (Caza & Milton, 2011; Coutu, 2002; Fredrickson, Tugade, Waugh, & Larkin, 2003; Kahn, Barton, & Fellows, 2013; Powley, 2009; Rerup, 2001). Moreover, research suggests leaders can play an important role in creating a context for organizational resilience (Beck & Plowman, 2009; Duhigg, 2012; Rajah & Arvey, 2013). Organizations that face a constantly uncertain and dynamic environment (like wildland firefighting and HROs) cannot rely solely on strategies aimed at reducing uncertainty. Rather, they must perform reliably *despite* uncertainty. Our research suggests specific practices through which organizations proactively engage with difficult situations (rather than avoid them entirely), integrate the reality of what is happening (rather than hoping for the best) and respond in flexible, adaptive ways.

Our findings should be considered in light of three limitations. First, our data are cross-sectional so we cannot ascertain the causality of our arguments. Future research should use longitudinal designs to verify the causal nature of our arguments. Second, our performance outcome comes from the same source as the independent variables. To ensure a large sample of firefighters and fires, we needed to use a key informant design and a perceptual measure of performance. A key informant design should minimize risks of common method bias because the informant is reporting on collective rather than their own performance (minimizing social desirability pressures) and prior research suggests that perceptual measures of performance are consistent with more objective measures in such circumstances (Glick et al., 1990). But future research could validate our findings using different measures of performance. Lastly, firefighting is a very unique uncertain, ambiguous context, and it is unclear whether the results would hold up in other settings. However, our theorizing, as well as prior work on HROs (Weick et al., 1999), suggests that processes of anomalizing and proactive leader sensemaking should generalize to contexts characterized by high levels of uncertainty and ambiguity. Still, we encourage other researchers to

further examine anomalizing and proactive leader sensemaking in other contexts.

In this study, we have theorized and tested two novel micro-level processes that enable rapid and ongoing sensemaking under conditions of uncertainty. We find that anomalizing and proactive leader sensemaking play crucial roles in determining success of wildland firefighting teams. We hope that it inspires further examination of these two constructs and investigation of this important context.

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References

Aiken, L. and West, S. (1991), *Multiple regression: Testing and interpreting interactions*, Sage, Newbury Park, CA.

Baron, R.M. and Misovich, S.J. (1999), 'On the Relationship Between Social and Cognitive Modes of Organization', in Chaiken, S. and Trope, Y. (eds), *Dual Process Theories in Social Psychology*, The Guilford Press, New York, pp. 586–605.

Barton, M.A. and Sutcliffe, K.M. (2009), 'Overcoming Dysfunctional Momentum: Organizational Safety as a Social Achievement', *Human Relations*, Volume 62, Number 9, pp. 1327–1356.

Beck, T.E. and Plowman, D.A. (2009), 'Experiencing Rare and Unusual Events Richly: The Role of Middle Managers in Animating and Guiding Organizational Interpretation', *Organization Science*, Volume 20, Number 5, pp. 909–924.

Bigley, G.A. and Roberts, K.H. (2001), 'The Incident Command System: High-Reliability Organizing for Complex and Volatile Task Environments', *Academy of Management Journal. Academy of Management*, Volume 44, Number 6, pp. 1281–1300.

Blatt, R., Christianson, M.K., Sutcliffe, K.M. and Rosenthal, M.M. (2006), 'A Sensemaking Lens on Reliability', *Journal of Organizational Behavior*, Volume 27, Number 7, pp. 897–917.

Burns, T. and Stalker, G.M. (1961), *The Management of Innovation*, Tavistock Publications, London.

Caza, B.B. and Milton, L.P. (2011), 'Resilience at Work: Building Capability in the Face of Adversity', in Spreitzer, G. and Cameron, K. (eds), *The Oxford Handbook of Positive Organizational Scholarship*, Oxford University Press, Oxford, pp. 895–908.

Chatterjee, S. and Price, B. (1991), *Regression Analysis by Example* (2nd edn), John Wiley & Sons, New York.

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*, Volume 20, Number 5, pp. 846–860.

Churchman, C.W. (1968), *The Systems Approach*, Dell New York, New York.

Coutu, D.L. (2002), 'How Resilience Works', *Harvard Business Review*, Volume 80, Number 5, pp. 46–50.

Duhigg, C. (2012), *The Power of Habit: Why We Do What We do in Life and Business*, Doubleday, Canada.

Faraj, S. and Sproull, L. (2000), 'Coordinating Expertise in Software Development Teams', *Management Science*, Volume 46, Number 12, pp. 1554–1568.

Faraj, S. and Xiao, Y. (2006), 'Coordination in Fast Response Organizations', *Management Science*, Volume 52, Number 8, pp. 1155–1169.

Fredrickson, B.L., Tugade, M.M., Waugh, C.E. and Larkin, G.R. (2003), 'What Good are Positive Emotions in Crises? A Prospective Study of Resilience and Emotions Following the Terrorist Attacks on the United States on September 11th, 2001', *Journal of Personality and Social Psychology*, Volume 84, Number 2, pp. 365–376.

Gittell, J.H. (2002), 'Coordinating Mechanisms in Care Provider Groups: Relational Coordination as a Mediator and Input Uncertainty as a Moderator of Performance Effects', *Management Science*, Volume 48, Number 11, pp. 1408–1426.

Glick, W.H., Huber, G.P., Miller, C.C., Doty, D.H. and Sutcliffe, K.M. (1990), 'Studying Changes in Organizational Design and Effectiveness: Retrospective Event Histories and Periodic Assessments', *Organization Science*, Volume 1, Number 3, pp. 293–312.

Goodman, P.S. and Leyden, D.P. (1991), 'Familiarity and Group Productivity', *Journal of Applied Psychology*, Volume 73, pp. 81–86.

Jett, Q.R. and George, J.M. (2003), 'Work Interrupted: A Closer Look at the Role of Interruptions in Organizational Life', *Academy of Management Review. Academy of Management*, Volume 28, Number 3, pp. 494–507.

Kahn, W.A., Barton, M.A. and Fellows, S. (2013), 'Organizational Crises and the Disturbance of Relational Systems', *Academy Of Management Review. Academy of Management*, Volume 38, Number 3, pp. 377–396.

Klein, G., Pliske, R., Crandall, B. and Woods, D.D. (2005), 'Problem Detection', *Cognition, Technology and Work*, Volume 7, Number 1, pp. 14–28.

Klein, K.J., Ziegert, J.C., Knight, A.P. and Xiao, Y. (2006), 'Dynamic Delegation: Shared, Hierarchical, and Deindividualized Leadership in Extreme Action Teams', *Administrative Science Quarterly*, Volume 51, Number 4, pp. 590–621.

Lipshitz, R. and Strauss, O. (1997), 'Coping with Uncertainty: A Naturalistic Decision-Making Analysis', *Organizational Behavior and Human Decision Processes*, Volume 69, Number 2, pp. 149–163.

Locke, E.A., Saari, L.M., Shaw, K.N. and Latham, G.P. (1981), 'Goal Setting and Task Performance: 1969–1980', *Psychological Bulletin*, Volume 90, Number 1, pp. 125–152.

Madsen, P.M., Desai, V.M., Roberts, K.H. and Wong, D. (2006), 'Mitigating Hazards Through Continuing Design: The Birth and Evolution of a Pediatric Intensive Care Unit', *Organization Science*, Volume 17, Number 2, pp. 239–248.

Murphy, P.R. and Jackson, S.E. (1999), 'Managing Work-Role Performance: Challenges for 21st Century Organizations and Employees', in Ilgen, D.R. and Pulakos, E.D. (eds), *The Changing Nature of Work Performance*, Jossey-Bass, San Francisco, pp. 325–365.

Perin, C. (2005), *Shouldering Risks: The Culture of Control in the Nuclear Power Industry*, Princeton University Press, Princeton, NJ.

Perrow, C. (1967), 'A Framework for the Comparative Analysis of Organizations', *American Sociological Review*, Volume 32, Number 2, pp. 194–208.

Powley, E.H. (2009), 'Reclaiming resilience and safety: Resilience activation in the critical period of crisis', *Human Relations*, Volume 62, Number 9, pp. 1289–1326.

Rajah, R. and Arvey, R. (2013), 'Helping Group Members Develop Resilience', in DuBrin, A.J. (ed.), *Handbook of Research on Crisis Leadership in Organizations*, Edward Elgar Publishing, Incorporated, pp. 149–173.

Rerup, C. (2001), ' 'Houston, We Have a Problem': Anticipation and Improvisation as Sources of Organizational Resilience', *Comportamento Organizational E Gestao*, Volume 7, Number 1, pp. 21–44.

Rerup, C. (2009), 'Attentional Triangulation: Learning from Unexpected Rare Crises', *Organization Science*, Volume 20, Number 5, pp. 876–893.

Roberts, K.H. (1990), 'Some Characteristics of High-Reliability Organizations', *Organization Science*, Volume 1, pp. 160–177.

Roberts, K.H., Madsen, P.M., Desai, V.M. and Van Stralen, D. (2005), 'A Case of the Birth and Death of a High Reliability Healthcare Organization', *Quality and Safety in Health Care*, Volume 14, pp. 216–220.

Roe, E. and Schulman, P.R. (2008), *High Reliability Management: Operating on the Edge*, Stanford University Press, Palo Alto, CA.

Rulke, D.L. and Galaskiewicz, J. (2000), 'Distribution of Knowledge, Group Network Structure, and Group Performance', *Management Science*, Volume 46, Number 5, pp. 612–625.

Schulman, P.R. (2004), 'General Attributes of Safe Organizations', *Quality and Safety in Health Care*, Volume 13, Number 1, pp. 39–44.

Starbuck, W.H. and Farjoun, M. (2005), *Organization at the Limit: Lessons from the Columbia Disaster*, Blackwell, New York.

Sutcliffe, K.L. and Vogus, T. (2003), 'Organizing for Resilience', in Cameron, K., Dutton, J.E. and Quinn, R.E. (eds), *Positive Organizational Scholarship*, Berrett-Koehler, San Francisco.

Sutcliffe, K.M. and Christianson, M.K. (2011), 'Managing the Unexpected', in Cameron, K. and Spreitzer, G. (eds), *Handbook of Positive Organizational Scholarship*, Oxford University Press, Oxford, UK, pp. 843–855.

Sutcliffe, K.M. and Weick, K.E. (2008), 'Information Overload Revisited', in Starbuck, W.H. and Hodgkinson, G. (eds), *Handbook of Organizational Decision Making*, Oxford University Press, Oxford, UK, pp. 56–75.

Thompson, J.D. (1967), *Organizations in Action*, McGraw Hill, New York.

Turner, B. (1976), 'The Organizational and Interorganizational Development of Disasters', *Administrative Science Quarterly*, Volume 21, Number 3, pp. 378–397.

Vaughan, D. (1996), *The Challenger Launch Decision*, University of Chicago Press, Chicago.

Vogus, T.J. and Sutcliffe, K.M. (2007a), 'The Safety Organizing Scale: Development and Validation of a Behavioral Measure of Safety Culture in Hospital Nursing Units', *Medical Care*, Volume 45, Number 1, pp. 46–54.

Vogus, T.J. and Sutcliffe, K.M. (2007b), 'The Impact of Safety Organizing, Trusted Leadership, and Care Pathways on Reported Medication Errors in Hospital Nursing Units', *Medical Care*, Volume 45, Number 10, pp. 997–1002.

Vogus, T.J. and Welbourne, T.M. (2003), 'Structuring for High Reliability: HR Practices and Mindful Processes in Reliability-Seeking Organizations', *Journal of Organizational Behavior*, Volume 24, pp. 877–903.

Watts-Perotti, J. and Woods, D.D. (2009), 'Cooperative Advocacy: An Approach for Integrating Diverse Perspectives in Anomaly Response', *Computer Supported Cooperative Work-the Journal of Collaborative Computing*, Volume 18, Number 2–3, pp. 175–198.

Weick, K. (2001), *Making Sense of the Organization*, Blackwell Publishing, Malden, MA.

Weick, K.E. (1993), 'The Collapse of Sensemaking in Organizations: The Mann Gulch Disaster', *Administrative Science Quarterly*, Volume 38, Number 4, pp. 628–652.

Weick, K.E. (1995), 'South Canyon Revisited: Lessons from High Reliability Organizations', *Wildfire*, Volume 4, pp. 54–68.

Weick, K.E. (2011), 'Organizing for Transient Reliability: The Production of Dynamic Non-Events', *Journal of Contingencies and Crisis Management*, Volume 19, Number 1, pp. 21–27.

Weick, K.E. and Sutcliffe, K.M. (2006), 'Mindfulness and the Quality of Organizational Attention', *Organization Science*, Volume 16, Number 4, pp. 409–421.

Weick, K.E. and Sutcliffe, K.M. (2007), *Managing the Unexpected* (2nd edn), Jossey-Bass, San Francisco.

Weick, K.E., Sutcliffe, K.M. and Obstfeld, D. (1999), 'Organizing for High Reliability: Processes of Collective Mindfulness', in Staw, B.M. and Cummings, L.L. (eds), *Research in Organizational Behavior*, Vol. 21, JAI Press, Inc, Greenwich, CT, pp. 81–123.

Winner, L. (1975). 'Complexity and the Limits of Human Understanding', in LaPorte, T. (ed.), *Organized Social Complexity: Challenge to Politics and Policy*. Princeton University Press, Princeton.

Appendix A
Anomalizing

(1) We actively looked for instances of small things going wrong to try to learn what was happening.
(2) People were rewarded or thanked for spotting potential trouble spots.
(3) We were encouraged to express differing points of view.
(4) We assessed each situation on its own rather than assuming it would be similar to other situations we'd experienced.
(5) When members had different opinions, we tried to understand one another's views.

Proactive leader sensemaking

(1) My boss actively sought input from a broad range of folks when making decisions.
(2) My boss actively encouraged subordinates to question decisions that didn't make sense to them.
(3) My boss encouraged people to bring up potential problems.
(4) My boss listened to the less experienced members of my group when they brought up ideas or issues
(5) My boss actively listened when different views were presented.
(6) My boss rejected or ignored input from others.
(7) My boss told us to pay attention to one another's input or ideas.
(8) My boss told us that our task required us to work well together.

Managing Safety: Ambiguous Information and Chronic Unease

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Managers rarely have full and unequivocal data on their external environment or on the state of their internal processes and in this paper we discuss how they deal with ambiguity, in relation to organizational safety. Drawing on our research into managers' safety intelligence and on the value of chronic unease for safety management, we show how both requisite anxiety and problem solving skills can help managers make the best use of ambiguous safety information.

1. Introduction

There are many sources of ambiguity in the corporate world – conflicting expert advice, mixed findings from staff surveys, volatile financial markets, inconclusive audit reports, imprecise incident analyses, obscure regulatory pronouncements. Paradoxically, while modern organizations are faced a plethora of information sources, managers rarely have full and unequivocal data on their external environment or on the state of their internal processes. The organizational and business intelligence they do receive is frequently incomplete, contradictory, inconsistent, based on untested assumptions and thus ambiguous. The Oxford English dictionary defines the term *ambiguous* as 'open to more than one interpretation, not having one obvious meaning'. Ambiguous information poses specific challenges to managers and not all managers know how to deal with this. Schoemaker, Krupp, and Howland (2013) discussing the key managerial skill of anticipation wrote, 'Most organizations and leaders are poor at detecting ambiguous threats and opportunities on the periphery of their business' (p. 131). In this paper, we focus on how senior managers deal with these ambiguities, with particular reference to safety information, although

the material would also be pertinent to crisis management, which can involve 'decision making in the dark' (Lagadec, 2013).

There is an extensive business and economics literature on ambiguous information, it examines how this is processed, how it influences decision making and the well-documented phenomenon of 'ambiguity avoidance' (e.g., Ellsberg, 1961; Trautmann, Veider, & Wakker, 2008) where clear probabilities (of risk) are preferred to 'vague probabilities'. We define ambiguity more broadly than the economists, encompassing not only vague probabilities (e.g., Snow, 2010), but also any other lack of clarity caused by safety information being incomplete, equivocal, unclear or conflicting. We conceptualize ambiguity as contributing to a state of uncertainty (i.e., not definitely knowing or not being perfectly clear). It is notoriously difficult for managers to measure the current status of safety and to predict future levels of risk on their worksites (Knegtering & Pasman, 2013). Typically, they are encountering some degree of uncertainty even though their audit data records, accident trend curves and lost time incident bar graphs can present safety profiles that appear to be seductively unambiguous. Grote (2014, p. 34) describes this kind of uncertainty as 'not knowing for sure' and says it is ubiquitous in organizations.

Senior managers are of particular interest in relation to ambiguous information, as they are charged with predicting the future of their organization; consequently, they must define both short- and long-term goals, and devise strategic policies to meet them (Mintzberg, 1978; Zaccaro, 2001). One of their responsibilities is to monitor the external and in-house environments for threats and opportunities (Thietart & Vivas, 1981) while operating in a highly uncertain, complex environment, overloaded with information (Hambrick, 1989). Senior managers determine direction and performance (Day & Lord, 1988); consequently, they can have a significant effect on safety, although this aspect of their work is rarely studied (Flin, 2003, 2006). Yet, workforce perception of managerial commitment to safety is frequently measured (Flin, Mearns, O'Connor, & Bryden, 2000; Guldenmund, 2000) and this is one of the most predictive components of safety climate in relation to injuries and other safety outcomes (Beus, Payne, Bergman, & Arthur, 2010; Christian, Bradley, Wallace, & Burke, 2009).

Given that senior managerial work typically requires decision making on incomplete and sometimes contradictory information (e.g., Bratvold & Begg, 2010; Ho, Keller, & Keltyka, 2005), then ambiguity should be considered when investigating how senior leaders manage safety in organizations. Effective safety management at a senior level requires an appreciation of the inadequacy of information flowing upward in the organization and an awareness of possible smoothing and filtering to reduce apparent ambiguities and to deliver clear, 'good news' messages to the top level. Major accidents in the energy sector (e.g., Chernobyl nuclear plant, 1986; Piper Alpha oil platform, 1988; Texas City refinery 2005; *Deepwater Horizon* drilling rig, 2010; Fukushima Daiichi nuclear plant, 2011) have revealed the risks of managerial complacency and over-reliance on reassuring indicators of the safety status. New technologies, decision support systems and increased automation mean that workers' skills in managing emerging risks can be eroded. In these energy sector accidents, the proximity to danger was much closer than either the workers or the managers realized.

Grote (2007, 2012) describes how organizations can manage uncertainties (situations where there are only insufficient or ambiguous information for decision making) in two ways, by minimization and by coping (akin to Schulman, 1993 anticipation and resilience). The strategy to minimize uncertainty focuses on standardization, control and planning with the ultimate aim to avoid disturbances of the normal operations. She argues that this strategy is especially relevant for organizations whose operational malfunction would result in severe consequences for the business, humans or the environment. The second strategy, coping with uncertainties is not so much concerned with fighting uncertainties, but

engaging in actions to minimize their impact. These allow flexible adaptation, by providing options for action rather than fixed plans, opportunities for cooperation and learning, as well as decision support tools. Most organizations require a balance of stability and flexibility; the relative weighting depending on tasks and technologies. While most organizations are driven to reduce uncertainties, the high level of complexities in senior managerial work makes the coping strategy a necessity. Grote (2009) provides detailed examples of organizational strategies to deal with uncertainty, principally from the Swiss rail industry, but she does not specify exactly how managers deal with ambiguity in relation to safety information.

We first consider the ways in which managers approach safety-related problems in an attempt to understand current risks. They can deal with inherent ambiguities by avoidance, toleration or by actually embracing it and recognizing its value, which leads to information-seeking actions. Second, we reflect on the role of 'chronic unease' in managers coping with ambiguities regarding the state of safety in their organizations.

2. Problem-solving behaviours

Brophy (1998) described problem solving as working towards a goal when the means to getting there are not known. Dealing with complex and novel organizational problems is a key component of a leader's role (Mumford, Zaccaro, Hardin, & Fleishman, 2000) and this is central to how managers endeavour to understand and to control operational risks. As such, senior managerial problem solving can have a proximate, direct impact on organizational safety. Because the way senior managers solve problems shapes organizations and work conditions (e.g., equipment, staffing levels), this can have an immediate effect on the status of safety. Senior managers who have a deep understanding of safety and appreciate the consequences that their decisions may have in this area, are more likely to have a positive effect on safety.

It is acknowledged that senior managers will often not solve problems themselves, but rather ensure that others do so. However, senior leaders can influence more junior managers, for example by signalling the organization's safety priorities through communication and reinforcement behaviours. Thus, the senior manager's approach has an indirect effect on safety, via safety culture (Zohar & Luria, 2005). Fruhen et al. (2014a), in a study of 'safety intelligence', interviewed senior managers from European air traffic management companies, using open questions and scenarios with ambiguous situations. They found that methods used by some managers for dealing with safety problems were related to safety commitment; namely the ability to reflect about

potential causal factors from many angles, the consideration of various information sources when understanding a problem, and the capability to generate numerous ideas for solutions. This flexible approach to uncertainty and ambiguity can protect senior managers from 'jumping to conclusions' and help them to critically examine causal factors behind a surfacing issue.

These problem-solving strategies allow senior managers to gain a closer estimate of the risks they are dealing with: doing so can result in better control of uncertainties, can help reveal ambiguity, as well as ways to resolve it. Senior managers who reflect about problems in detail, considering many angles, can react more effectively and over time can improve their understanding of organizational realities and risks. Breadth of thinking lets them adopt a more holistic approach and can enable them to anticipate future problems (see the Eurocontrol, 2013 *White Paper on Senior Managers and Safety* based on this research). This process of extended information gathering and the detection of ambiguity is likely to be supported by chronic unease, a critical 'mindset' for managers.

3. Chronic unease in managers

The term 'chronic unease' was adopted by Reason (1997) as a contrast to complacency that might result from the absence of negative events and lead 'people [to] forget to be afraid' (p. 39). It contains the acknowledgement that not all risks can be controlled or minimized and it is likely to stimulate actively seeking out ambiguities and coping with uncertainties, as well as striving to control them.

The dangers of complacency, especially for individuals and organizations working in more hazardous settings, are highlighted in both the safety and high reliability organization (HRO) literatures. Discussing the structural failures that caused the Alexander Keilland drilling rig accident in Norway, Weick (1987) commented 'Part of the mindset for reliability requires a chronic suspicion that small deviations may enlarge, a sensitivity that may be encouraged by a more dynamic view of reliability' (p. 119, underline added). Schulman (1993) describing reliability in a nuclear power plant endorses the benefits of 'conceptual slack' (p. 364), a divergence in perspectives among members of an organization about how things are operating. Instead of regarding this negatively as a confusion or ambiguity, this is appreciated as a positive protective mechanism that counters overconfident illusions of organizational well-being. Similarly, Rochlin (1993) said that in an HRO, the absence of surprises over a long period of time was a reason for anxiety: The lack of adverse events being interpreted as a sign that the organization's error-detection mechanisms might be decaying, rather than creating a sense of comfort. This approach towards

reliability is described as making HROs successful at managing risks, because reliability is a dynamic non-event, i.e., an ongoing condition, lacking definite evidence of the state of the system (Weick, 1987). Managers of HROs assume that they might not fully comprehend the complex systems they operate. This assumption leads these organizations to exhibit a 'motion mania', which is reflected in a many-angled approach of constant improvement towards issues (Rochlin, 1993, p. 35). It should be noted that not all organizations manage to achieve and maintain such an imaginative and pessimistic approach towards risks. For example, the top management team of the Exxon Shipping Company was described as having failed to consider possible accidents of large magnitude and their potentially disastrous consequences, prior to the *Exxon Valdez* accident in 1989 (Roberts & Libuser, 1993). Similarly in Haddon-Cave's (2009) incisive report into the loss of a Royal Air Force Nimrod aircraft, which caught fire during mid-air refuelling, killing all 14 crew, he criticized, among others, the management of one of the large contractor firms.

> In my judgement, BAE Systems' attitude to the NSC [Nimrod Safety Case] was fundamentally affected by the prevailing malaise that, because the Nimrod had operated safely over 30 years, it could be assumed that the Nimrod was 'safe anyway' and that, therefore, the NSC exercise did not really matter. (11.16).

A recent review by Fruhen, Flin & Mcleod (2014b) found that while the HRO literature had mentioned chronic unease, and it has been described by other authors as relevant to effective safety management (e.g., Hudson, 2003), it had not been conceptualized in detail. From an analysis of existing descriptions, Fruhen et al defined chronic unease as a manager's tendency to experience discomfort and concern about the control of risks. They emphasized that the discomfort is not primarily concerned with threats and hazards per se, but rather with the manager's sense of whether or not these risks are being sufficiently controlled and whether operational decisions are based on sufficient safety information. In doing so, chronic unease can promote an appreciation and acknowledgement of uncertainties in the day to day running of a complex operation. Each manager is likely to differ in the extent to which unease will be helpful to his or her management of safety issues – the optimal level will depend on the context and personal characteristics.

From a thematic analysis of the limited literature, Fruhen et al (2014b) proposed that chronic unease develops through a psychological process and that the extent to which managers experience unease is based on five factors: their vigilance, flexibility of thinking, propensity to worry, pessimism and the ability to

imagine negative consequences (i.e., requisite imagination; Westrum & Adamski, 1999). (The cognitive components (flexible thinking) were also found in Fruhen et al.'s study of safety intelligence and problem solving described earlier.). The experience of unease leads managers to think critically about the cause of their discomfort, examining situations from more angles, as captured in flexible thinking. This process can help managers to transpose or channel their sense of unease, in itself a very qualitative and 'soft' risk sounding-board, into a behavioural strategy to identify possible hidden risks, ambiguities and which organizational activities to examine more closely. In doing so, chronic unease can be understood as a mental filter that can help managers prioritize their attention to the issues giving them most concern. It enables senior managers to not only select the types of problems to focus on, but also to identify the less obvious issues that make them feel uncomfortable. A subsequent interview study with senior managers (Fruhen & Flin, 2015) confirmed the relevance of these components of chronic unease and described related behaviours and consequences.

As mentioned earlier, one of the big challenges for managers is information overload (Mintzberg, 1978). In addition to the pervasive uncertainty concerning the accuracy and completeness of safety information, there is the threat of having too much information and having to decide what to focus on and what to ignore. Chronic unease can facilitate the detection of ambiguity and drive the manager to resolve it. It can function as a filter, helping managers to attend to hazardous issues that are concealed behind more salient concerns.

Chronic unease can also influence the way senior managers interact with subordinates and may inspire them to approach uncertainties in a similar way. Westrum (1991) specifically highlighted top-level leadership as an important factor in the development of organizational cultures that favour inquiry. He described the role of top-level leaders in mindful organizations as the 'maestros' (p. 406), who support the expression of doubt, encourage critical thinking and place faith in their people. These types of leadership behaviours resonate with transformational leadership (Bass, 1985). Previous research has found aspects of transformational leadership style to be linked to positive safety outcomes in organizations (e.g., Kelloway, Mullen, & Francis, 2006; Zohar, 2002). The encouragement of critical thinking is one strategy used by transformational leaders: intellectual stimulation. This includes behaviours such as questioning old assumptions, stimulating new ways of doing things and encouraging expressions of ideas and reasons. The exertion of behaviours that encourage inquiry and information flow in organizations may be linked to the sense of chronic unease in managers.

It also needs to be considered whether chronic unease for safety could have negative consequences for individuals who repeatedly engage in behaviours that involve constant vigilance, driven by worry. Extreme chronic unease could be a harmful attribute, not only for the manager's ability to cope with ambiguous issues, these traits at an abnormal level can be associated with reduced well-being, stress and even aspects of anxiety and depression. Thus we would propose that the relationship between chronic unease and efficacy in safety management has a curvilinear nature (see Figure 1). Too little chronic unease and the resulting complacency means that warning signals are ignored, ambiguities are marginalized, there is no systematic search for negative indicators, and adverse consequences are rarely considered. Too much and the manager is disabled by the level of anxiety with consequent deleterious effects on decision making, action and mental health. At the optimal level, which will be individually determined, the sense of chronic unease about organizational safety prompts the continued search for hidden threats, the extended consideration of ambiguities and anomalies, and the appreciation of disconfirming evidence.

The proposed curvilinear relationship for chronic unease is based on Janis and Mann's (1977) conflict model of stress and decision making, where they described coping patterns in decision conflict situations (ambiguity about the best option) with distinctive levels of stress. Where the decision maker believes there is very little or no risk, then he or she 'complacently decides to continue whatever he or she has been doing, ignoring information about the risk of losses. . . . there is no decisional conflict and accordingly little or no stress' (Mann, 1992, p. 209). They called this state 'unconflicted adherence'. Similarly, when the decision maker reacts to a challenge by precipitously changing to a new course of action without giving the matter much thought, again there is no perceived conflict between options, no ambiguity and hence little or no stress. This was called unconflicted change. When the decision maker is unable to choose between competing options, and this does cause severe anxiety, then defensive avoidance can occur in the shape of procrastination, fanciful rationalizations or 'passing the buck' to someone else. Of most relevance to the earlier discussion of chronic unease are the remaining two states. In hypervigilance, there is recognition of the serious risks in competing courses of action, the stress level is extreme (cf. high chronic unease) creating a state akin to panic with the individual preoccupied with the threatened losses. The resulting behaviours can include impulsive actions, vacillation and simplistic, repetitive thinking. Such high levels of anxiety might exist because a manager is not well-suited to their position, or is ill-equipped with knowledge and support from their work environment. However, it might also be a forceful indication that the work is actually highly risky and should be stopped in order to avoid a catastrophe.
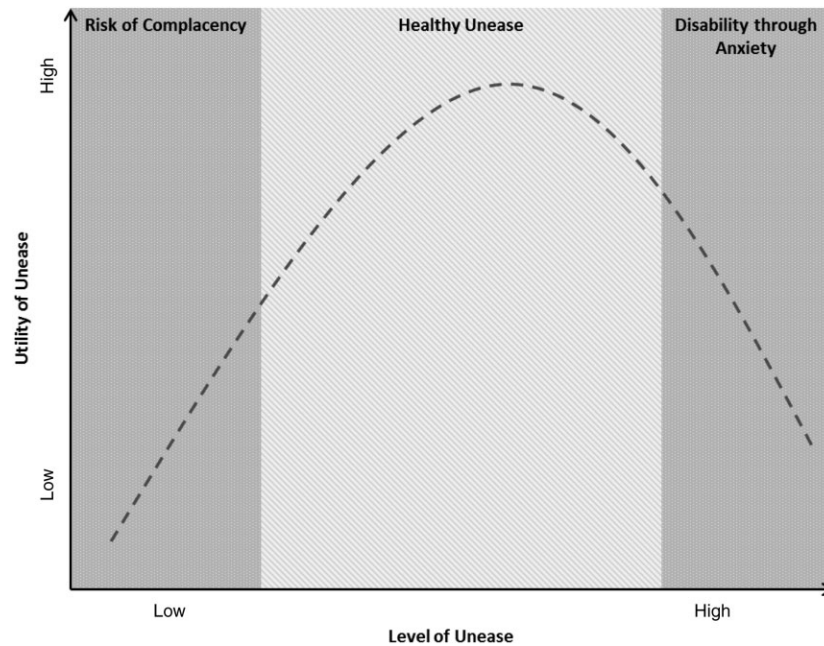
Figure 1. A utility function of unease. *Note:* The cut-offs of healthy unease will differ in each manager and is also bound to contextual factors. The cut-offs of healthy unease will differ in each manager and are also bound to contextual factors.

The desirable level of chronic unease for safety is similar to what Janis and Mann called vigilance. There is a moderate level of stress in this condition, the decision maker recognizing that there are serious risks imbued in competing alternatives, but having confidence about the likelihood of finding an adequate solution in the available time.

> He searches painstakingly for relevant information, assimilates it in a relatively unbiased manner, and evaluates alternatives carefully before making a choice (Mann, 1992, p. 210).

Essentially, these represent the information-gathering and processing activities described earlier as characteristic of safety intelligence. The costs associated with the cognitive effort required for vigilance are what Reason (1997) described as the 'price for safety' (p. 39).

The importance of such managerial vigilance is well recognized in the business world (Day & Schoemaker, 2008). Vigilant leaders having curiosity, creating a supportive climate for gathering and sharing information, monitoring peripheral regions of the business and engaging in timely and imaginative interpretation of weak signals. To do this well, they require 'a high tolerance for ambiguity and even a willingness to embrace paradox' (p. 47). So the more effective managers do not shy away from ambiguous information. They do not try to oversimplify, they appreciate the complexities of their operational domains and realize that multiple perspectives will be required to build a picture of their risk profile.

4. Conclusion

To avoid the risks of complacency about organizational safety, a mild sense of chronic unease in managers, along with the appreciation of the need for good safety intelligence, is desirable. The resulting alertness and flexible thinking are aimed at noticing the ambiguities, gathering more information, realizing that sometimes this may produce more questions than answers. Among those emerging disconnects and contradictions lurk the weak signals, the cues indicating hazardous conditions, where additional scrutiny is now merited. It is the tolerance for ambiguity and the appreciation of the messy nature of operational life (Roe, 2013) that enables managers to assess the reality of safety on their worksites.

Acknowledgements

References

Bass, B. (1985), *Leadership Beyond Expectations*, The Free Press, New York.

Beus, J., Payne, S., Bergman, M. and Arthur, W. (2010), 'Safety Climate and Injuries: An Examination of Theoretical and Empirical Relationships', *The Journal of Applied Psychology*, Volume 95, pp. 713–727.

Bratvold, R. and Begg, S. (2010), *Making Good Decisions*, SPE Books, Richardson, TX.

Brophy, D. (1998), 'Understanding, Measuring, and Enhancing Collective Creative Problem-Solving Efforts', *Creativity Research Journal*, Volume 11, pp. 199–229.

Christian, M., Bradley, J., Wallace, J. and Burke, M. (2009), 'Workplace Safety: A Meta-Analysis of the Roles of Person and Situation Factors', *The Journal of Applied Psychology*, Volume 94, pp. 1103–1127.

Day, D. and Lord, R.G. (1988), 'Executive Leadership and Organizational Performance: Suggestions for a New Theory and Methodology', *Journal of Management*, Volume 14, pp. 453–464.

Day, G. and Schoemaker, P. (2008), 'Are You a Vigilant Leader?', *MIT Sloan Management Review*, Volume 49, pp. 43–51.

Ellsberg, D. (1961), 'Risk, Ambiguity and the Savage Axioms', *The Quarterly Journal of Economics*, Volume 75, pp. 643–669.

Eurocontrol (2013) *White Paper. Senior Managers and Safety*, http://www.eurocontrol.int/sites/default/files/article/content/documents/nm/safety/safety_intelligence_white_paper_2013.pdf (accessed 20 February 2015).

Flin, R. (2003), 'Danger Men at Work': Management Influence on Safety', *Human Factors and Ergonomics in Manufacturing*, Volume 13, pp. 261–268.

Flin, R. (2006), 'Erosion of Managerial Resilience: Vasa to NASA', in Hollnagel, E., Woods, D. and Levinson, N. (eds), *Resilience Engineering: Concepts and Precepts*, Ashgate, Aldershot.

Flin, R., Mearns, K., O'Connor, R. and Bryden, R. (2000), 'Measuring Safety Climate: Identifying the Common Features', *Safety Science*, Volume 34, pp. 177–192.

Fruhen, L.S., Mearns, K., Flin, R. and Kirwan, B. (2014a), 'Skills, Knowledge and Senior Managers' Demonstrations of Safety Commitment', *Safety Science*, Volume 69, pp. 29–36.

Fruhen, L.S., Flin, R. and McLeod, R. (2014b), 'Chronic Unease for Safety in Managers: A Conceptualisation', *Journal of Risk Research*, Volume 17, pp. 969–979.

Fruhen, L.S. and Flin, R. (2015), 'Chronic unease' for safety in senior managers. An interview study of its components, behaviours and consequences. *Journal of Risk Research* (in press).

Grote, G. (2007), 'Understanding and Assessing Safety Culture Through the Lens of Organizational Management of Uncertainty', *Safety Science*, Volume 45, pp. 637–652.

Grote, G. (2009), *Management of Uncertainty – Theory and Application in the Design of Systems and Organisations*, Springer, London.

Grote, G. (2012), 'Safety Management in Different High-Risk Domains – All the Same?', *Safety Science*, Volume 50, pp. 1983–1992.

Grote, G. (2014), 'Adding a Strategic Edge to Human Factors/ Ergonomics: Principles for the Management of Uncertainty as Cornerstones for System Design', *Applied Ergonomics*, Volume 45, pp. 33–39.

Guldenmund, F. (2000), 'The Nature of Safety Culture: A Review of Theory and Research', *Safety Science*, Volume 34, pp. 215–257.

Haddon-Cave, C. (2009), *An Independent Review into the Broader Issues Surrounding the Loss of the RAF Nimrod MR2 Aircraft XV230 in Afghanistan in 2006*, Stationery Office, London.

Hambrick, D. (1989), 'Guest Editor's Introduction: Putting Top Management Back in the Strategy Picture', *Strategic Management Journal*, Volume 10, pp. 5–15.

Ho, J., Keller, R. and Keltyka, P. (2005), 'How do Information Ambiguity and Timing of Contextual Information Affect Managers' Goal Congruence in Making Investment Decisions in Good Times vs Bad Times', *Journal of Risk and Uncertainty*, Volume 31, pp. 163–186.

Hudson, P. (2003), 'Applying the Lessons of High Risk Industries to Healthcare', *Quality and Safety in Health Care*, Volume 12, Suppl. 1, pp. i7–i12.

Janis, I. and Mann, L. (1977), *Decision Making: A Psychological Analysis of Conflict, Choice and Commitment*, Free Press, New York.

Kelloway, K.E., Mullen, J. and Francis, L. (2006), 'Divergent Effects of Transformational and Passive Leadership on Employee Safety', *Journal of Occupational Health Psychology*, Volume 11, pp. 76–86.

Knegtering, B. and Pasman, H. (2013), 'The Safety Barometer. How Safe Is My Plant Today? Is Instantaneously Measuring Safety Level Utopia or Realisable', *Journal of Loss Prevention in the Process Industries*, Volume 26, pp. 821–829.

Lagadec, P. (2013), *Navigating the Unknown. A Practical Lifeline for Decision Makers in the Dark*, Crisis Response, Thatcham, UK.

Mann, L. (1992), 'Stress, Affect and Decision Making', in Yates, F. (ed.), *Risk and Decision Making*, Wiley, New York.

Mintzberg, H. (1978), 'Patterns in Strategy Formation', *Management Science*, Volume 24, pp. 934–948.

Mumford, M.D., Zaccaro, S.J., Hardin, F.D. and Fleishman, E.A. (2000), 'Leadership Skills for a Changing World', *Leadership Quarterly*, Volume 11, pp. 11–35.

Reason, J. (1997), *Managing the Risks of Organizational Accidents*, Ashgate, Aldershot.

Roberts, K.H. and Libuser, C. (1993), 'From Bhopal to Banking, Organizational Design can Mitigate Risk', *Organizational Dynamics*, Volume 21, pp. 15–26.

Rochlin, G.I. (1993), 'Defining 'High Reliability' Organizations in Practice: A Taxonomic Prologue', in Roberts, K.H. (ed.), *New Challenges to Understanding Organizations*, Macmillan, New York, pp. 11–32.

Roe, E. (2013), *Making the Most of Mess. Reliability and Policy in Today's Management Challenges*, Duke University Press, Durham, NC.

Schoemaker, P.J., Krupp, S. and Howland, S. (2013), Strategic leadership: The essential skills. *Harvard Business Review*, Volume 91, Number 1, pp. 131–134.

Schulman, P. (1993), 'The Negotiated Order of Organizational Reliability', *Administration & Society*, Volume 25, pp. 353–372.

Snow, A. (2010), 'Ambiguity and the Value of Information', *Journal of Risk and Uncertainty*, Volume 40, pp. 133–145.

Thietart, R.A. and Vivas, R. (1981), 'Strategic Intelligence Activity: The Management of the Sales Force as a Source of Strategic Information', *Strategic Management Journal*, Volume 2, pp. 15–25.

Trautmann, S., Veider, F. and Wakker, P. (2008), 'Causes of Ambiguity Aversion; Known Versus Unknown Preferences', *Journal of Risk and Uncertainty*, Volume 36, pp. 225–243.

Weick, K. (1987), 'Organizational Culture as a Source of High Reliability', *California Management Review*, Volume 24, pp. 112–127.

Westrum, R. (1991), *Technologies and Society: The Shaping of People and Things*, Wadsworth, Belmont, CA.

Westrum, R. and Adamski, A.J. (1999), 'Organizational Factors Associated With Safety and Mission Success in Aviation Environments', in Garland, D., Wise, J. and Hopkin, V. (eds), *Handbook of Aviation Human Factors*, Erlbaum, London, pp. 67–104.

Zaccaro, S.J. (2001), *The Nature of Senior Executive Leadership: A Conceptual and Empirical Analysis of Success*, American Psychological Association, Washington DC.

Zohar, D. (2002), 'The Effects of Leadership Dimensions, Safety Climate and Assigned Priorities on Minor Injuries in Work Groups', *Journal of Organizational Behavior*, Volume 23, pp. 75–92.

Zohar, D. and Luria, G. (2005), 'A Multilevel Model of Safety Climate: Cross-Level Relationships between Organization and Group-Level Climates', *The Journal of Applied Psychology*, Volume 90, pp. 616–628.

Operators' Improvisation in Complex Technological Systems: Successfully Tackling Ambiguity, Enhancing Resiliency and the Last Resort to Averting Disaster

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Complex safety-critical technological systems breakdowns, which are often characterized as 'low probability, high consequence', could pose serious threats for workers, the local public, and possibly neighboring regions and the whole country. System designers can neither anticipate all possible scenarios nor foresee all aspects of unfolding emergency. Front-line operators' improvisation via dynamic problem solving and reconfiguration of available recourses provide the last resort for preventing a total system failure. Despite advances in automation, operators should remain in charge of controlling and monitoring of safety-critical systems. Furthermore, at the time of a major emergency, operators will always constitute the society's both the first and last layer of defense; and it is eventually their improvisation and ingenuity that could save the day.

Operators are maintained in [complex technological] systems because they are flexible, can learn and do adapt to the peculiarities of the system, and thus they are expected to plug the holes in the designer's imagination (Professor Jens Rasmussen, 1980, p. 97).

1. Introduction

The 2009 astonishing emergency water 'landing' and safe evacuation of US Airways Flight 1549 has been called the 'Miracle on the Hudson'. Notable American philosopher and psychologist William James (1842–1910) stated with prescience that 'great emergencies and crises show us how much <u>greater</u> our vital resources are than we had supposed' (emphasis added).

This moment of celebrity and celebration is a focused moment to consider the greater factors (and actors) that converged and created this and other un-choreographed but beautiful ballet of rescue and survival.

The Presidential Policy Directive 21 (Office of the Press Secretary, 2013) defines resilience as the ability to 'prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions'. This is similar to the generic definition of resiliency, as 'the power or ability to return to the original form, position, etc., after being bent, compressed, or stretched; elasticity'. Without understanding the vital role of human and organizational factors in technological systems and proactively addressing/facilitating their interactions

during unexpected ('beyond design basis') events, recovery will be a sweet dream and resiliency will only be an unattainable mirage.

Moreover, improvisation is considered as an 'engine' of resiliency (Grøtan, Størseth, Rø, & Skjerve, 2008). Improvisation in safety critical situation, which inhabits ambiguous information, could result in either mitigation or prevention of catastrophic system failures or a less favorable outcome (Trotter, Salmon, & Lenne, 2014). In order to create an environment that fosters successful improvisation, numbers of factors such as expertise, teamwork quality, training and information flow and feedback have to be in place (Grøtan et al., 2008; Trotter, Salmon, & Lenné, 2013). Two examples of successful improvisation, which averted assured disasters, were the landing of flight 1549 and restoration of Fukushima Daini Nuclear Power Station after the 2011 Tōhoku earthquake and tsunami, which are the main focus of this paper.

2. US Airways Flight 1549 and Fukushima Daini Nuclear Power Station

The cast of heroes did a fantastic job on that fateful day. Capt. Chesley B. 'Sully' Sullenberger III, and his first officer, Jeffrey Skiles have been appropriately saluted for one of the greatest feats of skillful airmanship ever seen. The many years of regular and simulation-based crew training and assessment that these crews had received prepared them to respond professionally to the rapid sequence of unexpected adverse events. According to Ms. Kathryn O. Higgins, the assigned National Transportation Safety Board (NTSB) board member, the 'very senior flight attendants' was one of the main reasons everyone survived after 'landing' (or ditching) on the Hudson. She observed that 'This is a testament to experienced women doing their jobs, because they were, and it worked'.

The landing of flight 1549 was a great example of a successful improvisation in the face of ambiguous information portraying an 'amazingly good' crew coordination on the flight deck 'considering how suddenly the event occurred, how severe it was, and the little time they had' to prepare'. This shows particularly on the non-verbal communication between Captain Sullenberger and first officer Jeff Skiles, although they 'did not have time to exchange words' through 'observation' and 'hearing'. they knew that they were on the same page. At the NTSB hearings, Captain Sullenberger mentioned the critical role of 'a dedicated, well-experienced, highly trained crew that can overcome substantial odds, work together as a team' (Fraher, 2011).

Other heroes include air traffic controllers at New York Terminal Radar Approach Control, who so calmly and professionally communicated with and helped the crew of the Airbus in their critical decision making during the emergency.

The New York rescuers that included ferries, tugboats, Coast Guard and others who, prompt in their arrival and bravely facing the deadly cold, picked up the passengers and crew from the floating airplane, performed the final act.

However, what else made this 'miracle' possible? The invisible 'glue' that made these different, independent operational entities rapidly assembles and coordinate together in a seamless fashion revolves around the concept of the high reliability organization (HRO). For 20 years, we have been conducting research to understand these organizations, which operate relatively error free, over long periods of time, and make consistently good decisions that result in high quality and reliable operations.

Another incident that was nothing short of a miracle was the restoration of four nuclear reactors at the Fukushima Daini plant. After the 2011 Tōhoku earthquake and tsunami, the four reactors at the Fukushima Daini Nuclear Power Plant automatically shut down. The heroic act of a dedicated group of human operators, who went out of their way and by encountering multiple sources of hazards and harms, taking personal risk, and by relaying on their ingenuity, teamwork, sensemaking, and dedication despite all odds, brought all four reactors to cold shutdown and consequently averted the second assured nuclear disaster in Fukushima prefecture with serious implications for travelling fallouts to Tokyo and need for its evacuation (Gulati, et al., 2014).

The Superintendent of the Fukushima Daini Nuclear Power Station, Mr. Naohiro Masuda, and his operators resorted to improvisation to save the day after experiencing station black out; and their improvised acts are too numerous to mention. Nevertheless, the most memorable noteworthy ones include, 'flexibly applying EOPs' (Kawamura, 2012) and 'temporary cable of 9 km length was laid by about 200 personnel within a day. Usually this size of cable laying requires 20 personnel and more than 1 month period' (Masuda, 2014). Their personal sacrifices and dedication of staying in the plant and continuing working in dire conditions, while not knowing whether their families survived the earthquake and tsunami, and working relentlessly to bring the four reactors to the cold shutdown state, are of epic proportion. These operators, who certainly are *unsung heroes*, deserve to also be considered as national heroes of Japan (Meshkati, 2014). Their problem-solving behaviour was the perfect examples for a successful knowledge-based level of cognitive control (for further information, please see the following SRK Framework).

Fukushima Daini operators once more verified and exemplified the notion that at the time of a major accident at a complex, large-scale technological systems, such as a nuclear power plant, human

operators always constitute the society's both the first and last layer of defence. The recently released seminal report of the US National Academy of Sciences, *Lessons Learned from the Fukushima Nuclear Accident for Improving Safety of US Nuclear Plants* (National Academy of Sciences, 2014), which of course for obvious reasons has focused more on Daiichi, affirmed this important fact:

> The Fukushima Daiichi accident reaffirms the important role that people play in responding to severe nuclear accidents and beyond-design-basis accidents more generally . . . Recovery ultimately depended on the ingenuity of the people on the scene to develop and implement alternative mitigation plans in real time . . . There is a growing evidence that people are a source of system resilience because of their ability to adapt creatively in response to unforeseen circumstances . . . *The Fukushima Daiichi accident reaffirmed that people [human operators] are the last line of defense in a sever accident* (emphasis added, p. J. 1 & 3).

3. Complex technological systems' failures, ambiguity and high reliability organization

When complex technological systems, such as aircrafts and nuclear power plants, move from routine to non-routine (normal to emergency) operation, the control operators need to dynamically match the system's new requirements. This mandates *integrated* and *harmonious* changes in information presentation, changes in performance requirements in part because of operators' inevitable involuntary transition to different levels of cognitive control, and reconfigurations of the operators' team (organizational) structure and communication.

In order to survive, a technological system must have the ability to respond to operational anomalies before any undesirable consequences, which the system seeks to avoid, can occur. That is, the control structure must run at a faster rate than the environment it seeks to control; or else, the system will lose control. However, a hierarchically structured team has only a limited control model of the system, which oversees. For instance, in the case of a power plant particularly during an emergency, the operators not only comply with emergency operating procedures (EOPs), they must also respond to the changing system's environment. To the extent that for every possible deviation in this environment that has not been foreseen by the 'hierarchy', control is transferred to the work domain level – to operators – and because of (their) survival needs and instincts, the system's control team inevitably embraces structural forms that *fit* the situational demands, often the more naturalistic form such as 'self-organizing'.

Moreover, the hierarchical (team) structure becomes even more counterproductive when decisions need to be made by the whole team using the 'team mind'.

As task uncertainty increases in complex systems (typical in 'non-normal' or emergency situations), the number of exceptions to routine operations increases, overloading organizational hierarchy. In order to meet the new challenges, the organization must use another mechanism to sustain itself. Furthermore, the 'normal function' of tightly coupled technological systems is to operate on the boundary to loss of control. That is, people are involved in a dynamic and continuous interaction with the failure and hazard (Rasmussen, 1989). Thus, 'touching the boundary to loss of control is necessary (e.g., for dynamic "speed-accuracy" trade-offs)' (Rasmussen, Pejtersen, & Goodstein, 1994). This is a rapidly changing environment, and in order to survive it, the system should be able to respond in a safe and effective manner. Occasionally, it may require an *improvised* response from the operator(s), but it should certainly be coordinated and in concert with others' activities and stay within the boundaries or 'space' of acceptable work performance (Rasmussen, 1989). Otherwise, it would be just *noise* in the control of the system and could lead to errors. It must also be able to flexibly reconfigure and synchronize all of its system elements to address the threatening issues. The HRO approach enables independent systems to become interdependent in a manner that any organization can accomplish. The fundamental characteristics of an HRO foster a culture of trust, shared values, unfettered communication and process improvement. It nurtures, promotes and takes advantage of distributed decision making, 'where the buck stops everywhere'.

According to Weick and Sutcliffe (2001), 'hallmarks of high reliability' or major characteristics of HROs include preoccupation with failure, reluctance to simplify interpretation and sensitivity to operations, when they are 'anticipating and becoming aware of the unexpected'. In addition, when the 'unexpected occurs'. HROs attempt to contain it by committing to resilience, and deferring to expertise.

Fukushima Daini and US Airways Flight 1549 are two great examples showing that HROs can detect, contain and rebound from unexpected events. An HRO is not necessarily error free, but errors do not disable it; the system absorbs or adapts to disruptions without fundamental breakdowns. Through fast, real-time communication, feedback and *improvisation*, the system can restructure or reconfigure in response to external (or internal) changes or pressures. In these organizations, worst-case scenarios are always imagined, modelled and rehearsed.

In HROs, expertise is distributed and the system controller typically defers to the person with the expertise relevant to the issue they are confronting. An

expert is not necessarily the most experienced or the highest ranked person; it is usually someone at the 'sharp end' – where the real work is done. In other terms, HROs aim to empowering expert people closest to a problem and shifting leadership to people who have the answer to the problem at hand.

It is the nature of complex, tightly coupled and complexly interactive systems, according to Reason (1987), to spring 'nasty surprises'. As case studies repeatedly show, accidents may begin in a conventional way, but they rarely proceed along predictable lines. Each accident is a truly novel event in which past experience counts for little, and where the plant is returned to a safe state by a mixture of good luck and hard, knowledge-based effort. Accident initiation and its propagation through possible pathways and branches within the system is a highly complex and hard to foresee event. It is analogous to the progression of a crack in an icy surface, which can move in several directions, hit different levels of thickness, and if not stopped, can cause the surface to break up and open ('uncover the core' and break the system).

The safe, efficient operation and resiliency of infrastructural technological systems is a function of the interactions among their three major human, organizational and technological (i.e., engineered) subsystems. The role of each individual subsystem, which is alike a link in a chain, can determine and affect the integrity of the whole system; obviously, the chain (i.e., system) could break down if any link breaks down. Most failures of technological systems have been caused by breakdowns of the weakest links in this chain, which are most often the human or organizational subsystems. Through fast, real-time communication, feedback and improvisation, the system can restructure or reconfigure in response to external (or internal) changes or pressures. Worst-case scenarios should always be imagined, modelled and rehearsed.

Operators' control of complex, large-scale technological systems can be termed *coordination by pre-planned routines* (Woods, 1987). However, coordination by pre-planned routines is inherently 'brittle'. Because of both pragmatic and theoretical constraints, it is difficult to build mechanisms into pre-planned routines that cope with novel situations, adapt to special conditions or recover from human errors in following the plan. When pre-planned routines are rotely invoked and followed, performance breaks down in the light of under-specified instructions, special conditions or contexts, violations of boundary conditions, human execution errors, bugs in the plan, multiple failures, and novel situations (incidents not planned for; Woods, 1987). This is the problem of *unanticipated variability*, which happens frequently during emergencies at complex technological systems. Moreover, in virtually every significant disaster, or near disaster, in complex systems,

there have been some points where expertise beyond the pre-planned routines was needed. This point involves multiple people and a dynamic, flexible and problem-solving organization. Handling unfamiliar events (e.g., emergencies) also requires constant modification of the design of the organization, coordination and redeployment of resources (Meshkati, 1991). However, as it has been observed and reported many times, usually, the pre-programmed routines of decision support in expert computing systems sets the organization in a static design (Sloane, 1991).

Ambiguity can interfere with the coordination of pre-planned routine as people might interpret ambiguous information differently. Resilient organizations are ready to respond to unforeseen events by fostering characteristics like flexibility, creativity and spontaneity, which are filtered through individuals' capacity to perceive, understand and make sense of events (Grøtan, et al., 2008). Sense making is one the main characteristics of HROs. Studies show that HROs strive to develop the ability to identify situations that had the potential to evolve into safety critical situations by learning from previous events (Dekker & Woods, 2010). Experience provides individuals with a valuable pool of information and knowledge to draw on when engaging in pattern recognition, which could consequently enable them to identify leverage points to create a successful improvised solution (Trotter et al., 2013).

Complex and safety critical organizations' emphasize on order and control and reliance on routine to reduce the probability of error could suppress creativity and innovation when faced with an unexpected situation. Improvisation in such organizations could be affected by the 'chronic temptation to fall back on well-rehearsed fragments to cope with current problems even though these problems don't exactly match those present at the time of the earlier rehearsal' (Weick, 1998, p. 551).

Ambiguity triggers innovation. If individuals and organizations shy away from ambiguity in the workplace and relationships, they would only be able to reproduce routine actions (Ahmed, 1998). 'Requisite imagination' is a required principle for a resilient organization (Grøtan, et al., 2008).

Furthermore, it has been empirically validated that experts in high stress demanding situations do not usually operate using a process of analysis. Even their rules of thumb are not readily subjected to it; whereas most of the existing artificial intelligence-based automated systems always rely on analytical decision process. If operators of complex systems rely solely on computer's analytic advice, they would never rise above the level of mere competence – the level of analytical capacity – and their effectiveness would be limited by the inability of the computer systems to make the transition from analysis to pattern recognition and other more intuitive efforts (Dreyfus & Dreyfus, 1986).

4. A few words about the role of Skill, Rule and Knowledge-based (SRK) framework in addressing ambiguity

The SRK model is a powerful framework for holistic analyses of different aspects of complex human–machine systems. In Moray et al.'s (1993) judgment, the SRK model is 'nothing less than a paradigm shift in the study of complex human–machine interactions' (p. 12). Also, according to Reason (1990), 'the SRK framework is a market standard for the human reliability community the world over' (p. xiii). The SRK taxonomy of cognitive processing developed by Rasmussen is a useful model for representing operator information processing (Rasmussen, 1983; Rasmussen, 1986). Within this model, cognitive performance is divided into three, qualitatively different levels of processing, skill-based, rule-based and knowledge-based behaviour, which utilize three different types of information, referred to as signals, signs and symbols, respectively.

According to Rasmussen (1986), skill-based behaviour 'represents sensorimotor performance during acts or activities that, after a statement of an intention, take place without conscious control as smooth, automated, and highly integrated patterns of behavior'. The information that guides this type of behaviour is in the form of signals, which 'have no "meaning" or significance except as direct physical time-space data'.

Rule-based behaviour is defined as the composition of a sequence of skill-based subroutines that are 'typically consciously controlled by a stored rule or procedure that may have been derived empirically during previous occasions, communicated from other persons' know-how as an instruction or cookbook recipe, or it may be prepared on occasion by conscious problem solving and planning'. Rule-based behaviour is goal directed, but 'very often, the goal is not even explicitly formulated, but is found implicitly in the situation releasing the stored rules'. The information that is utilized during this type of behaviour is in the form of signs, which 'refer to situations or proper behavior by convention or prior experience; they do not refer to concepts or represent functional properties of the environment'. 'Signs can only be used to select or modify the rules controlling the sequencing of skilled subroutines; they cannot be used for functional reasoning, to generate new rules, or to predict the response of an environment to unfamiliar disturbances'.

Knowledge-based behaviour occurs in situations in which a goal is 'explicitly formulated, based on an analysis of the environment and the overall aims of the person. Then, a useful plan is developed – by selection, such that different plans are considered and their effect tested against the goal; physically by trial and error; or conceptually by means of understanding of the functional properties of the environment and prediction of the effects of the plan considered'. Because reasoning at this level is based upon the individual's mental model of the system, this type of processing can also be referred to as 'model-based' reasoning. 'To be useful for causal functional reasoning in order to predict or explain unfamiliar behavior of the environment, information must be perceived as symbols. Whereas signs refer to percepts and rules for action, symbols refer to concepts tied to functional properties and can be used for reasoning and computation by means of a suitable representation of such properties'. Symbols 'are defined by and refer to the internal, conceptual representation that is the basis for reasoning and planning'.

The determination of whether skill- or rule-based processing will occur is based primarily upon the level of experience of the individual. As one is learning a new process, performance is dominated by rule-based behaviour. As these rules become internalized, however, the sequence of actions required begin to be integrated into smooth patterns, which no longer need to be consciously attended to be performed correctly. The distinction between rule- and knowledge-based behaviours, on the other hand, is generally determined by the familiarity of the current situation. In unfamiliar situations, an appropriate set of rules for action may be either unavailable or not immediately obvious. In this situation, reasoning about the state of the system will be necessary in order to determine a course of action. Once this goal is selected, processing may shift back to rule-based or even skill-based reasoning as the required steps are performed.

Improvisation implies the presence of imagination and reluctance to simplify, the ability to interpret signals in different ways and be sensitive to different variety of inputs (Grøtan, et al., 2008). Research shows that experience and practice improves people's intuition and patter recognition to be more skilled-based rather than based on 'potentially faulty heuristic' (Trotter et al., 2013).

Skill-based behaviour and rule-based behaviour are both considered to be primarily perceptual in nature while knowledge-based behaviour is considered to be analytical in nature. Vicente and Rasmussen (1992) report that results from a variety of studies indicate that perceptual processing tends to be faster and, although not as exact in its result, can lead to performance, which has lower variability than does analytical processing, which can lead to more extreme errors. This type of processing is seen as more appropriate for the often time-critical type of performance that is required of the operators of complex processes. Further, the authors state that there is some evidence that individuals attempt to utilize simple perceptual strategies in favour of analytical processing even while performing complex tasks, and that this indicates that perceptual processing is preferred to analytical processing.

At the same time, the authors note, the control of complex processes will require analytical or knowledge-based reasoning, particularly when reacting to an unfamiliar fault condition. The overall goal of ecological interface design that flows from these findings is to allow the operator to perform control tasks at as low a level of processing as possible while providing appropriate support for all three processing levels. The following guidelines have also been generated, each corresponding to a specific level of cognitive control (Vicente et al., 1992).

The nuclear reactor operators' response to nuclear power plant disturbances is shown in Figure 1 (Meshkati, Buller, & Azadeh, 1994). The operators are constantly receiving data from the displays in the control room and looking for change or deviation from standards or routines in the plant. It is contended that their responses during transition from the Rule-based to the Knowledge-based level of cognitive control, especially in the Knowledge-based level, are affected by the

safety culture of the plant and are also moderated or influenced by their cultural background. Their responses could start a vicious circle, which in turn could lead to inaction, which wastes valuable time and control room resources. Breaking this vicious circle requires 'boldness' to make or 'take over' decisions so that the search for possible answers to the unfamiliar situation does not continue unnecessarily and indefinitely. It is contended that this new situation when there is no standard operating procedures (SOPs) and EOPs that can be called up, requires 'boldness' to break out (from the aforementioned iterative vicious cycle) and to solve the system's problem requires improvisation. Operators need to continue to operate and control the system in a totally new and unprecedented environment and adverse conditions. They work as a team, conduct a real-time situational analysis, brainstorm, develop solutions, evaluate alternatives, and execute the most feasible and available ones immediately. Coming up with an unprecedented plan is strongly culturally driven, and is a
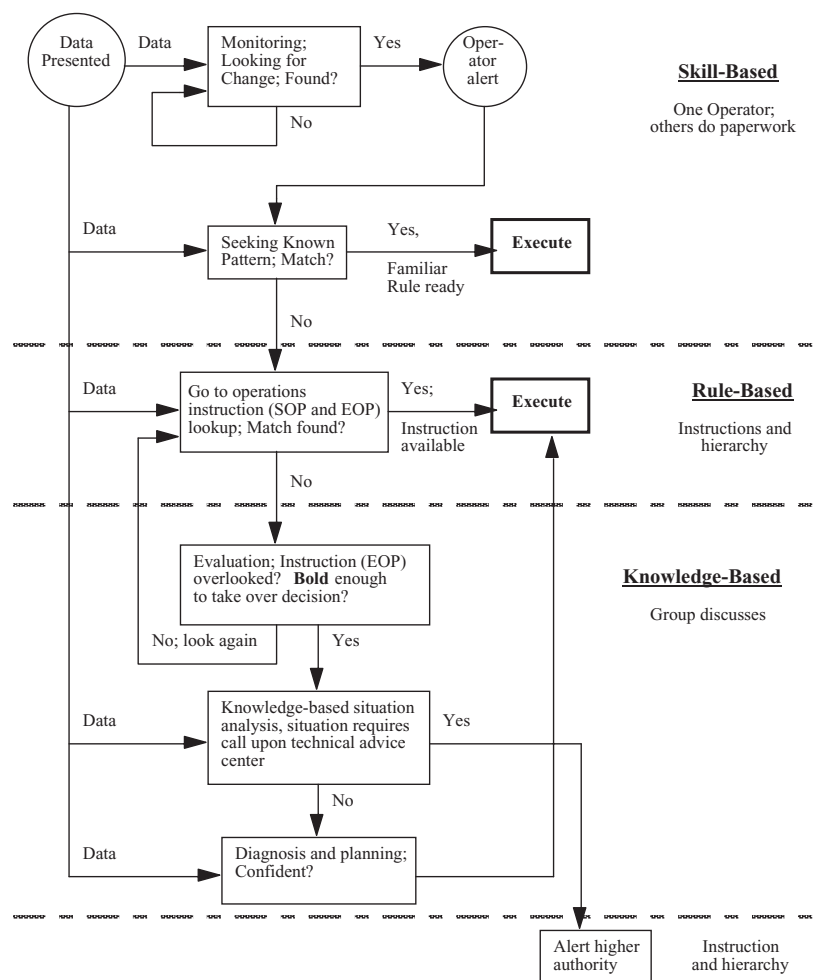
Figure 1. Model for nuclear power plant operators' responses to disturbances. EOP, emergency operating procedures; SOP, standard operating procedures (source: Rasmussen, personal communication, 1992).

function of the plant's organizational culture, reward system and the regulatory environment. Boldness, of course, is also influenced by operators' personality traits, risk taking and perception (as mentioned before), which are also strongly cultural. Improvisation requires mastery of the subject matter, a total system comprehensive (including knowledge of key components, sub-systems and their potential interactions) and ability to extrapolate the behaviour of the newly 'improvised' and patched up system, and to shepherd it to the safe state. Other important aspects of the national culture include 'hierarchical power distance' and 'rule orientation' (Lammers & Hickson, 1979), which govern the acceptable behaviour and could determine the upper bound of operators' boldness.

5. Conclusion

As the experience of US Airways Flight 1549 and Fukushima Daini Nuclear Power Station demonstrated, operators' improvisation in the absence of computer-aided control or inapplicability of SOPs and EOPs is the last resort of averting an assured disaster and saving the day. Improvisation, in turn, is conducted at the Knowledge-based level of cognitive control and requires among others a deep, total system comprehension ('internalized knowledge') of the technological system and its interacting subsystems, along with supportive organizational framework and dedication, boldness and positive attitude of the operating personnel.

For the foreseeable future, despite increasing levels of computerization and automation, human operators will have to remain in charge of the day-to-day controlling and monitoring of complex technological systems, since system designers cannot anticipate all possible scenarios of failure, and hence are not able to provide pre-planned safety measures for every unexpected event and contingency. Professor Jens Rasmussen's earlier mentioned epigraphic and climactic observation, ("operators are maintained in [complex technological] systems because they are flexible, can learn and do adapt to the peculiarities of the system, and thus they are expected to plug the holes in the designer's imagination"), which can also be considered as the finale for this article, has most succinctly articulated this conclusion.

References

Ahmed, P.K. (1998), 'Culture and Climate for Innovation', *European Journal of Innovation Management*, Volume 1, Number 1, pp. 30–43.

Dekker, S.W.A. and Woods, D.D. (2010), 'The High Reliability Organization Perspective', in Eduardo, S., Jentsch, F. and Maurino, D. (eds), *Human Factors in Aviation*, Academic Press, Boca Raton, FL, pp. 123–143.

Dreyfus, H.L. and Dreyfus, S.E. (1986), *Mind Over Machine*, The Free Press, New York.

Fraher, A.L. (2011), 'Hero-Making as a Defence Against the Anxiety of Responsibility and Risk: A Case Study of US Airways Flight 1549', *Organisational and Social Dynamics*, Volume 11, Number 1, pp. 58–78.

Grøtan, T.O., Størseth, F., Rø, M.H. and Skjerve, A.B. (2008), 'Resilience, Adaptation and Improvisation – Increasing Resilience by Organising for Successful Improvisation', *The 3rd Symposium on Resilience Engineering*. Antibes, Juan-Les-Pins, France, October.

Gulati, R., Casto, C. and Krontiris, C. (2014), 'How the Other Fukushima Plant Survived', *Harvard Business Review*, Volume July–August, pp. 111–115.

Kawamura, S. (2012), 'Lessons Learnt from Fukushima Daini NPP and Status of Fukushima Daiichi NPP', *Atomexpo*, http://2012.atomexpo.ru/mediafiles/u/files/Present2012/Kawamura.pdf (accessed March 4, 2015).

Lammers, C.J. and Hickson, D.J. (1979), 'A Cross-National and Cross-Institutional Typology of Organizations', in Lammers, C.J. and Hickson, D.J. (eds), *Organizations Alike and Unlike: International and Interinstitutional Studies in the Sociology of Organizations*, Routledge & Kegan Paul, London, UK, pp. 420–434.

Masuda, N. (2014), 'East Japan Earthquake on March 11, 2011 and Emergency Response at Fukushima Daini Nuclear Power Plant', *IAEA*, http://www-pub.iaea.org/iaeameetings/cn233p/OpeningSession/6Masuda.pdf (accessed March 9, 2015).

Meshkati, N. (1991), 'Integration of Workstation, Job, and Team Structure Design in Complex Human–Machine Systems: A Framework', *International Journal of Industrial Ergonomics*, Volume 7, pp. 111–122.

Meshkati, N. (2014), 'The Unsung Heroes of Fukushima'. *The Japan Times*, 25 August.

Meshkati, N., Buller, B.J. and Azadeh, M.A. (1994), *Integration of Workstation, Job, and Team Structure Design in the Control Rooms of Nuclear Power Plants: Experimental and Simulation Studies of Operators' Decision Styles and Crew Composition While Using Ecological and Traditional User Interfaces*, University of Southern California, Los Angeles.

Moray, N., Jones, B.J., Rasmussen, J., Lee, J.D. and Vicente, K.J. (1993), *Performance Indicator of the Effectiveness of Human–Machine Interfaces for Nuclear Power Plants*. Technical Report, University of Illinois at Urbana-Champaign, Department of Mechanical and Industrial Engineering, Urbana, IL.

National Academy of Sciences (2014), *Lessons Learned from the Fukushima Nuclear Accident for Improving Safety of US Nuclear Plants*. NAS Committee on Lessons Learned from the Fukushima Nuclear Accident for Improving Safety and Security of US Nuclear Plants, Washington DC: The National Academy Press.

Office of the Press Secretary (2013), 'Presidential Policy Directive – Critical Infrastructure Security and Resilience', *The White House*, 12 February. http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil (accessed Octoer 2014).

Rasmussen, J. (1980), 'What Can Be Learned from Human Error Reports?', in Duncan, K.D., Gruneberg, M.M. and Wallis, D. (eds), *Changes in Working Life*, Wiley, New York, NY, pp. 97–113.

Rasmussen, J. (1983), 'Skills, Rules, and Knowledge; Signals, Signs, and Symbols, and Other Distinctions in Human Performance Models', *IEEE Transactions on Systems, Man, and Cybernetics*, Volume 13, Number 3, pp. 257–266.

Rasmussen, J. (1986), *Information Processing and Human–Machine Interaction: An Approach to Cognitive Engineering*, North-Holland, New York.

Rasmussen, J. (1989), *Human Error and the Problem of Causality in Analysis of Accidents*. Unpublished invited paper for Royal Society meeting on Human Factors in High Risk Situations, 28–29.

Rasmussen, J., Pejtersen, A.M. and Goodstein, L.P. (1994), *Cognitive Systems Engineering*, Wiley, New York.

Reason, J. (1987), 'Cognitive Aids in Process Environments: Prostheses or Tools?', *International Journal of Man-Machine Studies*, Volume 27, pp. 463–470.

Reason, J. (1990), *Human Error*, Cambridge University Press, New York, NY.

Sloane, S.B. (1991), 'The Use of Artificial Intelligence by the United States Navy: Case Study of a Failure', *AI Magazine*, Volume 12, Number 1, pp. 80–92.

Trotter, M.J., Salmon, P.M. and Lenné, M.G. (2013), 'Improvisation: Theory, Measures and Known Influencing Factors', *Theoretical Issues in Ergonomics Science*, Volume 14, Number 5, pp. 475–498.

Trotter, M.J., Salmon, P.M. and Lenne, M.G. (2014), 'Impromaps: Applying Rasmussen's Risk Management Framework to Improvisation Incidents', *Safety Science*, Volume 64, pp. 60–70.

Vicente, K.J. and Rasmussen, J. (1992), 'Ecological Interface Design: Theoretical Foundations', *IEEE Transactions on Systems, Man, and Cybernetics*, SMC-22, 589–606.

Weick, K.E. (1998), 'Introductory Essay: Improvisation as a Mindset for Organizational Analysis', *Organization Science*, Volume 9, Number 5, pp. 543–555.

Weick, K.E. and Sutcliffe, K.M. (2001), *Managing the Unexpected: Assuring High Performance in an Age of Complexity*, Jossey-Bass, San Francisco, CA.

Woods, D.D. (1987), 'Commentary: Cognitive Engineering in Complex and Dynamic World', *International Journal of Man-Machine Studies*, Volume 27, p. 1987.

Where Is the Organization Looking in Order to Be Proactive about Safety? A Framework for Revealing whether It Is Mostly Looking Back, Also Looking Forward or Simply Looking Away

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Despite the desire to utilize proactive safety metrics, research results indicate imbalances can arise between economic performance metrics and safety metrics. Imbalances can arise, first, because there are fewer proactive metrics available relative to the data an organization can compile to build reactive metrics. Second, there are a number of factors that lead organizations to discount proactive metrics when they conflict with shorter-term and more definitive reactive metrics. This paper introduces the *Q4-Balance Framework* to analyse economy-safety trade-offs. Plotting the sets of metrics used by an organization in the four-quadrant visualization can be used to identify misalignments, overlap and false diversity. It results in a visualization of the set of metrics an organization uses and where these conflict or reinforce each other. The framework also provides a way to assess an organization's *safety energy* as a kind of analysis of an organization's capability to be proactive about safety.

1. Introduction

Through decades of development of indicators of past performance and safety, many organizations have gotten better at using such indicators to reduce incidents and to repair systems after incidents occur. As some of the more successful industries struggle to lower accident rates further while also anticipating higher demands and complexity in their operations, they want to become more proactive. Proactive

indicators can indeed be part of 'support mechanisms that create foresight about the changing shape of risk, before harm occurs' (Woods, 2009). Together with research communities, industries are trying to define proactive indicators; they seek to better anticipate and avoid incidents or losses of performance rather than being mostly limited to responding after the fact and having to deal with the consequences of adverse events.

However, in addition to the challenges of defining such indicators, critical issues lie in how organizations use proactive indicators in the context of other goals and information. In particular, research results indicate imbalances can arise between economic performance metrics and safety metrics despite the desire to utilize proactive safety metrics. Imbalances can arise, first, because there are fewer proactive metrics available relative to the data an organization can compile to build reactive metrics. Second, there are a number of factors that lead organizations to discount proactive metrics when they conflict with shorter-term and more definitive reactive metrics. The central problem is that what organizations pay attention to (monitor, assess, investigate) impacts their capacity to respond to or avoid adverse events, and ultimately their resilience in the face of adverse events (whether this term is defined relative to safety or economic goals).

In this paper, we describe the novel Q4-Balance Framework, which is an empirically based conceptualization and representation of the portfolio of indicators an organization is using. Plotting the sets of metrics used by an organization in the four-quadrant visualization can be used to identify misalignments, overlap and false diversity. It results in a visualization of the set of metrics an organization uses and where these conflict or reinforce each other. This representation is an instrument for allowing organizations to better visualize what they are paying attention to, i.e., for:

(1) Allowing the organization to identify how it is collecting information about its performance (e.g., which indicators it is using).
(2) Reflecting on issues associated with the portfolio of indicators (e.g., imbalances, absences).
(3) Investing resources meaningfully to improve its portfolio.

We also introduce the notion of *safety energy*, which emerged from applying the Q4-Balance Framework to support exchanges with practitioners. This notion represents how an organization uses its resources towards safety-oriented indicators, and aims at capturing the organization's capability to be proactive in safety management. The framework and the notion of safety energy provide ways to assess an organization's capability to be proactive about safety.

2. Organizations' use of performance indicators

> The past seems incredible, the future implausible. (Woods, 2009)

Put simply, the existence and use of indicators in an organization reveal whether it is: mostly looking *back*, also looking *forward* or simply looking *away*.

2.1. Looking back vs. looking forward

The general situation in organizations is that of a large prevalence and nominal reliance on reactive indicators. Reactive indicators offer the undeniable advantage of computing variables associated with past events, i.e., events that have actually occurred. Learning can occur from those indicators and organizations can change the course of their actions in successful ways based on such indicators. However, organizations are also increasingly aware of the fundamental limitations associated with looking back only, and seek for ways to become more proactive about safety.

Many organizations and industrial sectors have achieved excellent safety levels, and most of those safety improvements are based on lagging indicators and after the fact analyses. Yet for even these organizations their record of success is punctuated by notable accidents. For example, aviation has achieved notable safety levels, as illustrated by Figure 1, but still experiences failures such as the accidents Überlingen, Air France 447 and Linate. To maintain and extend exemplary safety records like aviation, organizations would like to use proactive metrics that anticipate and warn of areas of possible increased safety risks and be able to act in advance of incidents and accidents. In fact, and especially because it has made significant progress through reactive safety, aviation is a leading sector in the search for proactive measures, e.g., setting national and international requirements (e.g., safety management systems in aviation; European Commission, 2011). As a sector, aviation recognizes that the capacity to be more proactive becomes critical, as efficiency and workload demands increase, as extreme weather events occur more frequently, as new technologies are introduced, and as potential system improvements are considered.

Today's organizations operate in an increasingly complex environment as organizations adapt to meet increased pressures for efficiency and productivity in a changing technological, environmental and competitive world while maintaining or improving its record of safety (ACARE, 2012). This increase in complexity requires new metrics that allow organizations to identify when brittleness is increasing and evaluate cost-effective sources of resilience (Hollnagel et al., 2006). Reactive safety approaches can look at specific risk
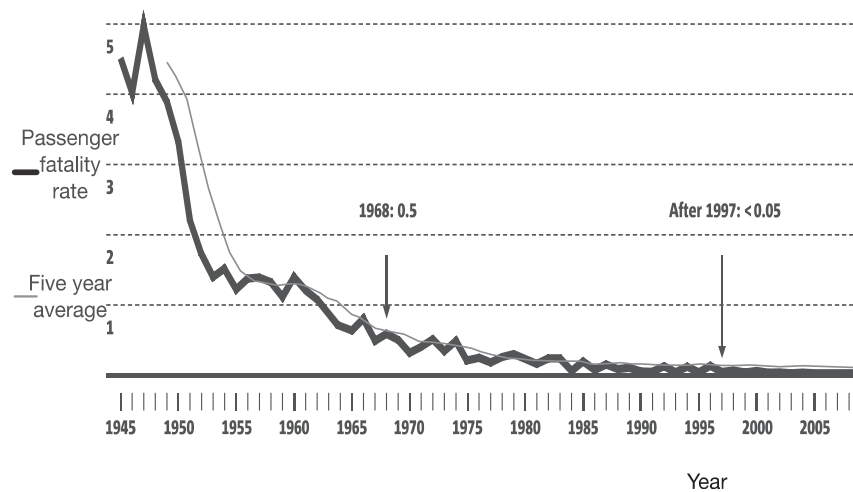
Figure 1. Evolution of passenger fatality rate in aviation: do we need proactive safety indicators? (source: EASA, 2010).

factors one or a few at a time. Proactive measures, especially given the increasing complexity of systems, help identify emergent phenomena and multifactor patterns that can contribute to new risks (Herrera, 2012).

One impediment to anticipate changing or new risks before they lead to serious incidents or accidents is a dearth of valid and practical proactive safety metrics (see Hale, 2009). But another impediment is the tendency for organizations to discount available proactive safety indicators when they come into conflict with short-term economic and productivity pressures (Cook & Woods, 2006; Woods, 2005, 2006). This was seen most vividly in the events leading up to the Columbia Space Shuttle accident where productivity metrics and pressures took priority over indicators of a change in safety risks, i.e., the energy and location of debris (foam) strikes as well as surprises in the source of debris and phase of flight when these strikes occurred (CAIB, 2003).

2.2. Looking away

Research in various domains suggests that, often, information about risks or opportunities does exist somewhere in the organization before adverse events develop or opportunities are no longer available. A central issue is what the organization does about it, how it uses this information to make decisions. Research actually documents two different aspects of this problem: (1) humans (*a fortiori* organizations) might discount information that does not fit with established knowledge; and (2) such tendencies are reinforced by the uncertain and ambiguous nature of information, especially in the typical organizational context of conflicting goals and pressures.

2.3. Examples

The 2003 Columbia space shuttle accident is a widely documented case, in particular in the literature about high-reliability organizations and resilience engineering. It constitutes a prime example of an organization of a highly regarded track record of success and safety led to discount evidence about its incorrect analytical models in the face of production pressures ('faster, better, cheaper'). Following the observation of foam debris during the shuttle's launch, concerns were indeed raised about the lack of capacity to analyse foam debris impact and evaluate shuttle integrity. Such analyses were key to evaluate the capacity of the shuttle to re-enter the atmosphere at the end of the mission. Three indicators existed to point out that analytical models used were outside of the engineering envelope. The investigation report (CAIB, 2003) actually suggests that a mis-assessment was in place that foam strikes pose only a maintenance issue and not a risk to orbiter safety. Furthermore, this mis-assessment resisted no less than 79 opportunities to be revised. As Woods (2009) explains, 'it was not simply the mis-assessment, but rather the organization's inability to re-evaluate the assessment and re-examine incoming evidence about the vulnerability that is troubling'.

The initial Egyptian attack in the 1973 Arab–Israeli War has been characterized as a 'fundamental surprise' (Lanir, 1986). In this historical case too, various indicators existed that could have led the Israeli government to take different actions, especially: evidence had been available from intelligence sources about operations being in preparation, and signs of Egyptian troops movements in the Suez Canal area. However, both these elements of information were discounted due to the uncertainty associated (source trustworthiness,

movements characterized as training operations), and key to the problem, to the fact that they did not fit with established models of adversaries intent and capabilities: a different interpretation of this evidence was simply inconceivable. At a large organizational scale, this case corresponds to failures of sensemaking, more precisely to the incapacity to re-frame in the face of conflicting evidence (Klein, Moon, & Hoffman, 2006).

A more recent example is provided by the examination of a recent cyber security breach experienced by Target stores (Riley, Elgin, Lawrence, & Matlack, 2014). In this case, the organization had recently invested in a new cyber security system that correctly provided the two central capabilities it was designed for: warnings about suspicious activity, a form of proactive indicator and a security 'buffer', implementing a network environment in which adverse actions did not have immediate consequences on security. However, these proactive indicators were discounted and the breach was not recognized as serious. Delayed actions ultimately allowed the situation to escalate and high volumes of sensitive information to be stolen. Cyber security is exemplar of domains in which the existence of warnings about potential adverse events is the norm, and high-visibility companies and organizations face such issues constantly (e.g., attackers probing for security breaches or experimenting with new techniques and tools). Moreover, such warnings are often ambiguous as they can also correspond to legitimate, but unusual activity (Branlat, Morison, & Woods, 2011). In such a noisy environment, investigating and acting on all indicators

would be costly or even counter-productive. In addition to cyber defence issues associated with sensemaking (correctly identifying illegitimate activity), security goals also need to be resolved against other organizational priorities such as the need to provide network services or the cost of revealing security breaches to customers.

2.4. Why do organizations tend to discount information?

Research has revealed factors that lead organizations to discount proactive metrics when they conflict with shorter-term and more definitive reactive metrics (the Columbia accident provides the classic example; see earlier and Woods, 2005). Reactive measures tend to be much more tractable and appear more definitive than proactive ones. For example, frequencies can be established from standard databases and reporting systems, and these can be compiled according to different categorization schemes when one is dealing with events that have already occurred (as noted in the column headings in Figure 2).

Proactive metrics tend to look for patterns and relationships that can help recognize anomalies early (Klein, Pliske, Crandall, & Woods, 2005). These are much harder to compile semi-automatically, but are valuable especially because these indicators have the potential to trigger re-evaluation and re-conceptualization about changing risks before serious incidents or accidents occur. However, they are also easier to discount because of the fundamental uncertainty or ambiguity
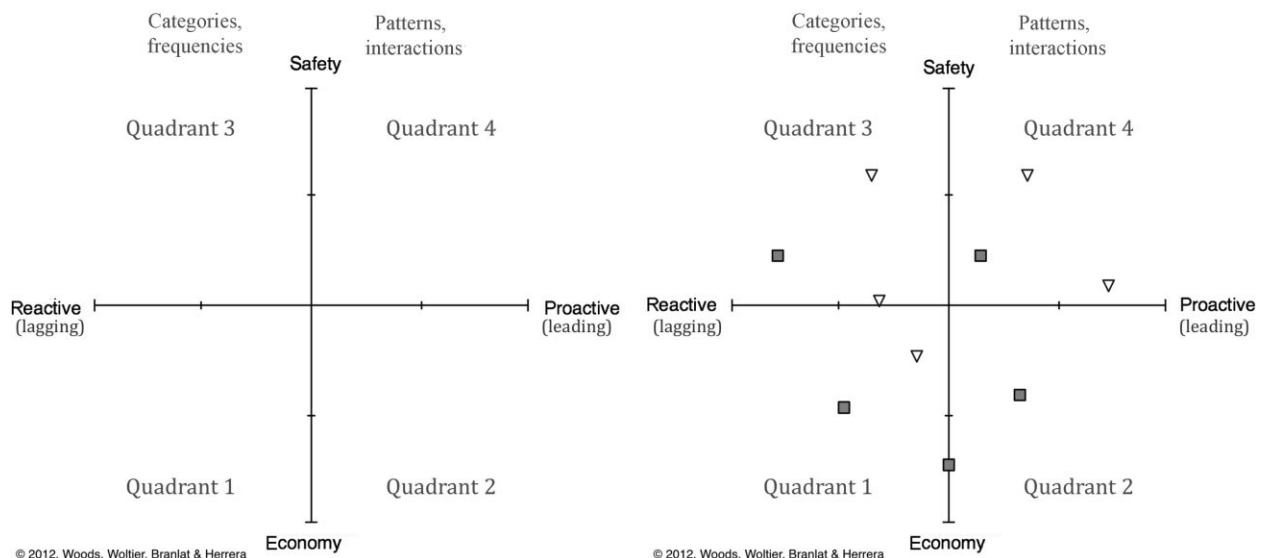
Figure 2. The Q4-Balance Framework. Panel A (*left*) shows that performance metrics fall into a space defined by two dimensions: reactive-proactive (x axis); economy safety (y axis). As a result, metrics are grouped into four quadrants (quadrant 1 = reactive-economic; quadrant 2 = proactive-economic; quadrant 3 = reactive safety; quadrant 4 = proactive safety). Panel B (*right*) shows how specific performance metrics used by specific organizations can be plotted as a position in this space to assess the distribution across the quadrants. In our illustration, the indicators represented might be the ones used by services such as quality (squares) and safety (triangles) departments. Such representation can reveal patterns of imbalance that hinder organizations as they confront trade-offs in risks and uncertainties.

associated with looking into the future and because of perceived potential for acting unnecessarily – an issue that often leads to the discounting of information that exists in an organization (e.g., about a risk), but which would lead to actions that conflict with other goals (especially production goals).

Such issues relate to the difficulties organizations have to deal with early warnings (especially in a noisy background, as in the domain of cyber security), as well as to fundamental trade-offs between short-term (acute) and long-term (chronic) goals. They also relate to a fundamental paradox of safety: because successful actions on safety might prevent adverse events to occur, it is difficult to prove after the fact that the absence of such events is precisely due to the actions rather than other factors (e.g., just luck).

3. Balancing Economy Safety Trade-Offs: The Q4 Framework

The tendency to discount safety indicators and metrics when they conflict with economic and productivity pressures is well documented. The need for proactive safety indicators has been recognized as critical if safety successes are to be extended and sustained as previous successful organizations adapt to change and complexity. This has lead to efforts to identify proactive metrics. But the critical question is how to overcome tendencies to discount proactive safety metrics when they conflict with economic pressures (Woods, 2009)? Discounting arises in part because proactive indicators inherently are ambiguous as a form of early problem detection (Klein et al., 2005).

The authors have drawn on work on proactive safety metrics and advances towards measures of system resilience to develop one way forward to meet this challenge. The balancing economy safety trade-offs framework (or Q4-Balance Framework) allows an organization to map the full set of metrics it uses into four quadrants defined by two dimensions – economy/safety and reactive/proactive as shown in Figure 2. The resulting visualization provides the means to develop and utilize a balanced portfolio of metrics that assesses the state of and interactions across all of the performance dimensions critical to modern systems and organizations.

3.1. Basic structure

Q4-Balance Framework in Figure 2 depicts relationships between classes of performance metrics. Performance metrics fall into a space defined by two dimensions: reactive-proactive (the endpoints on the x axis in Figure 2A); economy safety (the endpoints on the y axis in Figure 2A). The specific performance metrics

or indicators used by a specific organization can be plotted relative to the two axes: safety/economy and reactive/proactive. A set of indicators used by an organization to guide decisions can be seen in a pattern formed by the distribution of the indicators over the 2×2 space of performance measurements as shown in Figure 2B. The structure of Figure 2 reveals an emergent pattern where metrics can be grouped into four classes – economy-reactive, economy-proactive, safety-reactive, safety-proactive – shown as the quadrants 1 through 4, respectively.

Examples of the indicators that could be found for each quadrant are (based on discussions with the aviation industry):

- Q1 (reactive-economic): turn over (last year), revenue, share of home market, earning before interest and taxes (EBIT), EBIT margin, yield, etc.
- Q2 (proactive-economic): new aircraft orders, financial preparedness, market growth, expected traffic volumes, etc.
- Q3 (reactive safety): technical failures, incidents, etc.
- Q4 (proactive safety): integrate across domains and actors, preparedness, resources to respond, interactions and interdependencies, cascading effects and unintended consequences, anticipate bottlenecks ahead and prepare for future events, etc.

Note that indicators such as the ones listed for Q4 do not currently exist, but correspond to information the organizations would like to have access to in order to be more proactive.

3.2. Noticing imbalances

The Q4-Balance Framework provides the analytic and visual basis to assess balance and imbalance across the four interdependent classes of metrics highlighted in the four-quadrant visualization. Imbalances arise when there are fewer proactive metrics relative to reactive ones as shown in Figure 3A. The prevalence of reactive over proactive metrics in a portfolio is shown as shift in the balance point (the 0,0 point in x–y space) so that the left two quadrants are larger and the right two quadrants have shrunk in size indicating the misbalance in the metrics portfolio. A misbalance can show an organization focusing on reactive metrics while weak on proactive metrics. This will have an impact on the ability to anticipate and cope with future situations. Importantly, research on measures of resilience and brittleness, such as methods to forecast the risk of loss of resilience, provide a new paradigm for developing valid and useful proactive metrics that apply to both safety and longer-term economic viability (business continuity).
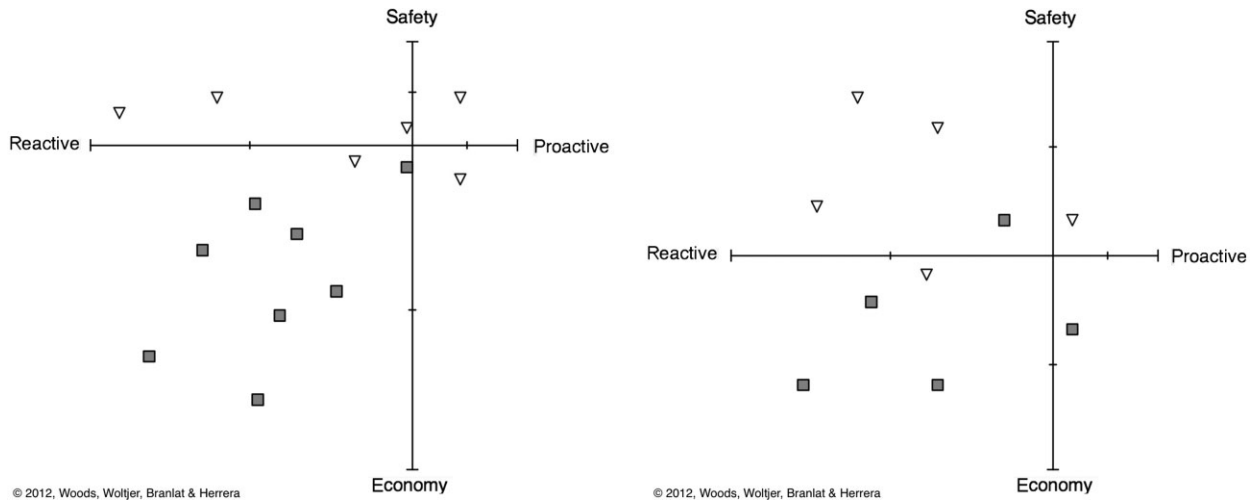
Figure 3. Sample patterns of imbalance. Some classes of metrics tend to dominate others when there is uncertainty or conflict. Panel A (*left*) depicts the tendency for reactive metrics (odd quadrants) to get priority over proactive ones (even quadrants). Panel B (*right*) depicts the tendency for reactive-economy indicators (quadrant 1) to take precedence over proactive metrics, especially proactive safety indicators, when there is uncertainty, conflict and differential costs at stake. Note that in both of the cases illustrated in this figure, the indicators that show threats to longer-term economic viability also tend to be discounted relative to reactive-economic metrics.

Figure 3B depicts the class of imbalance where reactive economic indicators dominate organizational decision making leading to discounting of safety indicators and to discounting of proactive indicators in general. Metrics that capture different aspects of resilience are a particularly valuable means to redress this imbalance, as these were developed specifically in order to assess the risk of this basic pattern (Cook et al., 2006).

3.3. An example: Alaska Airlines flight 261

The application and use of the Q4-Balance Framework is illustrated based on work with aviation organizations as they begin to implement the Safety Management Systems requirement for a proactive approach to safety.

Based on the investigation report (NTSB, 2003), the probable cause for the 2000 Alaska Airlines flight 261 accident was a loss of airplane pitch control resulting from the in-flight failure of the horizontal stabilizer trim system jackscrew assembly's acme nut threads. This failure is thought to have been due to insufficient lubrication of the jackscrew assembly and excessive wear, in conjunction with the absence of a fail-safe mechanism of the particular aircraft (MD-80). The event occurred in the context of noteworthy organization and regulation changes:

- Alaska Airlines' decision to extend lubrication intervals and Federal Aviation Administration's (FAA's) approval of that extension, which *increased* the *likelihood* of excessive wear.
- Alaska Airlines' extension of end play check interval and the FAA's approval of that extension, which allowed the progress to failure *without detection*.

A later analysis of this aviation accident (Woltjer & Hollnagel, 2007) was used as a source of data on the indicators used by an airline prior to and after the accident. The set of indicators were used to populate the Q4 visualization.

The representation of indicators prior to the accident (Figure 4, left) shows a clear imbalance in the portfolio of indicators, with a strong focus on reactive production indicators. After the accident (Figure 4, right), the industry, as a whole, reacted by investing more on proactive indicators, including safety indicators. The result of this reaction was a more balanced portfolio of indicators, which suggests a greater capacity to monitor and detect problems and ultimately avoid the type of event that caused the Alaska Airlines flight accident.

The visualization for this airline around a particular accident was then used to stimulate discussions on proactive safety management with representatives from other organizations in across aviation including regulators, maintenance personnel, and accident investigation board and safety managers. The visualization helped both operational and management personnel reflect on proactive safety and on how organizations respond when conflicts between metrics are made salient.

4. Safety energy

Figure 2A, as shown earlier, presents an idealized view of a balanced portfolio of indicators, in which all indicators are considered with equal importance. It assumes, for instance, that the organization is devoting a similar amount of resources towards updating and
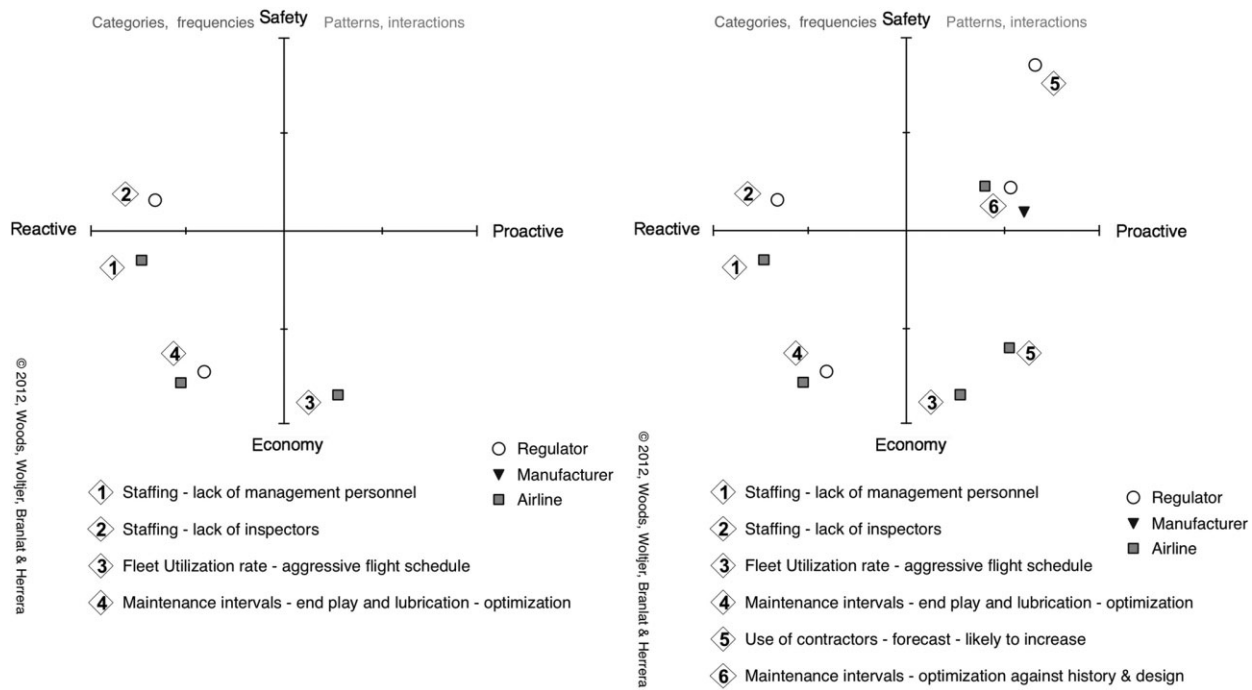
Figure 4. Contrasting the use of indicators in the industry prior (left) and after (right) the Alaska Airlines flight 261 accident (based on NTSB, 2003).
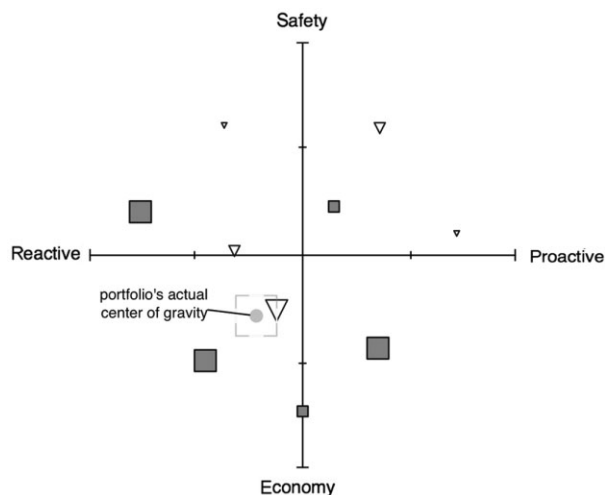
Figure 5. Towards the notion of safety energy: the organization is not paying as much attention to all its indicators. The existence of indicators is not, by itself, sufficient to establish a balanced portfolio.

monitoring all its indicators. In reality, imbalances are likely to occur based on how much importance the organization gives to its various indicators.

Not considering the efforts it actually makes towards the various indicators in its portfolio risks giving the organization a false sense of balance, in particular, of capability to be proactive. In Figure 5, economic and reactive indicators consume much of the organization's

attention, shifting the actual centre of gravity of the portfolio in spite of the existence of safety-oriented and proactive indicators.

The notion of *safety energy* emerged from applying the Q4-Balance Framework to support exchanges with practitioners. Safety energy aims at qualifying the resources the organization is devoting to safety-oriented indicators, and at assessing its capability to be proactive in safety management.

First, the notion emphasizes the fact that such resources are necessarily finite and that they are consumed by a variety of conflicting tasks. The assessment of safety energy moves through a series of steps organized around activities of a safety organization that consume its 'energy,' that is, the expertise, time and networking activities of the primary and secondary safety personnel. To illustrate, the first step asks: how much safety energy remains after the safety group(s) work on documentation and bookkeeping tasks (expressed as a percentage of the total safety energy of the group)? The second step asks: of the remaining, how much is consumed in required reactive safety tasks (e.g., looking into failures the organization has experienced)? What remains after these two steps is the energy available to invest in proactive safety (at this point in the assessment, organizations may find, to their dismay, that the remaining energy available for proactive safety turns out to be quite low). The steps continue by examining how the remaining energy available for proactive safety is invested.

Second, safety energy is a dynamic quantity: it contracts or expands in the face of the organization's reaction to ever-changing goals and conditions of operation. Once we have determined what 'energy' the organization invests in proactive safety, the question remains of what the organization does with it over time, in particular when pressures or *opportunities* arise. For instance, pressures to emphasize success records in order to support marketing priorities in a competitive economy risk diverting resources that were devoted to proactive safety towards bookkeeping. On the other hand, issues revealed through adverse events occurring in the organization's industrial sector represent windows of opportunity to proactively investigate similar risks and potential measures within the organization.

5. Discussion

5.1. Recap: a three-step process

The Q4-Balance Framework and notion of safety energy offer an organization a process with which it can assess its commitment to safety, especially to proactive safety and make strategic decisions on where to invest its resources. It follows three steps:

Step 1: the organization's portfolio of indicators
This initial step involves collecting indicators across the organization. From the Q4-Balance representation, the organization can identify issues such as imbalances, misalignments, overlap and false diversity; or, on the other hand, a well-balanced portfolio of indicators.

Step 2: how the organization uses the information generated
The Q4-Balance representation can then be used to track how the organization's portfolio has evolved over time, especially in the face of specific adverse events or organizational changes that have created new work conditions (e.g., new pressures). Looking at the portfolio of indicators over time offers a way to identify risks of discounting evidence.

Step 3: safety energy
Finally, the organization can use the notion of safety energy to capture and reflect on how it is using its resources towards safety. The assessment of safety energy also follows a three-step process that unveils:

(1) How much safety energy remains after the safety group(s) work on documentation and bookkeeping tasks;
(2) How much is consumed in required reactive safety; and

(3) The remaining 'energy' available to invest in proactive safety.

Note that the Q4-Balance representation offers a convenient way to visualize how much 'bookkeeping' needs to occur as a result of the type of indicators used in the organization.

5.2. Implications and future directions

Theoretically for safety science, the Q4-Balance Framework provides a new path to model the safety-economy goal conflict. We believe this approach can explain paradoxes about safety such as why is it so difficult to make and sustain a business case for safety. Practically for safety management, the Q4-Balance Framework provides a visualization to reveal balance or imbalance in a portfolio of performance metrics. The Q4-Balance first describes metrics that are currently used by an organization. Second, it can be used as a part of an assessment of resilience in terms of balance, conflict resolution and discounting dynamics (as well as to identify additional metrics for quadrant 4). Third, it can serve as a critical tool to help an organization manage its safety investments relative to financial pressures. The visualization of the portfolio helps determine when interventions are needed to sustain safety and which type of interventions (deciding what to do and following through so that these investments produce an impact). When subsets of metrics in the different quadrants align, the overall picture is consistent, despite the uncertainties associated with each specific metric, so that the organization can make investment decisions with confidence. When there is a divergence between reactive and proactive indicators and between safety and economic indicators, organizations can conclude that their ability to balance trade-offs and to assess changing risks has weakened or new risks could arise to threaten organizational performance in the future (Hollnagel, 2011). New analyses are underway in aviation and health care to develop guidance to analysts on how to plot/position indicators in the quadrants, how to capture discounting, and new ways to populate quadrant 4. Our experience applying the Q4-Balance Framework with members of the aviation industry suggests an important point: building a very accurate representation of an organization's or industry's portfolio of indicators is hard. However, in spite of potential inaccuracy or incompleteness, the value of these representations was very promising as a *basis for discussion and reflection on where the organization or industry is looking (or not)*.

In summary, despite the desire to utilize proactive safety metrics, research results indicate that short-term pressures lead organizations to discount proactive metrics when they conflict with shorter-term, more definitive reactive metrics. The Q4-Balance Framework analyses and tracks economy safety trade-offs. Plotting

the sets of metrics used by an organization in the four-quadrant visualization can be used to identify misalignments, overlap, false diversity as well as to identify complementary and reinforcing metrics that produce a balanced portfolio for an organization. The framework and the notion of safety energy provide ways to assess an organization's capability to be proactive about safety, and to make strategic investments towards this goal.

References

Advisory Council for Aviation Research and Innovation in Europe (ACARE) (2012), Strategic Research and Innovation Agenda (SRIA).

Branlat, M., Morison, A.M. and Woods, D.D. (2011), Challenges in Managing Uncertainty During Cyber Events: Lessons from the Staged-World Study of a Large-Scale Adversarial Cyber Security Exercise. In *Proceedings of HSIS 2011: ASNE Human Systems Integration Symposium, October 25–27, 2011*. Vienna, VA.

CAIB (Columbia Accident Investigation Board) (2003), Report, 6 vols. Government Printing Office, Washington, DC.

Cook, R.I. and Woods, D.D. (2006), 'Distancing through Differencing: An Obstacle to Learning Following Accidents', in Hollnagel, E., Woods, D.D. and Leveson, N. (eds), *Resilience Engineering: Concepts and Precepts*, Ashgate, Aldershot, UK, pp. 329–338.

European Aviation Safety Agency (EASA) (2010), *Annual safety review 2010*.

European Commission (2011), Flightpath 2050 Europe's Vision for Aviation. Report of the High Level Group on Aviation Research. Publications Office of the European Union, Luxembourg.

Hale, A. (2009), 'Special Issue on Process Safety Indicators', *Safety Science*, Volume 47, p. 459.

Herrera, I. (2012), Proactive Safety Performance Indicators, Resilience Engineering Perspective on Safety Management. PhD Thesis Norwegian University of Science and Technology (NTNU), Norway, Trondheim.

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

Hollnagel, E. (2011), 'Epilogue: Resilience Analysis Grid', in Hollnagel, E., Paries, J., Woods, D.D. and Wreathall, J. (eds), *Resilience Engineering in Practice*, Ashgate, Aldershot, UK, pp. 253–272.

Klein, G., Pliske, R., Crandall, B. and Woods, D. (2005), 'Problem Detection', *Cognition, Technology, and Work*, Volume 7, Number 1, pp. 14–28.

Klein, G., Moon, B. and Hoffman, R.R. (2006), 'Making Sense of Sensemaking 2: A Macrocognitive Model', *Intelligent Systems, IEEE*, Volume 21, Number 5, pp. 88–92.

Lanir, Z. (1986), *Fundamental Surprise: The National Intelligence Crisis*, Decision Research, Eugene, OR.

NTSB (2003), *Loss of control and impact with Pacific Ocean, Alaska Airlines Flight 261, McDonnell Douglas MD-83, N963AS, about 2.7 miles north of Anacapa Island, California, January 31, 2000* (Aircraft Accident Report No. NTSB/AAR-02/01). National Transportation Safety Board, Washington, DC.

Riley, M., Elgin, B., Lawrence, D. and Matlack, C. (2014), Missed Alarms and 40 Million Stolen Credit Card Numbers: How Target Blew It. *Bloomberg Businessweek*.

Woltjer, R. and Hollnagel, E. (2007), The Alaska Airlines Flight 261 Accident: A Systemic Analysis of Functional Resonance, in Proceedings of the 14th International Symposium on Aviation Psychology. Dayton, OH.

Woods, D.D. (2005), 'Creating Foresight: Lessons for Resilience from Columbia', in Starbuck, W.H. and Farjoun, M. (eds), *Organization at the Limit: NASA and the Columbia Disaster*, Blackwell, Malden, MA, pp. 289–308.

Woods, D.D. (2006), 'Essential Characteristics of Resilience for Organizations', in Hollnagel, E., Woods, D.D. and Leveson, N. (eds), *Resilience Engineering: Concepts and Precepts*, Ashgate, Aldershot, UK, pp. 21–34.

Woods, D.D. (2009), 'Escaping Failures of Foresight', *Safety Science*, Volume 47, Number 4, pp. 498–501.

Managing Uncertainty: The Engineer, the Craftsman and the Gardener

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According to Thorngate's impostulate of theoretical simplicity (1976), descriptions of social phenomenon can display only two of the three following characteristics: simplicity, generality, and accuracy. When we apply this insight to the modeling of ambiguity, we find three theorizing archetypes that we refer to as the stances of the Engineer, the Craftsman and the Gardener. We argue that the Craftsman stance is the only helpful stance for organizations operating in high tempo/ambiguous environments with a duty of high reliability. We provide instances in the case of firefighting. Finally, we discuss the managerial implications of this line of reasoning, especially how High Reliability Organizing ideas, rooted in the theories of sense-making, should be used in the perspective of the craftsman stance.

1. Introduction

The questions that triggered this article can be stated as follows: how do people in organisations enact uncertainty? When dealing with uncertain situations, they rely on representations that are, in essence, uncertain. We wondered whether the process through which they create uncertain maps of the world influences what they consider as uncertain in their environment and how they deal with it. We first tried to answer this question by examining the process of theorising. We further explored this question in the context of theorising about organisational failure. Finally, we confronted our theoretical model with the observation of firefighters who constantly face uncertain and dangerous situations.

1.1. Defining uncertainty

Traditionally, there exist two types of uncertainty: incompleteness and ambiguity (Weick, 1995a). Uncertainty as incompleteness is due to a lack of information, whose forms are already known. Its reduction requires financial resources, time or calculation capacities. Uncertainty as ambiguity stems from an equivocal situation in

which a set of stimuli can receive several plausible interpretations. Its removal requires some kind of *invention*. We observe that the processes involved in the reduction of uncertainty often mix both types, dynamically interlacing the question of data and interpretation (March, Sproull, & Tamuz, 1991). This is probably why many organisational theories generally discuss uncertainty as partial knowledge (in regard to data or plausible interpretations).

2. Stances of organisation science theories towards uncertainty

We suggest that there is an isomorphism between the uncertainty of theoretical models and the modeling of uncertainty. Indeed, to represent reality a theory is bound to make approximations. They induce an epistemic uncertainty, which in turn determines the type of uncertainty taken into account by the model and its recommendations to manage it.

To characterise the approximations made in the process of theorising, we used Thorngate's insight. According to the author (Thorngate, 1976), theories in social science can possess only two of the three

following characteristics: simplicity, generality and accuracy. We describe these three characteristics below.

2.1. Simple (vs. complex)

A theory is simple when it proposes a linear causal model, without feedback loops. It usually can be expressed in a simple sentence (Weick, 1999).

2.2. General (vs. local)

Within a positivist perspective, generality means external validity. It holds in every context and is confirmed by successive tests. Within a social-constructivist view, for which verification through empirical tests is impossible and meaningless, validity becomes plausibility. Weick describes the criterion of validity as plausibility as follows (Weick, 1989, p. 524): 'When theorists apply selection criteria to their conjectures, they ask whether the conjecture is interesting, obvious, connected, believable, beautiful, or real, in the context of the problem they are trying to solve.' The interest of a plausible theory comes from the change in perspectives and the possible actions it induces through the new relationships it suggests.

2.3. Accurate (vs. ambiguous)

A theory is accurate when it produces enactments that can be unequivocally related to the theory's categories.

We suggest that there are three theorising archetypes, depending on the 'abandoned' characteristic, and that organisational theories can be distinguished according to these trade-offs.

2.4. Analytical theorising: simple, accurate and local

2.4.1. Characteristics
Analytical theorising consists of breaking down a phenomenon into precisely defined variables linked by causal relationships. As a consequence of Thorngate's insight, these simple and accurate theories lose the property of generality. They aim to predict and control and therefore tend to be increasingly focused and narrow.

2.4.2. An epistemic uncertainty of validity
Because these models trade generality for predictability on local domains, their exact fields of validity are never fully known. The applicability of these models to situations other than those that produced them is always in doubt. This question is unsolvable for at least two reasons. First, a model is considered as true until a counter example is found. Second, its conditions of

application – often rhetorically referred to as 'all else being equal' – can never be verified.

2.4.3. Managing uncertainty: the engineer's stance
The models produced by analytical theorising see the world's uncertainty as a lack of information, i.e., an incompleteness that should be reduced by more data, tests and calculations. There is coherence between:

– theorising that, out of rigour, limits the domain of validity for its established results and recommends more data for greater validity;
– uncertainty conceptualised as a lack of information; and
– managerial recommendations to reduce this uncertainty which consist of increasing one's knowledge database and access to information.

We suggest referring to this type of theorising as the *engineer's stance* because it seeks the optimal solution and is based on a calculating intelligence that considers models as tools for predictability and control. We offer three typical examples. Many economic or rational choice theories consider information as a commodity that can be purchased to reduce uncertainty. For instance, the agency theory sees a major source of uncertainty as stemming from the information asymmetry between the principal and the agent. Its main recommendation for the principal (such as administrators or shareholders) consists of investing in information systems to monitor and discourage the agent's potential opportunistic behaviours (Eisenhardt, 1989, p. 64). Another example from the rational choice theories can be found in March's famous exploration-versus-exploitation dilemma, which engages decision makers to optimise their investments by choosing between decreasing the uncertainty of future profits (by collecting costly information about possible futures) and increasing their current profits (March, 1991). A third example illustrating the engineer's stance is observed when lessons learned by organisations translate into the refinement of procedures, protocols and the proliferation of rules, as when firefighters need to comply with 48 rules of engagement (see section 4).

2.5. Metaphoric theorising: simple, general and ambiguous

2.5.1. Characteristics
These theories propose causal, linear models that strive for generality. The property of generality should be understood as plausible and generic. They often take the form of 'meta-models', i.e., a set of loosely defined variables and the relationships between these variables. The user of the model inserts his own ideas about these variables and relationships in his specific context and

examines the results of the model's formulation and the new perspectives it opens (Weick, 1979, p. 235). This type of theorising sacrifices accuracy for plausibility for several reasons. In some settings, accuracy is impossible and its search paralyses action. Accuracy is impossible because people perceive the world through filters, because the objects perceived at some point in time continue to change while we evaluate them and because our assessments change the world (Starbuck & Milliken, 1988). It can also hamper action because the logic of action is based on simplification and the search for accuracy takes up time that is necessary for action (Weick, 1995a, p. 61).

2.5.2. An epistemic uncertainty of meaning

Loosely defined categories can produce ambiguous statements. Moreover, people are never certain to correctly enact the proposed categories. Finally, by essence, these models can never be tested and it cannot be decided whether a bad outcome results from a poor enactment or a bad model. As a result, the meaning of these models is always in question. Their value comes mostly from the ideas and actions they spur for their users. They aim to trigger creativity for the purpose of action and to continue the ongoing project. It can be noted that this intrinsic ambiguity is turned into a source of invention (March, 1979).

2.5.3. Managing uncertainty: the craftsman's stance

Metaphoric theorising sees the world's uncertainty fundamentally as ambiguity. First, ambiguity is seen as a central characteristic of organisational life and influences most activities (Cohen, March, & Olsen, 1972; Weick, 1979, 2000). This is due to limited cognitive capacities of organisational members, unstable preferences, indecisive causality relationships between the different organisational activities, or between a given action and the environment response. Then the reduction of ambiguity is considered as more important than the reduction of incompleteness because the cost of inaccuracy is often smaller than the cost of inaction in organisations (Bruner, 1973, p. 30). As a result, the managerial recommendations in metaphoric models focus on the development of sense-making processes that can remove equivocality. There is coherence between:

- theorising that sacrifices accuracy for plausibility and becomes itself somewhat ambiguous;
- uncertainty conceptualised as ambiguity; and
- the management of uncertainty focused on the development of sense-making processes that can remove ambiguity.

This coherence is fundamentally linked to the principle of *requisite variety*. The concept of requisite variety was first introduced by Ashby (1957) in the context of system regulation and control, and further developed by Buckley for complex adaptive systems such as organisations (Buckley, 1968). According to Buckley, organisations encode their environment in order to be able to discriminate meaningful events and act upon them. The environment's variety can be assessed by the number of possible distinct events. The principle of *requisite variety* applied to organisations states that organisations can persist if the variety of the encoding matches the variety of their environment. And because most environments' variety is nearly infinite, systems have to solve the problem of mapping the relevant variety in a changing environment. Then persistence depends upon successful encoding as well as the destructuring and restructuring processes. A Weickian application of this principle entails considering that the world's ambiguity should be reflected in the organisational processes and interpretation schemes: 'When applied to organizations, the implication of requisite variety is that organizational processes that are applied to equivocal inputs must themselves be equivocal' (Weick, 1979, p. 189). Hence, the world's fundamental ambiguity is reflected in metaphoric theorising.

We suggest calling this approach to theorising the *craftsman's stance*, which shapes the meaning of an equivocal world for the sake of projects, manifesting a behavioural intelligence.

2.6. Complexity theorising: accurate, general and complex

2.6.1. Characteristics

These models are often based on the description of individual behaviours or elementary organisational properties and the systemic outcome of their interactions, often involving feedback loops. They seek to mirror the complexity of reality and sacrifice simplicity for variety (in Ashby's sense). Complex theorising creates models that seek to be as varied as the world they describe.

2.6.2. An epistemic uncertainty of causality

Complex theorising creates what Starbuck called the Bonini paradox, named for a student who successfully modelled a firm with software programming, but who could not identify the causal chains explaining the firm's behaviour. Hence, the more realistic the model is, the harder it becomes to understand the reality it represents (Starbuck, 2006). Starbuck also notes that such models are impossible to validate because it is not possible to find the model's processes that generated a given outcome (2006, p. 13). Moreover, a small error in the measurement of variables can have non-linear

effects and unpredictable outcomes. The epistemic uncertainty is thus about causality.

2.6.3. Managing uncertainty: the gardener's stance

The uncertainty represented in complex theorising is both incompleteness and ambiguity. The determination of how to manage uncertainty is not trivial, partly because ambiguity can have beneficial effects. First, it can enable collective action by numbing potential conflicts of interest (March, (1996). Then it can trigger exploration and learning. Hedberg, Nystrom, and Starbuck (1976) show that ambiguous authority structures, unclear objectives and contradictory responsibilities contribute to the questioning of traditions. Redundant tasks can be considered as replications of potentially instructive experiments. Internal debates triggered by ambiguity multiply occasions for questioning the environment. March also expresses the same idea referred to as the 'optimal clarity problem': accuracy articulates actions and performance more clearly, but kills creativity (March, 1979, p. 30). Finally, ambiguity reshuffles power and ideological influence to those who can make sense of ambiguous situations (Crozier & Friedberg, 1977). To sum up, ambiguity can contribute to organisations' persistence (March, (1996, p. 285). As a result, recommendations for managing uncertainty are difficult for complex theorising that describes systems for which the consequences stemming from a given action are hard to predict and ambiguity potentially beneficial.

A first series of recommendations consists of monitoring the trade-offs that the organisation maintains and fine-tuning them through successive self-adjustments in order to accelerate or decelerate organisational changes. For instance, Hedberg, Nystrom, and Starbuck (1976) recommend monitoring the degree of consensus, contentment, affluence, faith, consistency and rationality reflected in organisational processes.

A second series of recommendations concerns small actions focused on what can be influenced. They are inspired by some sort of organisational wisdom reflected by three aphorisms proposed by March. *Pessimism without despair* endeavours to perform small actions that limit nuisances and make the immediate environment less hostile. *Indifference without losing faith* seeks opportunities to change the course of events. *Optimism without hope for reward* pursues its ideal whatever the consequences (Weil, 2000, p. 159).

There is coherence between:

- theorising that tries to mirror the world's variety, and for which causality between series of events remains uncertain;
- uncertainty conceptualised as incompleteness and ambiguity; and
- the management of uncertainty by small actions and the monitoring of its consequences.

We borrow the term *gardener* from March and Olsen who used it to describe a good governor ((1989, p. 94). Weil describes this approach as follows:

> Because he cannot fully understand the complex causality relationships that govern social phenomenon and because he lacks means of action and control, the engineer is disarmed. The gardener accepts this powerlessness with respect to the forces of nature. However, he knows that he can seed at the right time, regularly uproot weeds, and adapt his watering to the sunshine. These mundane actions performed with consistency will increase the chances of fostering the emergence of a more beautiful, truer, fairer world. (Weil, 2000, p. 159)

This is the *gardener's stance*, a figure who takes action on the little things under his control, without expecting to control nature, and who contemplates the beauty of a world beyond his comprehension.

The three types of trade-offs between generality, simplicity and accuracy performed more or less implicitly by theories can be summarised with Weick's amused comment: 'Accurate-simple explanations say everything about nothing, general-simple explanations say nothing about everything, and general-accurate explanations say everything about everything but are unintelligible' (Weick, 1999, p. 801).

3. Uncertainty and the demand for high reliability

Uncertainty is obviously an issue for organisations that want to avoid catastrophic outcomes while having limited knowledge about their environment or themselves. Most theories pertaining to organisational reliability or resilience reflect one of the three archetypes suggested above. We review these theories and present their strengths and weaknesses.

3.1. The engineer's stance

Hollnagel (2004) suggests that accident models can be classified into three categories: sequential, epidemiological and systemic. The engineer's stance is characteristic of sequential models. The underlying idea is that accidents result from a sequence of events interlinked by causal relationships. The initial causes should be identified, eliminated or contained to prevent new accidents. This thinking prevails in root cause analyses, accident anatomy concepts (Green, 1988) or with the dominos model (Heinrich, 1931). These models are simple and accurate in Thorngate's sense. Their reach remains local because the reduction of accidents to a chain reaction ignores many variables that potentially impact organisational performance. For instance, these analyses lead to

revised procedures. The implementation of these revised procedures changes organisational actors, beyond what procedures require, as when people feel more confident about organisational knowledge after new rules are adopted. As a result, the organisation has changed and the applicability of the model that was forged with the former state of the organisation will not necessary hold.

The second category concerns epidemiological models. While they also reflect the engineer's stance, they contain some features of the craftsman that are noteworthy. These models are based on the analogy of the development of illnesses. The conceptual novelty resides in the introduction of latent errors or pathogen agents (Reason, 1987), describing the pre-existing conditions that made possible the sequence that led to the accident. They may concern the design, construction phase, organisational processes, training programme, communication channels, human-machine interface, etc. As a result, the focus on the relationship between latent factors and the immediate causes of the accidents brings us closer to the complexity of phenomenon than pure sequential models do. With this perspective, prevention efforts aim at:

– identifying and monitoring the conditions that foster the unwanted variability of performance; and
– implementing or re-enforcing barriers that mitigate or block the negative consequences of these variations (alarms, personal protection equipment, containment, supervision, safety briefings, etc.).

Despite the more refined description of reality brought on by the concept of latent factors, these models confront the principle of sequential models based on the propagation of effects from an initial point to an end point, with a causality direction (Hollnagel, 2004). However, they introduce some seeds of craftsmanship. They remain simple; the chain reactions are linear. But they lose the property of accuracy, as they become more difficult to specify in details (Hollnagel, 2004, p. 58). This is to the benefit of their evocative power that creatively opens some perspectives by the illness metaphor applied to analysis and prevention methods. If the medical metaphor reduces the ability to accurately specify the model, which repels the engineer, it in turn attracts the craftsman because it serves the generality of the tools at his disposal.

Nevertheless, epidemiological models remain inspired by the engineer's stance because their ambition is to predict and anticipate in advance the system's pathological conditions in order to mitigate them. The management of uncertainty boils down to the extension of the completeness of models.

When applied to reliability, Schulman (1993) summarises what we called the engineer's stance as follows:

Under one theory, reliability would stem from a constant, certain, predictable set of performances. All system conditions would be fully specified and anticipated. Term this the 'anticipatory model' of reliability – an approach that equates reliability to invariance. Here an organization ought to determine its functions, or at least strive to determine them, unambiguously and completely. Once 'correct' job performance is specified, it should be 'locked in' once and for all through formal procedures, unvaryingly applied. A unified chain of command guarantees swift action and preserves the 'perfect' model.

This description of analytical models shows that they aim to reduce uncertainty as much as possible by developing capacities to extend their knowledge. The difference between analytical models and other theorising comes from the fact that the latter considers uncertainty as irreducible. Unlike analytical models, other theorisations strive after generality and thus seek to produce descriptions that always hold. The price is that their models integrate uncertainty not as residual but as constituent. As a result, they address the question of its continuous management. For metaphoric theorising, uncertainty is managed by providing creative tools that help remove ambiguity. Complex theorising, reflecting the richness and variety of the world, manages uncertainty through self-assessments and appropriate self-adjustments.

3.2. The craftsman's stance

In his presentation of reliability models, Schulman describes a second perspective, which he observed in Diablo Canyon nuclear power plant and that presents many characteristics of the craftsman's stance:

A second approach to reliability is possible. Here reliability would be equated not with invariance but with resilience. Being responsive to, rather than trying to weed out, the unexpected would be the ultimate safeguard of stable performance. Despite the knowledge and elaborate procedures of an organization, its technology, it would be believed, is still capable of surprises. This expectation of surprise would not only be a state of mind, it would be recognized as an important organizational resource.

In order to manage unexpected situations, the best an organisation can do is to increase resources at the disposal of those who will deal with them. Among important resources stand behavioural and conceptual slack, i.e., diversity in action repertoires and analytical perspectives about the world. The idea is that organisations are better prepared when their reservoir of ideas and actions is large enough, so that people can

choose those that help them make sense of the situation at hand and recombine behaviours to improvise ad hoc solutions. We can note that this is a completely symmetric view with respect to the engineer's stance, from which sources of deviation from the 'perfect model' should be eliminated.

At least two theoretical streams borrow metaphoric models: high reliability organising (HRO) and the normal accident theory, often presented as being in conflict.

HRO provides tools, meta-theories, intended to help groups better enact and interpret the situations they are facing. For instance, HRO theorists bring to the foreground five principles that should increase the early detection of weak signals and the containment of errors: preoccupation with failure, reluctance to simplify, sensitivity to operations, deference to expertise and commitment to resilience (Weick, Sutcliffe, & Obstfeld, 1999). These principles should guide how people interact when making sense of what is going on. They are simple, ambiguous and creative.

Interestingly enough, Perrow's normal accident theory (Perrow, 1984) makes the same trade-offs. It highlights that accidents are ineluctable when systems have components that are tightly coupled and linked to one another in non-linear ways. The reasoning is straightforward: when an error happens in one of the components, it ramifies to other components (property of tight coupling), while people have difficulties understanding what is happening (property of complex integration) until the system fails. This theorising is relatively simple (if a system holds such properties, it will suffer a systemic accident) and general (it is true whatever the system). But it is not very precise because tight coupling and interactive complexity are hard to establish. For instance, these properties can be transient because a stressful situation degrades coordination, deteriorates the quality of interactions or distorts people's perceptions (Weick, 1990, p. 587). However this theory is creative because it incites organisational members to pay attention to tight couplings (between individuals or between technical or organisational components), the potential for interactive complexity and conditions fostering their emergence.

Metaphoric model users bet on creative ambiguity in order to set the group's intelligence in motion; the organisation and its members are the source of reliability. This strength is also their vulnerability, in that ambiguity can stop being creative and paralyse action (Weick, 1998) or lead to the collapse of meaning (Weick, 1993).

3.3. The gardener's stance

The third type of accident model proposed by Hollnagel is systemic. In this view, organisational accidents are emerging outcomes stemming from the combination of events, rather than resulting from a simple causal chain. It aims to model the dynamics of interactions and non-linear effects. It borrows the concept of latent factors from epidemiological theories in the form of the blunt end (vs. sharp end) analogy (Woods, Cook, & Sarter, 1994). According to this model, operators involved physically in risky processes are positioned at the sharp end of a lance, while people or factors affecting safety through indirect constraints such as social norms, management supervision, working conditions, etc. are positioned at the blunt end. An interesting change with respect to epidemiological models entails considering the variability of systems as irreducible and even necessary to organisational learning or systems' developments (Hollnagel, 2004, p. 64). We can note a similarity with March's complex theorising on the uncontrolled variability as exploration or controlled variability as exploitation (March, 1991). The disciples of these models will look for unusual dependencies and common operating conditions correlated to accidents, and will monitor and control the variability of subsystems' performance with the goal to distinguish between what is potentially useful and what is potentially dangerous. A large number of these models fall under the theoretical stream of resilience engineering. Its paradigm stands as follows:

> In Resilience Engineering failures do not stand for a breakdown or malfunctioning of normal system functions, but rather represent the converse of the adaptations necessary to cope with the real world complexity. Individuals and organizations must always adjust their performance to the current conditions; and because resources and time are finite it is inevitable that such adjustments are approximate. Success has been ascribed to the ability of groups, individuals, and organizations to anticipate the changing shape of risk before damage occurs; failure is simply the temporary or permanent absence of that. (http://www.resilience-engineering-association.org).

This perspective seeks to integrate the complexity of accident phenomenon and strives for accuracy in its implementation. For instance, the Functional Resonance Accident Model breaks down a system in functional units described by six parameters: input, output, preconditions, resources (energy, equipment, manpower, etc.), time and control (plans, procedures, guidelines, etc.). Each parameter of a given functional unit is potentially linked to the parameters of other units, reflecting the functions' interdependencies. This makes a complex network of interactions including feedback loops, that varying common working conditions excite (like an electrical system). Failure corresponds to the resonance in negative performance of one or several units (Hollnagel, 2004).

To sum up, complex theorising proposes complex models that attempt to mirror the variety of reality (Ashby, 1957; Weick, 1979). However, they create the same problems of prediction as in the real world. They tend to prescribe self-monitoring and continuous self-adjustments but remain vague about concrete action. Indeed, making adjustments on the basis of the distinction between what is potentially useful from what is potentially dangerous assumes a predictive capacity that complex system theory denies at the same time.

3.4. The case of organisations confronted with unexpected situations in high-tempo, high-risk settings

3.4.1. The obligation of generality

In turbulent, unpredictable environments, theories with only local reach, such as analytical models, are not very useful. Not only are their anticipations about the environment's future state rarely realised, but also the very processes of anticipating and training weaken their capacity for resilience. For instance, anticipating processes contribute to disturbing organisational members by increasing their stress when they discover that their routines do not work despite their training (Weick, 1990). They also encourage complacency by letting people think that all possibilities have been considered, leading to the late discovery of problems (Hedberg et al., 1976). These two phenomena illustrate the fact that predictions influence social reality (Merton, 1936; Starbuck et al., 1988) which can make these predictions either fail – which is a problem for organisations in dangerous settings – or succeed, as with self-fulfilling prophecies.

Analytical models lead to efforts to reduce the residual uncertainty but instead end up increasing it. This is not due to the model itself but to its use by social actors. As a result, we are left with metaphoric and complex models.

3.4.2. The obligation of action

Based on complex mapping, the gardener's stance consists of taking actions on the little things under his control in order to increase the likelihood of the occurrence of positive events, while also remaining aware that most active causes escape his reach. This attitude is not very promising for organisations with a high demand for reliability and looking for more than just increasing the likelihood of positive outcomes. It might be lucid but not very operational, echoing the problematic status of action inherent to this stance. The only theorisation left is metaphoric. In this perspective, uncertainty revolves around meaning, i.e., plausible causal maps of the situation. HRO seems to be the only candidate remaining. We do not imply that this theoretical stream is better

than the others, but the trade-offs made between accuracy, simplicity and generality address the problem posed by the demands of high reliability in high-tempo, dangerous and ambiguous situations.

We also can view the choice of the craftsman's stance and HRO from a slightly different angle by considering the risks taken by each theoretical stance. The risk of analytical models is overconfidence in acquired knowledge. This is potentially dangerous because it causes errors of diagnostic, complacency that reduces mindfulness, oversimplifications or escalation of commitment, etc. The symmetrical risk is born by complex models that could lead to an overcautiousness that minimises acquired knowledge and overestimates what remains to be known. Its main harm is that it can paralyse action. Metaphoric theorising seems more balanced. First, the ambiguity of meta-theories creates and maintains ambivalence with respect to one's knowledge; the ambiguity of its content manifests the fallibility of any knowledge. Then because ambiguity triggers creativity, metaphoric models provide conceptual tools to improvise, e.g., recombining parts of knowledge or action repertoires for new purposes, in order to meet situational demands. As a result, it gives the user a bit of confidence for action: what people know is limited, but can be sufficient to progress as long as they use what they know to improvise (Weick, 1998). This last remark might sound like an act of faith; it is a gamble, perhaps the only one that we can make. This is the distinctive feature of HRO theory which sees in organisations the source of high reliability, and not only the problem (Koenig, 2007).

4. The case of wildland firefighting

We wanted to test the idea that the craftsman stance was indeed the most appropriate in certain settings. We studied firefighting organisations, which were relevant to our question because they operate in high-tempo, turbulent environments where errors can become catastrophic for both civilians whose properties or lives are threatened or for firefighters themselves.

We conducted an explorative study of type 1 incident management teams, i.e., teams of 40–60 members in charge of the management of the largest and most complex emergency operations (in our case, wildland fires). We collected data through direct observations of training programmes and several weeks-long operations, archives (documents established during incidents such as Incident Action Plans (IAPs) or Complexity Analyses and training documents), interviews of Incident Management Team (IMT) members during and after operations, and interviews of 12 national experts involved in the annual type 1 team training and qualification process at the National Advanced Fire and Resource Institute.

Based on the features of sense-making processes (Weick, 1995a), our analysis sought to understand how firefighters made sense of their identity, how they enacted their world, what kind of resources they used to construct transient maps, the nature of these maps and what implicit theorising was active in these processes.

When the initial response to an incident fails, such as the initial attack on a wildland fire, the management of the situation is handed over to a group of specialised individuals that will structure the response and manage the various interdependent tasks related to the incident, such as operations, planning, logistics, finance, responders' safety and public information. This group is called an IMT. The Agency Administrator (in charge of managing the land where the fire started) sets general objectives for the Incident Commander (IC). These objectives often revolve around three themes: safety of firefighters and residents, containing the fire within geographic limits, and minimising suppression costs. The IC then validates the translation of these goals into operational objectives and tactics proposed by the operations section chief. The fire is divided into functional or geographic sectors (called divisions and branches) corresponding to three types of missions: direct attack, indirect attack and point protection (structures, businesses, infrastructures, etc.). Within this framework, each division supervisor or branch director assesses his needs and required resources to carry out the mission.

Since our perspective is sense-making, we present a brief description of four variables that strongly influence sense-making processes in IMTs: action principles, places of organisational influence, planning process and the nature of interactions.

4.1. Action principles

IMTs consider themselves as high-level, highly skilled emergency professionals, capable of managing complex situations by rigorously implementing procedures; they 'bring order to chaos'.

4.2. Command

IMTs are fundamentally decentralised. The structuring of command that accompanies the growth of the organisation is bottom-up. If too numerous, divisions are 'branched', i.e., grouped under the supervision of a branch director. However, the unit of analysis for fire tactics remains the division.

4.3. The planning process

The planning process is distributed and extremely codified. The day is divided in one or several operational periods. The incident management processes set regular pre-defined meeting times within the operational period and designate the participants to these meetings that enable them to collect information, review tactics and objectives, set operational tasks, give briefings, etc. Plans are documented in the IAP. In large and complex fires, assignments are loosely integrated and under-specified, and the plan exists more as a guide for situated action.

4.4. Interactions within teams

The format of interactions is long, rare and free. Interactions allow for rich discussions on the developing situation. As for content, they include exchanges about items or hypotheses at the origin of the current situation. This makes it easier to reconstruct a more accurate and plausible picture if needed. The exchanges unfold between two individuals who bring and indirectly contribute their personal experience. In that sense, they are intersubjective.

How do firefighters enact their world, how do they think about uncertainty, and what kind of theorising is implicit? Interestingly enough, two types of theorising are simultaneously present in the firefighting organisations we observed.

4.5. The engineer's analytical theorising

The Incident Command System (ICS) governs most of firefighters' principles for actions. It consists of rules, standard operating procedures, the specification of functions, various types of resources, training and qualification programmes, etc. Designed to be accurate and unambiguous, it was put in place as a national standard to enable multiple agencies to work together with the same language and processes. Firefighters are trained to work with others who have this mindset of being explicit and accurate, one of the characteristics of the engineer's stance.

When we reviewed the analytical theorising, we observed its tendency to increasingly refine knowledge into narrower and narrower fields, i.e., its tendency to specialise. We find the same orientation in firefighters' organisations: functions and their associated training and qualification processes are extremely specialised. With specialised knowledge, uncertainty lies in the interfacing, in the 'space between' (Madsen, Desai, Roberts, & Wong, 2006). Within firefighting organisations, people tend to simplify their analysis when sharing with other functions and therefore create areas of ambiguity, for instance during strategy meetings or planning meetings. We found another feature in line with this tendency of refining knowledge into a narrower field: in order to enlarge the overall domain of validity of the prescriptions, organisations tend to overlap rules, each one being relevant in their small field of

application. As a pure application of this dynamic, there are 48 rules that firefighters should comply with when engaging a fire. Proliferation of rules, synergetic with highly specialised knowledge, has been making procedural and safety rules more and more complex. Managing uncertainty by an inflation of rules is typical of the engineer's stance. Another typical feature is the emphasis on accountability and control, keeping in mind that prediction and control are the ambition of analytical theorising. The agency administrator sets his objectives for the IMT based on the wildland fire situation analysis. The analysis in turn is based on the assessment of the probability of success of each tactical option as well as of fire suppression costs and gains (natural resources and structures saved). Once the objectives are set, the agency administrator signs a delegation of authority to the IC who will countersign each day to confirm his acceptance. The IC then develops the incident objectives that cascade throughout the entire organisation. They are monitored and controlled according to the principle of management by objectives. This is naturally designed to be able to steer the organisation, but it also reinforces the anticipatory reliability principle (typical of the engineer's stance) according to which the chain of command suppresses organisational slack, for instance by limiting deviations from the objectives, Standard Operating Procedures, etc.

4.6. The gardener's complex theorising

There is the strong belief that fire is potentially extremely dangerous, always capable of surprises, and that the fire behaviour is beyond our full understanding and control. Note the similarity to the gardener's idea that most active causes escape his reach. This conviction is exemplified in the Lookout, Communication, Escape route, Safety zone (LCES) routine: every team engaging a fire should obey the rule by providing a lookout who will monitor the fire, maintain communication between the lookout and the rest of the team, and pre-identify escape routes and safety zones. The LCES routine says that people can trust the ability of a crew to control the situation (by monitoring the fire and providing safety) but to distrust it as well because the fire is still capable of surprise and a swift retreat may be necessary. We find another instance with the last of the 10 firefighting orders: 'Fight fire aggressively, having provided for safety first'. This implies that firefighters should fully engage in action, but that such an engagement can be dangerous. As a result, assignments are usually underspecified, such as 'construct a line from A to B' without mention of duration. And a large autonomy is given to teams in divisions with the underlying idea that they will do their best in unpredictable local environments.

In large and complex fires, people do not try to build time-sensitive integrated tactics. They leave such big

schemes for the search of opportunistic actions, allowed by changes in conditions (terrain, weather, etc.), with the idea that the sum of these actions will simplify and improve the overall situation.

Firefighters take actions that reflect a complex view of the world. They act as a gardener to change the 'little' things under their control and to increase the likelihood of the occurrence of positive events, while at the same time remaining aware that most active causes escape their reach. In fact, some experts in wildland fires do not hesitate to include the 'management of stakeholders' expectations' in their assessment of successful fire suppression.

4.7. To sum up our analysis, firefighters think as engineers and act as gardeners

We suggest interpreting this result as follows. The engineer's stance leads members to feel that the system they are part of is trustworthy and will be able to handle the situation. We met many people who talked about 'the beauty of the ICS'; the trust is not only given to the formal system (the ICS) but also to the staff, leading to an attitude that can be described as a presumption of logic (Meyer & Rowan, 1977). This means that people interpret others' action as necessarily relevant. It is exemplified in IMTs by the tacit norm 'no news is good news' or their identity of highly skilled emergency professionals. This presumption of logic becomes a presumption of control that gives people sufficient confidence to act. Interestingly enough, when they do, they behave as cautious gardeners, opportunistically acting on things under their control, fully aware that they are not totally in control. We suggest that this organisational dynamic enables people to operate simultaneously with confidence and cautiousness.

When considered at the organisational level, the simultaneous enactments of interconnected maps should result in the continuous ability to meet situational demand. As a result, the subsequent organisational theorising should hold the properties of generality and complexity (in the sense of requisite variety). In the case of fire organisations, each member enacts a complex map. Simple, accurate ICS processes link all these maps. Consequently, they constitute a system that is complex and general. Note that another alternative was possible: each member enacting metaphoric maps, all interconnected through an interaction pattern that makes the emerging system complex. And because metaphoric theorising is general, the resulting system is also general and complex. This pattern was observed by Weick and Roberts (1993) in their analysis of aircraft carriers' high reliability.

Our interpretation also helps to understand why the introduction of HRO principles in parts of firefighting training programmes, which was initially received with

very positive feedback, starts to be the object of some scepticism. First, HRO encourages organisational slack: more decentralisation, more autonomy of lower levels and more alternative ideas about how to handle things. As a result, the presumption logic and control is undermined. This can result in a loss of confidence in the system throughout the organisation, destabilising the confidence–cautiousness balance. There is yet another reason: paradoxically, there might be a loss in variety at the organisation level. ICS processes drive the connection pattern between HRO-based maps. But they need to be enacted differently to form a complex system. For instance, collective moments (such as tactics meetings or planning meetings) should include more debate and discussion of alternatives. Because this is not always the case, an oversimplified connection pattern results in an oversimplified organisational action pattern.

5. Conclusion

In this article, we suggested three types of processes to map and manage the world's uncertainty, considered as lack of information or excess of plausible interpretations. We called them the engineer, craftsman and gardener's stances. Accident theories can be categorised according to these stances, i.e., their view about uncertainty. At the group level, it seemed relevant to prefer the craftsman's stance because of the obligations for action and generality in dangerous and/or high-tempo environments. More broadly, it seemed that a balance between confidence and cautiousness could be successfully reached by metaphoric sense-making. The observation of incident management teams showed that this balance could be stricken differently at the organisational level. We found the simultaneous presence of analytical and complex theorising, and that this mix enables the emergence of complex and general maps and enactments at the organisational level and a satisfying confidence–cautiousness balance.

How could this translate into recommendations? Note that Thorngate's insight applies to our own discourse. As a result, our recommendations would either be too local, ambiguous or vague about actions to take. A possible way of breaking this recursive uncertainty might be to consider this article as a set of ideas that change agents should develop and exploit simultaneously through different stances. For instance, some could *engineer* change by identifying the dominant individual stances and design the appropriate organisational pattern that would lead to an emerging system that is complex and general. Others could train organisational members to *craft* the world of uncertainly with these ideas in order to help them creatively find meaningful actions for each specific situation. Finally, others would *garden* the balance between confidence and cautiousness. For instance, if people tend to get overconfident, they would either introduce confidence-mitigating or cautiousness-enhancing processes.

References

Ashby, W.R. (1957), *An Introduction to Cybernetics*, Chapman & Hall Ltd, London.

Bruner, J.S. (1973), *Beyond the Information Given*, Norton, New York.

Buckley, W. (1968), 'Society as a Complex Adaptive system', in Buckley, W.F. (ed.), *Modern Systems Research for the Behavioral Scientist*, Aldine Publ. Co., Chicago, IL, pp. 490–513.

Cohen, M., March, J.G. and Olsen, J.P. (1972), 'A Garbage Can Model of Organizational Choice', *Administrative Science Quarterly*, Volume 17, Number 1, pp. 1–25.

Crozier, M. and Friedberg, E. (1977), *L'acteur et le système: les contraintes de l'action collective* (Seuil.), Paris.

Eisenhardt, K.M. (1989), 'Agency Theory: An Assessment and Review', *The Academy of Management Review*, Volume 14, Number 1, p. 57.

Green, A.E. (1988), 'Human Factors in Industrial Risk Assessment – Some Early Work', in Goodstein, L.P., Andersen, H.B. and Olsen, S.E. (eds), *Task, Errors and Mental Models*, Taylor and Francis, London, UK, pp. 193–208.

Hedberg, B.L.T., Nystrom, P.C. and Starbuck, W.H. (1976), 'Camping on Seesaws: Prescriptions for a Self-Designing Organization', *Administrative Science Quarterly*, Volume 21, pp. 41–65.

Heinrich, H.W. (1931), *Industrial Accident Prevention*, McGraw-Hill, New York.

Hollnagel, E. (2004), *Barriers and Accident Prevention*, Ashgate Publishing Ltd, Aldershot, UK, p. 226.

Koenig, G. (2007), HRO International Conference – Deauville, 2007. In *Karlene Roberts, l'exigence de fiabilité*.

Madsen, P., Desai, V., Roberts, K.H. and Wong, D. (2006), 'Mitigating Hazards through Continuing Design: The Birth and Evolution of a Pediatric Intensive Care Unit', *Organization Science*, Volume 17, Number 2, pp. 239–248.

March, J.G. (1979), 'Ambiguity and the Engineering of Choice', *International Studies of Management & Organization*, Volume 9, Number 3, pp. 9–39.

March, J.G. (1991), 'Exploration and Exploitation in Organizational Learning', *Organization Science*, Volume 2, Number 1, pp. 71–87.

March, J.G. (1996), 'Continuity and Change in Theories of Organizational Action', *Administrative Science Quarterly*, Volume 41, Number 2, pp. 278–287.

March, J.G. and Olsen, J.P. (1989). *Rediscovering Institutions: The Organizational Basis of Politics*, New York: Free Press.

March, J.G., Sproull, L. and Tamuz, M. (1991), 'Learning from Samples of One or Fewer', *Organization Science*, Volume 2, Number 1, pp. 1–13.

Merton, R. (1936), 'The Unanticipated Consequences of Purposive Social Action', *American Sociological Review*, Volume 1, Number 6, pp. 894–904.

Meyer, J.W. and Rowan, B. (1977), 'Institutionalized Organizations: Formal Structure as Myth and Ceremony', *American Journal of Sociology*, Volume 83, pp. 340–363.

Perrow, C. (1984), *Normal Accidents: Living with High-Risk Technologies*, Princeton University Press, Princeton, NJ, p. 451.

Reason, J. (1987), 'An Interactionist's View of System Pathology', in Wise, J. and Debons, A. (eds), *Information Systems: Failure Analysis*, Springer-Verlag, Berlin, pp. 211–220.

Schulman, P.R. (1993), 'The Negotiated Order of Organizational Reliability', *Administration and Society*, Volume 25, Number 3, pp. 353–372.

Starbuck, W.H. (2006), *The Production of Knowledge*, Oxford University Press Inc, New York, p. 1994.

Starbuck, W.H. and Milliken, F.J. (1988), 'Executives' Perceptual Filters: What They Notice and How They Make Sense', in Hambrick, D.C. (ed.), *The Executive Effect: Concepts and Methods for Studying Top Managers*, JAI Press, Greenwich, CT, pp. 35–65.

Thorngate, W. (1976), 'Possible Limits on a Science of Social Behavior', in Strickland, J.H., Aboud, F.E. and Gergen, K.J. (eds), *Social Psychology in Transition*, Plenum, New York, pp. 121–139.

Weick, K.E. (1979), *The Social Psychology of Organizing*, Addison-Wesley Pub. Co., Reading, MA, p. 294.

Weick, K.E. (1989), 'Theory Construction as Disciplined Imagination', *Academy of Management Review*, Volume 14, Number 4, pp. 514–531.

Weick, K.E. (1990), 'The Vulnerable System: An Analysis of the Tenerife air Disaster', *Journal of Management*, Volume 16, Number 3, pp. 571–593.

Weick, K.E. (1993), 'The Collapse of Sensemaking in Organizations: The Mann Gulch Disaster', *Administrative Science Quarterly*, Volume 38, pp. 628–652.

Weick, K.E. (1995a), *Sensemaking in Organizations*, Vol. 38, Sage Publications Inc, Thousand Oaks, CA, p. 237.

Weick, K.E. (1995b), 'What Theory Is Not, Theorizing Is', *Administrative Science Quarterly*, Volume 40, pp. 385–390.

Weick, K.E. (1998), 'The Attitude of Wisdom: Ambivalence as the Optimal Compromise', in Srivastva, S. and Cooperrider, D.L. (eds), *Organizational Wisdom and Executive Coverage*, Lexington, San Francisco, CA, pp. 40–64.

Weick, K.E. (1999), 'Conclusion: Theory Construction as Disciplined Reflexivity: Tradeoffs in the 90s', *The Academy of Management Review*, Volume 24, Number 4, p. 797.

Weick, K.E. (2000), 'Sources of Order in Underorganized Systems: Themes in Recent Organizational Theory', in Weick, K.E. (ed.), *Making Sense of the Organization*, Blackwell Publishing, Malden, MA, pp. 32–56.

Weick, K.E. and Roberts, K.H. (1993), 'Collective Mind in Organizations: Heedful Interrelating on Flight Decks', *Administrative Science Quarterly*, Volume 38, pp. 357–381.

Weick, K.E., Sutcliffe, K.M. and Obstfeld, D. (1999), 'Organizing for High Reliability', *Research in Organizational Behaviour*, Volume 21, pp. 81–123.

Weil, T. (2000), *Invitation à la lecture de James March*, Les Presses de l'Ecole des Mines, Paris, p. 180.

Woods, D.D., Cook, R.I. and Sarter, B.N. (1994), *Behind Human Error: Cognitive Systems, Computers and Hindsight*, CSERIAC, Columbus, OH.

Ambiguity as Grasp: The Reworking of Sense

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Ambiguity may lead us to insert abstractions into our experience that create a greater number of unanticipated, unintended consequences. When people move closer to the flux of ambiguity, they work to make sense of it. High reliability organizations react to ambiguity by increasing it momentarily. To increase ambiguity is to grasp more of the situation, to refrain from simplifications, and to strive for a workable level of ambiguity. This argument is developed through a focus on connotations of ambiguity, assumptions for organizing around ambiguity, and implications for practice. To grasp ambiguity is to adopt an attitude of wisdom.

To trace something unknown back to something known is alleviating, soothing, gratifying and gives moreover a feeling of power. Danger, disquiet, anxiety attend the unknown – the first instinct is to eliminate these distressing states. First principle: any explanation is better than none. . . . The first idea which explains that the unknown is in fact the known does so much good that one "holds it for true" (Nietzsche, 1968, p. 51; cited in Lagadec, 2010, p. 3).

We mistake the change of a feeling of doubt into a feeling of assurance as knowledge (Bacon, 2012, p. 54).

1. Introduction

There are at least two answers to the question, 'how do organizations react to ambiguity'. First, faced with ambiguous information, organizations tend to reach for assurance in what they already know. Second, they may act *within* ambiguity and deepen it momentarily, accepting that it is malleable, chronic, disrupting and unsettling. The second possibility is the topic of this article. The second possibility is an implied subtext in ongoing work on high reliability organizing.

High reliability organizations react to ambiguity by increasing it momentarily. This occurs when they pay more attention to discrepancies, complications, details and ignorance, all in an effort to sustain ongoing projects. To increase ambiguity is to grasp more of the situation. Ambiguity is not about solving puzzles where all the pieces lie on the table awaiting rearrangement. Instead, to 'grasp' ambiguity is to comprehend it adequately, to simplify it self-consciously and to accept that the simplification is fleeting, incomplete and will fail. To grasp ambiguity is to refrain from the simplifications inherent in types, categories, stereotypes and habits. Instead, one settles for a workable level of ambiguity, but no more. To grasp ambiguity is to impose a plausible next step, but then to treat plausibility as both transient and as something compounded of knowledge and ignorance. Grasp is the acceptance that behind ambiguity lies more ambiguity, not clarity. It is the realization that clarity is costly because it discards so much potential information. And it is the realization that progress produces complication rather than resolution. In Rachel Halliburton's (2002) words, 'Clarification should not be confused with simplification'.

To develop this argument, I first review several connotations of the word 'ambiguity' so that we have a

better grasp of what the 'it' is to which organizations are responding and what the 'who' is that is doing the responding. Second, I propose four assumptions about organizing that influence our understanding of how dynamic organizations react to ambiguity. Third, I conclude with implications for acting with ambiguity to ambiguity.

2. Connotations of the word 'ambiguity'

Traditionally, the word 'ambiguity' means that events are open to more than one interpretation (American Heritage Dictionary, 1992, p. 56), a meaning that is suited for organizations since they are sites for multiple meanings of contested issues. These contested issues are based on plausible but different interpretations, doubts and uncertainties. Mary Douglas (2002, p. 47) begins to refine our thinking when she contrasts 'ambiguity' with 'anomaly' and describes ambiguity as 'a statement capable of two interpretations' and an anomaly as 'an element that does not fit a set or series'. Ambiguity connotes reliability that can be threatened in one of two ways, either by multiple plots that are imposed on an unfolding sequence or by an error of omission or commission that disrupts a sequence.

Example: The stuck semaphore

On October 22, 1979, 5 people were killed and 51 were injured in Invergowrie Scotland when a passenger train traveling at 60 mph slammed into a stopped passenger train in front of it. The semaphore signal that was supposed to signal the speeding train to stop 'was raised above the horizontal by at least 6 degrees but by not more than 10 degrees: in such a position it should have been taken to be an imperfectly exhibited signal and thus treated as at Danger, but for some reason the train driver passed the signal and continued into the occupied section' (Report on the Collision that occurred on 22nd October 1979 at Invergowrie in the Scottish region British Railways, Her Majesty's Stationery Office, January 16, 1981, p. 10). It was concluded that since the signal was at an angle *between* proceed and stop, and closer to proceed, the driver interpreted it as proceed and drove into the rear of the stopped train just around a bend.

'Uncertainty' is perhaps the most common synonym for ambiguity. But uncertainty differs because it also tends to imply something more general and less forceful. Uncertainty 'denotes a lack of assurance or conviction' (American Heritage Dictionary, 1992, p. 1872). Information that is 'uncertain' 'may range from a mere falling short [of certainty] to an almost complete lack of

knowledge or conviction especially about the result or outcome of something' (Merriam-Webster, 1984, p. 841).

Example: Escape fire

At Mann Gulch, foreman Wagner Dodge tried to save his crew from a fire blow-up that was coming right at them, by burning grass off the ground in front of them. This would burn a hole in the fire where his crew could lie down. That way the fire would burn around them, not over them. Only Dodge understood what he was doing. The rest of the crew didn't. Their interpretation was that Dodge had gone crazy since he was lighting a fire right in the middle of their escape route. The combination of high wind, fire behind and in front of them, slippery steep terrain, tools that had been dropped farther down the hill, and a person yelling 'to hell with that, I'm getting out of here' conveys confused desperation and neither assurance nor conviction.

People who study sensemaking often refer to ambiguous events as 'equivocal', by which they mean an event is of uncertain significance and open to two or more interpretations. For example, some ancients argued that the sun revolved around the earth (geocentric) while others claimed the earth revolved around the sun (heliocentric). The elements were the same, but the interpretations were different. A straightforward example of an equivocal event is one that is interpreted as *both* similar to and different from previous experience and therefore of uncertain significance.

Example: 'Considerable' avalanche danger in backcountry skiing

The loss of three lives in a backcountry avalanche at Tunnel Creek, on the backside of Cowboy Mountain, 75 miles east of Seattle, was preceded by an avalanche warning that was the most equivocal of the 5 degrees of warning possible. The warning level of 3, labeled 'considerable,' means 'Natural avalanches possible. Human triggered avalanches probable. Be increasingly cautious in steeper terrain' (Tremper, 2008, pp. 304–5). As one member of the skiing party put it, 'I was uneasy about the "considerable" danger of an avalanche but didn't speak up' (Michelson, 2012). True, the specific warning urged 'caution,' but the 16 people in the backcountry ski party were all experienced skiers and the warning was of 'uncertain significance'. It was both a warning and a challenge. What was rendered dangerously insignificant by this equivocal warning were additional red flags such as new snow, a proposed trail that was actually a gully that consolidated snow movements, a group

composed of 16 people which is 12 more than the recommended size of 4, a general forecast of avalanche danger, the proposed skiing area marked as 'off limits,' and confident locals who were eager to demonstrate their prowess on this slope.

A different meaning of the word ambiguity is captured by the word 'crucible'. A crucible is a severe test, 'a place, time, or situation characterized by a confluence of powerful intellectual, social, economic or political forces' (American Heritage Dictionary, 1992, p. 448). A compact use of the word is Taylor and Van Every's statement that organization is realized 'in the crucible of the quotidian' (2000, preface, p. x), which, for the rest of us, means organization is realized in the daily tests (conversations) at work, tests that come at us from all directions, with multiple meanings and with incessant demands for prioritization. As Robert Chia (2005) puts it, 'Managing is firstly and fundamentally the task of becoming aware, attending to, sorting out, and prioritizing an inherently messy, fluxing, chaotic world of competing demands that are placed on a manager's attention' (p. 1092).

Example: Confusion in a railyard

A northbound train, the Silver Star, was stopped at the station at Hamlet, North Carolina. The last car on the train was business car number 310, where the executives were eating breakfast. The radio in the business car had been switched to the yard radio channel while the train was being serviced. A brakeman in the nearby railyard, not knowing that the transmission button on his radio was stuck in the 'On' position, yelled, 'Hell! Stop the movement, hold on a second dammit. I'm all screwed up'. Grabbing the radio handset on board the business car, the startled vice president of Seaboard Coast Line Railroad identified himself and demanded the offending party immediately reciprocate, to which came the reply, 'I may be all screwed up, but I ain't that screwed up!' (Riddell, 1999, p. 81).

In the context of organization and organizing, ambiguity is sometimes treated as the relaxation of order. The image is from Chia (1999, p. 225). 'Organization. . . . [is a] reality-maintaining activity which stabilizes the "real" sufficiently for us to act purposefully in response to a deluge of competing and attention-seeking external stimuli. . . . (M)erely relaxing the deeply entrenched organizational and institutional habits, which keep "organizations" together and which enable them to be thought of as "thing-like", is itself sufficient to allow change to occur of its own volition'. This 'change' is often experienced as ambiguity. The relaxation of reality-maintaining activity is evident in the following tragedy.

Example: Friendly Fire

After the Gulf War, on April 14, 1994, twenty six people were killed by friendly fire when two friendly helicopters were shot down by two US Air Force F-15 fighters during peace-keeping operations. The F-15 pilots mistook the two US helicopters for Russian Hinds helicopters. A crew of 19 Air Force officers in an AWACs aircraft that was monitoring and controlling all 4 aircraft, did nothing to stop the shoot down. 'The Hind was constructed in his [lead F-15 pilot] mind's eye at the intersection of a sufficiently ambiguous stimulus, a strong set of expectations, and a perverse desire to see an enemy target' (Snook, 2000, p. 76).

It is also possible to view ambiguity as a stage in the process of how understanding develops across time. William Schutz (1979) proposed that understanding passes through three stages: superficial simplicity, confused complexity, profound simplicity. In the beginning, our ideas have a flavour of *superficial simplicity*. We all have our favourite High Reliability Organization slogans (e.g., keep it simple stupid), swift diagnoses (e.g., there is too much theory), standard remedies (e.g., we need another rule), and automatic simplifications (e.g., it is operator error). Gradually, we become aware of exceptions to the simplifications and our understanding becomes more *complex and confused*. This is progress because we are trying to grasp a broader range of inputs than was true before. Having worked within confusion and having used it as a pretext to rework ideas, we then may find *profound simplifications* that are now more meaningful than they were originally. For example, out of confusion may come simplicities such as 'nothing is permanent', 'hubris lowers reliability', 'complication improves simplification' or 'capability controls awareness'.

Example: Novice brakeman develops understanding.

Bob, an old-hand as a railroad brakeman, was training a new man on the job and instructed the novice to 'Do everything I do'. The train they were working had passed by a siding and was 'backing into the siding so that an oncoming train loaded with servicemen could pass. Bob lined the switch and was swinging his lantern to give the circular back-up sign [to the engineer] when the handle snapped off and the globe flew into the woods. The cubbing brakie did just as Bob told him, making the circular motion twice and letting his own lantern fly. Hurriedly grabbing a fusee, Bob then frantically taught him the hand signal to get the engineer to stop the oncoming train' (Riddell, 1999, p. 79).

3. Assumptions

Assumptions make a difference in how one organizes to deal with ambiguity. To 'grasp' ambiguity is to organize, mindful of at least four constraints. Organizing itself is

1.   Always ambiguous.
2.   Always a substitution.
3.   Always interrupted.
4.   Always relational.

3.1. Always ambiguous

William James (1987, p. 782) described the 'original' ambiguity, captured by sense and feeling, that is temporarily obscured by layers of imposed concepts, strategies and tactics. 'Pure experience in this state is but another name for feeling or sensation. But the flux of it no sooner comes than it tends to fill itself with emphases, and these salient parts become identified and fixed and abstracted; so that experience now flows as if shot through with adjectives and nouns and prepositions and conjunctions'. Substituting emphases and abstractions, as we will see below, creates a greater number of unanticipated, unintended consequences. This is why people have to be aware and mindful of what any concept excludes and of the words used to abstract portions of the flow.

It is easy to conclude that this move from flux to 'active condensation' (Irwin, 1977, p. 26) is rare and has little to do with ambiguity. However, the transformation is more common and less stable than we think. Moments of accomplishment also tend to be moments of complication. As John Dewey's puts it, each achievement settles something. But, 'from the side of what comes after, it complicates, introducing new problems and unsettling factors. There is something pitifully juvenile in the idea that "evolution," progress, means a definite amount of accomplishment which will forever stay done' (Dewey, 1922, p. 285).

We have no choice but to work within ambiguity, so how we rework that ambiguity is what matters.

3.2. Always a substitution

William James (1987, p. 1008) is famous for this sentence 'If my reader can succeed in abstracting from all conceptual interpretation and *lapse back* into his immediate sensible life at this very moment, he will find it to be what someone has called a big, blooming buzzing, confusion, as free from contradiction in its "much-at-onceness" as it is all alive and evidently there'. This is the constant ambiguity mentioned in assumption 1. What is less well known is that a few sentences later he makes the more crucial point that '*The intellectual life of man consists in his substitution of a conceptual order for the perceptual order in which his experience originally comes*'

(James, 1987, pp. 1008–9, italics in original). We do not realize how much we ignore, but we realize it when projects are interrupted and structures break down. What we then see are failed substitutions that previously concealed ambiguity that was always there.

3.3. Always interrupted

Expectations and project are the locales and names for most of the reality-maintaining work of organizing. This suggests that better management is 'mindful when it is aware of its own expectations, the limited horizon of these expectations, and the need for ongoing corrections' (Czarniawska, 2005, p. 271). Awareness of expectations often increases both when projects are disrupted and when components of the disruption become the object of attention. 'In every waking moment, the complete balance of the organism and its environment is constantly interfered with and as constantly restored. . . . Life is interruptions and recoveries. . . . At these moments of a shifting of activity, *conscious feeling and thought arise and are accentuated*' (Dewey, 1922, pp. 178–179, italics added).

An interruption does not generate a cool abstraction. Instead, it generates a 'charged thought'. As Sid Winter argues, organizational action is not choice points and cost benefit analysis. Instead, deliberation occurs in response to 'the stimulus provided by the experienced frustration and perceived inadequacy of existing habitual responses' (Winter, 2013, p. 129). When emotions are engaged by a task, but established habits are insufficient to accomplish it, interruption becomes a generative trigger for learning (see Barton & Sutcliffe, 2009). In effect, habits are turned inside out. And the participant reworks the past, present and future into a more adaptive next step.

What is important for our understanding of ambiguity are indications that ambiguity takes the form of habits turned inside out which reveals their histories and their futures. That more complex picture generates a new framework to deal with the interruption. And whatever framework does temporarily structure the interruption, still remains a substitution that glosses over 'blooming, buzzing confusion'.

3.4. Always relational

An organization is not the individual writ large, but the individual is a group writ small. 'Each individual carries those parts of the collective knowledge that makes possible individual action with regard to organizational concerns' (Cook & Yanow, 1993, p. 385).

One way to think about the individual as a 'group writ small' is to propose that organization emerges in communication. Taylor and Van Every (2000) argue that conversation is the *site* for organizational emergence

and language is the textual *surface* from which organization is read. Thus, organizations are talked into existence locally, and are read from the language produced there, which can generate clarity as well as ambiguity. The intertwining of text and conversation turns flux into a situation that is comprehensible and that can then serve as a springboard for action.

If we pull back from individual conversations and adopt a more macro view, the organization remains conversational. Taylor et al. (2000) portray such an organization as a network of multiple, overlapping, loosely connected conversations, spread across time and distance [that] collectively preserves patterns of understanding that are more complicated than any one node can reproduce. The distributed organization literally does not know what it knows until specific actors articulate it. This ongoing articulation gives voice to the collectivity and enables interconnected conversations and conversationalists to see what they have said, to understand what it might mean, to learn who they might be and potentially to say things differently with different effects.

For an organization to act, 'its knowledge must undergo two transformations: (1) it has to be textualized [think conceptual substitution] so that it becomes a unique representation of the otherwise multiply distributed understandings [think ambiguity]; (2) it has to be voiced by someone who speaks on behalf of the network [think individual with "organizational concerns"] and its knowledge' (Taylor et al., 2000, p. 243). Communication, language, talk, conversation and interaction are crucial sites in organizing around ambiguity. Familiar phrases in talk related to crises, phrases such as 'Drop your tools' at Mann Gulch wildland fire, 'We are at takeoff' in the Tenerife Air disaster, 'If I don't know about it, it isn't happening' uttered by paediatricians before child abuse was discovered, 'This virus looks like St. Louis Encephalitis' when West Nile virus was misdiagnosed, 'Our pediatric heart cases are unusually complex' when Bristol Royal Infirmary's death rate was highest in UK, 'These fingerprints are a close enough match to the prints at the Madrid commuter train bombing' from FBI laboratory, 'That odor is bug spray' when odor was actually lethal gas escaping at Bhopal, all of these represent textual surfaces constructed at conversational sites where people made sense of prior actions in ways that constrained and normalized subsequent actions.

4. The practice of managing ambiguity

To move towards practice in the face of ambiguity, we first get our bearings from Todd LaPorte. 'We must act when we cannot foresee consequences; we must plan when we cannot know; we must organize when we cannot control' (La Porte, 1975, p. 345). With these

imperatives in mind, the earlier arguments suggest the following as a framework for grasping ambiguity:

1. Every experience counts.
2. Every experience can be deepened.
3. Every experience is sifted conceptually.
4. Every experience 'makes' sense.
5. Every experience is composed of wary improvisation.

4.1. Every experience counts

Every experience modifies the experiencer, which means every experience counts. John Dewey makes this abundantly clear in his notion of the continuity of experience. 'The basic characteristic of habit is that every experience enacted and undergone modifies the one who acts and undergoes, while this modification affects, whether we wish it or not, the quality of subsequent experience. For it is a somewhat different person who enters into them . . . (T)he principle of continuity of experience means that every experience both takes up something from those which have gone before and modifies in some way the quality of those which come after' (Dewey, 1997, p. 35). The person you are when you wade into ambiguity is modified by that experience. Therefore, when you encounter what looks like the same event in the future, it is not the same because you are not the same.

4.2. Every experience can be deepened

If you accept the assumption of continuity of experience, then there is a clear imperative for action: so act as to increase the meaning of present experience. 'Progress means increase of present meaning, which involves. . . . complication and extension of the significance found within experience. . . . If we wished to transmute this generalization into a categorical imperative we should say: "So act as to increase the meaning of present experience. . . . (S)tudy the needs and alternative possibilities lying within a unique and localized situation" (Dewey, 2002, p. 283).

4.3. Every experience is sifted conceptually

To gain a clearer picture of what is implied and what is left out when one strives to grasp ambiguity, visualize your efforts as similar to working with a sieve, a utensil with a mesh filter that catches substances that have some set pattern but allows all other patterns to fall through and pile up below. The ideas that we use to keep from being overwhelmed by ambiguity constitute the mesh. 'A conceptual scheme is a sieve' (James, 1981, p. 455). 'The result of the thoughts' operating on the data given to sense is to transform the order in which

experience *comes* into an entirely different order that of the *conceived* world. . . . The conceptual scheme is a sort of sieve in which we try to gather up the world's contents. Most facts and relations fall through its meshes, being either too subtle or too insignificant to be fixed in any conception. But whenever a physical reality is caught and identified as the same with something already conceived, it remains on the sieve, and all the predicates and relations of the conception with which it is identified becomes its predicates and relations too; it is subjected to the sieve's network, in other words'.

A good example of sifting is NASA's reaction to foam-shedding 82 seconds into the disastrous flight of the Columbia space shuttle. They labelled the shedding 'almost in-family', which meant that the shedding was treated as 'a reportable problem that was previously experienced, analyzed, and understood' (CAIB, 2003, p. 122).

That labelling was convenient, it could be fitted to pre-existing predicates and relations. But the labeling was wrong. The puff of smoke was treated as a familiar nuisance that could be fixed back on the ground. It is as if the puff was caught on the mesh of a sieve, linked to prevailing predicates and relations, and the more complete contextual data were treated as insignificant and too subtle for further attention.

To organize more mindfully in the face of ambiguity is to do the equivalent of changing the mesh of the sieve, re-examining facts and relations that fall through, and doubting that they are as subtle or insignificant as first thought. As we have argued, abstractions are abridgements of concrete flux. As we pay more attention to the *seemingly* subtle and insignificant, we experience more ambiguity. What is striking in all of this is that we are actually moving *closer* to the flux that was there before we imposed our framework on it, before it was 'sifted'. The experience of ambiguity, thus, provides a clearer look at the confluence that is responsible for an interruption. 'Seeing is forgetting the names of the things one sees' (Weschler, 2008) and the forgetting is nothing less than the conversion of 'things' back into indeterminate situations that could be re-conceptualized more pragmatically with different labels. To forget the names of the things seen is to remove some but not all predicates.

4.4. Every experience 'makes' sense

When people move closer to the flux of ambiguity, they work to *make* sense of it by using the resources of (1) Social context, (2) Identity, (3) Retrospect, (4) salient Cues, (5) Ongoing projects, (6) Plausibility and (7) Enactment (Weick, 1995). These seven can be retained by means of the acronym, SIR COPE. These seven are important not only because they affect one's initial sense of what the ambiguous story may be, but more importantly, the seven influence the extent to which people will update and develop their sense of an ambiguous situation. These properties, in other words, have an effect on the willingness of people to rework their initial story and adopt a newer story that is more sensitive to the particulars of the present context. This reworking is far from an exercise in fantasy or elimination. Instead, one's sense of what is going on is constrained by agreements with others, consistency with one's own stake in events, the recent past, visible cues, projects that are demonstrably underway, scenarios that are familiar, and actions that have tangible effects. When one or more of these sources of grounding are themselves hazy, ambiguity deepens, moments are turned inside out and effort is directed towards assurance or rework. Other things being equal, given a choice among organizational designs, all of which seem to manage other issues equally well, the choice should favour a form that allows for more conversations, clearer identities, more use of elapsed action as a guide, unobstructed access to a wider range of cues, more focused attention on interruptions whenever projects are disrupted, wider dissemination of stories and deeper acceptance of the reality that people face situations that are of their own making.

4.5. Every experience is composed of wary improvisation

Interruptions and improvisation seem to go together, and this affinity suggests one possibility of how organizations react to ambiguity. Gilbert Ryle (1979) describes the improvisational quality of everyday life. '(T)o be thinking what he is here and now up against, he must both be trying to adjust himself to just this present once-only situation and in doing this to be applying lessons already learned. There must be in his response a union of some Ad Hockery with some know-how' (p. 129).

This is not making something out of nothing. Instead, it is 'on-the-spot surfacing, criticizing, restructuring and testing of intuitive understandings of experienced phenomena' while the ongoing action can still make a difference (Schon, 1987, pp. 26–7). Familiar materials juxtaposed in an ambiguous assemblage are recombined in ways that are plausible given the context but unlikely to resolve the ensuing ambiguities. To improvise is to steer the existing ambiguity into further complications. To grasp ambiguity is to treat those further complications as normal, natural trouble.

5. Conclusion

Reliable organizing assumes that ambiguity is permanent, and interpretations are impermanent. Trouble occurs when we assume the opposite, namely, ambiguity

is impermanent and interpretations are permanent. To grasp ambiguity is to rework sense, repeatedly, since both you and the world change continuously even though you continue to navigate using unchanging, discontinuous concepts. Organizing for high reliability is attuned to chronic ambiguity because it is sensitive to small failures, inaccurate simplifications, distractions, overlearned habits and pretensions to expertise (Weick & Sutcliffe, 2007). The application of HRO principles can create a workable level of ambiguity, but not its complete disappearance. As more attention is directed to failing, simplification, operations, options and expertise, ambiguity lingers but its content shifts. It shifts towards things that people are better able to control, things such as earlier signs of failing, simplifications that ignore the significant and subtle, forecasts and memories that distort a clear picture of what is happening right now, potential resources for adaptation that are at hand even though unused, and doubts in search of people with answers.

In a more general sense, to grasp ambiguity is to adopt an attitude of wisdom. 'The essence of wisdom . . . lies not in what is known but rather in the manner in which that knowledge is held and in how that knowledge is put to use. To be wise is not to know particular facts but to know without excessive confidence or excessive cautiousness. . . . [T]o both accumulate knowledge while remaining suspicious of it, and recognizing that much remains unknown, is to be wise' (Meacham, 1990, pp. 185, 187). To hold this attitude is to remain somewhat wary, doubtful and dubious, which means there is always some ambiguity woven into action. Viewed in this context, an increase in ambiguity, relative to what you already are experiencing, is not that disabling nor does it lead you to flee into the first interpretation that promises assurance.

Acknowledgement

References

American Heritage Dictionary. (1992), *American Heritage Dictionary of the English Language*, (3rd edn), Houghton Mifflin, New York.

Bacon, M. (2012), *Pragmatism: An Introduction*, Polity, Malden.

Barton, M. and Sutcliffe, K. (2009), 'Overcoming Dysfunctional Momentum: Organizational Safety as a Social Achievement', *Human Relations*, Volume 62, Number 9, pp. 1327–1356.

CAIB (2003), *Columbia Accident Investigation Board: Report*, Vol. 1, US Government, Washington.

Chia, R. (1999), 'A 'Rhizomic' Model of Organizational Change and Transformation: Perspectives from a Metaphysics of Change', *British Journal of Management*, Volume 10, pp. 209–227.

Chia, R. (2005), 'The Aim of Management Education: Reflections on Mintzberg's 'Managers not MBAs', *Organization Studies*, Volume 26, Number 7, pp. 1090–1092.

Cook, S.D.N. and Yanow, D. (1993), 'Culture and Organizational Learning', *Journal of Management Inquiry*, Volume 2, Number 4, pp. 373–390.

Czarniawska, B. (2005), 'Karl Weick: Concepts, Style, and Reflection', *Sociological Review*, Volume 53, pp. 267–278.

Dewey, J. (1922–2002), *Human Nature and Conduct*, Dover, Mineola.

Dewey, J. (1997), *Experience and Education*, Free Press, New York.

Douglas, M. (2002), *Purity and Danger*, Routledge, London.

Halliburton, R. (2002), Panto Makeover for the Bard. *London Evening Standard*.

Irwin, R. (1977), Notes Toward a Model, *Exhibition Catalog for the Robert Irwin Exhibition*, Whitney Museum of American Art, April 16–May 29, 1977, pp. 23–31 (New York: Whitney Museum of American Art).

James, W. (1981), *The Principles of Psychology*, Vol. 1, Cambridge University Press, Harvard.

James, W. (1987), *Writings: 1902–1910*. New York, Library of America.

La Porte, T.R. (1975), 'Complexity and Uncertainty: Challenge to Action', in La Porte, T.R. (ed.), *Organized Social Complexity*, Princeton University, Princeton, NJ, pp. 332–356.

Lagadec, P. (2010), 'Beyond Charted Research: A Personal Tribute to Todd R. LaPorte', *Journal of Contingencies and Crisis Management*, Volume 19, Number 1, pp. 3–8.

Meacham, J.A. (1990), 'The Loss of Wisdom', in Sternberg, R.J. (ed.), *Wisdom*, Cambridge, New York, NY, pp. 181–211.

Merriam Webster. (1984), *Merriam Webster's Dictionary of Synonyms: A Dictionary of Discriminated Synonyms with Antonyms and Analogous and Contrasted Words*, Merriam Webster, New York.

Michelson, M. (2012), 'Tunnel Vision', *Outside Magazine*, 14 November.

Nietzsche, F. (1968), *Twilight of the Gods*, Penguin, Baltimore.

Riddell, D. (1999), *From the Cab: STORIES from a Locomotive Engineer* Pentrex, Pasadena, CA.

Ryle, G. (1979), 'Improvisation', in Ryle, G. (ed.), *On Thinking*, Blackwell, London, pp. 121–130.

Schon, D.A. (1987), *Educating the Reflective Practitioner*, Jossey-Bass, San Francisco.

Schutz, W. (1979), *Profound Simplicity*, Bantam, New York.

Snook, S. (2000), *Friendly Fire*, Princeton University, Princeton.

Taylor, J.R. and Van Every, E.J. (2000), *The Emergent Organization: Communication as its Site and Surface*, Erlbaum, Mahwah.

Tremper, B. (2008), *Staying Alive in Avalanche Terrain*, Mountaineers Books, Seattle.

Weick, K.E. (1995), *Sensemaking in Organizations*, Sage, Thousand Oaks.

Weick, K.E. and Sutcliffe, K.M. (2007), *Managing the Unexpected: Resilient Performance in an Age of Uncertainty*, Jossey-Bass, San Francisco.

Weschler, L. (2008), *Seeing Is Forgetting the Name of the Thing One Sees: A Life of Contemporary Artist Robert Irwin*, University of California, Berkeley.

Winter, S.G. (2013), 'Habit, Deliberation, and Action: Strengthening the Microfoundations of Routines and Capabilities', *The Academy of Management Perspectives*, Volume 27, Number 2, pp. 120–137.