There is no such thing as a black swan process incident

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There should be no surprises with respect to catastrophic occurrences in the process industries unless knowledge deficiencies exist. The current paper examines documentation supporting this assertion and attempts to demonstrate that there is no such thing as a black swan incident in the process industries. Recent process safety literature shows that warning signs are always present prior to an incident and that we must train employees to practice within an effective safety culture. Research has also shown there is a fine line between information and knowledge, and that we must distinguish between the two before making high-risk decisions. In a knowledge society, therefore, there should be no black swans; all individuals in a company hierarchy must learn to detect warning signs.

Keywords: black swan, process incident, low probability, high consequence, warning sign

Introduction

Nassim Nicholas Taleb (Taleb, 2010) describes the metaphoric term *black swan* as a highly improbable event having three principal characteristics: (i) it is not expected (i.e., is an outlier), (ii) it has an extreme impact, and (iii) it is explainable and predictable after-the-fact. The final characteristic also embraces the notion that after such an event, we attempt to provide explanations that make it appear less random and more predictable than it actually was. In his book (Taleb, 2010), the author offers speculation regarding black swans and suggests that black swans are the root of each significant event – good or bad – that has occurred throughout history. He also states that the underlying cause of our inability to acknowledge black swans is that humans tend to focus on things already known to us and therefore fail to consider those for which we lack knowledge. According to Taleb (2010), this in turn leads to an inability to estimate opportunities and to vulnerability to the impulse to simplify, narrate and categorize.

The current paper focuses on the idea that black swan events would only be true to those who have no knowledge or experience in the matter, therefore suggesting that there are no black swans in a knowledge society. The term black swan originates from the (Western) assumption that black swans were non-existent as all swans accounted for were white. This theory was of course disproved, a fact which might seem obvious in hindsight since other species of animals varied in color. If we look at this definition from another perspective, and make an assumption that the documentation regarding the non-existence of black swans was generated by a society lacking scientific knowledge, training in the relevant subject, and expertise – then can we not assume that with the right tools and knowledge by ornithologists, the black swan theory is in fact not true? There was a strong discrepancy between information and knowledge in this case; we cannot assume we are knowledgeable about swans simply because there is information stating that all swans are black. A catastrophic event in the process industry which some might consider as a black swan, may very well not be seen as such by others who hold significant knowledge and experience in the matter.

Thus, the scope of the current contribution is low probability/high consequence process incidents (some of which have been denoted as black swans by process safety practitioners). The motivation for the analysis presented here comes from the fact that these incidents have received considerable attention recently in both the popular and technical literature. The specific objective of this work is to elucidate the key role of warning signs (or signals) that a low probability/high consequence process incident could occur; herein lies the notion that knowledge is paramount in preventing these events. This manuscript builds on concepts developed in a previous conference presentation without paper (Amyotte et al., 2013).

Low Probability/High Consequence Incidents

A number of questions arise when attempting to define and categorize low probability/high consequence events; for example:

- How low a probability and how high a consequence should one use?
- How can we estimate a probability of occurrence from infrequent events occurring at widely varying intervals (Makridas and Taleb, 2009)?
- Which consequence categories should be used – injuries, fatalities, property/asset loss, production loss, environmental harm, on-site, off-site?
- How does one consider the perception of the risk receptor?

Drawing on the work of Paltrinieri et al. (2012), Gowland (2013) provides helpful guidance on a possible categorization scheme:

- **Known knowns** – events we know about and for which we can plan,
- **Known unknowns** – events we can predict even if they have not occurred yet,
- **Unknown knowns** – events that have occurred but are not remembered (e.g., due to loss of corporate memory), and
- **Unknown unknowns** – events not yet predicted or which have been dismissed as realistic.

It is the last item in the above list – *unknown unknowns* – that captures what are increasingly being referred to in the literature as black swan events. For example, Mascone (2013) categorizes all of the following process and non-process disasters as black swans: terrorist attacks of September 11, 2001, Hurricane Katrina, credit crisis and great recession, Gulf of Mexico oil spill, Fukushima Daiichi nuclear reactor meltdowns, and Superstorm Sandy. When viewing this listing, one inevitably wonders if these events were all explainable and predictable only after-the-fact (the third black swan characteristic of Taleb, 2010).

The black swan landscape becomes even more confusing when the findings in Table 1 are analyzed. Flixborough and Bhopal are indicated to be black swans by Murphy and Conner (2012) because of the unforeseen consequences of large vapour cloud explosions and toxic gas releases, respectively. Buncefield and BP Texas City, however, are not categorized as black swans by Gowland (2013). A belief that cold petrol (gasoline) vapour could not explode in the open air (Buncefield), and the inappropriate use of occupational safety performance indicators to assess process safety performance (BP Texas City), played key roles in these incidents. At best (or worst), Buncefield would be classed as an unknown known given the reminder by Professor Trevor Kletz that similar explosions had occurred in Newark, New Jersey in 1983, St. Herblain, France in 1991, and Italy in 1995 (Kletz, 2010).

Table 1 Major process incidents classified and/or not classified as black swan events (unknown unknowns).

Incident (Year)	Black Swan? – Yes	Black Swan? – No
Flixborough (1974)	Murphy and Conner (2012)	
Bhopal (1984)	Murphy and Conner (2012)	
Buncefield (2005)		Gowland (2013)
BP Texas City (2005)		Gowland (2013)
Macondo (2010)	Murphy and Conner (2012)	Murphy and Conner (2013)
Fukushima (2011)	Murphy and Conner (2012)	Mannan (2013)

Table 1 also indicates some disagreement on whether the Macondo and Fukushima incidents should be viewed as black swan events – by the same and also different practitioners. How then, does one account for these discrepancies? Differences of opinion between two or more parties are of course possible, and it is always possible for one party to have a change of opinion over time. But what is the underlying basis for such a fundamental shift having potentially significant consequences? We – and others – would contend that the answer is related to the knowledge of the observers themselves.

A Knowledge Perspective

Aven (2013) defines a black swan as follows (with bold-facing and underlining added here for emphasis):

- Generally speaking, an **extreme** event that is a **surprise** relative to the present **knowledge**/beliefs <u>of persons to be specified</u>, and
- From a risk perspective (A,C,U – events, consequences, uncertainties), an **extreme** event that is a **surprise** relative to the **knowledge** <u>defined by the A' events of the risk assessment</u> (i.e., an unknown unknown). This is the atypical accident scenario of Paltrinieri et al. (2012) – a scenario deviating from normal expectations of unwanted events or worst case reference scenarios, and thus not deemed credible by common risk assessment processes.

Each definition incorporates the facts that black swans are extreme, come as a surprise, and involve knowledge deficiencies. The general definition speaks of the knowledge of individuals, whereas the risk-based explanation codifies knowledge in terms of the identified credible scenarios (which of course rely at some point on the knowledge of individuals). These practical definitions are quite useful in providing the black swan concept with a structure that is familiar to those engaged in risk management endeavours. We are now in a better position to identify the types of knowledge that will be essential to prevent low probability/high consequence process incidents; high on such a knowledge list must be the signals that warn of impending disaster, as described in the next section.

First, though, we make an important distinction between *information* and its counterpart, *knowledge*. While information (i.e. data, drawings, engineering principles, etc.) is critical to process safety assurance, it is knowledge that is embodied in the black swan definitions of Aven (2013). Hansson (2002) comments that knowledge is a composite concept having both objective and subjective components; knowledge must flow from correct information in a manner that incorporates correct beliefs. Quoting from Piirto (2012): *Information becomes knowledge when it is interpreted by individuals and given a context and anchored in the beliefs and commitments of individuals*.

Warning Signs

Here we briefly examine the following aspects of potential warning signs for low probability/high consequence process incidents: (i) their nature, (ii) how they can be detected, and (iii) why they might not be heeded. These points form the basis for the discussion on incident prevention given in the subsequent section.

With respect to ease of recognition, process incident warning signs can be weak or strong in addition to their physical (e.g., asset integrity) or conceptual (e.g., safety culture) nature. Numerous resources are available for guidance on potential warning signs. For example, *Flirting with Disaster* (Gerstein, 2008) – published in the popular literature – is essentially a book about early warnings. The publications of sociologist Andrew Hopkins, such as *Failure to Learn: The BP Texas City Refinery Disaster* (Hopkins, 2009a), are especially helpful in understanding the relationship between warning signs and the elements of an effective safety culture and safety management system.

From a technical engineering perspective, work on leading and lagging indicators by organizations such as the Center for Chemical Process Safety of the American Institute of Chemical Engineers (e.g., CCPS, 2012) is also beneficial in identification of warning signs. CCPS (2012) provides additional advice on examination of the following areas for warning signs:

- leadership and safety culture,
- training and competency,
- process safety information,
- procedures (operating and maintenance),
- asset (mechanical) integrity,
- risk analysis and management of change,
- audits,
- learning from experience, and
- near-miss and incident reporting/investigation.

Many tools are available to broadly identify hazards and accident scenarios, assess likelihood and estimate consequences over the design life cycle in the process industries: PHA (process hazard analysis), QRA (quantitative risk assessment), PRA (probabilistic risk assessment), LOPA (layer of protection analysis), DRA (dynamic risk assessment), etc. However, with respect to *Recognizing Catastrophic Incident Warning Signs in the Process Industries* (the title of CCPS, 2012), the more critical approach would seem to be the integration of warning sign detection and prevention methods into the actual process safety management (PSM) system. One clearly sees the management system cycle of *plan, do, check, act* in the integration scheme recommended by CCPS (2012):

- **Plan:** Perform initial warning signs survey.
- **Do:** Build warning sign analysis into management system.
- **Do:** Use new system and track related action items.
- **Check:** Evaluate effectiveness in next compliance audit.
- **Act:** Maintain vigilance against recurring warning signs.

While solid advice on warning sign detection is available in the technical literature, it is obvious from recent incidents that these signals can go unheeded. A number of questions therefore require attention so as to address this anomaly: (i) Can we only see warning signs after-the-fact? (ii) Are warning signs strong enough to even notice? (iii) Do expectations prevent warning sign perception? (iv) Is there a lack of risk awareness in the workplace? Answering these and similar questions means looking to the social science literature (especially in the fields of psychology and sociology). Concepts such as conjunction fallacy (Camerer and Kunreuther, 1989; Heuer, 1999), WYSIATI (*What You See Is All There Is*) and optimism (Kahneman, 2011), normalization of deviance (Hopkins, 2009b), and others identified in the following section are then seen to be relevant to the issue of heeding warning signs and thus acting to prevent low probability/high consequence incidents.

Prevention of Low Probability/High Consequence Incidents

We offer three suggestions for the prevention of low probability/high consequence incidents. The first employs the CCPS (2012) recommendation of integrating warning sign detection and prevention methods into the PSM system, and is shown in Table 2.

Table 2 Suggestions for prevention of low probability/high consequence process incidents.

Risk Awareness Impediment	Improvement Means	PSM Concept (CCPS, 2012)
Cognitive dissonance	Consistency of behaviours and values	Commitment to process safety
Lack of perception of vulnerability	Workplace appeals Storytelling	Understanding hazards and risks
Lack of self-efficacy	Training Individual performance standards	Managing risks
Conjunction fallacy	Storytelling Assurance of corporate memory	Learning from experience

The second recommended approach is an increased reliance on **all** aspects of the hierarchy of risk control measures (inherently safer design, passive engineered devices, active engineered devices and procedural/administrative measures). This is chiefly a call for robust process plant design utilizing the principles of inherent safety (e.g., minimization, substitution, moderation and simplification; Kletz and Amyotte, 2010). But is also a call for more effective use of the lower levels in the hierarchy such as the procedural measure of training; see Gladwell (2008) for a general perspective on training, and also the targeted CCPS process safety leading indicator of *training for PSM critical positions* (CCPS, 2012).

Our third suggestion for prevention of low probability/high consequence incidents is shown in Figure 1. Here we illustrate our contention that further advances in process safety performance will be most effectively achieved within a paradigm of knowledge management and communication. Building on the previously recognized regimes identified in Figure 1, the knowledge to be managed will come from engineering considerations as well as the natural, management and social sciences. The previous safety culture paradigm is crucial In this regard; helpful general and process-specific references include the chapter on *The Ethnic Theory of Plane Crashes* in Gladwell (2008), the report *Diverse Cultures at Work: Ensuring Safety and Health Through Leadership and Participation* prepared by the European Agency for Safety and Health at Work (Starren et al., 2013), the document *Corporate Governance for Process Safety. Guidance for Senior Leaders in High Hazard Industries* developed by the Organisation for Economic Co-operation and Development (OECD, 2012), and the book *Safety, Culture and Risk* written by Andrew Hopkins (Hopkins, 2005).

Case Studies

Three case studies are now presented to place the previous conceptual discussion into practical terms. We begin with a recent process incident that under no circumstances should be viewed as a black swan. This is followed by a look at the issue of dust detonations (which might be a surprise to some practitioners), and finally an example drawn from the offshore oil and gas industry.

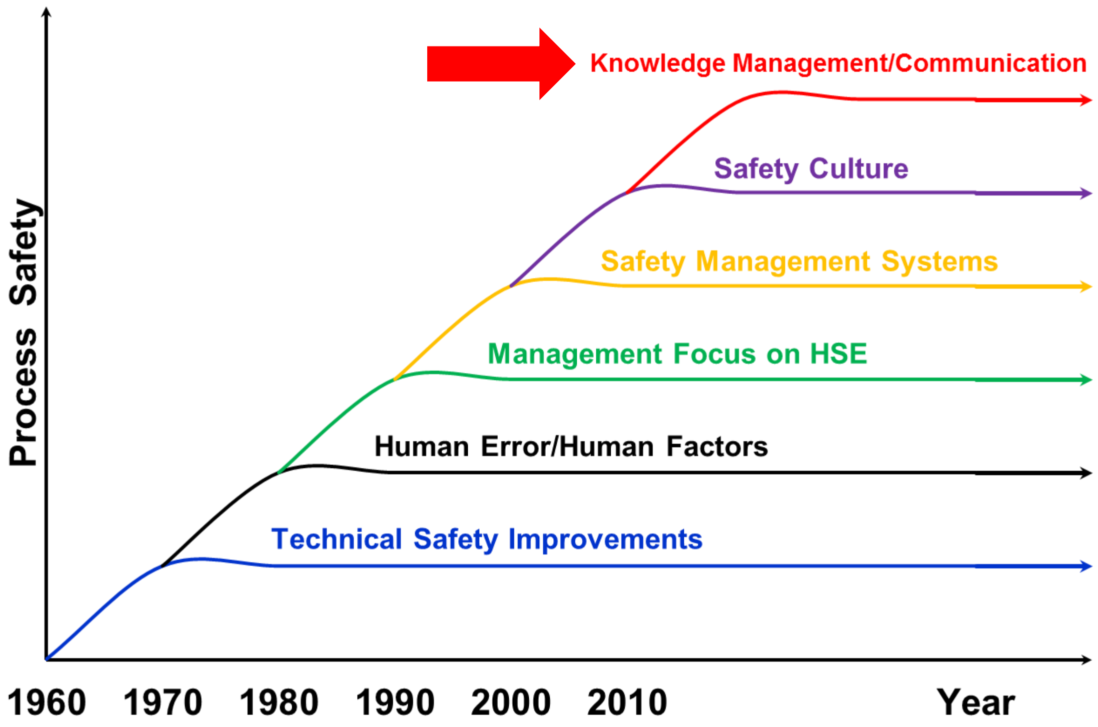

Figure 1 Evolution of safety performance in the process industries (updated from Pasman and Suter, 2004 and De Rademaeker et al., 2013).

Chevron Richmond Refinery

On August 6, 2012, the Chevron U.S.A. Inc. Refinery in Richmond, California, experienced a catastrophic pipe failure in the #4 Crude Unit. The pipe ruptured, releasing flammable, hydrocarbon process fluid which partially vaporized into a large vapor cloud that engulfed nineteen Chevron employees. All of the employees escaped, narrowly avoiding serious injury. The flammable portion of the vapor cloud ignited just over two minutes after the pipe ruptured. The ignition and subsequent continued burning of the hydrocarbon process fluid resulted in a large plume of unknown and unquantified particulates and vapor (Figure 2) traveling across the Richmond, California, area. In the weeks following the incident, approximately 15,000 people from the surrounding area sought medical treatment due to the release. Testing commissioned by the U.S. Chemical Safety and Hazard Investigation Board (CSB) and the California Division of Occupational Safety and Health (Cal/OSHA) determined that the pipe failed due to thinning caused by sulfidation corrosion (Figure 3), a common damage mechanism in refineries. (Quote from the Summary section in CSB, 2013).

Clearly this is an extreme event. But should it be seen as a surprise relative to the knowledge of individuals or to the state of knowledge defined by a credible scenario analysis? The answer on both counts is a resounding no; identifying this incident as a black swan process event would be entirely inappropriate. The Chemical Safety Board interim report (CSB, 2013) indicates there were far too many warning signs that were in fact accident precursors. The following list of warning signs drawn from CSB (2013) demonstrates the importance of acting on lessons learned from site operations, company operations, and more broadly from what is happening within the industry itself:

- results from previous corrosion inspections at the Chevron Richmond refinery,
- sulfidation corrosion incidents at other Chevron refineries including the El Segundo refinery,
- a sulfidation corrosion incident and ensuing fire at BP's Cherry Point refinery, and

- a 2006 CSB Safety Bulletin on *Positive Material Verification* providing further information on the specific matter of corrosion of carbon steel.

Earlier in this paper we raised the matter of risk receptor perception with respect to the black swan phenomenon. Figure 4 and the following quote indicate that the false use of a label indicating surprise on the part of a responsible organization will find little favour with the affected public: *The future success of the chemical industry will depend more on social license to operate than technological advancement* (Fung, 2013).

(To our knowledge, no one has actually termed this particular incident a black swan. We are simply making the point that it is a clear example of a process incident that is not a black swan – by any definition.)

Figure 2 Hydrocarbon plumes due to pipeline rupture (left) and flare (right) at Chevron Richmond refinery (photograph on poster handed out by public interest group during CSB public meeting on April 19, 2013).

Figure 3 Pipeline degradation due to sulfidation corrosion at Chevron Richmond refinery (CSB, 2013).

Figure 4 Photograph on other side (with respect to Figure 2) of poster handed out by public interest group during CSB public meeting on April 19, 2013.

Dust Detonations

Many, but certainly not all, industrial practitioners know that combustible dust (particulate matter) will explode when the conditions of the explosion pentagon are satisfied: (i) fuel, (ii) oxidant, (iii) ignition source, (iv) mixing, and (v) confinement (Amyotte, 2013). These dust explosions typically occur as deflagrations in which the speed of the reaction front is subsonic.

But can a dust detonation (i.e., an extreme event) having a sonic or supersonic reaction front speed occur? To answer this question we return to the first black swan definition given by Aven (2013): generally speaking, an extreme event that is a surprise relative to the present knowledge/beliefs of persons to be specified. From this generalist perspective, a quick internet search of credible resources indicates that dust detonations are not common in industry, and the vast majority of industrial dust explosions indeed occur as deflagrations (James, 2001; Exponent, 2012).

So should a dust detonation be considered a black swan event? Answering this question requires consideration of the second black swan definition given by Aven (2013): from a risk perspective (A,C,U – events, consequences, uncertainties), an extreme event that is a surprise relative to the knowledge defined by the A' events of the risk assessment. A more exhaustive literature search will now reveal that detonations of combustible dust have been shown to occur under laboratory conditions that optimize the fuel, geometry and flow criteria for DDT (deflagration-to-detonation-transition). Relevant material (fuel) conditions include: (i) high reactivity, (ii) fine particle size distribution, (iii) low moisture content and (iv) ease of dispersion. Critical boundary (geometry and flow) conditions include: (i) a sufficient run-up distance, (ii) a wide flow channel, and (iii) turbulence generated by wall surface roughness or obstacles in the flow path (such as the buckets in a mechanical elevator and underground machinery as shown in Figures 5 and 6, respectively).

These material and boundary conditions form the basis for dust detonation warning signs related to the PSM concepts of process safety information, risk analysis and management of change. A dust detonation is therefore a credible scenario in, for example long coal mine galleries (Amyotte et al., 1988) and long, wide lines as may be found in pulverized fuel power plants (James, 2001). The overall conclusion is that general information, although perhaps widely accessible, is inadequate when it comes to identifying black swans. Information must be placed in a specific context and adopted within the belief system of an organization before it can be managed as knowledge.

Figure 5 Uptake leg of bucket elevator with open panel showing individual buckets.

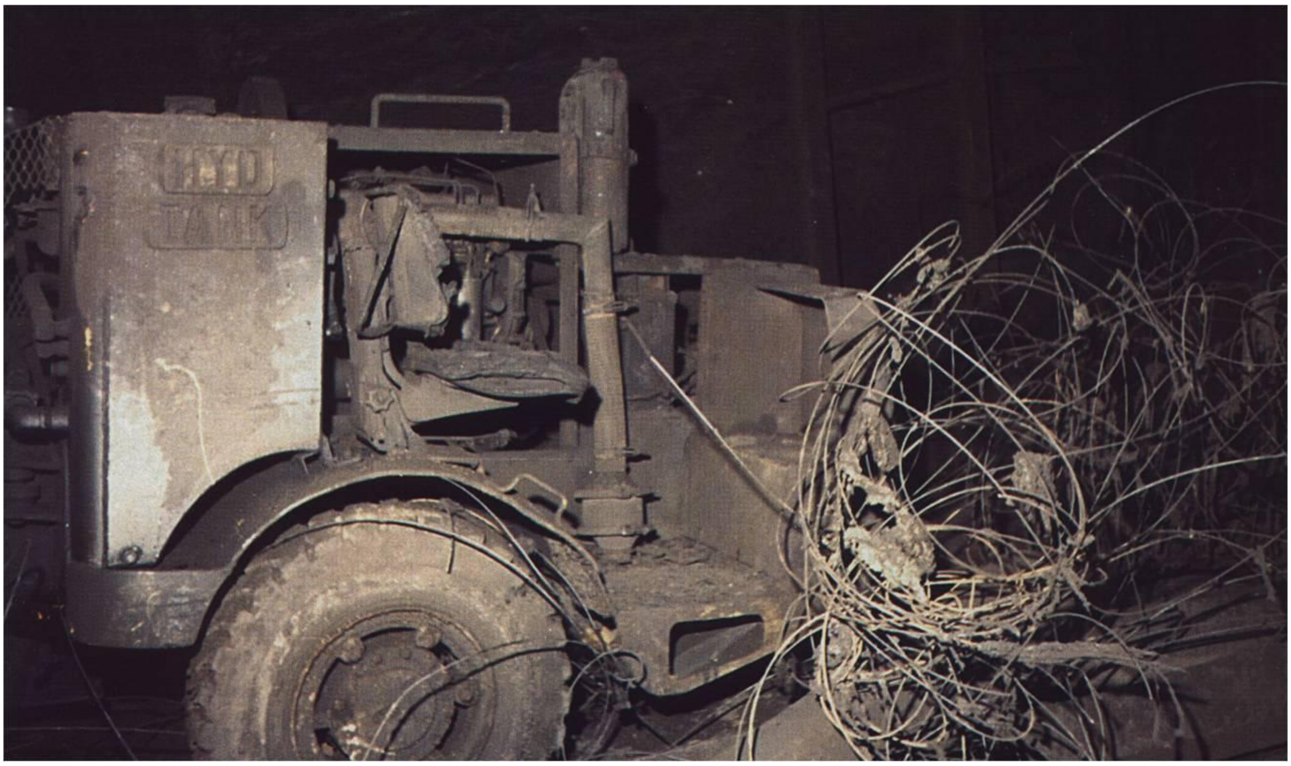

Figure 6 Boom truck in gallery of Westray coal mine (Richard, 1997).

Offshore Oil and Gas Industry

Based on the experience of one of the current authors, a brief commentary is offered here on information and knowledge uncertainty in the offshore oil and gas industry given the number of players involved. Consider the case of Company A (a survey company) hired to position the well infrastructure. In doing so, Company A acquires relevant data and distributes it to Company B, which is tasked with managing drilling and production on the platform as well as all subcontractors (including Company A) on behalf of the overall decision-maker, Company C (the oil and gas producer). The data passed from Company A to Company B is information in the form of drawings and reports. Following the argument of Hansson (2002), Company B would now hold information on the well position and thus must understand how Company A attained this information so that it can make a knowledgeable decision. If Company B simply looks at the drawings and reports, without understanding the information and relying solely on trust in the findings of Company A, then Company B has no knowledge on the subject and cannot possibly make a justifiable decision.

Although this might seem a trivial example of the distinction between information and knowledge on an offshore production platform, a lack of knowledge of well positioning can have disastrous consequences. Highly technical industries require a significant amount of knowledge and expertise on various levels which unfortunately leads to further uncertainties; complexity is a major cause of scientific uncertainty (Hansson, 2002). Combatting a lack of knowledge on all levels in the offshore industry is an ongoing challenge because many day-to-day decisions are based on information and uncertainty, which then introduces a degree of risk to the operations. Hansson (2002) states that to cope with these uncertainties, we need to develop strategies for information-processing and decision-making that take these factors into account.

An interesting development in this regard is the recent paper by Aven and Krohn (2014). These authors propose a new way of thinking about risk that builds on four pillars: (i) a conceptual risk framework, (ii) risk assessment and management, (iii) quality management with a focus on improvements, and (iv) the concept of mindfulness. Aven and Krohn (2014) draw on Hopkins (2005) in describing mindfulness (which is synonymous with safety culture) in terms of five characteristics: (i) preoccupation with failure, (ii) reluctance to simplify, (iii) sensitivity to operations, (iv) commitment to resilience, and (v) deference to expertise. Most importantly, the conceptual risk framework of Aven and Krohn (2014) distinguishes among three levels of unforeseen/surprising events: (i) those completely unknown to the scientific environment (i.e., true unknown unknowns or black swans), (ii) those not on the list of known events from the perspective of the people who conducted the risk assessment, and (iii) those on the list of known events but deemed to represent negligible risk.

Concluding Remarks

If we are able to differentiate between information and knowledge, then in theory there should be no low probability/high consequence (or unknown unknown, or black swan) incidents in a knowledge society. If an organization adopts an effective safety culture and all that this entails, then the organization's activities will be based on knowledge which can greatly reduce uncertainty, which in turns reduces risk. By promoting safety culture considerations, we can also expect improvements in the safety management system, the creation of inherently safer designs, and more open and effective communication.

The literature suggests that many industry leaders agree that black swans are in fact predictable and that black swans to do not exist in a knowledge society. We must train employees to recognize warning signs before-the-fact; with adequate education, knowledge and tools, there is a greater possibility that these warning signs will not be ignored. We must re-evaluate the way we asses risk, and understand that decisions are often based on information and not knowledge. By educating employees, managers and leaders to become risk-aware at the individual level, we facilitate a knowledge society and ward off the ubiquitous black swan in terms of both the inappropriate use of the label and an unfortunate return to the notion that major process incidents are simply not predictable.

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