Risk Management; a behavioural perspective

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Abstract

The risk contributor is usually regarded as responsible for risk mitigation and accident compensation, especially when the risk is due to the operation of a commercial company. The culpability of risk has resulted in several approaches to safety management. Risk management based on quantitative risk analysis (QRA) emerged in the defence and nuclear industry during and after WW2 and is by now introduced in almost every industry with high-risk potential. During this period risk analysis and management as a profession has evolved considerably. Technical failures and operator errors used to be considered as the prime causes of accidents in the early days of risk analysis. Based on investigations of major accidents in the latter half of the last century, poor safety culture and mismanagement were introduced as possible additional causes of major accidents. Human error in decision-making is however rarely quantified and thus not included in QRA. Knowledge from the experimental analysis of behaviour is absent in practical or operational risk management. This paper advocates an approach to risk management where the decision part of the chain of events is explicitly included. The behavioural perspective introduced implies that the application of experimentally based behaviour science and QRA both should be pursued, mainly because quantitative risk analysis is a strong, and probably the best, defence against decision errors. In an operational situation, management must do trade-offs between objectives where safety is but one of several considerations. When the risk is not quantified, safety looses out to other more easily quantified objectives of a company. The fatal decision error that led to the Challenger accident is used as an example.

Keywords: QRA; risk management; behaviour science, hazard adaptation; Challenger accident.

1. Introduction

When the action of an individual or the operation of a company is the primary risk contributor, most people will agree that those responsible for damage and harm are also responsible for risk mitigation and compensation for losses should the risk materialize. This logic is also reflected in legislations and standards. ISO 31000 "Risk Management" was released in 2009, with general guidelines on how a company can control risk. When risk control is seen globally and with the wider perspective including society and regulators, the concept most often used is risk governance rather than "risk management", see for instance White paper no 1 by IRGC (Renn 2005) and van Asselt and Renn (2011). Governmental agencies are authorised to regulate high-risk operators through legislation, safety audits and accident investigations, and with considerable transnational cooperation. Recipes for how to reduce operational risk to an acceptable level are commonly described as Safety Management Systems (SMS). The initial approach to SMS came as a reaction to accidents, to prevent their re-occurrence. A more proactive approach based on risk analyses has emerged to complement the re-active accident tradition. Today, there are several versions of SMS available, reflecting professional preferences as well as the characteristics of specific industries and risks. A safety industry has emerged, where safety service providers offer risk consultants, tools and methods to assist high-risk clients in becoming compliant with safety regulations. However, in situations where the high-risk decisions are actually made, most stakeholders are not present, including those that represent society. Ideally speaking, the risk owner (the company) and the regulator (representing the society), have a common, ideal goal, which is to reduce risk to a level that is acceptable. Reality is quite different because the two are driven by different motives or behavioural contingencies of reinforcement. The perspective expressed in this paper is risk mitigation as seen primarily from a company’s view. A private company is a commercial entity that in order to exist must generate profit sufficient to be attractive to investors. And the regulators, representing the society, are partly under the influence of safety professionals and partly governed by legislations and politicians. The former group is mainly concerned with minimizing risk, and the latter (politicians) is driven by the possibilities of being re-elected, which means to avoid negative media exposure, i.e. to amend unnecessary stops in operations and avoid accidents. This dichotomy is obviously a simplification, but drives home the essential difference between a commercial company and the regulatory establishment.

The proactive aspect of SMS goes back to The Reactor Safety Study (Rasmussen et.al. 1975), which probably was the first "total" quantitative risk analysis (QRA). The analysis was based on a system reliability approach, where technical failures were modelled using Boolean logic, represented graphically as fault trees. Although the report was much debated, it formed the basis for similar analyses in other industries and was an early attempt to use the results from risk analysis as basis for decision-making. The fault tree modelling approach also made it possible to include the human operator as a system component that could fail, like a valve or a pump. Man-machine interaction and human reliability thus became parts of QRA. When empirically based equipment failure rate repositories were developed and human (mis)use was included in the failure rates, the need for separate human reliability data and modelling was reduced.

In the following years to come, investigations of several major accidents indicated that risk contributors could be found not only in the immediate proximity of the accidental event, i.e. the operator, but also in decisions made by (top) management and owners. This shift in focus is commensurable with the advance of technology which had changed the human role from manual labour to planning and decision-making.

Management, organisation and culture were included as topics to be addressed in SMS requirements and legislations. Risk management became less based on QRA and more on safety audits and compliance monitoring.

When the human error perspective shifted from operator to management, the question of responsibility and misbehaving moved from the shop floor to the Board Room. How a given organisation and company culture actually influence human behaviour is however far from clear, and there is no common agreement of how an organisation should look like in order for operations to be safe. To estimate human error probabilities for well-defined motoric and mechanical tasks are possible, although not easy; it is more difficult to do so for decision errors. As a consequence, risk based SMS where decision-making errors are included is practically non-existing. Qualitative analyses, like Safe Job Analysis and hazard identification and assessment based on a Risk Matrix approach, are on the other hand used quite often. Although qualitative analyses can provide much useful information, there are occasions when a quantitative approach is a better way to bring the message through to the decision makers.

The solution proposed in this paper is to reinstate QRA as the prime basis for risk management while at the same time utilising recent findings from behaviour and cognitive science so that decision errors are included. Neglecting risk exposure or number of opportunities for failure, which is not uncommon in (qualitative) risk assessments, is similar to a well-studied cognitive bias called base-rate ignorance. Psychological factors that may inhibit an analysis of decision-making will be explained in the following. Before a possible behavioural approach to risk management is further described, some of the most common approaches to risk management are discussed.

2. Psychological defences and risk management

Risk management is simply the application of results from risk analyses to make decisions where the actual risk level is part of the decision basis. There can be many reasons why risk management systems do not explicitly address the reliability of decision making. One of them might be related to a general human tendency to avoid or neglect uncertainty. Furthermore, most engineers and economists that constitute the professions from which managers are recruited are trained to produce exact solutions expressed as single numbers. They are usually not familiar with reliability theory, stochastic models and probability distributions. Furthermore, selection of leaders usually favours the overconfident who are not supposed to express doubts of what actions to take. If they have to deal with outcomes that are uncertain, the uncertainty is often expressed as best and worst-cases. They may believe these to be accurate statements, but in reality the decision makers do not know what confidence limits these cases represent. They may not be aware of their own ignorance since overconfidence or the optimism bias is probably one of the most common human fallacies (Moore and Healy 2008).

A QRA that also considers uncertainty could to some extent protect against overconfidence. However, to conduct a proper QRA, you will normally need to define the objectives, then to identify the threats against achieving the objectives, the efficiency of barriers, the severity of the consequences and their probability of occurrence, just to mention a few of the more important ones. To each one of them, there are associated uncertainties, i.e. lack of information for various reasons. And to add to the complexity, the analysis as well as the subsequent decision is multiattributed. Not only can there be more than one kind of negative outcome; like fatalities, injuries, material damage, reputation damage, downtime costs, repair cost, etc. There might also be several kinds of positive effects; like satisfied clients, profits to be made, increased market share, recognition from peers and management, etc. Both negative and positive outcomes are uncertain and related to the same decision. The favourite workable and practical solution is to let department managers advocate their specific considerations, whereupon top management balance the contributions and make the final decision. Because judgements under uncertainty do not necessarily follow a rational logic (Kahnemann 2011), the whole decision process is vulnerable to cognitive biases of various kinds.

In a dynamic operational setting where decisions are to be made on short notice, risk analyses are seldom prepared for reasons explained above. If generic risk scenarios or safety cases are being prepared in advance, the chances increase that they may be used to aid in the evaluation of high-risk decisions. Even when risk scenarios are not prepared in advance, but hazard event data exist, a better decision basis can be achieved with only a little data processing as will be explained later. The decision to launch Challenger was such an occasion where a simple quantitative risk analysis could have made all the difference.

3. Accident based Risk Management

On January 28 1986, the Space Shuttle Challenger exploded in a spectacular way due to the burn-through of two O-ring seals between sections of the solid-fuel booster (SFB). The Presidential Commission on the Space Shuttle Challenger Accident (also known as the Rogers Commission) concluded that poor organizational culture and deficient decision-making processes at NASA were among the main indirect causes of the accident (Rogers et.al. 1986). The U.S. House Committee on Science and Technology released its own report on the Challenger accident (House Report 99-1016, 1986). The committee agreed with the Rogers Commission’s conclusion regarding the technical causes of the accident, and was even more critical in its assessment of the accident's non-technological causes: "… the fundamental problem was poor technical decision-making over a period of several years by top NASA and contractor personnel, who failed to act decisively to solve the increasingly serious anomalies in the Solid Rocket Booster joints" (page 4, 5).

The Challenger disaster is probably one of the most thoroughly studied cases in the history of major accidents; see Vaughan (1996) for an overview based on a sociological perspective. Organizational structures, defence-in-depth, commercial pressure and non-technical, soft barriers, became essential aspects of the causal picture and complemented the traditional view of technical failures and operator error as the primary causes. Expressions like "tightly coupled systems", "normal accidents" and "interactive complexity" had recently been introduced by Perrow (1984) to explain major accidents. The attention had shifted from the operator to a much wider perspective; organisation and safety culture. The concept of organizational accidents and the Swiss cheese metaphor were introduced to illustrate how systems, i.e. organisations, could fail (Reason 1997). The Swiss cheese model is a visual representation of how barriers can line up and fail simultaneously, a notion similar to the more precise boolean AND gates used to model and calculate system reliability.

4. Judicial based Risk Management

Accidents cause harm and sometimes lives are lost. The question of liability and accountability has over the years led to controversies between lawyers and safety workers. Who is liable for an accident and can he or she be held accountable and be prosecuted in court? In order to prevent accidents from re-occurring, safety work is depending on information. The most interesting information may come from the very individuals that in a judicial perspective can be found guilty in causing the accident. This dilemma was put to test in the Ford Pinto case. A memo that had been sent to senior management at the Ford Motor Company compared the cost of redesign of the hazardous positioned fuel tank with the out-of-court settlement cost of humans that would suffer from future accidents. It is worth noticing that such an analysis was in line with recommendations given by the National Highway Traffic Safety Administration (NHTSA) who also provided a value of a lost life that Ford could use in the cost benefit calculation (Birsch and Fielder 1994). The memo concluded that the Ford Company would save almost $70 million by allowing the accidents to occur. Ford continued to produce the Pinto without introducing safety measures until the infamous memo was leaked to the press in an August 1977 article in Mother Jones magazine. It led to criminal charges, an avalanche of lawsuits, a recall of all Pintos, and Ford got some of the worst press an American car company has ever received.

A possible side effect of the Pinto story is that such reactions can have fuelled a reluctance of companies in US to apply risk analyses as basis for their safety efforts, because no-cure-no-pay lawyers could use the results in future lawsuits. It is reason to believe that the Pinto case prepared the ground for the introduction of the concept of the amoral calculator as a way of describing different types of business firms on how they would respond to safety regulation and enforcement (Kagan and Scholz 1984). The amoral calculator type of companies and management were said to be mainly driven by self-interest and profit-maximization; because they were assumed to calculate costs and benefits in relation to risk mitigation to see what the they could get away with. The scapegoats of the past used to be operators at the sharp end of the line; now the attention and blame had shifted to upper management. This change is more an expression of political correctness than science. An unfortunate implication is that doing cost benefit calculation of risk reducing measures by itself could be considered an amoral act. This is detrimental to safety, not only because it limits the use of quantitative risk analysis in safety work, but also because it will be difficult to identify the most cost effective risk reducing measures.

The proposition that the accident could be explained by referring to amorally calculation was refuted by Vaughan (1996, page 68): "morally calculating managers intentionally violating rules to achieve organization goals does not explain the Challenger accident". Vaughan called her analysis of the Challenger accident “the sociology of mistake”, as mistakes, mishap, and disaster were proposed as being socially organized and systematically produced by social structures that were internalized by the actors, thus leading to a "normalization of deviance". Investigations of other major accidents, e.g. the Colombia Space Shuttle accident in 2003, echoed this statement as occasional incidents are perceived as normal events and part of the daily business, and are therefore not taken seriously (CAIB 2003). When a major disaster occurs, people are astonished. It has become a “black swan” to use the expression of Taleb (2007).

4. High Reliability based Risk Management

There are however some organisations that have succeeded in avoiding catastrophes in an environment where accidents can be expected due to risk factors and complexity (Weick and Roberts 1993). There is no simple explanation of why the so called high reliability organisations (HRO) achieve such remarkable safety performance. Factors like highly trained-personnel, effective reward systems, frequent process audits and continuous improvement efforts have been mentioned. Other factors said to characterise HRO are a reluctance to simplify interpretations, commitment to resilience, and deference to expertise (Weick and Sutcliffe 2007). As normal accident theory starts with the accident while HRO starts with the absence of accidents, the latter approach can be seen as optimistic compared to the rather pessimistic normal accident view. It is also interesting to observe what is common to the two approaches. Neither of them requires risk analysis as the basis for safety management, and neither is based on findings from the experimental analysis of behaviour. It is therefore pertinent to ask if a combination of quantitative risk analysis and behaviour science based on the experimental analysis of behaviour can provide additional insight. Using terminology from the experimentally based version of behaviour science, the expression "normalization of deviance" can be re-phrased as risk acceptance behaviour not brought under discriminative control of the actual risk. The right remedy can then be identified: quantitative risk analyses must be performed along with the establishment of learning conditions that can bring the risk acceptance behaviour under discriminative control of the factual risk level. A necessary condition is that the risk level and trend must be estimated with a reasonable degree of accuracy and confidence.

5. Behavioural Risk Management

Risk acceptance behaviour is a mix of operant and respondent behaviour; two main types of behaviour (Skinner 1953) or rather ingredients of behaviour. The expression 'operant' is used because the organism operates on the environment, and operant behaviour is selected by its consequences, i.e. by how the environment reacts to the emitted behaviour. The operant behaviour repertoire is the result of the individual's learning history since birth. The cerebral cortex part of the brain is involved in operant behaviour, and is therefore rather "new" in an evolutionary sense. Respondent behaviour on the other hand is involuntary and a function of the learning history of the species. Respondent behaviour is the result of natural selection, sometimes referred to as Darwinian selection. The amygdala and older parts of the brain are involved in respondent behaviour, which is "old" in an evolutionary sense. Both types of behaviour can be brought under control of new stimuli through various conditioning processes.

Operant and respondent behaviour interact in complicated ways, and are frequently the subject of research in behaviour and brain science. Kahnemann received the Nobel memorial prize of economics in 2002 for his prospect theory based on research of cognitive bias and the limitation of man’s rationality, leading to a new research field called behavioural economics. Basic assumptions related to the concept of economic man are questioned in this research tradition (Angner 2012) and as Ariely (2009) points out, the irrationality of man is quite predictable.

Respondent behaviour was initially studied experimentally by Ivan Pavlov who is regarded as the founding father of classical conditioning. Human “pre-programmed” responses to potential dangerous situations are sometimes referred to as the three F’s: Fear, Flight or Fight. A quick and correct response, either flight or fight, to a dangerous situation causing fear had high survival value in the ancient past because the correct response enabled later reproduction and transfer of genes to the offspring. The two modes, operant and respondent behaviour, are both involved in risk acceptance behaviour. When the emotional influence is strong, it can dominate behaviour, setting aside reason and sensible thinking.

6. Behavioural conditions for the Challenger launch decision

Prior to some major accidents, and the Challenger case was such an example, a decision was clearly defined: shall we launch the shuttle or not? Because the border between risk acceptance and risk too high is not visible, an objective and quantitative risk measure is needed. Relevant hazard data did exist for the Shuttle, but a risk analysis was not done. The launch was carried out despite strong objections from senior technical staff expressing serious safety concerns due to low temperatures. The BBC Education video “A Major Malfunction” (Higgins et. al. 1996) gives a vivid insight into the discussions that took place between technical and administrative management at

NASA and Thiokol prior to launch. The launch had very high media attention. It was the first time a woman was part of the crew, and her special task was to be the front figure of the Presidential Campaign “Teacher in Space”. A delay would mean that the teacher would give lectures for empty classrooms. Thiokol’s contract as SFB manufacturer with NASA was up for renewal and not yet signed. The whole Space Shuttle program had for some time been criticized for not meeting its performance targets. Pressure was therefore high to avoid another postponement. There had however been several cases of problems with the rubber O-rings like blow-by’s and erosions on previous launches. Technical personnel argued that the flexibility of the O-rings was severely reduced at lower temperatures and that the O-ring´s sealing performance had not been tested below 40°F (4.5°C). The worst case with several O-ring incidents had also occurred at the so far lowest temperature of 53°F. The management at NASA disagreed: every launch (counting 24) since its inception in 1981 had been successful and they argued that there was no evidence of a correlation between O-ring problems and low temperatures. The argumentation from both sides became quite intense and emotional. In the figure below, incidents are illustrated as they were used in the discussions.

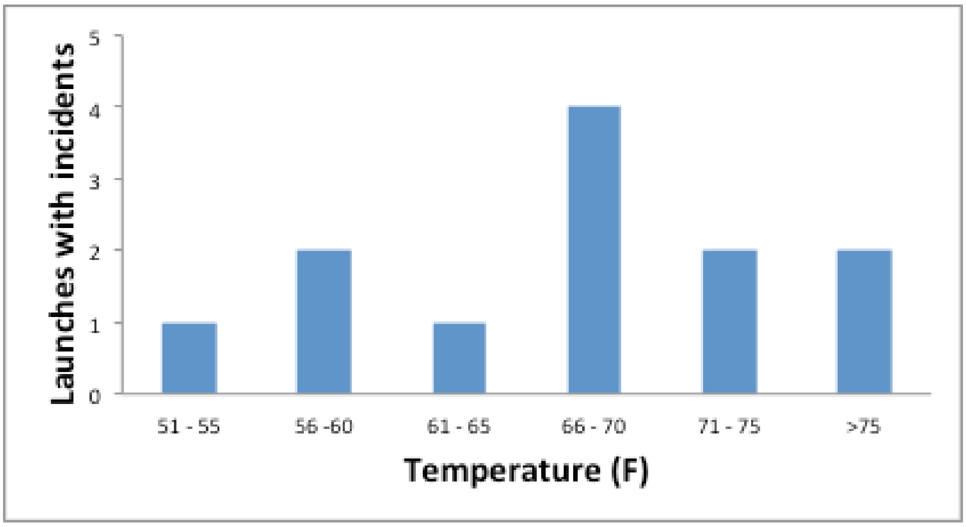

Figure 1. Number of launches with O-ring problems as a function of temperature (F)

As Fig. 1 shows, there had been as many launches with O-ring problems at higher temperatures as at lower (Temperature data from Rogers et.al. 1986, Chapter VI [129-131]). This can be seen as support for the pro-launch arguments made by management who “won” the discussion, but lost the shuttle.

Several cognitive and behavioural processes are relevant for the Challenger launch decision error. The research literature is abundant with experimental studies of different cognitive biases like the optimism bias, anchoring bias, availability bias, confirmation bias, etc. Operant conditioning also played a major role as risk acceptance behaviour over time was shaped towards higher and higher risk, a process named hazard adaptation in this paper. The process was allowed to happen because of the absence of risk acceptance limits and QRA that could have been used to estimate the actual risk. When the decision was made, cognitive dissonance fuelled by self-justification cemented the positions, even long after the accident; as was documented in the BBC video and the accident investigation reports.

The base-rate fallacy

Making a launch decision based on occasions of O-ring problems and launch temperatures as illustrated in Fig. 1 are an example of the base-rate fallacy, because only launches with problems are considered. A base rate fallacy is defined as making judgments of the probability with which an event will occur, and ignore the base rate and to concentrate on other information (Collins English Dictionary 2015). In the Challenger case, the base rate means the total number of launches, and other (irrelevant to safety) information is all the extraneous reasons to launch ("Teacher in space", contract not being signed, etc.). The cognitive bias of base-rate ignorance is well documented (Tversky and Kahneman 1974) and its robust resistance to training and rational thinking may be an indication of a considerable respondent content.

Risk can be seen as a function of the probability with which an event may happen and how severe it might turn out to be, see Aven and Renn (2009) for an overview and a discussion. Gerd Gigerenzer (2002) recommends the use of relative values like frequencies rather than the more difficult concept of probability, as we then are more likely to steer away from deceptive heuristics. Risk is expressed relative to exposure, like the number of events or incidents relative to the number of opportunities for incidents to happen, which is the launch base-rates. When catchy and stereotypical descriptions dominate or replace base-rates, decisions will be based on deceptive heuristics reflecting these stereotypes. Kohler (1996) criticizes the base-rate research tradition for using artificial decision situations, arguing that in real life, people do not ignore base-rates but consider them relative to the situation and to how the information is presented. The situation prior to the launch of Challenger was however indeed realistic, with a potential enormous consequence severity. Did this lead to more rational decision behaviour, or were the decision makers still prone to deceptive heuristics? The latter alternative is more likely, because pressure breeds emotions and decision errors, whether the situation is realistic or artificial.

Gilovich and Savitsky (1996) summarize it elegantly with stating that heuristics are "judgmental shortcuts that generally get us where we need to go – and quickly – but at the cost of occasionally sending us off course”. The off course cost in the Challenger case was the lives of 7 crew members, a 32 months hiatus in the Shuttle Program and an economic additional expense of 5.5 Billion US $.

Hazard adaptation

Major accidents are rare and the contingencies of reinforcement for risk acceptance behaviour are therefore not derived from accidents; they must be artificially produced. Most risk management systems use risk acceptance limits to determine if risk-reducing actions are necessary. The ALARP (As Low As Reasonably Practicable) concept is probably the most used method for that purpose, introducing the possibility of a cost-benefit approach to risk mitigation (French et.al. 2005). In principle, risk decisions shall be based on factual evidence of risk incurred by the chosen alternative compared with other options, provided that these options are within acceptable risk limits. That is the ideal situation; reality is quite different. Valid and reliable evidence of risk level that can serve as discriminative stimuli for risk acceptance behaviour will normally not be available unless proper quantitative risk analyses are conducted. In the absence of quantitative risk data, risk acceptance behaviour becomes susceptible to any source of information regarded as safety relevant, like successful trials without accidents. That explains why recurring incidents have a tendency to be perceived as normal events, and within the acceptable region. The normalization of unwanted events or "normalization of deviance", like the O-ring problems and the loose thermal insulation foam of the Columbia shuttle are both examples of the same phenomenon.

The concept of "hazard adaptation" is proposed here to denote the phenomenon of behavioural drift into accepting (i.e. not reacting to) higher risk levels. It is similar, but not equal to, risk compensation known from traffic safety as studied by Elvik (2004) and audit risk studies by Vrolix (2006). Risk compensation occurs when individuals adjust their behaviour after the introduction of a safety measure so that some of the extra safety margin is used, not for safety, but for some other purpose, like increasing the riskiness of the driving behaviour as pointed out by Dulisse (1997). Hazard adaptation is different in the sense that it is a culturally selected behaviour shared by a group of people. Conformity is obtained through imitation or model learning (Bandura 1971), by reinforcement of followers and punishment of the opposition. In the absence of quantitative risk acceptance limits and QRA, risk acceptance behaviour may thus become a form of "group think"; a concept introduced by Janis (1971).

Hazard adaptation fills the gap between social structure and the individual decision maker. It refers to risk acceptance behaviour that has undergone discrimination learning; a fundamental learning process of operant and respondent conditioning (Catania 2013). The behaviour "risk acceptance" is differentially reinforced and brought under control of ever more frequent and/or serious incidents. This may happen without awareness by those undergoing the learning process. The learning effect is not detected because no accident happens and because risk is not measured, opening up for the base-rate fallacy and hazard adaptation to do it’s quiet and callous work. Because the discrimination learning happens gradually and over a considerable time span, and due to the stochastic nature of risk, the slide towards more lenient risk acceptance behaviour is extremely difficult to recognize.

Cognitive dissonance

Cognitive dissonance was originally studied and labelled by Festinger (1957). According to Bem (1967), ‘..if a person holds two cognitions that are inconsistent with one another, he will experience the pressure of an aversive emotional state called cognitive dissonance, a pressure he will seek to remove, among other ways by altering one of the dissonant cognitions’.

In behaviouristic terms, cognitive dissonance can be understood as being produced by a form of negative reinforcement contingency, resulting in either escape or avoidance behaviour. Escape behaviour terminates the aversive stimulus, while avoidance prevents it from occurring and thus insulates the behaviour from the reinforcement contingencies that produced it in the first place. Avoidance behaviour can be maintained by conditioned aversive stimuli, like arguments and warnings with reference to the negative outcome. If strong conflicting emotions and values are involved, such behaviour is difficult to modify (Lerman, D. C. and Iwata, B. A. 1996), especially when those trying to persuade represent the aversive situation. Risk signifies at the same time both something negative with possible fatal outcomes, and something positive (deliver what is expected), and is therefore a classical cognitive dissonance contingency. Opinions of risks tend to be emotional, and accusations of risk as too high or acceptably low may prompt reactions of blame towards the opposition and self-justification towards one self's position.

In a cognitive dissonance interpretation of the launch discussions, one might say that two incompatible versions of NASA were represented: a responsible agency that serves the president and the nation, versus an irresponsible agency deliberately risking the lives of seven astronauts. NASA management solved the dissonance by strengthening the belief in launch success through refusing to accept any correlation between low temperatures and reduced sealing effect of the O-rings. In fact, such a relationship was not even investigated, as is typical of avoidance behaviour, although relevant data were available at the time. Quick risk estimation could easily have been done, e.g. using the approach described in the following section.

4. A simple risk analysis

Would compelling evidence of the considerable risk level due to the low temperature be enough to trigger a decision to postpone the launch? According to Hubbard (2009), even a simple risk analysis may provide an adequate basis for decision-making; if it is quantitative and based on factual evidence. Such a simple risk analysis does not take more than a few hours to conduct if the relevant raw data are available, as they were in the Challenger case. You need however to know what to look for and how to process the data. In any risk analysis it is important to define precisely the subject matter of the analysis, which normally is - in general terms - unwanted incidents that may lead to system failure. In the Challenger case it was O-ring problems that might lead to loss of mission. To state that the subject matter is launches with O-ring problems as shown in Fig. 1 is both inaccurate and misleading. It is therefore necessary to count the number of incidents. A single launch may contain none, one or several incidents.

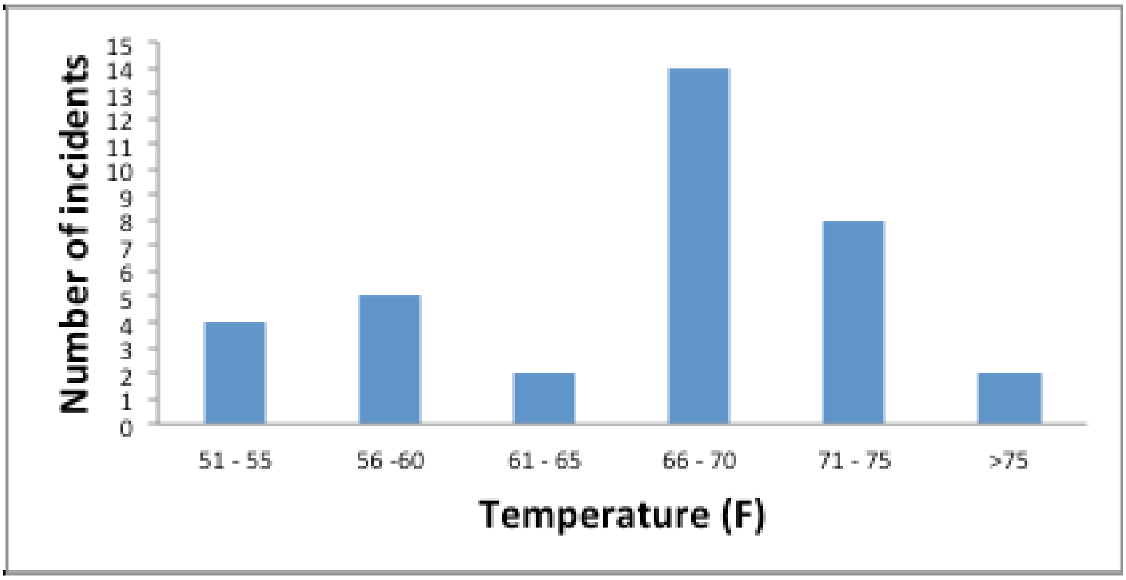

Figure 2. Number of O-ring incidents as a function of launch temperature

Launch STS-51C with Discovery experienced four incidents that occurred at a temperature of only 53 degrees F; the only launch at the temperature interval of 51-55 degrees. In a more thorough risk analysis, the incidents would be evaluated with respect to their seriousness, like the number and quality of remaining barriers. But in this example case based on empirical data, all incidents are treated as equal.

Only considering launches with problems is an example of base-rate ignorance or fallacy. Base-rates are equivalent to opportunities for error, i.e. the number of launches.

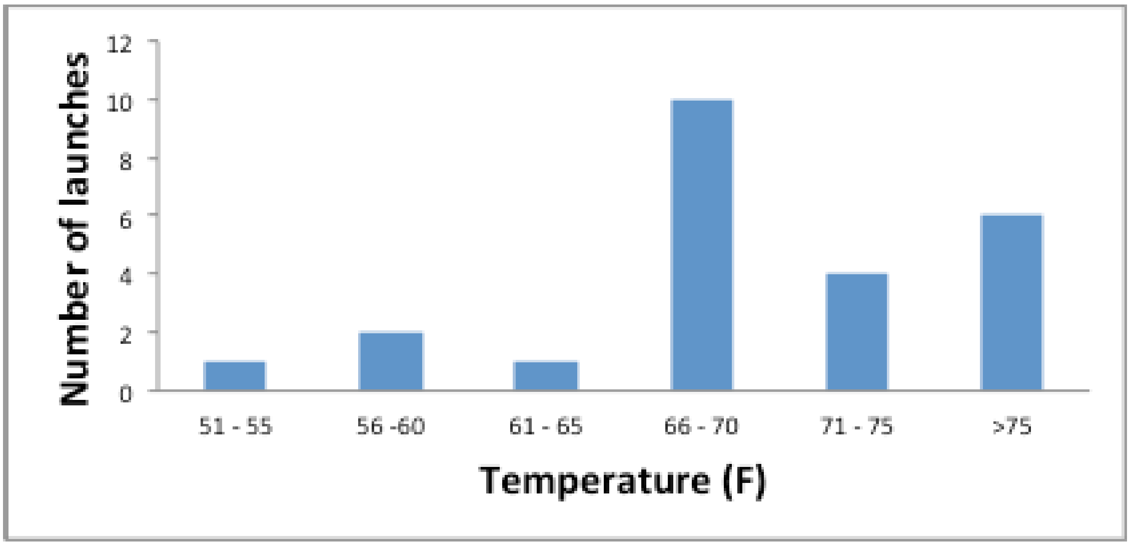

Figure 3. Number of launches as a function of launch temperature

To complete the simple risk analysis, the number of incidents must be divided with exposure, i.e. how often the problem had the opportunity to occur. In other words, information shown in Fig. 2 and Fig. 3 must be combined to show the incident rate per launch. This is achieved by dividing the number of incidents by the number of opportunities, i.e. the base-rates. This is illustrated in Fig. 4 where the rate (per launch) of O-ring problems is presented. By taking exposure into account, it is now much more difficult to claim that there is no relationship between O-ring problems (i.e. risk) and low launch temperature.

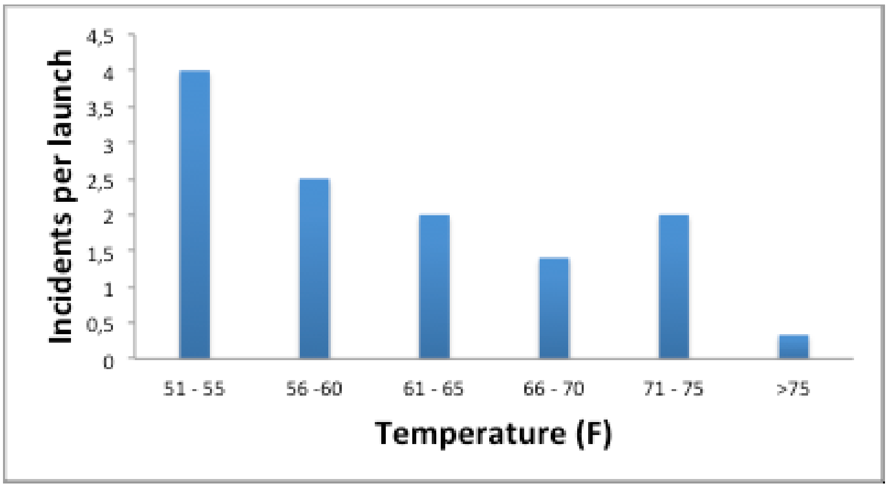

Figure 4. O-ring problems per launch as a function of temperature

To remove any doubt, the manufacturer's lowest testing temperature and the launch temperature of January 28 1986 for the Challenger shuttle was added as shown in Fig. 5. A line graph replaces the histograms to visualize the trend in risk level as the temperature decreases.

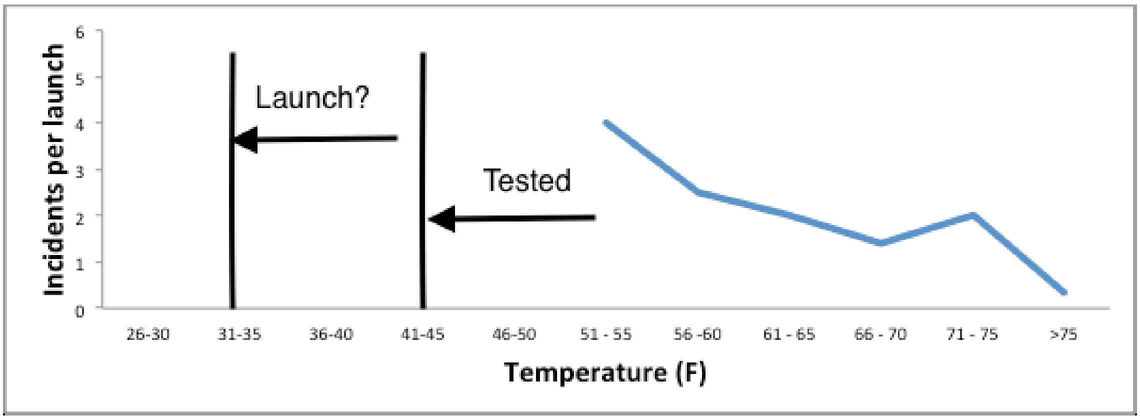

Figure 5. O-ring problems per launch including test and launch temperatures

Another feature that should be included in a risk analysis is change in O-ring failure rates over time. According to the report from the Roger Commission, there were twice as many O-ring incidents the last 12 launches as in the first 12. The trend towards more frequent and serious incidents continued. In 1985, the year before the disaster, 7 of the 9 launches experienced O-ring problems. Although technical personnel reacted, management did not pay attention to the increasing risk. Hazard adaptation was at work.

5. Discussion

The main component of risk acceptance behaviour is– or rather should be - operant behaviour, i.e. rational behaviour that is selected and modified by the consequences it produces. Risk acceptance had over the years been shaped and brought under discriminative control of increasingly higher risk levels through differential reinforcement, a learning process called hazard adaptation in this paper. The concept of hazard adaptation provides the missing link between descriptions of the organization and the individual behaviour. Hazard adaptation occurred due to lack of quantitative risk acceptance limits and quantitative risk measurements and calculations.

The safety management efforts of NASA were rather comprehensive and included incident reporting, hazard analyses, critical items registrations and Failure Mode and Effects Analysis (Shuttle Criticality Review and Hazard Analysis Audit 1988). These activities were however not sufficient to establish the correct kind of discriminative control of the risk acceptance behaviour so that sufficient safety margins were maintained. In the absence of quantitative and objective risk information, opinions regarding risk can easily become a battlefield of conflicting, emotionally loaded arguments due to the cognitive dissonance contingencies. Risk is an abstraction, and often highly uncertain due to lack of information or because existing information is interpreted differently depending on other motives. Risk acceptance behaviour may therefore be influenced in the direction matching the opinion of the strongest stakeholder.

Would the presence of a behavioural scientist in a top management team make any difference? It is unlikely, because cognitive dissonance contingencies produce behaviour that is extremely robust towards change (Tavris and Aronson 2013). Another reason might be that soft (behaviour) science is seen as having less merit than hard science. The negative notion of psychology as a soft science in a culture of hardnosed space engineers and managers would impede any serious impact. The job of managers is to make decisions, and when the going gets tough, the tough (manager) gets going. The result may be the development of a management culture in high-risk companies characterized by ´heuristic´-based decision-making disregarding open-mindedness.

7. Conclusions and further study

As there is no behaviouristic risk management system in operation that includes decision errors, a look at some of the better approaches to SMS might be a start. ICAO (2013) and the ARMS Working Group (2010) have proposed risk based SMS as a mandatory requirement for aviation operators and national regulators. Both event risk, like in the Challenger example, and more comprehensive safety issues are addressed. Other high risk industries are also in the process of implementing risk based SMS, so the future seems promising. The contribution from behaviour science is however still rather negligible. This unfortunate state of affair for the "soft science" part might be attributable to the lack of a unifying theory that integrates the different behavioural research disciplines. The most promising research fields are experimentally based cognitive science, radical behaviourism and brain science. Findings from the two first mentioned disciplines were used in this article.

Risk and uncertainty are not easy concepts to understand, partly because the base-rate fallacy can bring us astray. One way to get the message through is to explain the case using a story we all can relate to. Imagine that someone were to allege that a Volvo is a more dangerous car than a Ferrari, because over the course of a year there are more accidents involving Volvo cars. We know this conclusion to be dubious because we cannot limit the analysis to the number of accidents, but must also consider how many cars there are and the annual mileage of the two. In other words, we must take exposure or base-rates into account. Only then is it sensible to compare accident risks of the two car types. In the Challenger case, we must include all launches, not only those launches that contained O-ring problems. An indication of risk related to temperature can then be derived by looking at the incident rate per launch as a function of temperature.

Behaviour scientists and risk analysts have a common understanding of the importance of base-rates. If they are in a position to influence high-risk decisions, lives can be saved. To understand risk levels and trends, quantitative risk analyses are needed. To understand and avoid decision errors, relevant cognitive bias and the contingencies of reinforcement of risk acceptance behaviour must be analysed. By combining the two, a powerful recipe for an approach to risk management where decision errors are included may emerge.

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