**Individual Dynamic Risk Analysis (iDRA): A systematic review and network model development.**

[Authors and affiliations removed for double blind review]

**Abstract**

Dynamic Risk Analysis (DRA) is a continuous, adaptive process of risk evaluation that can play a fundamental role in the prevention, control and mitigation of new or changing risks in real time. In order to better understand DRA, a systematic review was conducted, followed by thematic analysis and the development of a network model. This model depicts weighted and directional connections to reveal the significance of information and decision making in managing dynamic risk. The research also reveals that people follow rules to a point but will then adapt to meet the challenge of unexpected circumstances. The influence of the environment is also evident, as it cannot only create unique risks but exacerbate existing ones. Throughout the literature there is some debate regarding the use of qualitative and quantitative risk assessment methods in managing dynamic risks. However, when allied with DRA, greater resilience may be added to safety management systems. Considering the factors identified in this research offers a new approach to the problem of managing new or changing risks. What this now means in practical terms is that there is potential to develop a syllabus for DRA training.

**Keywords:** Dynamic; risk; safety;operations; accident

**Introduction**

On 15 January 2009, US Airways flight 1549 famously ditched into the Hudson River after striking a flock of geese shortly after take-off. Having experienced a total loss of thrust from both engines, there were just four minutes from the moment of impact to the time of ditching. During this relatively brief period the pilot had to evaluate the situation, follow bird strike and engine failure protocols, communicate with Air Traffic Control (ATC), monitor engine diagnostics, consider the crew and passengers, identify possible courses of action, then select and implement a new flight plan. Arguably, it was the unconventional actions of the captain and flight crew on the day which saved the 155 persons on board (National Transportation Safety Board, 2010).

In stark contrast, the 1988 Piper Alpha oil disaster claimed 165 lives of the 226 persons on board, becoming the worst accident involving offshore oil operations in history. After an initial explosion from a gas leak, in less than two hours the entire platform was incinerated and collapsed into the sea. Of note, 81 of the deaths occurred in the accommodation block while personnel awaited rescue (Department of Energy, 1990a). What is significant is that the individuals who survived arguably only did so because they had assessed the prevailing risk and ignored what they had been told to do in the event of an emergency (i.e. they left the muster area and jumped from the platform into the sea). After the Piper Alpha disaster, the Cullen Report (Department for Energy, 1990b, p.355) highlighted the issues associated with an excess of regulation, policy or rules. In acknowledging that some legislation was necessary, it stressed that detailed rules could not possibly encompass all possible variations encountered in the workplace.

It is evident that written procedures are not a guarantee of safety. DRA stands out because it is an opportune, context specific and potentially controversial activity. As with any skill, it must be appropriately understood and then practiced in order to be accomplished proficiently. In both the US Airways and Piper Alpha scenarios, the dynamic nature of the risks were arguably known. What became critical was the dynamic analysis of the unexpected and changing situation. In both instances it was the combination of situational awareness and knowledge, allied with effective, quick decision making and willingness to act, that saved life.

Quantitative and qualitative risk assessment methods are an established element of any conventional safety management system. These entail the identification of potential hazards associated with an activity or process, plus an estimation of their likelihood and the severity should they materialise (Health and Safety Executive, 2019). Ordinarily, these are conducted prior to commencing an activity or process and routinely integrate with policy and procedures. They are not necessarily undertaken by those persons who will be responsible for their implementation. Conversely, DRA is synonymous with dynamic analysis and decision making in unexpected or changing conditions, where the risk is arguably greater, time may be limited and the opportunity for dialogue passed (Flin et al., 2008). While DRA can occur at every level of the risk management framework (Rasmussen, 1997), it is predominantly evident at the sharp end where activities or processes are conducted. In reality, this means that the persons situated to deal with the risk may not necessarily be trained or sufficiently experienced to do so effectively. It is because of this differentiation that this study will move away from the more conventional probabilistic and qualitative risk assessment methods to examine the concept of individual DRA (iDRA). The resulting information (model) will be used to develop and test a training framework for individual Dynamic Risk Analysis. This will be achieved in four stages:

1. Conduct a systematic review using Scopus, Web of Science & Google Scholar.
2. Carry out a narrative synthesis to produce a scree plot and identify key factors.
3. Use the key factors from the scree plot to develop an illustrative network model of DRA.
4. Explain the model using the US Airways flight 1549 and Piper Alpha scenarios.

In order to develop a network model of iDRA it is necessary to first understand the concept in detail. While there are a number of ways to achieve this, this research centres around a systematic review followed by a themed analysis.

**Method**

After preliminary trials, the search terms adopted were “risk\* AND (dynamic OR operat\*) AND (safe\*)”. There was no requirement to include additional items such as ‘management’ or ‘assessment’, as these would emerge naturally. The ‘operat’ word was included as the scoping study identified that the terms dynamic risk and operational risk were being used interchangeably in some fields (Yang et al. 2018; Barua et al., 2016; Kongsvik et al. 2015).

Using Scopus, the initial search returned 435,319 results (conducted 8th August 2018). Limiting the document type to articles, articles in press and reviews marginally lowered this figure to 342,012, which was then significantly reduced by applying inclusion and exclusion criteria (listed at Table 1 below). The remaining 8,050 articles were reviewed initially by title, abstract and keywords. Those which could be specifically associated with dynamic or operational risk, were retained; those which were deemed irrelevant, had no safety inferences, were incomplete or unavailable as full text were excluded. As Scopus could not retain more than 2,000 articles in archive this was accomplished by saving and reviewing the results by source Journal.

**Table 1.** Inclusion and exclusion criteria.

|  |  |
| --- | --- |
| **Inclusion** | **Exclusion** |
| Articles, Articles in Press, Reviews  English language only; full text online | Books, Conference papers, Surveys, Incomplete texts, Items which had to be paid for. |
|  | Subject Areas: Accounting, Astronomy, Biochemistry, Business, Computer Science, Dentistry, Earth & Planetary Science, Economics, Econometrics, Finance, Genetics & Molecular Biology, Immunology & Microbiology, Management, Materials Science, Maths, Physics, Veterinary. |
|  | Probabilistic and Qualitative risk assessment |

The 166 remaining documents were then re-examined, to ensure the explicit search criteria had been met, and then read in full to confirm suitability. A final count of 43 were subjected to a full text analysis, where the researcher read each document to identify key factors or themes. Meta-analysis was unachievable due to heterogeneity, so a narrative synthesis method was adopted to produce data. The process was subsequently repeated (20th December 2018) using Web of Science (version 5.31) where the initial search identified 73,428 documents. These were reduced to 3,457 after the application of the inclusion and exclusion criteria. The remaining 69 papers were reduced to 23 after a full text review. Finally, the sequence was repeated using Google Scholar (10th January 2019). Due to the lack of technical features, it was difficult to apply the same degree of rigor when conducting searches and applying selection criteria. Ultimately, the initial search revealed over 1.59M results which was then reduced to 1.46M by limiting results to journal articles and excluding patents or citations. Sorting by relevance rather than date mostly presented items which appeared in the other two searches. Ultimately, the first 100 results were sifted and gave just two additional articles, as shown in Table 2.

**Table 2.** Summary of the systematic review process.

|  |  |  |
| --- | --- | --- |
| **Scopus** | **Web of Science** | **Google Scholar** |
| Initial Search | | |
| 435,319 | 73,428 | 1.58M |
| Remainder after application of inclusion & exclusion criteria | | |
| 8,050 | 3,457 | 1.46M |
| Remainder after review by title, abstract and key words | | |
| 166 | 69 | 49[[1]](#footnote-1) |
| Remainder after full text review and removal of duplicates | | |
| 43 | 23 | 2 |
| **Total papers selected = 68** | | |

The distribution of source journals for the final selected papers is indicated at Figure 1.

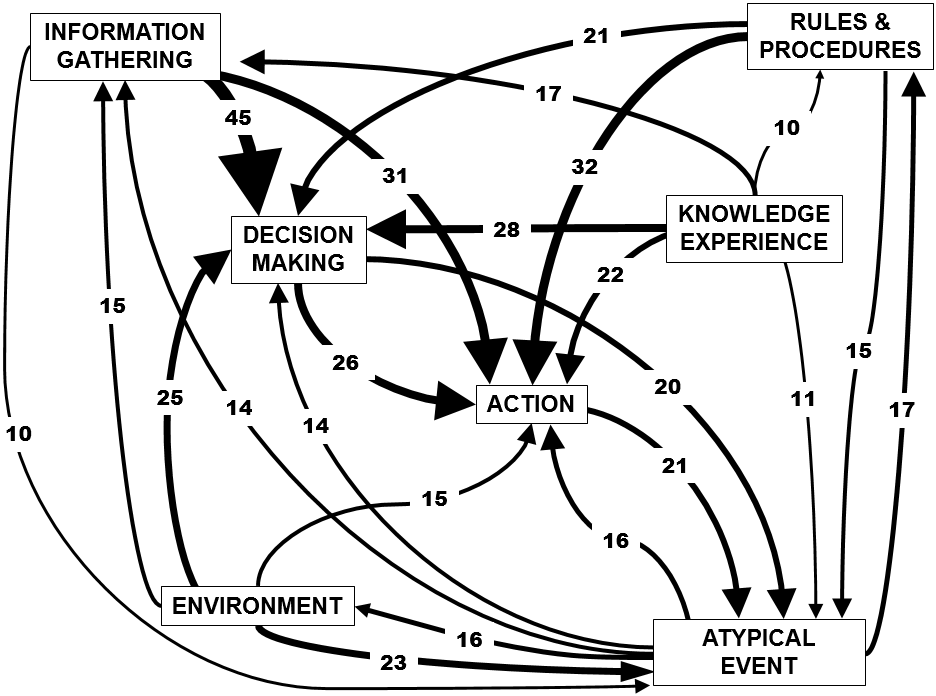
**Figure 1.** Publication sources by name showing percentage of papers from total.

**Figure 2.** Plot of the principal themes in order of frequency (out of 68 papers).

Following the selection of articles, a thematic analysis was conducted (Braun and Clark, 2006). Using a grounded theory approach, papers were individually codified to identify factors and categories (Corbin et al., 2014, and Wolfswinkel, Furtmueller & Wilderom, 2013). This enabled a scree plot of the factors to be generated (Figure 2). Subsequently, data for the network model was obtained by reviewing the articles and identifying links between themes. When this occurred, the nature and direction of the influence was physically annotated on the document for the record. To assist in the mitigation of bias, an independent researcher read and assessed ten randomly chosen papers in full. An agreement of 93% was found, which is considered within acceptable tolerances (Forster et al., 2019; Heikoop, et al., 2016; Parnell, et al., 2016; Rafferty et al., 2010). In order to concentrate on the most relevant factors, the cut-off was defined as the first significant drop in frequency from the most prevalent factor (the red line in Figure 2).

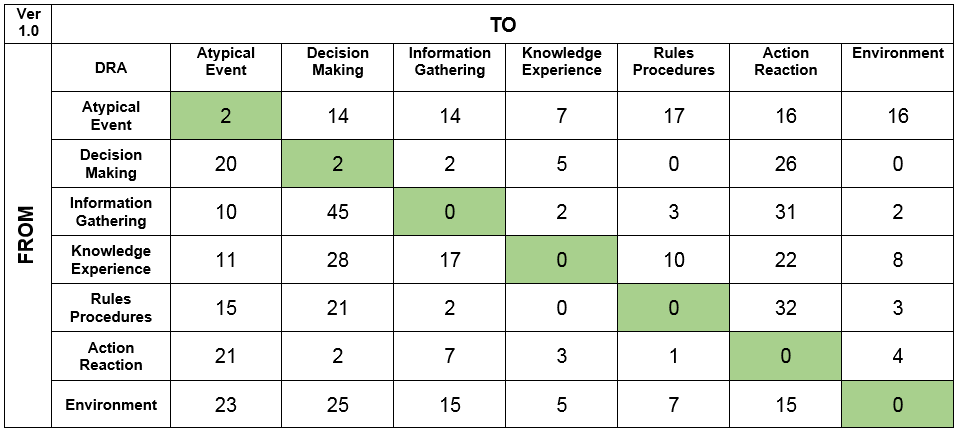
**Results**

Seven themes fell above the threshold cut-off; atypical event, decision making, information gathering, knowledge and experience, rules and procedures, action, and environment. These have been represented in Figure 3 as a network model that depicts the relationships and connections between the themes. Arrows are used to demonstrate the direction of influence and the numbers relate to occurrences within the literature, which is also visually represented by line thickness.



**Figure 3.** Network Diagram of the seven principal factors in DRA showing influence.

To avoid including excessive information, thereby cluttering the model or omitting key information (Wild and Hoppitt, 2019), the network value cut-off point for inclusion in this model was taken from scores with values above the mathematical average for the data (Figure 4).



**Figure 4.** Number of links between network factors (out of the 68 papers).

Each factor will now be discussed in more detail:

**Factor 1: Atypical Event**

The single most common factor identified within the review was an event that deviated from the norm. The results identified a variety of terms and these have been collated under the concept ‘atypical’. Examples include reference to the unexpected, unforeseen (Villemain and Gordon 2017), undesirable (Jocelyn et al., 2016), adverse (Favaro and Saleh 2016), unpredictable (Mauelshagen et al., 2013) unplanned, unwanted (Kongsvik et al., 2015), hazardous (Yang and Haugen, 2015; Knegtering and Pasman et al., 2013), novel (O’Keeffe et al., 2015), abnormal (Adedigba et al., 2018; Hayes, 2012) and extreme (Hardy and Comfort, 2015). The term ‘accident’ featured frequently, and circumstances ranged from risks which were known and prepared for (Chang et al., 2016) to totally unpredictable, catastrophic events which had never previously occurred (Murphy and Conner, 2012). Grote (2015) investigates uncertainty and also suggests that some events can be rare, stemming from the coincidence of known circumstances, or unpredictable.

By their nature, atypical events may create knowledge and information that stimulates decision-making which leads to action. They can also transpire from the presence or absence of the other network factors, such as poor decision-making, insufficient information, action that is slow or inappropriate, or extreme environmental factors. Perhaps more obviously, they can also adversely influence the natural or the working environment. In some cases, stringently following rules and procedures, using previous knowledge or inappropriate application of personal experience are also known to have led to an accident (Scott-Parker et al., 2018). This then raises the question of how to mitigate risks which cannot be quantified or are not reasonably predictable.

Such occurrences are typically characterised by uncertainty (Pasman et al, 2018; Yu et al. 2018; Zhang et al., 2018; Cuvelier and Falzon, 2015; Grote, 2015;), time and resource pressures (Kongsvik et al., 2015), complexity (Adedigba et al., 2018; Pate-Cornell and Regan, 1998; Bolsover, 2015), and generate situations that personnel were unprepared or untrained for (Jocelyn et al., 2016). An observation from the research is that an atypical event can also lead to a subsequent atypical event, as reflected in the US Airways incident where the double engine failure at low altitude led to a successful ditching.

Such occurrences offer opportunities for learning (Sujan et al., 2017) and may lead to the generation of knowledge and skill in those involved, whether directly or indirectly. Hopper and Dean (1992) find discussion regarding accidents limited and suggest that learning from experience is invaluable, especially where a fatality or serious injury has occurred. Ideally, any experiential learning will be communicated throughout the organisation, with rules and procedures being reviewed and updated routinely. Subsequently, after an atypical event, a variety of safety related products including reports, guides, regulations and standards may be introduced (Jocelyn, et al., 2016). Summala (1996) notes that accidents may lead to regulatory reform or higher levels of enforcement, as well as an increase in assurance activities. Equally, failure to learn from experience may lead to further accidents (Pasman et al. 2018).

**Factor 2: Decision Making**

Decision-making is taken as meaning ‘*the process of reaching a judgement or choosing an option, sometimes called a course of action, to meet the needs of a given situation”* (Flin et al., 2008, p. 41). The research reveals that although all other factors lead into, and thereby influence, decision making, the decision-making itself influences only two other elements within the network - either action or an atypical event. Again, this may have positive or negative connotations; the action may be appropriate or inappropriate and the atypical event may be managed or increased. Kongsvik et al. (2015) suggest flawed decision making to be a central contributory factor in major accidents. Yang and Haugen (2016) review how operational decisions impact risk and find that accidents can stem from poor decision making. They also note how dynamic events encountered during operations might necessitate instantaneous decision making. The research also identifies that decision making can lead to further decision making.

Operational decisions may be influenced by various factors. According to Yang and Haugen (2016), they depend on immediacy, the information available, the person making the decision, and the significance of the decision itself. Summala (1996) identifies risk perception as a factor whereas Gilbert et al. (2007) found hazard proximity and level of authority to be influential. Kongsvik et al. (2015) acknowledge that decision making in emergency situations is time pressured and has differing priorities to routine decision making. Hardy and Comfort (2015) note that decision making in extreme, high-risk situations can be more complex. They also suggest that, in these situations, decision making veers more towards experience as the technical manuals and rule books can become ineffective. This is echoed by Pasman et al. (2018) who establish that decisions based on skills may be quicker than those based on rules. Grote (2015) uses the nuclear disaster at Fukushima to illustrate how culture can influence decision making.

Rosness (2009) analyses decision making in detail and observes that not all decisions lead to action; the decision to do nothing is still a decision. Hayes (2012) suggests that short-term decision making is an integral part of daily workplace activities. Cuvelier and Falzon (2015) consider the trade-off between understanding and action when making decisions in dynamic situations, when time or resources are limited, suggesting adaptation to be a key trait. Some researchers have also referred to ‘heuristics’ (Rasmussen, 1997; Halvorsen, 2016; Cuvelier and Falzon, 2015) in managing dynamic conditions, where judgements are employed to achieve a reasonable solution.

It is evident that monitoring risk and exploiting information aids decision-making (Jocelyn, et al. 2016). Monitoring activities enhance situational awareness and potentially allow people to appreciate the time available in which to make the decision (Favaro and Saleh 2016). Real-time monitoring is found to reduce the surprise factor and allows operators to better understand the risk picture, which subsequently supports decision making (Paltrinieri and Reniers, 2017). Villa et al. (2016) suggest real-time monitoring to be the main process in managing dynamic risks.

**Factor 3: Information Gathering**

Information affects the ability for people to make decisions and take action (Halvorsen, 2016). Information is taken as meaning *‘facts or details learned about something’* (Collins English Dictionary, 2019). Information can stem from many sources, via technical interfaces (alarms, gauges, monitors and indicators), through the human senses (sight, sounds, smells), by human interaction (being conveyed), or simply from past experience. It can also be real-time, or it can be delayed. In the research, the link from information gathering to decision making offers the largest value from the entire range of data (see Figure 4). The significance of this is not lost as real-time information is found to be crucial in decision-making (Chang et al., 2016).

Haugen (2016) offers that decisions are made using the information available at the time. Therefore, the quality of the information will likely reflect the quality of the decision. In dynamic situations there is clearly a balance to be achieved between the time taken to gather and assimilate the information and its timeliness in being available to support the decision. This idea is acknowledged by Cuvelier and Falzon (2015) who observe that taking time to gather information can delay decisions and actions. To mitigate his problem, Yu et al. (2018) advocate communicating any relevant information to aid decision making, even if it means socialising uncertainty.

Although information can be obtained through a variety of means, itstill requires a degree of analysis and interpretation (Fang et al., 2018). Rezvani and Hudson (2016) found the analysis and sharing of information to be the most common role of middle managers. They also identified that multiple sources of information, when linked, can improve the risk picture and more information allowed management to react to events sooner. In some circumstances, the information required may relate to rules and procedures relevant to the situation, and failure to follow these can result in fatality (Lofquist et al. 2017). In complex situations, it is feasible that not all protocols will be known. Therefore, if the relevant information is not available when needed, then decisions are likely to be based upon what is understood at the time, even if it is in violation of the rule(s). This notion is reinforced by Jackson et al. (2013) who found rule compliance to deteriorate in failing situations.

It is evident that qualitative and quantitative risk evaluation methods can be used to provide information and prepare workers to deal with dynamic events. Information gained through risk assessment is an important aspect of risk management and decision-making (Molesworth et al., 2006). Villa et al. (2016) endorse this view but note that different risk assessment or analysis methods can generate different information. However, there are a number of areas of debate when considering different approaches to DRA, such as flexibility and adaptability (Villemain and Godon, 2017; Zhang et al., 2018) the capacity to cater for complex situations (Khan et al., 2018; O’Keeffe at al., 2015), or the ability to accommodate real-time risk (Yang et al., 2018; Favaro and Saleh, 2016).

**Factor 4: Knowledge & Experience**

Knowledge and experience are factors synonymous with the human aspects of a safety system. Where knowledge relates to acquired information and understanding (Collins English Dictionary, 2019), experience is more about the acquiring of skills and the practical application of knowledge. At a fundamental level, knowledge and experience facilitate decision making via an ‘IF-THEN’ logic. Therefore, those with more experience can arguably draw from a greater resource than those without (Scott-Parker et al., 2018). This also helps maintain attention by reducing mental load, thereby enhancing the speed and confidence in which decisions are made.

From the research, it appears that knowledge and experience are used as a means of mitigating uncertainty surrounding workplace risks (Gilbert et al., 2007) or when rules are incomplete (Hopkins, 2011). They are also shown to expedite decision making in some situations (Villemain and Godon, 2017). In the context of dynamic risk, Rezvani and Hudson (2016) suggest knowledge is vital for manging complex situations. However, there are limitations and the context of the workplace appears key; a lack of knowledge may be considered dangerous as the consequences of decisions, or intricacies of a scenario, may not be properly understood (Abrahamsen et al., 2018). This is reinforced by Jocelyn, et al. (2016), who cite a lack of experience as one of the main factors in workplace accidents, and Khan et al. (2018), who highlight issues associated with inadequate technical knowledge. Vidal-Gomel (2017) argues that worker experience is only relevant in the context it was gained.

Mental models arguably play a major role in situational awareness. Hardy and Comfort (2015) note that, in recognition primed decision making, learning from experience is key, as responders can draw on this to create a plan of action. That said, there is evidence to suggest that the application of wrong schema can not only lead to poor situational awareness (Scott-Parker et al., 2018) and incorrect assumptions (Rafferty et al. 2010), but invoke inappropriate decisions (Walker and Latosuo, 2016; Dien, 1998). Similarly, Hopper and Dean (1992) show that experience can actually lead to complacency and provide several examples of where this has resulted in worker injury.

The influence of knowledge and experience is not restricted to the individual level. In considering distributed cognition, the knowledge and experience of individuals within the system may be shared or combined to achieve a solution (Chatzimichailidou et al., 2015; Llory, 1997). There also appears a relationship between rule compliance and the application of experience. While rules can be used to guide behaviour, the introduction of local knowledge and personal experience may in fact result in different actions being conducted (Yang and Haugen, 2016; Summala, 1996). This may be essential when trying to comply with an excess of rules and procedures whilst concurrently reacting to atypical events (O’Keeffe at al., 2015). Mauelshagen et al. (2013) note how risk-based decisions draw heavily from experience, which facilitates a more flexible approach to problem solving than rule compliance alone. Hayes (2012) suggests that conforming to rules remains the foremost consideration but experience and technical knowledge ultimately steers decision making.

**Factor 5: Rules and Procedures**

The results of the review identify a strong reliance on rules and procedures when operating in a safety context. Such items range from the strategic legislative and regulatory artefacts to the lower tier, operating procedures and local protocols. In almost every case there is acknowledgement that rules and procedures should be followed but acceptance that this may not be possible in some circumstances. Indeed, rules and procedures are no guarantee of safety (Gilbert et al.,2007; Dien, 1998) and accidents still happen even when rules are adhered to (Morel and Chauvin, 2006). There is common understanding that rules and procedures cannot cover all contingencies (Pasman et al., 2018; Rasmussen 1997; O’Keefe et al., 2015). Generic procedures cannot cater for localised variations, so adaptation can occur (Hale and Swuste, 1998; Yang and Haugen, 2018). Hopper and Dean (1992) reveal that they are not always appropriate and may in fact increase risk.

The idea of managing risk dynamically raises a number of interesting issues when considering rule compliance (Hopkins, 2011). O’Keeffe at al. (2015) studied how rules in the workplace were applied in practice and identified two principal influences - time available and knowledge. They also propose that a notional boundary of acceptable risk is used to limit procedural adaptation. However, if an atypical situation occurs, the established operating envelope may flex (Hayes, 2012). In considering rules and procedures there is a balance to be met. Lofquist et al. (2017) identified that overly prescriptive rules and stringent rule compliance regimes grant no capacity to adjust to unexpected situations; if too ambiguous then they may be ineffective, as experienced in the Ladbrook Grove rail collision (Stanton and Barber, 2008). Similarly, incomplete or missing procedures can also result in unwanted consequences (Knegtering and Pasman, 2013). O’Keeffe at al. (2015) challenge strict rule compliance in favour of a more general, adaptive, risk focused approach, where rules should be seen as adaptable in complex situations. Similarly, Wears and Hunte (2016) argue that procedures should support unpredictability rather than constrain it. Grote (2015) argues the case for flexible rules in order to help mitigate uncertainty. Dien (1998) perceives the issue from a different perspective and argues that the use of strict rules means that the workforce doesn’t need to be as skilled.

Although accidents can be triggered through a failure to comply with rules, in many contexts, rule adaptation may be considered a regular aspect of work best managed locally (Hale and Borys, 2013b). Sometimes, when dealing with uncertainty, local rules are permitted. Molesworth et al. (2006) found rule interpretation correlated with the risk level - the greater the risk then the more rules were interpreted to suit a situation. Hopper and Dean (1992) argue that atypical events can lead to development of, or changes in, regulation. According to Rochlin (1999) “…*operational safety depends on more than a set of observable rules and procedures*”. Paltrinieri and Reniers (2017) reveal how atypical events can be triggered when attempts are made to conform with inappropriate regulation.

**Factor 6: Action**

The management of dynamic risk typically necessitates action. This may be a single isolated act or circumstances may necessitate a series of corresponding or lower tier actions in order to accomplish an overarching objective. Rezvani and Hudson (2016) outline how information leads to decision making, which subsequently leads to action. This action may be to carry out an instruction but may also be to ask for further information, seek clarification, contest a proposal or to even to do nothing. Favaro and Saleh (2016) advocate that action is triggered by information, an idea strongly supported by the DRA network model (Figure 3). O’Keeffe at al. (2015) note how actions are dynamically re-evaluated in light of new information. In an adverse event, safety interventions aim to prevent escalation or lessen the impact. Hopper and Dean (1992) illustrate how speed of action can avert disaster. Interestingly, Gilbert et al. (2007) suggests an atypical event will invoke less shock to a system if a normal work setting maintains safety by making continuous adjustments.

Kongsvik et al. (2015) propose that action can either be the result of a deliberated decision or occur as an immediate response, where there is no period of contemplation. Villemain and Godon (2017) find reactive actions to be the most frequent, a notion already established elsewhere (Kahneman, 2011). Depending on the situational context this may be a positive or negative trait - an appropriate, timely response may mitigate the risk where acting too quickly, without full situational awareness, could intensify it. Depending on the situation, Sujan et al. (2017) suggest experience and expertise will guide action, which can be derived from conscious decision making or triggered intuitively. Hale & Borys (2013a) discuss ‘action rules’, where rules are used to guide actions, and discuss the idea of translation where the action taken is founded on contextual interpretation. Yang and Haugen, (2018) indicate that system familiarity facilitates quicker action and may prevent undesirable situations from deteriorating further. In certain situations, the taking of action alone may not be sufficient and that monitoring the effect of the action, as well as the reactions of others, may be required. Unfortunately, as Perry and Wears (2012) suggest, managers have the tendency to attribute the absence of incidents to an effective system rather than the actions and operational adjustments being made by workers.

In some instances, rule interpretation and procedural compliance can be a significant factor in determining a course of action (Morel and Chauvin, 2006; Hayes, 2012). Hayes (2012) also finds actions can be based on a ‘line-in-the-sand’ approach where managers use their experience and judgement to determine an action. Hardy and Comfort (2015) assert that, in extreme events, actions need to be coordinated or else the situation may be intensified. Jocelyn, et al. (2016) offer several examples where both action (e.g. circumventing safeguards and adapting machinery) or a lack of action (e.g. inadequate training, absence of procedures, and lack of risk assessment) have contributed to accidents with machinery.

**Factor 7: Environment**

The final factor, environment, plays a key role in two distinct ways. First, there is the

physical environment, which includes aspects such as weather, temperature, altitude, sea conditions, geology, and so on. Second, there is the organisational environment where socio-technical interactions and workplace relationships influence decision making, knowledge acquisition, communication and rule compliance. In both cases, risk influencing factors depend on the environment and context in which they manifest (Yang et al., 2018).

The physical environment can act as a barrier to information flow or limit situational awareness. It can also present additional hazards or trigger accident scenarios. It can make difficult situations more complex (Norazahar et. al., 2018). Yu et al. (2018) note how the natural environment (wind, rain, temperature) impacts decision making and the ability of personnel to perform their duties, especially during emergency procedures. Zhang et al. (2018) refer to the hazards presented in a harsh marine environment and complicated geological conditions during offshore oil and gas drilling operations. Similarly, Hopper and Dean, (1992) highlight the safety implications of an Arctic maritime environment. Khan et al. (2018) identify risk factors of sea ice, remoteness, unpredictable climatic changes and extremes of weather and how they each impact navigation and communication systems. Villemain and Godon (2017) find a hostile environment to exacerbate risk, with complex terrain, extremes of temperature, and remoteness being key factors. A survey by Chang et al. (2016) found the environment to be the most important risk factor for airline pilots. Favaro and Saleh (2016) observe how environmental conditions influence aircraft and necessitated dynamic decision making by the air crew. Molesworth et al. (2006) suggest that environmental complexity can make hazard identification difficult. Song et al. (2016) simply note that the environment influences safety and the more severe the environment the greater the effect.

The unpredictable and dynamic nature of the environment leads to modification of schema (Scott-Parker et al., 2018). Yang and Haugen (2018) illustrate how hazards may stem from the external environment and suggest that some high-risk activities may be managed by means of operating envelopes. O’Keefe et al. (2015) propose environmental influences are best managed via heuristics. Islam et al. (2017), consider the environment to illustrate error producing conditions and performance shaping factors.

When considering the working environment, the attitude of management and co-workers can influence operational risk. Gilbert et al. (2007) refer to the constraints of the working environment. Knegtering and Pasman (2013) note how a positive attitude to safety within the working environment reduces the probability of an accident. Summala (1996) observe that differing environmental conditions change the risk picture and lead to changes in behaviour. Unexpected changes in the work environment draw greater cognitive attention. Knowledge and experience add resilience to the safety management system, but such an approach is reliant on organisational culture in allowing people to operate freely (Villemain and Godon, 2017). Sujan et al. (2017) offer that the working environment and safety culture will influence learning from experience.

**Application of the DRA network model to US Airways flight 1549 and the Piper Alpha disaster.**

Both adaptation events presented in the introduction may be characterised by rapidly changing circumstances, time critical decision making and the presence of inappropriate policy or procedures. Although there are a number of precursors, the factors are mainly considered from the point at which the atypical event occurs. Taking information from the US National Transportation Safety Board report (NTSB, 2010) and Public Inquiry into the Piper Alpha Disaster (Department for Energy, 1990a & 1990b), the network model has been used to evaluate the US Airways flight 1549 and Piper Alpha incidents:

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| --- | --- | --- |
| **Factor** | **US Airways 1549** | **Piper Alpha** |
| **Atypical Event** | US Airways flight 1549 suffered a bird strike shortly after take-off from LaGuardia Airport, New York on 15 January 2009. Occurring at 2,818ft, the resulting double engine failure led to the plane ditching into the Hudson river just 4-minutes later.  While the double engine failure occurred at an altitude never experienced, there are several other atypical factors to note - in January the probability of bird strike is extremely low (United States Federal Aviation Authority, National Wildlife Strike Database, 2019). The altitude and distance from the airport at which the bird strike occurred was unusual; bird strike typically occurs at altitudes less then 500ft and within the immediate vicinity of the airport. This event was beyond the scope of the airports Wildlife Hazard Management Plan (NTSB 2010, Para 1.10.2) and there had been no warnings of bird activity on the day, or day before, the incident. Also, the impact was with migratory geese despite the population of resident geese being four times greater. Finally, the ratio of single to double engine failures resulting from such an event is around 30:1.  The event was managed under extreme time pressure. There were just four minutes from bird strike to ditching and then 24 minutes until the cabin and wings submerged. | Piper Alpha was a North Sea oil platform that caught fire and took less than 2 hours from initial explosion to be entirely destroyed. Occurring on 6th July 1988, it remains the worst offshore oil accident in history (Offshore Technology, 2019). |
| **Decision Making** | The incident comprised a single, principal decision maker (the captain) who made a series of calculated, logic-based decisions founded on his situational awareness and the information he was being offered by the first officer and LaGuardia ATC. Initially turning back to LaGuardia, concurrent attempts were made to follow procedure and restart the engines. Realising the futility of this, the decision was quickly made to seek alternative landing sites as altitude was lost. The ATC offered the alternatives, but these were rejected as stopping short would mean crash landing in the urban area.  Ultimately, the decision to land in the river was the only rational course of action and offered the highest probability of survival.  Deciding not to warn the crew and passengers to prepare for a water landing was a critical decision. Doing so would have meant that most people would be incorrectly positioned on impact as they looked for or donned their life vests. The final significant decision by the captain was in deciding to be the last man out of the aircraft so as not to induce panic.  The aircraft started to sink shortly after it had settled. Despite the obvious presence of the first responders and ferry boats, some passengers decided to jump into the freezing water. Those who decided not to jump into the water ensured they would not experience the same cold-water immersion related injuries of their counterparts. | Certain decisions prior to the disaster had a significant impact on events. These included converting the platform from oil to gas processing and not adjusting the safety requirements based on the new hazard (e.g. gas compression occurring adjacent to the operations control room; safety walls were designed for fire not blast/explosion). Also, the decision to continue with oil and gas operations while the upgrade work was being undertaken.  On the day of the disaster, the automatic fire suppression system had been switched to manual due to the hazard from the suction pumps in the water during diving operations. The system had not been returned automatic on completion of diving.  Once the incident was triggered, there were multiple, dispersed decision makers with limited awareness of the situation. The person responsible for controlling the situation, the Offshore Installation Manager (OIM), was indecisive. He had a critical role in making decisions and controlling events and was responsible for making the critical decision to abandon the platform. The emergency drill in the initial circumstances was to make for the lifeboats. However, the circumstances dictated that this was not possible, so personnel made their way to the fire-proof citadel of the accommodation module.  There were three key decisions made by personnel during the fire, (1) to immediately move to a lower level and jump from the platform, (2) to try and carry out the emergency drill but then revise this decision, in response to changing circumstances, and jump from the platform, and (3) stay and wait for rescue regardless. Each of these had a varying but significant impact on the outcome of events.  The installation managers on the two satellite rigs, Claymore and Tartan, decided to continue operations (pumping fuel into Piper Alpha) despite the obvious emerging disaster. Because of financial implications, they were waiting for the decision to be made at a higher level within the organisation.  Some decision making was opportunistic and the decision to evacuate the stricken rig occurred at different points for those who escaped. For example, a dive team who had just finished work attempted to follow evacuation procedures. On realising their route was obstructed, they instead decided to make their own way down to the sea. Again, the internal stairs were blocked by fire and smoke, so they used knotted lines to reach a platform just 20ft from the sea.  The decision by the fire-fighting ship to activate fire pumps and use spray (rather than water jets), provided heat shielding to smaller rescue vessels as well as those persons clinging to the superstructure or in the water. It also reduced the likelihood of the powerful water jets knocking people from the platform. |
| **Information Gathering** | While the captain took charge of the immediate situation, the first officer followed procedures and attempted to re-start the engines. As he did so he continuously updated the captain on his progress. This information helped inform subsequent courses of action.  As the captain was central to the event he was in receipt of real-time information and thereby had good levels of situational awareness. He understood that he was losing altitude at 18ft per second and that the rate of decent meant he could not return to the departure point. Alternative landing points were also unachievable and failing to reach them would mean crashing into urban area (from the point of collision there were 3 airports within a 10-mile radius capable of accepting the damaged aircraft).  As part of his estimate, the captain knew he needed a landing point of sufficient width and length with a smooth surface. The only location to meet these criteria was the river. The mitigation of collateral damage allied with the proximity to emergency services and availability of support reinforced the option. The captain also knew that the aircraft was certified for ditching, which meant it had certain facilities and equipment on board (e.g. exits above the water line fitted with inflatable raft/slides, life vests at every seat and seat cushions which could serve as floatation aids (NTSB Report, para 1.15.1.2).  There were no technical issues and communication equipment functioned correctly throughout the incident until water immersion eventually led to power failure. The Ground Proximity Warning System gave various audible alerts in the cockpit (e.g. for low altitude, low speed and terrain). When the ATC lost radar picture it was supported by a local air-tours helicopter who maintained visual contact. This allowed the ATC to receive some information. | Information remained unclear throughout the disaster and management failed to disseminate what they knew. The early loss of communication systems severely hampered the passage of information and limited situational awareness. This lack of information also delayed the response of the Search and Rescue teams (Cullen report, 1990, Part 1, Para 9.30).  Not all personnel waiting for rescue realised that the nature of the fire and thick smoke rendered evacuation by lifeboat or helicopter impossible. Had they realised the futility of their situation they may have taken a different course of action.  A number of personnel waiting in the accommodation module donned breathing apparatus and ventured out to evaluate their situation and look for a safe means of escape. |
| **Knowledge & Experience** | The captain was very experienced. At the time of the incident he had 19,663 flying hours with the airline, including 8,930 as Pilot in Command and 4,765 with the Airbus A320 (subject aircraft). He also knew that to land safely on water he had to touch down with wings level, nose slightly up (angle of 11**°**), a survivable rate of decent and a speed just above the minimum of 130 knots.  The first officer had less experience, with 15,643 flying hours, including 8,977 as second in command and just 37 with the A320 (NTSB Report, Para 1.5.1 and 1.5.2). Although less experienced than the captain, the first officer had recently undergone Airbus training and immediately recognised that the situation as being beyond the scope of the Electronic Centralised Aircraft Monitor, which automatically displays crew guidance on a screen when systems fail. In accordance with protocol, he used the Quick Reference Handbook and started following the appropriate checklist for double engine failure.  The three flight attendants were experienced and in date for Extended Over Water (EOW) training.  While the knowledge and experience of the passengers has little influence over events, they had received a pre-flight safety brief. Because the aircraft was configured for EOW flight this brief should also have included information regarding the locating, donning and wearing of life vests as well as action to be taken on ditching. Data from the Cockpit Voice Recorder identified that the brief given did not include all required information. Passenger safety information cards were in the back pockets of seats and the brace position was illustrated.  Knowing that the ditching location was not remote meant that first responders would be available at the scene fairly quickly.  The first responders were well prepared for the event. The New York Waterways ferries routinely conducted rescue training and exercises. Also, the local Port Authorities had conducted a mass casualty exercise just a month before the incident. | There was a mixed range of experience on board Piper Alpha and this varied between different groups depending on their role onboard. Survivors stated that, from the moment of the initial explosion, it was evident that something serious had occurred and evacuation would be necessary (Cullen Report, Part 1, Para 8.17). In some cases, specific knowledge or experience of the platform actually facilitated escape (Cullen Report, Part 1, Para 8.20). Conversely, some of those who remained in the assembly area did so because they lacked the necessary knowledge to find their own way to safety. Emergency drills and induction training was lacking and inconsistent, with some people not even knowing the location of the life rafts (Cullen Report, Part 1, Para 8.27). |
| **Rules & Procedures** | Some rules were violated due to situational constraints - the processes articulated in the Pilot’s Handbook being incompatible with the situation, e.g. the checklist for double engine failure was predicated on the aircraft having the necessary altitude and power (and thereby time) to carry out the relevant actions. Similarly, the certification for ditching was founded on quite precise metrics for glideslope, pitch, decent rate, airspeed and aircraft configuration (landing gear and flaps), none of which could be achieved by Flight 1549.  During the subsequent accident investigation, the pilot admitted not following procedure but argued that in doing so he would have endangered the lives of the crew and passengers. Also, the evacuation checklist was not followed in full as certain aspects were pointless in the circumstances (e.g. applying the parking brake).  After the accident, numerous rules and procedures were revised. Of significance was the introduction of standardised checklists for use in abnormal or emergency situations, a review of the brace position in light of different seating types and configurations, training for double engine failure, the ditching process | Arguably, a flawed permit to work system resides at the heart of this disaster. Controlling documents by work area rather than system meant that there was no accurate understanding of the risks associated with maintenance work.  The emergency evacuation process was incompatible with the situation that presented itself in this instance. Offshore installations were required to be self-sufficient for a period of time in an emergency event. However, these generic procedures made no allowance for the design of Piper Alpha and were predicated on the availability of the Control Room. Unfortunately, this had been destroyed and there was no alternative plan. The procedure for a major emergency also required the mobilisation of onboard emergency response teams. This was also unachievable due to the dispersion of personnel and the size and nature of the fire.  Despite the futility of the situation in the accommodation block, some people followed the rules and remained there, believing that they would be rescued. The emergency procedures required a standby vessel to be within 5 Nautical Miles. At the time of the disaster there were numerous vessels within that range which came to assist.  All 106 recommendations made in the Cullen Report were accepted by the industry. This led to some significant changes to future policy, rules and procedures. |
| **Action** | At the time of impact, the first officer was flying the aircraft but the  captain quickly assumed control and sent the ‘Mayday’. This action alerted the ATC and other aircraft in the area, giving them maximum time to react. It also gave flight 1549 priority over resources and triggered emergency actions by those on the ground. As the captain evaluated the situation the first officer attempted to follow protocol from the Quick Reference Handbook.  During the whole event, the captain’s actions were decisive and based on logical reasoning – trying to turn back to the airport of departure, seeking alternative landing sites, trying to restart the engines. The ATC acted proactively and in full support throughout, offering possible options and communicating with other agencies.  By activating the Emergency Alert Notification System, the ATC triggered a system of notifications alerting the Coast Guard, Police, Fire Department and other emergency responders of an aircraft accident. In addition, the City of New York incident management system commenced.  Actions by the flight attendants were in accordance with their training. The exit from the plane was supervised and controlled, despite one door being unavailable due to being buckled. The captain was the last man to leave, and this would have had positive influence on the conduct of the passengers and crew.  As aircraft started to sink, some people jumped into the river to be rescued by the nearby boats. The action by supporting agencies was effective. The quick reaction by the ferries mitigated the slightly slower response of the dedicated emergency services. | After the initial explosion, the duty operations manager activated the emergency stop, closing the oil and gas lines feeding into Piper Alpha. Other emergency actions were unable to be carried out due to loss of power and loss of access to the control room.  During the initial stages of the fire, confusion and a lack of effective leadership resulted in a divergent range of actions being carried out. Because the main alarm panel had been destroyed in the initial explosion, no audible alarm was sounded. By default, it was late evening, many personnel were already in the vicinity of the accommodation module (emergency muster point). However, a number of those who survived the disaster either didn’t reach this area or left on their own choice.  The actions of the OIM are detailed separately in the report on the Piper Alpha disaster (Department for Energy, 1990a, Para 8.35). Of particular are a lack of decisiveness, the failure to use the broadcast system to direct personnel to evacuate, and not acting to issue instructions to the Radio Operator (e.g. to call for helicopter support, to communicate with the fire and rescue boat, or to contact the organisation shore).  Away from the platform, fire-fighting vessels reported being in action on the scene within 10-minutes of the initial explosion. The other rescue boats in the vicinity quickly made their way to the scene and worked hard. Their rescue craft deployed and repeatedly exposing themselves to danger to collect survivors and bodies from the water. The fire-fighting and rescue vessel (Tharos) attempted to fight the fire but was fearful of injuring personnel with the high-pressure hoses.  The actions by the managers on the two satellite rigs, Claymore and Tartan, arguably led to the destruction of the Piper Alpha. By continuing to pump fuel into the stricken platform they caused an overpressure (against the closed valves) which caused the main fuel pipes to rupture.  There was no organised evacuation from the accommodation (Department for Energy, 1990a, Para. 8.12). Of those who survived, 27 descended ropes to the 20ft deck before jumping into the sea, 7 slid down ropes or fire hoses from the 68ft deck before dropping off into the sea, 5 jumped from the 68ft deck, 15 jumped from the 133ft deck, and 5 jumped from the helicopter deck at 178ft (Department for Energy,1990a, Para 8.23). |
| **Environment** | Arguably, it was the natural environment that triggered the event. The local population of geese had exploded over recent years and the hazard was well known, both locally and nationally. The ditching of the plane occurred in the day time with very favourable conditions. The weather was reported as being stable and it was a cold clear day with a light wind. With a broken cloud base at 3,700 ft, the visibility was good (NTSB Report, 2009, Para 1.7), which granted near perfect visual cues to the pilot and subsequently aided the rescue services. Although the river was cold (5**°**C/41**°**F), and the current ebbing at 1.4 knots, the river surface was calm.  When considering the working environment, the findings of the investigation suggested that “*The captain’s difficulty maintaining his intended airspeed during the final approach resulted, in part, from high workload, stress, and task saturation”* (NTSB Report, 2009, Para 3.1.17). | Piper Alpha was nearly 200ft high and exposed to the elements. Conditions reported at the time of the disaster were of wind speeds around 10-15 Knots, a wave height of 3 metres, and visibility beyond 10 miles. These were considered favourable for the use of small rescue craft being used to collect persons from the sea (Department for Energy, 1990a, Para 9.8 and 9.35). On the platform, the wind direction and strength played a key part in the movement of smoke. For those onboard, the thick smoke, intense heat, hot gases and fire obscured the infrastructure, making escape by lifeboat or helicopter impossible. The sea was also on fire in places. For the rescue vessels on the water, the sea swell and wave height made conditions difficult but not untenable. In fact, it was the intense heat and fire that was causing problems, by blistering paint and melting parts of the upper deck equipment, as well as debris. There was also a number of risks from the hydrogen sulphide gas. Eventually, the intensity of the fire after the second gas line ruptured forced the fire fighting and rescue vessels away from Piper Alpha.  The event happened during the hours of darkness and loss of power had further reduced light levels. For those people on the platform, the deteriorating situation caused disorientation, induced physical stress and clouded judgement. There was a general panic when the emergency lighting subsequently failed in the galley where most people had assembled (Department for Energy, 1990a, Para. 8.12).  The workplace environment also influenced events. Because of the financial implications, here was huge pressure on Claymore and Tartan not stopping oil and gas production. |
| **Outcome** | Unprecedented result - forced landings in water typically end in disaster. All 150 passengers and 5 crew were rescued and survived. | The disaster claimed 165 lives of the 226 persons on board. The principal cause of death was smoke inhalation (Department for Energy, 1990a) and most deaths occurred in the accommodation module. Two crewmen on a rescue vessel also died. |

**Discussion**

Effective, real-time dynamic risk management is predicated on accurate information and understanding the immediate risk picture. Despite policy and rules being present, operational variations will occur naturally within any given workplace. DRA is significant as it is arguably the people in the system who have the potential to mitigate an emerging or changing risk. Although the concept of dynamic risk is recognised throughout a range of industries and circumstances these did not emerge from the search and the chosen papers were from a fairly narrow field of subject areas. Indeed, from the articles reviewed, the concept appeared synonymous with complex processes and high-risk industries such as oil and gas, shipping, and the air industry.

The literature offered two perspectives of DRA. In the first instance, known unreliable or unstable (thereby dynamic) risks are considered in advance of an event (Song et al., 2016) and then managed if and when they deviate. This was particularly evident where unpredictable environmental factors, such as weather, sea-state, or temperature, changed operating conditions and influenced machinery, equipment or people. The second, more common understanding, is to perceive the actual analysis as being the dynamic aspect, were DRA is the process of reacting to events which may not be covered by policy, rules or procedures. This then presents the dilemma of how to manage circumstances which may be beyond the knowledge, experience or understanding of those involved.

There are several common characteristics attributed to dynamic risk. The first is the relatively short time between the materialisation of the risk and when action is required. Next is uncertainty, which refers to either the process being undertaken, the conditions surrounding that process, or human factors such as error, deviation, fatigue, workload, or failure to follow rules. Complexity is another aspect identified repeatedly. This stems from either the confluence of multiple risks or the presence or absence of unusual factors. In such cases, written rules, policies and procedures may offer limited guidance due to the context of the situation.

While some researchers were clearly referring to the concept, there was no attempt to offer a specific definition or explanation regarding what exactly was meant by ‘dynamic’ risk. For example, Perez and Tan (2018), consider DRA in the context of the duration of the oil drilling operation (months and years), which is significantly different to the health care industry which considers it to be a minute-by-minute activity (Sujan *et a*l., 2017 and Scott-Parker et al., 2018). In either case, these interpretations align neatly with the Safety-II paradigm (Hollnagel, 2015), where adaptation and compromise are considered necessary in addressing the numerous, changing risks in the workplace. The following are key discussion points appertaining to the seven factors:

**Atypical Event** Atypical events can be caused by the qualities of the other factors. Triggers such as good or bad decisions, the provision or absence of information and extreme environmental conditions have been identified. In addition, one atypical event can lead to another atypical event, as seen in US Airways 1549.

**Decision Making** While it is evident that managing dynamic risks can inspire decision making, the quality of the decision often depends on the degree of certainty of other factors, such as information, experience, and knowledge. It is also influenced by the nature of the event as well as the environment in which it occurs. A ‘bounded rationality’, or line-in-the-sand, approach is commonplace and pragmatic strategies appear best. It is difficult to retrospectively evaluate decision making in atypical scenarios as sound decisions may result in bad outcomes, and vice versa.

**Information Gathering** Ordinarily, information leads to decision making which then leads to action. In time critical situations there is often a trade-off where decisions are made with reduced information in order to promote action. The more time taken to gather information naturally means less time for decision making or action. This may subsequently result in less options being available or insufficient time to carry out the resulting action. This presents a problem as the more accurate and current the information the more effective the decision making is likely to be.

**Rules and Procedures** Where some dynamic risks may be addressed by following procedures, in the extreme it becomes more contextual - adaptation, decision making and action taking founded upon risk interpretation. Several papers specifically discuss the relationship between rule compliance and the adaptation of processes (Hollnagel, 2015; Hopkins, 2011; Lofquist et al., 2017). Indeed, there are several examples of where slavish adherence to policy, rules or procedures have proven detrimental. An adaptive approach to rule compliance appears pragmatic but is again reliant on the context of the risk.

**Knowledge and Experience** It is evident that knowledge and experience can play a positive role in the management of dynamic risks. However, there is some jeopardy and deferring to experience can be problematic, especially when complex, emergency scenarios are encountered. If, as the evidence suggests, there is a chance of the wrong schema being adopted then a bad situation may be made worse. It is argued that in high pressure, high risk, dynamic scenarios that Naturalistic Decision Making is the most appropriate paradigm.

**Action** In dynamic situations action is susceptible to a range of influences. Principally, its purpose is to prevent or mitigate. Yet, if inappropriate, it can aggravate or even lead to the atypical event in the first instance. As with decision making, successful action relies heavily on the other factors. Indeed, the experience and knowledge of the person taking the action allied with a thorough knowledge of the rules and procedures and timely, quality information appears the optimal solution.

**Environment** The environment plays an influential role in managing dynamic risk, but the manner and extent are entirely dependent on the situational context. Such influences can mitigate or aggravate. They can enable, hinder or even disable safety systems. The physical environment is more tangible than the working environment and its effects are better known. In some cases, decisions have been made, and a course of action decided, but cannot be executed due to environmental constraints.

The analysis of two well-publicised events (US Airways flight 1549 and Piper Alpha) has served to emphasise the DRA factors found in this research. While aspects such as complexity, degree of control and remoteness are evident, it is the quality and timeliness of information, the decision making and the environmental factors which are fundamental. While the risks were known, and to varying degrees planned for, it was the dynamic contextual analysis that was key. When reviewing the US Airways incident, it is perceived as a series of actions and interrogations with each response informing the next decision. Information appears timely and clear, limiting the number of options available due to circumstantial constraints. In contrast, despite having relatively more time, Piper alpha suffered from dispersed information, lack of situational awareness, and disjointed decision making. In each case, the differing environments undoubtedly played a part in their outcomes.

Ultimately, the results of this research have a potential practical application through the development of a syllabus for DRA training. Subsequent research will now consider the UK military and its management of dynamic risks. Notably, a recent Freedom of Information request (Ministry of Defence, 2017) specifically asked if the military receive DRA training. This received a short reply which acknowledged variations between the different elements of the Armed Forces (Royal Navy, Army and Royal Air Force) and revealed that training was generally directed at a narrow field of specialist personnel.

**Conclusion**

Although extreme, both Flight 1549 and the Piper Alpha events serve to highlight the potentially high stakes in atypical situations. That said, dynamic risk management occurs routinely throughout everyday workplace operations, not just in uncommon events. In many activities, policy, procedure and rules alone cannot cater for every possible eventuality, so safety management systems should allow for context specific adaptation. That said, there is a threshold beyond which trouble-shooting and innovation becomes corner cutting and violation.

From this study, iDRA appears to have differing levels of application, ranging from monitoring and trouble-shooting to catastrophe avoidance and disaster management. Where other risk management methods are concerned, they should be perceived as complimentary and not mutually exclusive; where quantitative and qualitative systems generally consider risks in advance of the activity, any new or changing risk is left to the operators to manage dynamically in the context of the situation, hence why this research centred purely on the factors surrounding the management of individual dynamic risk.

The principal factors identified in this paper are all interdependent. Understanding and accommodating these may add resilience to existing safety management systems, especially in the event of an accident. It is perhaps not surprising that each of these serve to demonstrate the significance of the human element in managing dynamic risks. While it is acknowledged that experience and training will offer a baseline of knowledge from which to draw, it is arguably in the innovation and adaptability of the people involved where the optimum solution lies. This knowledge will now be used to develop and test a training framework for individual Dynamic Risk Analysis.

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1. Prioritised by relevance, only the first 100 results were reviewed. [↑](#footnote-ref-1)