RAND EUROPE

Human and Organisational Factors in Major Accident Prevention

A Snapshot of the Academic Landscape

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Preface

This document describes selected findings of a study undertaken in early 2016. The study was intended to enhance understanding within TOTAL E&P Research and Development of the role of human and organisational factors (HOF) in major accident prevention. This document focuses on a core element of this study which provides a succinct examination of the body of academic work on the subject of HOF in major accident causation and prevention.

In the wider study, this analysis provided the foundation on which subsequent work was based, namely the identification of lessons identified in other high-hazard sectors - specifically nuclear and aviation - and an examination of oil and gas sector approaches to major accident prevention. However, this report focuses exclusively on the academic landscape and does not include an analysis of industry approaches. The research presented in this document is intended to provide a brief introduction to HOF approaches in academia and should be of interest to industry professionals seeking to build or strengthen academic partnerships, as well as academics specialising in human factors research.

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In addition, grateful thanks are extended to the academic experts who took part in interviews, without whom this study would not have been possible. Their affiliations and, in most cases, their names are listed in Appendix D; some interviewees' identities have been anonymised at their request. Thanks are also due to the participants at the data collection workshop for their valuable insights.

Within RAND Europe, the team is appreciative of the constructive comments and feedback provided by the quality assurance reviewers, Dr Susanne Søndergaard and Dr Giacomo Persi Paoli. Thanks are also due to Elizabeth Hammes for her literature review support.

Abbreviations

CINAHL	Cumulative Index to Nursing and Allied Health Literature
ETA	Event Tree Analysis
FAA	Federal Aviation Administration (USA)
FRAT	Flight Risk Analysis Tool
FTA	Fault Tree Analysis
HFACS	Human Factors Assessment and Classification System
HOF	Human and Organisational Factors
HRO	High Reliability Organisation
HSE	Health and Safety Executive (UK)
HTO	Human-Technology-Organisation
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
INSAG	International Nuclear Safety Group
IOGP	International Association of Oil and Gas Producers
LSE	London School of Economics and Political Science
MAP	Major Accident Prevention
MIT	Massachusetts Institute of Technology
MMD	Man-Made Disasters
NASA	National Aeronautics and Space Administration (USA)
NSU	Nova Southeastern University
OECD	Organisation for Economic Cooperation and Development
PRA	Probabilistic Risk Analysis
TEM	Threat and Error Management
UK	United Kingdom of Great Britain and Northern Ireland
USA	United States of America

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1. Introduction

Human and organisational factors (HOF) are a widely recognised cause of major industrial accidents,[1] yet there appears to be limited academic coverage of the types of initiative implemented to prevent such accidents. In recognition of this gap, RAND Europe was commissioned by TOTAL E&P Research and Development to conduct a wider study on HOF in major accident prevention including the initiatives adopted by various high reliability organisations to help prevent major accidents. This document describes some of the findings of this work, providing a high-level examination of academic insights relating to HOF in major accident prevention (MAP).

1.1. Background

Human and organisational factors are present in all sectors, including oil and gas, nuclear, aviation, manufacturing and mining industries. While HOF have long been recognised as having an important role in major accident prevention (MAP) within the nuclear and aviation sectors, it is only more in recent decades that HOF practices to prevent accidents have been developed in the oil and gas industry.

Health, safety and the environment (HSE) is a priority area for high-reliability organisations (HROs),[2] yet the past 30 years have seen a series of major accidents across high-hazard industries. Within the oil and gas sector, disasters have included: Piper Alpha (1988), the Texas City Refinery Explosion (2005), and Deepwater Horizon (2010). Examples of accidents in other high-hazard industries include the Fukushima nuclear power plant disaster (2011) and the loss of Air France Flight 447 (2009). In addition to loss of life, accidents often result in considerable financial losses – more than US $3 billion, for example, in the case of the Piper Alpha disaster.[3] Potential high casualty tolls, environmental damage, financial costs and other adverse impacts are strong incentives for industry to focus on preventing accidents.

The analysis of past accidents indicates that the performance of highly complex socio-technical systems[4] is dependent upon interactions between human, organisational, managerial, technical, social and

[1] Catino, 2008; Reason, 2000; Mearns et al., 2001; Meshkati, 1991.

[2] Lekka (2011) defines a 'high reliability organisation' or 'HRO' as an organisation that is able to manage and sustain almost error-free performance despite operating in hazardous conditions where the consequences of errors could be catastrophic.

[3] Saleh et al., 2010.

[4] 'Complex socio-technical systems' refer not only to engineered systems, e.g. an automobile or aircraft, but also the people and organisations associated with these systems. See Rouse & Serban, 2011.

environmental factors.[5] HOF is increasingly recognised as an important issue by HROs, particularly in relation to preventing explosions, fires, structural failures or other operational accidents.[6] For HROs, the relevance of near misses and critical incidents is particularly important: for these organisations, even apparently insignificant errors can combine to pose a major threat to the organisation, to individuals and to the environment.[7]

1.1.1. Defining 'human and organisational factors'

The term 'human factors' is subject to a range of interpretations. Gordon (1998) defines human factors as the study of the interactions between human and machine. However, this definition has more recently been expanded to include the effect of individual, group and organisational factors on overall safety. According to the UK Health and Safety Executive, the study of human factors should include a focus on environmental, organisational and job factors which influence work behaviour in a way that can affect health and safety.[8]

For the purposes of this report, the conceptualisation of human factors goes beyond traditional definitions and includes a focus on organisational systems. This reflects a recent shift in the academic literature – explained in more detail in Chapter 2 – whereby the study of 'human factors' has been expanded to encompass 'organisational factors', which include: management functions, decisionmaking, learning and communication, training, resource allocation and organisational culture.[9] This report treats the two concepts as separate and considers both human (individual) and organisational factors. A glossary listing further definitions relating to the study of HOF in MAP can be found in Appendix B.

1.2. Purpose and scope

This document – extracted from the wider study – provides an introduction to the role of HOF in MAP. By drawing on insights from academic experts and from the extensive body of existing academic literature on the topic, this report aims to further develop TOTAL's understanding of the academic landscape on HOF in MAP.

The focus of this study is on the prevention of major industrial accidents, rather than on individuals' occupational health and safety. For the purposes of this study, the RAND study team defines a 'major accident' as: '*an acute accident, such as a major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets*.'[10] Table 1.1presents what is included and excluded from the study scope.

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[5] Gordon, 1998.

[6] Bergh et al., 2014.

[7] Roberts, 1990; Zhao & Olivera, 2006.

[8] UK Health and Safety Executive, n.d.

[9] OECD, 1999.

[10] Petroleum Safety Authority Norway, n.d.

Table 1.1 Study Focus[11]

Study inclusions	Study exclusions
• Process safety	• Occupational safety
• Preventing releases of energy, chemicals and other hazardous substances	• Preventing trips, slips and falls
• Considering human, environmental and business implications	• Considering consequences at an individual human level only
• Changing systems	• Changing an individual's behaviour
• Dealing with major hazards such as fire, explosions and pollution	• Mitigating minor incidents such as cuts, broken bones, etc.

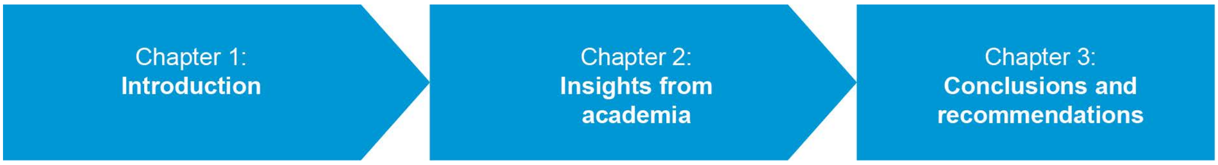
1.3. Report structure

As illustrated in Figure 1.1, the report contains two chapters in addition to this introduction:

- Chapter 2 provides an overview of the academic landscape in relation to HOF in the context of MAP.
- Chapter 3 presents conclusions and selected high-level recommendations for TOTAL that arise from the study findings.

In the wider study, the analysis presented in Chapter 2 was used as a foundation for drawing lessons from the experience of other high-hazard sectors - namely nuclear and aviation - and for examining oil and gas sector approaches to major accident prevention. However, this report focuses exclusively on the academic landscape and does not include an analysis of industry approaches.

Figure 1.1 Report structure and content



[11] The definition presented in Table 1.1 is based on a briefing note describing the differences between 'occupational safety' and 'process safety' published by the Energy Institute (2011a).

2. Insights from academia

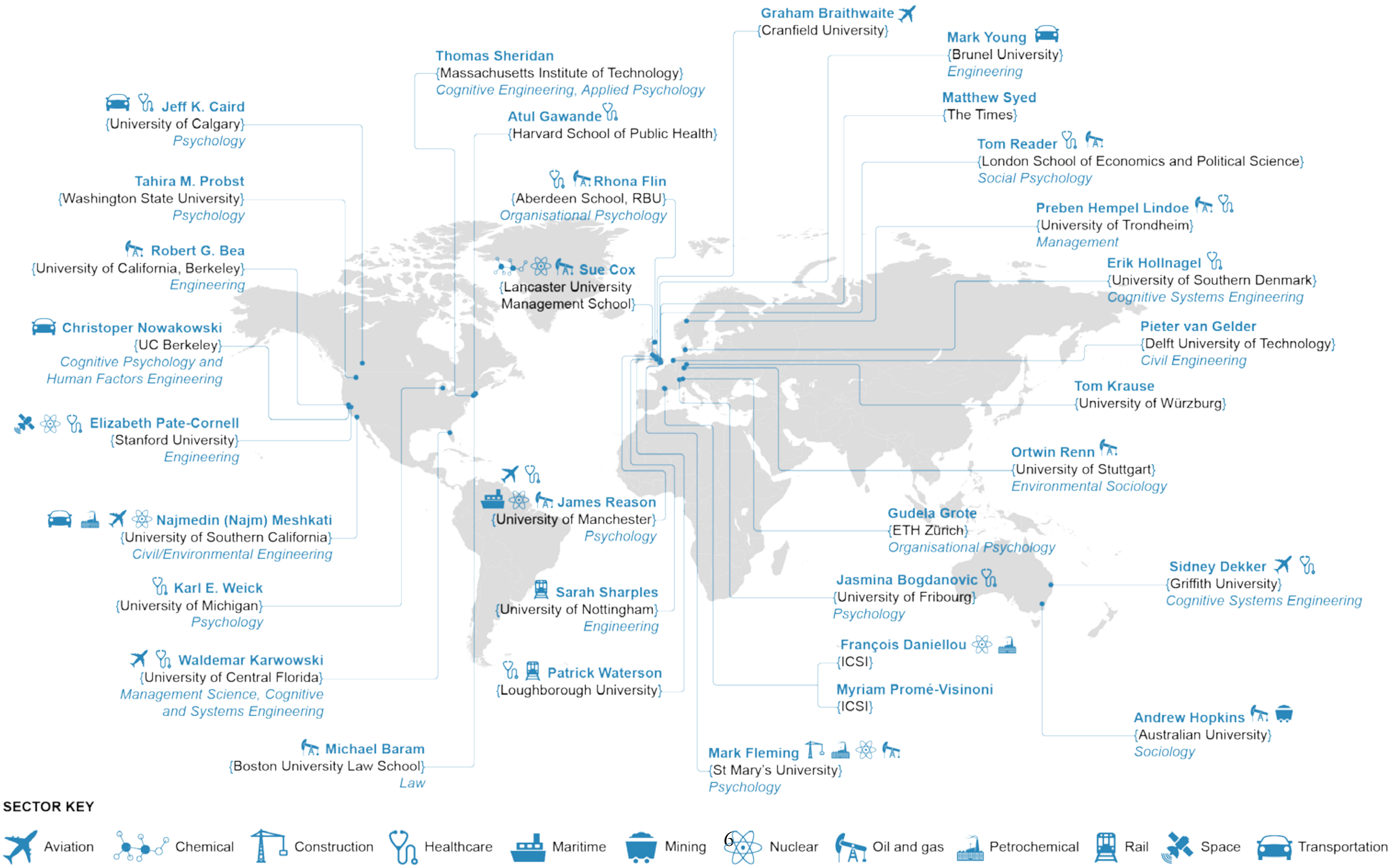
This chapter provides an overview of selected academic experts and approaches to HOF in accident causation, with a focus on how major areas of debate have changed over time. It then describes good practices and common challenges in MAP implementation, before discussing how academic theory can be translated into applicable tools for industry.

2.1. The academic landscape of HOF experts

The study of HOF is not an academic discipline in itself.[12] It is often viewed as a multidisciplinary area, spanning fields as diverse as cognitive psychology, socio-technical theory, organisational theory and management science. The literature on HOF in accident causation is extensive but fragmented, drawing on a range of HOF theories that include: Rasmussen's Probabilistic Risk Assessment (1975), Turner's Man-Made Disasters (1978), and Perrow's Normal Accident Theory (1984), among others. Figure 2.1 presents a map of selected academics with research expertise in human and organisational factors, illustrating where each academic is based as well as their disciplinary backgrounds and sector-specific expertise.

[12] RAND interview with Andrew Hopkins, 29 January 2016.

Figure 2.1 Map of selected academic experts



2.1.1. Academic networks of HOF experts

The review of academic literature highlighted several research collaborations between academic experts. Through a 'light-touch' analysis of the sources consulted as part of this review, RAND researchers identified articles that have been co-authored in order to capture information about wider academic linkages and networks. Based on this exercise, it is apparent that Professor Rhona Flin, from the School of Psychology at Robert Gordon University, Aberdeen, has co-authored papers with Dr Rachael Gordon and Dr Kathryn Mearns. Currently an independent consultant and previously at Robert Gordon University, Dr Gordon specialises in human factors and safety culture in the aviation and energy sectors. Dr Mearns, also previously at Robert Gordon University, is a principal human factors consultant at Amec Foster Wheeler and focuses on safety culture, safety leadership and human factors in the offshore workforce. Professor Flin has also co-authored with Professor Mark Fleming, a Professor of Safety Culture at Saint Mary's University, Canada, and Sean Whitaker, from the National Health Service (NHS).

Outside the UK, Øyvind Dahl from the Department of Safety Research (SINTEF) in Norway works on safety compliance in the offshore and petroleum industry. Dahl has co-authored with Dr Espen Olsen, from the University of Stavanger. Dr Espen Olsen's research focuses largely on organisational factors and safety climate in the petroleum industry, the offshore sector and in healthcare. Dahl and Olsen have published jointly on safety compliance on offshore platforms, focusing in particular on leadership involvement and work climate.

Several other academic networks were identified by RAND's source analysis. Specialising in safety and management in high-hazard industries, for example, Professor Emeritus Patrick Hudson (Delft University of Technology) has co-authored various papers with Professor Dianne Parker from Manchester University whose research focuses on human error and safety. Professor Sidney Dekker from Griffith University in Australia, whose main areas cover human error, accidents and failures, cognitive systems engineering, aviation safety and patient safety, has co-authored papers with Professor Margareta Lutzhoft (University of Tasmania), Professor James Nyce (Anthropology Department, Ball State University), and Roel van Winsen (Lund University).

Dr Scott Shappell and Professor Douglas Wiegmann have conducted joint research on transport systems. Dr Scott Shappell is from Embry-Riddle Aeronautical University, Department of Human Factors and Systems, and Professor Douglas Wiegmann, at the University of Wisconsin-Madison, focuses on system safety, accident investigation, cognitive systems engineering and human error analysis in aviation and healthcare. Specifically dealing with aviation and air transport systems, Dr Miltos Kyriakidis, Dr Arnab Majumbar and Professor Washington Ochieng have collaborated on multiple projects. Dr Miltos Kyriakidis is a researcher at the Singapore ETH Centre with his main areas of interests being around human factors, human performance, human reliability analysis, and safety of critical infrastructure, particularly in the transport sector. Research conducted by Dr Arnab Majumbar and Professor Washington Ochieng at Imperial College London focuses on investigations into air traffic management problems.

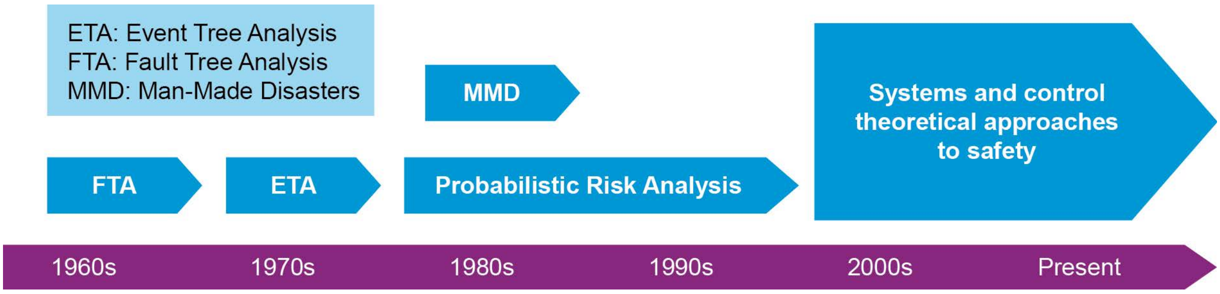
2.2. Major accident causation

Recent decades have seen fundamental changes in academic thinking on accident causation and system safety. This section explores two key trends: (1) a shift away from the view that accidents are caused by a single chain of events, with each event triggering the next; and (2) the expansion of 'human error' explanations to encompass 'human and organisational factors'.

2.2.1. Accidents are no longer considered to be caused by a single 'chain of events'

According to early academic thinking, accident causation should be seen as a single chain of events, with each event causing the next. By this logic, the analyst tries to infer backwards to a point where the initial cause is identified. Several popular theories have been based on this 'serial causation idea', including Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Probabilistic Risk Analysis (PRA), and Man-Made Disasters (MMD) theory. These theories are illustrated in Figure 2.2 below.

Figure 2.2 Evolution of selected academic theories



First introduced in 1962, Fault Tree Analysis (FTA) is one of the most widely applied methods in system reliability, maintainability and safety analysis.[13] Mainly used in safety and reliability engineering, FTA is a top-down, deductive failure analysis tool that views accident causation as a linear process. While it was first introduced for the US Air Force and further developed for Boeing, FTA was also later adopted in the nuclear, chemical and petrochemical industries, among other high-hazard sectors.[14]

Developed a decade after FTA, Event Tree Analysis (ETA) is a commonly applied technique used to identify the consequences that can arise from a potentially hazardous event.[15] Similarly to FTA, ETA is based on the 'serial causation' concept. It was first applied in risk assessments for the nuclear industry, but is now also used by the chemical processing, offshore oil and gas production, and transportation

[13] Pilot, 2002.

[14] Barlow, 2006.

[15] Cepin, 2011.

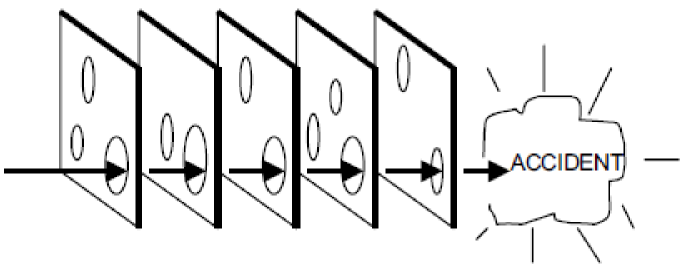
industries.[16] It is applicable to physical systems, with or without human operators, and can be used to support FTA.[17]

Event trees and fault trees are both used in Probabilistic Risk Analysis (PRA) – a tool introduced by Rasmussen to evaluate risks associated with complex systems.[18] Early forms of PRA had their origins in the aviation industry, before being adopted by other sectors such as nuclear, chemical and space. In the 1990s, US government regulatory agencies such as the Nuclear Regulatory Commission and the Environmental Protection Agency had begun to use risk-based regulation as a basis for improving safety.[19]

Introduced in the late 1970s, Barry Turner's Man-Made Disasters (MMD) attributes accidents to organisational and managerial factors, rather than to technology. MMD was developed in the abstract and is based on the premise that accidents are caused by a chain of factors that often accumulate unnoticed until the occurrence of the accident[20] – a theory that has been linked to the development of models including Heinrich's domino model (1931) and Reason's Swiss cheese model (1997).

In Heinrich's domino model, a series of dominoes represents causal events, with each triggering the next event when it 'falls'. The more recent Swiss cheese model also views accident causation as a linear process. Reason's model presents a series of 'defensive barriers', such as alarms, physical defences and frontline operators, which are represented by successive slices of Swiss cheese. The presence of 'holes' in any one 'slice' does not normally cause a negative outcome; this only happens when the holes in many layers line up to permit a trajectory of accident opportunity (see Figure 2.3). According to this theory, minor errors and failures can combine to produce major accidents.[21]

Figure 2.3 Reason's Swiss cheese model



Source: Sheridan, 2008.

[16] Andrews & Dunnett, 2000.

[17] Clements & Sverdrup, 1990.

[18] United States Nuclear Regulatory Commission, n.d.

[19] Stamatelatos, 2000.

[20] Turner, 1978.

[21] Reason, 2000.

More recent theories have departed from this paradigm of linear causation. While earlier models viewed accidents as resulting from a chain or sequence of events, system theory attributes accidents to the interactions among system components.[22] Within system theory, Nancy Leveson's 'Systems-Theoretic Accident Modelling and Processes' (STAMP) model views accidents as resulting from inadequate enforcement of safety-related constraints on the design, development and operation of the system. While this approach does not identify single causal factors, it provides an understanding of an accident that might be used to prevent future accidents, particularly regarding changes to organisational structure and engineering design, manufacturing and operations.[23]

Accident causation is now understood to be more complex than previously thought, as feedback between multiple events may be necessary for a so-called 'top event' to occur.[24] Critics of the 'linear causation' approach note that while accident investigations seek the 'contributing factors' to an accident, there is a degree of arbitrariness in choosing where to stop going back in the causal chain. At any point in the causal analysis, a failure or an error can be conceived of as a 'result' and not a 'cause'.[25]

2.2.2. Academic focus has shifted from 'human error' to 'human <u>and</u> organisational factors'

Human error

The role of human actions in major disasters has been widely acknowledged, with studies concluding that human error is responsible for approximately 80 per cent of accidents.[26] Early accident analyses have attributed industrial disasters, such as Three Mile Island, Bhopal and Chernobyl, to operator error.[27] For example, the Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident found that '*the root cause of the Chernobyl accident…is to be found in the so-called human element*'.[28]

Two types of human error are said to cause systems disasters: 'active errors' and 'latent errors'. While the effects of active errors are almost immediate, the consequences of latent errors may lie dormant in the system for many years before they combine with active failures and local triggers to create an accident opportunity. Active errors are more likely to be caused by frontline operators, such as control room crews and production operators, while latent errors tend to be made by designers, managers and other personnel removed from the direct control interface.[29]

As accidents are often activated by frontline operators, it is often more straightforward to attribute blame to these operators rather than to address the less-visible organisational issues that accumulate over time.[30]

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[22] Leveson, 2004.

[23] Leveson, 1995.

[24] Sheridan, 2008.

[25] Saleh et al., 2010.

[26] See Rasmussen, 1994; Catino, 2008; Perrow, 1984.

[27] Meshkati, 1991.

[28] IAEA, 1986.

[29] Gordon, 1998.

[30] Catino, 2008.

Latent factors can translate into error-prone conditions such as: time pressure, understaffing, inadequate equipment and fatigue. These factors can also create weaknesses in system defences, such as design deficiencies or untrustworthy alarms.[31]

Limitations of human error

Critics of human error theory argue that its popularity can be explained by 'convenience': blaming error on operators costs the company less and allows it to continue operating without changing its managerial structures or organisational procedures.[32] As Perrow (1986) notes, '*finding that faulty designs were responsible would entail enormous shutdown costs, finding that management was responsible would threaten those in charge, but finding that operators were responsible preserves the system*'.[33] 'Blame the operator' explanations can seriously impede an organisation's ability to learn from experience if the operator is replaced and it is assumed that the problem has been removed from the system.[34]

Another weakness of this approach is that it isolates human errors from their wider system context.[35] Far from being random, mishaps tend to fall into recurrent patterns – regardless of the people involved.[36] Some go as far as to argue that 'human error' is an outmoded idea,[37] with questions raised over whether error can be predicted, and whether its elimination is even desirable given that lessons can be learnt from mistakes. Despite criticism, the concept of human error remains in popular use both by the public and by researchers.

Expansion of 'human factors' to include 'organisational factors'

There has been a recent shift in the academic literature towards organisational factors.[38] Analyses now suggest that while the human factor element directly induces most accidents, this is only the 'first order cause' of an accident history based on pre-existing organisational factors.[39] While human factors approaches ask the question: 'who caused the accident?', organisational approaches also ask: 'what conditions and mechanisms have increased the possibilities of it happening?'; 'how and why did the defence systems fail?', and 'what can we do so that the event will not be repeated?'[40]

Meshkati (1991) has taken the redefinition of 'human factors' one step further, and argues that it is important to consider a combination of human, organisational <u>and</u> technological factors, and the

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[31] Reason, 2000.

[32] Catino, 2008.

[33] Perrow, 1986, p.146.

[34] Haunschild & Sullivan, 2002; Sagan, 1993.

[35] Reason, 2000.

[36] Ibid.

[37] Dekker, 2007.

[38] Reason, 1990; RAND interview with Andrew Hopkins, 29 January 2016; RAND interview with Patrick Waterson, 12 February 2016; RAND interview with Robert Bea, 18 January 2016; RAND interview with Ortwin Renn, 28 January 2016.

[39] Catino, 2006.

[40] Reason, 1997.

interactions between them. According to this view, system accidents are caused by the way that system parts – engineered, organisational and human – fit together and interact.[41]

2.3. Major accident prevention

2.3.1. Effective accident prevention approaches are understood to draw on 'no-blame' practices and a continuous reporting culture

According to Reason (2000), error management has two components: limiting the occurrence of dangerous errors and creating systems that are better equipped to address the incidence of errors and contain their damaging effects.[42] Where organisations attribute accidents to human error, they tend to direct management resources towards trying to make individuals less fallible through methods including: poster campaigns, disciplinary measures, threat of litigation and retraining. Where accidents are attributed to organisations and systems, organisations tend to implement a comprehensive management programme aimed at several different targets: the person, the team, the task, the workplace and the organisation as a whole.[43]

The literature highlights several good practices for industrial accident prevention. Scholars have argued that 'no-blame' practices in error management can enhance organisational learning. A 'no-blame' culture is defined as an organisational setting in which individuals are encouraged to signal errors and potentially hazardous situations by creating an atmosphere of trust.[44] The assumption that errors are inherent to human activity encourages openness about and disclosure of errors and near misses. This culture, in turn, fosters an effective reporting culture and the exploitation of such incidents to improve organisational processes.[45]

A reporting culture is also found to be essential to effective risk management.[46] According to Provera et al. (2008), a detailed record of errors and near misses can help organisations to uncover recurrent error traps and exploit these incidents to improve their operative processes. In aviation, medicine and other high-hazard sectors, human error taxonomies have been developed as error-reporting systems.[47] For example, both the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) (jointly) and the National Highway Traffic Safety Administration (NHTSA) maintain publicly available accident databases.[48]

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[41] Meshkati, 1991; RAND interview with Preben Hempel Lindoe, 13 January 2016.

[42] Reason, 2000.

[43] Ibid.

[44] Provera et al., 2010.

[45] Ibid.

[46] Reason, 2000.

[47] Baker & Krokos, 2007; Wiegmann & Shappell, 2003; Barach & Small, 2000; Holden & Karsh, 2007.

[48] Sheridan, 2008.

Training is also highlighted in the literature as being important.[49] The International Air Transport Association (IATA), for example, provides a range of training and e-Learning courses in fields such as aviation HOF, ground operations HOF, fatigue and personal mitigation strategies, and online safety management systems. Scholars also note the value of face-to-face interaction between operators, managers and other key stakeholders. According to Weick (1987), more information is conveyed when stakeholders are dealt with in person, which should help enable earlier detection of potential errors.

Box 2.1 presents a case study that focuses on the Hearts and Minds safety toolkit developed by Shell E&P. This case study was selected as the toolkit was mentioned in several interviews with academic experts.[50]

Box 2.1 The Shell Hearts and Minds safety toolkit

The Hearts and Minds toolkit was developed by Shell E&P, and has been used by organisations in a large range of industries – including oil and gas, chemical, aviation, marine, rail, defence and security, pharmaceutical, healthcare and manufacturing.[51] Based on two decades of university research, the toolkit is concerned with improving the culture of safety in an organisation. It is intended to help organisations improve their HSE performance by providing the process and tools to develop a strong safety culture.[52] Hearts and Minds is not designed to be an exclusive tool, and it can be incorporated into existing training and professional development programmes.

The toolkit comprises a range of supporting tools, which consist of:

- **HSE Understanding your Culture**: An engagement tool to identify local strengths and weaknesses. Can be used to engage individuals, discover their aspirations and build a case for change.
- **Seeing Yourself as Others See You:** HSE upwards appraisal tool to understand others' perceptions and identify how commitment is turned into action. Can be used to challenge the commitment and behaviours of any 'safety leaders'.
- **Making Change Last**: A change management tool for supporting improvement process or organisational change programmes. Can be used by organisations to design their own tools.
- **Risk Assessment Matrix**: A tool that helps individuals understand their risks, make them personal, and stimulate action.
- **Achieving Situation Awareness**: A tool that helps individuals make better risk-based decisions and justify them.
- **Managing Rule-Breaking**: A tool designed to prevent incidents being caused by rule-breaking. Can be used if procedures are not being followed, or if there is a need to improve

[49] Weick, 1987; Lindhout & Ale, 2009.

[50] RAND interviews with Rhona Flin, 3 March 2016; Graham Braithwaite, 10 February 2016; and Patrick Waterson, 12 February 2016.

[51] Energy Institute, n.d.(a).

[52] Energy Institute, n.d.(b).

procedures.

- **Improving Supervision**: A tool designed to improve the non-technical skills of supervisors. Can be used if the quality of supervision is identified as a possible cause of accidents.
- **Working Safely**: An intervention programme that builds on and supports existing programmes or can be stand-alone. Can be used if safe working practices are not being adhered to.
- **Driving for Excellence**. A suite of exercises to change the behaviour of drivers and the people who manage them.[53]

2.3.2. Economic pressures, regulatory constraints and cultural limitations can impede major accident prevention efforts

Accident prevention efforts have been constrained by several factors. A commonly cited issue for HROs is the tension between production and safety.[54] In the context of limited resources, it can be challenging for an organisation to maintain an acceptable quality of risk management while also pursuing a set of production targets.[55] Excessive pressure for production can both divert resources from accident prevention initiatives and reduce the time available to complete tasks, which, in turn, can lead to corner-cutting and more mistakes.[56] However, investment in safety is not necessarily in conflict with productivity: rather, it should be seen as supporting HROs' economic targets.[57] As accidents can incur major financial losses – in excess of US $3 billion in the case of the Piper Alpha disaster[58] – it is in the economic interests of companies to invest in accident prevention programmes.

Regulatory constraints can also hinder opportunities for organisations to learn from accidents. In some cases, legal accountability is said to lead to 'blame-deflecting' strategies, curtail open communication and reduce reporting of incidents or accident indicators.[59] This can result in missed opportunities for organisational learning, detection of unsafe conditions and trends, and ultimately accident prevention.[60] In many countries, HROs face a regulatory system in which human error is subject to criminal liability.[61] Under such a regime, individuals often refrain from signalling errors because of the fear of criminal prosecution. This means that organisations are impeded from learning from errors or near misses by the legal systems under which they operate.[62]

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[53] Energy Institute, n.d.(c); Hudson, 2007.

[54] Hovden et al., 2010; Sheridan, 2008; Meshkati, 1991; Rasmussen et al., 1990; Mearns et al., 2001; Saleh et al., 2010.

[55] Meshkati, 1991.

[56] Gordon, 1998.

[57] Sheridan, 2008.

[58] Saleh et al., 2010.

[59] Morris & Moore, 2000.

[60] Saleh et al., 2010.

[61] Provera et al., 2010.

[62] Provera et al., 2010.

Cultural constraints can create additional problems. For example, communication tends only to flow downwards in hierarchical organisations, which can create a barrier to error reporting and accident prevention. Organisations can lack an awareness of the potential fallibility of systems; this can result in a passive attitude towards errors and a punitive approach towards employees. In other situations, employees do not report individual errors due to fear of being blamed, which can result in concealment of problems and failure to address them in a timely and appropriate way.[63]

Another issue facing HROs concerns the insufficient data available to evaluate system and accident prevention. Too few accidents have occurred for statistical analysis, and there has not yet been any attempt to combine accident databases from different industries. A related challenge concerns the fact that different companies tend to use different accident reporting forms, which makes it problematic to draw direct data comparisons.[64]

Further challenges of note include: (1) lack of managerial commitment to MAP efforts; (2) integration problems created by a mixture of legacy and new technology systems; (3) a lack of 'human and organisational' specialists involved in MAP initiatives; and (4) increasing integration of activities across company boundaries, which can enhance the risk that the effects of individual errors can propagate widely.[65]

2.4. Pathways to impact

There is evidently a large pool of academic research on HOF in accident prevention. The following section first describes how this research has been drawn on by industry. It then addresses barriers to translating theoretical approaches into practical initiatives, before describing some practical examples of partnerships between academia and industry. Recommendations for strengthening cross-sector links are set out in Chapter 3.

2.4.1. The academia–industry interface

Analytical tools based on academic work have been developed for industry in certain cases. One interviewee remarked that the impact of academia on industry has been '*very substantial*', observing that Reason's work on human error has been particularly influential.[66] Another noted that '*the best projects are those where academics and industry representatives work together, and where academics have a good understanding of industry problems and requirements*'.[67]

When asked about the academia–industry interface, one interviewee noted that major industrial accidents, such as the 2005 Texas City Refinery explosion, often spark academic debate on HOF.[68] Further methods

[63] Weick & Sutcliffe, 2001.

[64] Gordon, 1998.

[65] RAND interview with Patrick Waterson, 12 February 2016.

[66] RAND interview with Ortwin Renn, 28 January 2016.

[67] RAND interview with Rhona Flin, 3 March 2016.

[68] RAND interview with academic, 13 January 2016.

of translating academic theory into industry practice raised in interviews included conferences, publications, working groups[69] and joint research programmes,[70] and HROs are also said to hire consultants to produce simplified versions of academic outputs to make them more accessible to industry stakeholders.[71]

2.4.2. Barriers to impact

While productive partnerships have been formed between academia and industry, interviewees also reported that much of the academic knowledge in the HOF domain is too abstract to have real practical applicability.[72] One interviewee described a '*graveyard of human factors processes*' that exist but which are not used by practitioners due to their overly complicated nature.[73] Many competing concepts exist, but academics have not yet agreed on a clear way to conceptualise and contextualise them.[74]

Despite Reason's influence on practical tools such as HFACS, academics have argued that his Swiss cheese model of accident causation lacks applicability in a real-world setting. According to Shappell and Weigmann (2000b), the theory fails to specify what the 'holes in the cheese' represent in the context of day-to-day operations. For the system failures or 'holes' to be detected before an accident occurs or is identified during the investigation process, it is important to understand what they signify.

Interviewees mentioned several other barriers to impact. For example, many analytical tools were said to be industry- or domain-specific, which can limit their wider applicability.[75] The different timescales, priorities and incentives for academic and industry stakeholders were also said to be a challenge. According to one academic interviewee, academics are driven by publication targets, while industry representatives are more interested in practically applicable analysis and methods that prevent accidents and allow organisations to maintain productivity.[76] Moreover, while industry stakeholders are said to seek quick research-based solutions, academics often require more time to develop their research outputs.[77]

2.4.3. Practical examples of academia–industry engagement

While interviewees highlighted several barriers to impact, there is also evidence of productive partnerships between academics and industry representatives. Academic research on HOF intersects with industry practice in various ways. Models of engagement include working groups, joint research programmes, and publications. Analytical tools have also been developed specifically for industry by academic experts. For example, the Hearts and Minds toolkit described in Box 2.1was developed by Shell and was based on research funded between 1980 and 2000. This research was conducted by the Universities of Leiden,

[69] RAND interview with Ortwin Renn, 28 January 2016.

[70] RAND interview with Preben Hempel Lindoe, 13 January 2016.

[71] RAND interview with academic, 13 January 2016.

[72] RAND interview with Andrew Hopkins, 29 January 2016.

[73] RAND interview with Patrick Waterson, 12 February 2016.

[74] RAND interview with Ortwin Renn, 28 January 2016.

[75] RAND interview with academic, 10 February 2016.

[76] RAND interview with Patrick Waterson, 12 February 2016.

[77] Ibid.

Manchester and Aberdeen, and the toolkit is now used extensively by the energy industry and others to help improve safety culture by engaging the workforce.[78]

Conferences are another means by which knowledge relating to human factors is transferred between academia and the oil and gas sector. For example, the Energy Institute hosts a series of conferences to encourage the exchange of ideas between academia, industry and regulatory bodies. These explore themes relating to effective safety management, human factors systems, education and training to build safety knowledge, and lessons learned from case studies.[79]

In a similar way, workshops can promote information-sharing between academia and industry. For instance, the IOGP has previously conducted workshops involving senior managers with responsibility for safety and HSE professionals in IOGP member companies, as well as academic experts from various universities. The workshops focused on accident investigation and analysis, safety reporting, evaluation of accident reporting, responsibility for standards setting, contractor management and striking a balance between safety and profitability – an area that is discussed further in Section 2.3.2.

Industry also engages with academia by funding postgraduate research. For example, the Energy Institute currently funds PhD research on improving health, safety and the environment (HSE) performance through culture and behaviour. The Institute has specifically requested topics with practical applicability – that is, topics that tackle energy industry needs, which can then developed as a tool/tools, and which show promise for improving energy industry HSE performance.[80] PhD studentships such as these can provide a research base upon which to develop industry practice.

In some cases, analytical tools have been developed for industry based on academic human factors research. For example, the Human Factors Analysis and Classification System (HFACS) tool is based on Reason's human error theory.[81] Drawing on Reason's concept of latent and active failures, HFACS bridges the gap between theory and practice by providing investigators with a comprehensive, user-friendly tool for identifying and classifying the human causes of aviation accidents. HFACS has been used by the Federal Aviation Administration and the US Navy, Marine Corps, Army, Air Force, and Coast Guard, among other organisations, for use in aviation accident investigation and analysis.[82]

Convened under the auspices of the International Atomic Energy Agency (IAEA), the International Nuclear Safety Group (INSAG) is an example of a joint working group that consists of academic and industry experts. It brings together safety experts from the nuclear industry, research and academic institutions and regulatory organisations to provide authoritative guidance on nuclear safety policies and principles.[83]

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[78] Holstvoogd et al., 2006.

[79] Energy Institute, 2016a.

[80] Energy Institute: 2016b.

[81] Shappell & Weigmann, 2000b; Reason, 1990.

[82] Shappell & Weigmann, 2000b.

[83] IAEA, 2015.

In addition to participating in joint working groups, universities and companies often collaborate through joint research ventures. Box 2.2 describes one such collaborative initiative between Nova Southeastern University and Embraer Aircraft Holdings.

Box 2.2 Cross-sector collaboration: Nova Southeastern University and Embraer Aircraft Holdings

To strengthen the links between industry and academia, Nova Southeastern University (NSU), based in Florida, and Embraer Aircraft Holdings established a partnership in 2013 to improve human factors research in aviation.[84] This collaborative initiative involved a series of research projects and seminar projects relating to human factors, delivered through NSU's Institute for the Study of Human Services, Health and Justice. As agreed in a Memorandum of Understanding signed in 2013, NSU and Embraer have submitted joint proposals to the US Department of Transportation's Federal Aviation Administration in order to win projects aimed at advancing human factors research and its impact on industry practices. In addition to projects on Fatigue-Risk Management, a Flight Risk Analysis Tool (FRAT) and Threat-and-Error Management (TEM), NSU and Embraer have conducted human factors research on mental health and the environment. The purpose of the seminar projects has been to raise awareness of these issues among pilots, aviation safety professionals, aviation students and the public.

[84] General Aviation News, 2013.

3. Conclusions and recommendations

This chapter first provides an overview of some core insights from academia regarding HOF in MAP. It then provides a selection of recommendations (extracted from a longer list of recommendations which appeared in the wider study) for human factors experts in industry and academia, building on the issues and challenges described in the previous sections.

3.1. Summary of key findings

HOF is not, in itself, an academic discipline; it is a multidisciplinary area that draws on fields ranging from cognitive psychology to socio-technical theory (see Section 2.1). A wide variety of HOF theories exist, including Rasmussen's Probabilistic Risk Assessment (1975), Turner's Man-Made Disasters (1978) and Perrow's Normal Accident Theory (1984), among others (see Appendix F: List of selected industry initiatives).

'Human factors' theory has been expanded to included 'organisational factors'. While human error remains influential – with studies attributing 80 per cent of accidents to individuals' mistakes – there is now a broader understanding of factors affecting system safety (see Section 2.2.2). Academics have also departed from the view that accidents are caused by a single chain of events, with each event causing the next (e.g. Heinrich's domino theory (1931), Reason's Swiss cheese model (1997)). Accident causation is now seen as less linear and more complex (see Section 2.2.1).

The literature highlights several 'good practices' in accident prevention: (1) adopting a 'no-blame' approach to error management; (2) establishing a reporting culture, which involves maintaining a detailed record of errors and near misses; and (3) providing training tailored to the specific HOF challenges faced by an organisation (see Section 2.3.1). These practices are designed to improve operative processes and enhance organisational learning.

Nonetheless, accident prevention efforts can be impeded by economic pressures, regulatory constraints, cultural limitations and a shortage of reliable evaluation data. As discussed in Section 2.3.2, pressure for production can divert resources from accident prevention initiatives. In organisational cultures that focus on human error, employees do not report errors due to fear of being blamed, which can lead to accidents that could have been addressed at an earlier stage.

Despite barriers to implementing academic work (see Section 2.4.2), academic research translates to industrial practice in several ways. These include: conferences, publications, academia–industry working groups, joint research programmes and analytical tools for industry based on academic work (see Sections 2.4.1 and 2.4.3).

3.2. Selected recommendations

As discussed in Section 2.4.2, a number of organisations have succeeded in building effective partnerships between academia and industry. However, academic interviewees observed that the large body of academic knowledge in the HOF domain tends to be abstract, theoretical and not focused on industry practice. It is often too high level and theory-based to have immediate practical applicability to industry. According to academic interviewees, a range of major HOF theories exist but consensus has not been reached within the research community regarding how to define and apply these concepts in a way that has actionable utility for industry.

At the same time, academic interviewees reported a perception that industry stakeholders could do more to engage with the HOF academic research community to capitalise on academic expertise in this area, as part of a wider programme of organisational learning and innovation for safety management.

Recommendation 1: A standardised HOF taxonomy should be developed for the oil and gas sector, drawing on both industrial and academic inputs

Despite the existence of a large body of research literature on HOF in MAP, current academic debate and industry practice is affected by the lack of a commonly accepted taxonomy of HOF in major accident causation and prevention – particularly in relation to the specific HOF risks within the oil and gas sector. Such a taxonomy would enable a common understanding of HOF risks, as well as helping move academic debates away from issues of definition and instead stimulating new research into the specific challenges of the oil and gas industry. It could also support the implementation of standardised error reporting and training procedures across oil and gas companies, facilitating knowledge exchange concerning best practices and reducing the 'learning curve' for staff and contractors moving from one company's safety management system to another. Given the credibility and accessibility associated with the IOGP's endorsement and publication of industry-wide initiatives and best practice, the taxonomy would benefit from IOGP 'sponsorship'. Its development could be undertaken under the auspices of the IOGP Human Factors subcommittee in consultation with stakeholders from across industry and with input from academia.

Recommendation 2: An accessible overview of HOF theories and trends over time should be developed for the oil and gas sector

While a wide range of HOF theories exist – including Rasmussen's Probabilistic Risk Assessment (1975), Turner's Man-Made Disasters (1978) and Perrow's Normal Accident Theory (1984) – a clear and comprehensive summary of these theories has yet to be published. To support industry understanding of human factors, academic experts should develop an accessible overview of these schools of thought with a particular focus on how academic thinking on the subject has changed over time, how these changes have been affected by developments in industry practice, and on emerging focus areas. As far as possible, this work should highlight ways in which academic theories can be translated into day-to-day industry practice. This could be achieved by academics drawing on inputs from oil and gas sector stakeholders, for example through interviews, focus groups, surveys or other research methods.

Recommendation 3: Oil and gas sector companies should continue to develop effective engagement models in partnership with universities and research institutes

To facilitate knowledge transfer between academia and industry, stakeholders in both domains should pursue a range of measures to promote both formal and informal exchanges. A number of organisations have built successful partnerships between academia and industry, and these efforts should be built upon. Engagement models could include: inter- and intra-sector joint working groups; funding of research programmes; reciprocal attendance at and involvement in workshops and conferences; support for secondments between industry and academia; incentives for company staff to undertake mid-career and/or part-time postgraduate study into HOF subjects; provision of company HOF experts to provide teaching or other guidance to universities; sponsorship of PhD fellowships; provision of industry placements to HOF students; and sharing of company data for study by researchers. Such initiatives would demonstrate and develop the practical impact of academic research on industrial practice and vice versa through knowledge transfer and engagement. Examples of efforts in this area are discussed in Section2.4.1.

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Appendix A: Technical approach

This appendix describes the RAND study team's approach to conducting interviews and literature review; the core data collection methods for this study.

Literature review

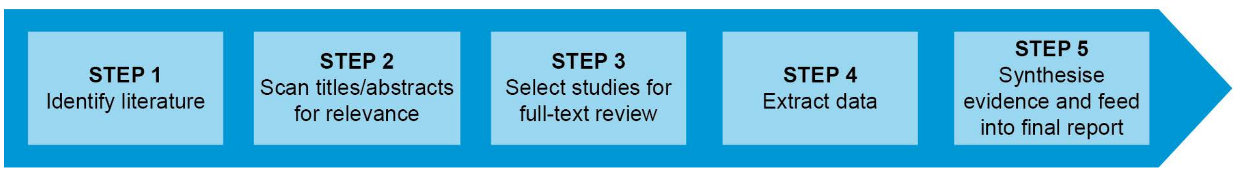
The RAND Europe study team conducted a literature review that focused on insights from academia on the role of HOF in MAP.

To prepare the literature review, a RAND librarian conducted an initial search of the academic literature (see Appendix E). In light of the multidisciplinary nature of HOF (see Chapter 2), the RAND librarian consulted business, management, health and behavioural science databases for materials that focused on HOF, MAP and safety management across multiple domains. The following databases were included in the search:

- Academic Search Complete
- Business Source Complete
- SCOPUS
- Web of Science
- PubMed
- Cumulative Index to Nursing and Allied Health Literature (CINAHL)
- PSYCHInfo.

No limitations were imposed according to publication year, language, country or population of focus. Once duplicates had been removed across databases, this initial search yielded 1,252 results for the search on 'insights from academia'. The RAND study team then reviewed the titles and abstracts of these sources for relevance, excluding irrelevant sources and conducting full-text review and data extraction of the included sources. The RAND literature review approach is illustrated in Figure A.1.

Figure A.1 Literature review process



The review of academic databases was intended to map out the major scholarly debates and changing academic trends. It also enabled the study team to identify academic interviewees and additional literature sources through a 'snowballing' approach.

The study team captured structured information from the included sources in a 'data extraction form'. This information was categorised in an Excel spreadsheet in order to make it readily analysable for RAND researchers. The document represents the data repository on which much of the subsequent analysis has been based, with a separate worksheet used for each of the research themes. The 'data capture' categories included:

- Source reference (author(s), date, title)
- Study purpose and methods
- Key definitions (e.g. 'human factors', 'accident', etc.)
- Role of HOF in MAP
- Role of HOF in MAP
- Academic landscape and changes in understanding of HOF over time
- Vignettes: description of HOF-based MAP initiatives
- Challenges associated with MAP
- Key findings
- Quality assessment: citations/peer reviewed.

An extract from the spreadsheet is included in Figure A.2 below.

Figure A.2 Data extraction sample

REFERENCE	STUDY BACKGROUND		HUMAN AND ORGANISATIONAL FACTORS ('HOF')	
Author(s), year, title	**Study purpose**	**Study methods**	**Definitions** (e.g. 'human factors', 'organisational factors', 'accident')	**Role of HOF in causing major accidents**
Hovden, J., E. Albrechtsen & I. Herrera. 2010. Is There a Need for New Theories, Models and Approaches to Occupational Accident Prevention? *Safety Science*, 48: 950-956.	To review established and emerging models in the occupational accident prevention field	Literature review	**Accident**: a hazard materialising in a sudden, probabilistic event (or chains of events) with adverse consequences (injuries). Classification is a tool to standardise the collection and analyses of data on accidents. There are four standard categories (Kjellen, 2000): **(1) Damage/loss**: includes injuries and fatalities, material and economic losses, reputation, etc.; **(2) Incident**: subdivided into **Type (fall, slip, explosion, etc.)** and **Agency (machine, vehicle, tool, etc.)**; **(3) Hazardous condition**: covers defective tools, unsafe design, housekeeping, etc.; **(4) Unsafe act**: covers errors and omissions. In addition, accidents can be categorised according to arena, i.e. where the accident happens, the type of activity involved, system characteristics, etc.	**HOF** combine with other **stressors** that may lead to accidents. Contextual stressors influencing working life risks include: **changing political climate and public awareness**, **market conditions** and **financial pressures**, **competence and educational concerns**, and the **fast pace of technological change** (Rasmussen, 1997). The 'information revolution' can create pitfalls such as **information overload, high demand for information,** and **communication problems**. **Language barriers** between co-workers can lead to occupation accidents.
Saleh, J. H., K. B., Marais, E. Bakolas, R. V. Cowlagi. 2010. Highlights from the Literature on Accident Causation and System Safety: Review of Major Ideas, Recent Contributions, and Challenges, Reliability Engineering and System Safety, 95: 1105-1116.	To provide an overview of the literature on **accident causation and system safety**	Literature review	**Incidents** or **accidents** are often classified according to the severity of their consequences. For example, the Mining Program within the National Institute of Occupational Health and Safety defines a **mine disaster** as an event that involves five or more fatalities. Similar threshold-based definitions exist for other industries. The Department of Energy defines an **accident** as 'an unwanted transfer [or release] of energy that, due to the absence or failure of barriers and controls, produces injury to persons, damage to property, or reduction in process output'. Defining **High Reliability Organisations** has proven challenging. Roberts proposed the following definition: a subset of hazardous organisations which has enjoyed a record of high safety over long periods of time. **HROs** share several key characteristics: **(1) Preoccupation with failure and organisational learning** - i.e. treating any lapse as a symptom that something may be wrong with the system; encouraging reporting of errors; **(2) Commitment to and consensus on production and safety as concomitant organisational goals** - HROs are said to be distinctive in managing the tension between production and safety; **(3) Decentralised and centralised operations, and deference to expertise** - HROs are said to be distinctive in shifting from centralised authority during routine operations to local/decentralised authority for hazardous situations and deferring to experts; **(4) Organisational slack and redundancy** - Organisational slack can provide additional resources during unexpected undesirable events or hazardous situations. Redundancy in this context is the ability to provide for the execution of a task if the primary units fail or falter. **Safety culture** is used to denote an aspect, or a subset, of an **organisational culture**. One definition is that: 'safety culture is attitudinal as well as structural, relates both to organisations and individuals, and concerns the requirement to match all safety issues with appropriate perceptions and actions'.	When carefully analysed, many accidents share a conceptual sameness in the way they occur, through a combination of **system design** and **technical flaws**, **operational or workforce failings**, and **compromised organisational behaviours and management shortcomings**. In addition, **deficient regulatory oversight** can be an important contributor to the causal chain leading to system accidents. This sameness is the story of the Bhopal, Piper Alpha and BP Texas City refinery accidents and many others. While **accident investigations typically seek the 'root cause' of and 'contributing factors'** to an accident, there is however often a **degree of arbitrariness in interpreting what is an error and in choosing where to stop going back in the causal chain.** At any point in the causal analysis, a failure or an error can be conceived of as a 'result' and not a 'cause'. The **tension between production and safety** is a recurrent theme in the accident causation literature. Sacrificing safety for increased production is frequently identified as a key determinant in many accidents.

Engagement with experts

RAND researchers also conducted nine interviews with academic experts. The purpose of these interviews was three-fold: first, they were intended to expand upon and validate the emerging findings of the literature review as well as to clarify any areas of confusion or conflict. Second, they allowed for the elicitation of information not available within the literature including, for example, information about ongoing initiatives or programmes that may not have been documented. Third, the interviews allowed for the identification of additional interviewees and further sources of literature that were not collected through the data-gathering exercise.

The study team developed an interview 'protocol' to be used when conducting semi-structured interviews.[85] This guidance document was designed to help the interviewer cover all the desired topics while allowing scope for flexibility, and was adjusted for each of the three focus areas. It was also designed to ensure that, as far as possible, respondents were all asked the same questions in a similar way. The interview protocols can be found in Appendix C, and Appendix D provides a list of interviewees.

The interviews, which lasted one hour each, were primarily conducted by telephone. Interviewees were offered three confidentiality options: (1) interviewees could be named and quoted in the report; (2) interviewees' contributions could be partially anonymised by including interviewees' organisational affiliations (industry, organisation and/or job role) but not their names; or (3) interviewees could be fully anonymised.

[85] Semi-structured interviews combine specific questions with flexibility to ask unplanned follow-up questions. By contrast, structured interviews follow a specific protocol with all interviewees asked exactly the same questions; and unstructured interviews consist of a free-flowing conversation on a given topic.

Appendix B: Glossary

Table B.1 provides a list of key definitions relating to the study of HOF in MAP. It should be noted that multiple – and sometimes competing – definitions exist for the same terminology in the HOF literature. For example, the term 'human factors' is subject to a range of interpretations. While Gordon (1998) defines human factors as the study of the interactions between human and machine, this definition has also been expanded to include the effect of individual, group and organisational factors on overall safety.[86]

Table B.1 Key definitions

Term	Definition	Source(s)
High Reliability Organisation	An organisation that is able to manage and sustain almost error-free performance despite operating in hazardous conditions where the consequences of errors could be catastrophic.	*Lekka, 2011*
Human error	Human acts that are considered to deviate from some kind of reference act. Human error can be categorised into two groups: active errors, which have an instantaneous effect and are usually made by frontline operators; and latent errors, which lie concealed within the system until they combine with other factors to destroy the system defence.	*Reason, 1990; Gordon, 1998*
Human and organisational factors	Often viewed as separate and identifiable issues in the cause of an event. Examples include: lack of training, incorrect procedures, poor decisionmaking and ineffective communication.	*IAEA, 2014*
Human factors	Environmental, organisational and job factors, and human and individual characteristics which influence behaviour at work in a way which can affect health and safety. Also called 'ergonomics'.	*Health and Safety Executive, n.d.*
Macro-ergonomics	Human factors at the macro level, macro-ergonomics, is focused on the overall people-technology system level and is concerned with the impact of technological systems on organisational, managerial and personnel systems.	*Meshkati, 1991*

[86] Sanders & McCormick, 1993.

Major accident	An acute accident, such as a major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets.	*Petroleum Safety Authority Norway, n.d.*
Micro-ergonomics	Human factors at the micro level, 'micro-ergonomics', is focused on the human–machine system level and is concerned with the design of individual control panels, visual displays and workstations.	*Meshkati, 1991*
Near miss	A situation where corrective actions have prevented deviations from provoking adverse organisational outcomes. An event that could have caused an accident, but for some barrier did not result in a real accident.	*Zhao & Olivera, 2006; Catino, 2008*
Organisational climate	A multidimensional construct that encompasses leadership, roles and communication. Organisational climate is thought to exert a strong influence on individual motivation to achieve work outcomes, and has also been found to influence knowledge and skills by increasing participation in activities such as training.	*James & McIntyre, 1996; Brown & Leigh, 1996*
Risk	The product of the probability of an accident or event occurring and the (assumed negative) consequences that necessarily accompany that event.	*Sheridan, 2008*
Safety climate	A specific form of organisational climate which describes individual perceptions of the value of safety in the work environment. This encompasses a range of factors: management values (e.g. management concern for employee well-being), management and organisational practices (e.g. adequacy of training, provision of safety equipment), communication, and employee involvement in workplace health and safety.	*Neal et al., 2000*
Safety culture	The safety culture of an organisation is the product of individual and group values, attitudes, perceptions, competencies and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organisation's health and safety management. Organisations with a positive safety culture are characterised by communications founded on mutual trust, by shared perceptions of the importance of safety and by confidence in the efficacy of preventive measures.	*HSE, 1993*

Appendix C: Interview protocol

This appendix provides an overview of the questions asked during the research interviews. Interviews were semi-structured in the sense that the following list of questions was used as a guide to address key topics rather than as a rigid framework. Before asking any substantive questions, interviewees were asked about their professional background to develop an understanding of their perspective.

The questions below were asked to the academic experts who took part in the interviews:

Current Academic Landscape:

- What is the current academic landscape in terms of the study of human and organisational factors (HOF), especially in relation to major accident prevention? What major debates/schools of thought exist?
- How has the understanding/focus of HOF changed over time?
- What is the likely future of research in this area? Are there any specific areas of particular significance?
- What is the impact of academic work on industrial/operational practice and what are the pathways to impact?

Current Practice in Industry:

- What are the primary challenges and risks posed by HOF in the oil and gas sector (or industry more generally)?
- Are HOF recognised as a major factor in accident prevention?
- How are HOF addressed in major accident prevention efforts/initiatives within industry? (E.g. tools, guidance, technologies, processes, etc.)
- Are there specific examples of historic or current 'best practice'/major initiatives?
- What lessons can be learned from other sectors which may be applicable to the oil and gas industry?

Appendix D: List of interviewees

We are grateful to the numerous academic experts who took part in interviews and informed the conclusions of this study. Where consent has been given, their names and/or affiliations are listed in the table below. Contributions have been anonymised in this table and throughout the report in certain cases where interviewees have requested to remain anonymous.

Academic experts

Interviewee name	Position	Organisation
Prof Michael Baram	Professor of Law Emeritus	Boston University Law School
Prof Robert Bea	Professor Emeritus of Engineering and Project Management Systems	University of California, Berkeley
Prof Graham Braithwaite	Director of Transport Systems and Professor of Safety and Accident Investigation	Cranfield University
Prof Rhona Flin	Professor of Industrial Psychology	Aberdeen Business School, Robert Gordon University, Aberdeen
Prof Andrew Hopkins	Emeritus Professor	Australian National University
Prof Preben Hempel Lindoe	Professor Emeritus of Civil Protection	University of Trondheim
Anonymous	–	–
Prof Ortwin Renn	Professor of Environmental Sociology and Technology Assessment	University of Stuttgart
Dr Patrick Waterson	Reader in Human Factors and Complex Systems	Loughborough University

Appendix E: Literature review search strategy

This appendix describes the search terms selected, the databases consulted and the search strategy used by the RAND study team in preparing the literature review database.

1. Search terms

The following search terms were selected to source relevant literature:

- "major organizational accidents"
- "major accidents"
- "major accident prevention"
- "major accident prevention program OR programme"
- "organizational accidents"
- "severe accidents"
- "accident causation"
- "severe accident research"
- "systemic accidents"
- SARNET – Severe Accident Research Network
- SEVESO II Directive
- "System safety"
- "occupational safety"
- "safety management"
- "safety management system"
- "safety management program or programme"
- "safety culture"
- "Risk management"
- "risk assessment"
- "process safety management"
- "Human factor"
- "human error"
- "organizational or organizational factors"
- "decision making"
- "managerial factors"
- "occupational safety"

- "industrial safety"
- "reliability engineering"
- "high-reliability organizations"
- "process safety"
- "process industries"
- "normal accident theory"
- "high reliability theory"
- "nuclear reactors"
- "nuclear power plants"
- "nuclear facilities"
- Offshore
- Gas
- LNG or Liquid Natural Gas
- Oil
- Petrol*
- Model*
- Framework*
- "accident model"
- "accident investigation"
- "accident prediction model"
- Simulation

2. Databases

The RAND librarian consulted seven databases:

- Academic Search Complete
- Business Source Complete
- SCOPUS
- Web of Science
- PubMed
- Cumulative Index to Nursing and Allied Health Literature (CINAHL)
- PSYCHInfo.

3. Search strategy

In order to identify a broad range of literature, no search limitations were applied by publication date, language, population, geographical scope or publication type. A separate search was run across each of the seven databases. Table D.1 illustrates the search strategies used when consulting Business Source Complete to provide an indication of the types of searches that were run.

Table D.1 Business Source Complete search strategies

Set	Search strategy	Hit count ( )=hits before duplicate removal
	TI OR SU OR AB(accident* OR "accident prevention" OR "occupational safety" OR "industrial safety" OR "accident prevention program*" OR "severe accident*" OR "severe accident research*" OR "industrial safety*" OR "system safety" OR "safety management" OR "safety management system*" OR "safety management program*" OR "safety management programme*" OR "safety culture" OR "process safety" OR "process industr*" OR "normal accident theory" OR "high reliability theory" OR "high-reliability theory" OR "process safety management" OR "reliability engineering" OR "high reliability organi?ation*" OR "high reliability industr*" OR "high-reliability organi?ation*" OR "high-reliability industr*" OR mitigat* OR "prevention initiative*") And TI OR SU OR AB(("human factor*" OR "organi?ational factor*" OR "managerial factor*" OR "human error*") AND TI OR SU OR AB((review* OR "literature review*" OR literature OR "systematic review*" OR "critical review*" OR "meta-analysis" OR "meta-analys*" OR "meta analys*" OR metaanalys*)	48 (85)