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Development of integrated human reliability assessment methods for accident investigation in the oil and gas industry

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Development of Integrated Human Reliability Assessment Methods for Accident Investigation in the Oil and Gas Industry

By

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Critical Overview Document (COD)

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Dedication

I wish to dedicate this work to the memory of my late father and mother who passed away to the great beyond believing that this will be achieved by the grace of GOD.

Abstract

Significant progress has been made in the direction of “engineering out” technological causes of accidents that have characterised the technology age. Inherently safer designs have introduced several ‘layers of protection’ (LOP) or ‘lines of defence’ (LOD) focused on reducing or eliminating technological causes of accidents. It is arguable that human and organisational factors are significant factors behind the majority of the major accidents seen in the process industry today. The main aim of this PhD thesis is to develop a new Human Reliability Assessment (HRA) tool for the analysis of major accidents in the oil and gas industry. This tool will help oil and gas industry accident investigators make sense of accident reports and proffer appropriate remedial action that will stop or reduce reoccurrences. It will also help both employees and employers, policy decision-makers and regulatory agencies to learn lessons which in turn will result in potential cost and time savings. It has investigated all the aspects of human factors (HFs), human errors (HEs) and performance influencing factors (PIFs) related to major accidents in the in the oil and gas industries and proposed an integrated process safety management system (IPSMS) model.

The research adopted sequential explanatory and exploratory mixed methods. Each research output began with a review of academic literature and published reports. Major accident reports published by The International Association of Oil & Gas Producers (IOGP), Health and Safety Executive (HSE), World Offshore Accident Database (WOAD), the Process Safety Incident Database (PSID) and the U.S. Chemical Safety Board (CSB) were used for this research. Quantitative data was also collected for internal and external validation of the newly developed Human Reliability Assessment (HRA) tool. SPSS version 25 and case studies were used for statistical and case study analysis respectively, to show the internal validation of the tool or the developed approach.

In identifying and describing the different causal factors in 11 reviewed case study accidents, 54 categories of occurrences were identified with the HFACS, but a total of 80 were identified with HFACS-OGI. All industry specific categories which were difficult to identify with the HFACS were successfully identified using the HFACS-OGI. Whilst TRACEr proved to be flexible and adaptable for the oil and gas industry, it proved difficult to use for coding equipment failures. However, TRACEr-OGI was not only able

to identify human errors aligned to job context, organisational/facility context and operator context, it was also able to capture equipment error.

Numerous process safety management systems (PSM) and frameworks exist. However, no single management system is sufficient in addressing all human factor elements as outlined in HFACS. Consequently, this PhD thesis has identified the missing human factors in the current system and proposed an integrated process safety management system (IPSMS) model. Finally, a risk-culture-based implementation strategy was developed for this model, with recommendations on how to incorporate inherent safety culture and implement a Process Safety Management System in the process industry in a structured way, evolved from the various studies.

With the new knowledge and innovative models developed in this PhD project, accident investigators and decision makers are expected to gain a better understanding of human factors (HFs), human errors (HEs) and performance influencing factors (PIFs), as well as process safety management systems in the oil and gas industry. This PhD thesis is a synthesis of theories and concepts about accident causation, a mixture of qualitative and quantitative accident analysis and accident analysis initiatives.

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Glossary of Terms

Accident	-	An unplanned sequence of events that results in undesirable consequences.
Barrier	-	Anything used to control, prevent, or impede energy flows
Causal Factor	-	An event or condition in the accident sequence necessary and sufficient to produce or contribute to the unwanted result. Causal factors fall into three categories: • direct cause, • contribution cause, and • root cause.
Cause	-	Anything that contributes to an accident or incident.
Event	-	Something significant and real-time that happens.
Facility	-	The buildings, utilities, structures, and other land improvements associated with an operation or service and dedicated to a common function.
Fatal Accident Rate	-	The estimated number of fatalities per 10^8 exposure hours (roughly 1000 employee working lifetimes).
Hazard	-	The set of inherent properties of a substance, or a mixture of substances, that make it capable of causing adverse effects to humans, other organisms or the environment.
Hazard Analysis	-	The determination of material, system, process, and plant characteristics that can produce undesirable consequences, followed by the assessment of hazardous situations associated with a process or activity.
Human Error	-	Any human action (or lack thereof) that exceed some limit of acceptability (i.e., an out-of-tolerance action) where the limits of human performance are denied by the system. Includes actions by designers, operators, or managers that may contribute to or result in accidents.
Human Factors	-	Those biomedical, psychosocial, workplace environment, and engineering considerations pertaining to people in a human-machine system.
Human Factors Engineering	-	The application of knowledge about human performance capabilities and behavioural principles to the design, operation, and maintenance of human-machine systems so that personnel can function at their optimum level of performance.

Human Reliability Analysis	-	A method used to evaluate whether system-required human actions, tasks, or jobs will be completed successfully within a required time period.
Incident	-	An unplanned, unexpected event which has the potential to lead to an accident although may not do so.
Initiating Event	-	The event that initiates the scenario leading to the undesired consequence.
Layer Of Protection Analysis (LOPA)	-	A process (method, system) of evaluating the effectiveness of independent protection layer(s) in reducing the likelihood or severity of an undesirable event.
Mitigation	-	Reducing the risk of an accident event sequence by taking protective measures to reduce the likelihood of occurrence of the event, and/or reduce the magnitude of the event and/or minimize the exposure of people or property to the event.
Mitigation Event	-	Equipment and/or procedures designed to respond to an accident event sequence by hindering accident propagation and/or reducing the accident consequences.
Operator	-	An individual responsible for monitoring, controlling, and performing tasks as necessary to accomplish the productive activities of a system.
Performance Influencing OR Shaping Factors	-	Any factor that influences human performance. It may be external (heat, stress, etc.) or internal to the person (religious beliefs, education, personality, skills) and factors in the work situation (task demand, plant policy, plant design, training, etc.)
Process Safety	-	A discipline that focuses on the prevention and mitigation of fires, Explosions, and accidental chemical releases at process facilities.
Process Safety Management	-	A program or activity involving the application of management principles and analytical techniques to ensure the safety of chemical process facilities.
Recovery Factors	-	Factors that limit or prevent the undesirable consequences of a human error.
Risk	-	The quantitative or qualitative expression of possible loss that considers both the probability that a hazard will cause harm and the consequences of that event.
Root Causes	-	Management system failures such as faulty design, inadequate training, etc. that lead to the unsafe acts or conditions that resulted in an incident.

Safety	-	The expectation that a system does not, under defined conditions, lead to a state in which human life, economics or environment are endangered.
Safety Culture	-	It may be described as a product of the individual and group values, attitudes, competencies and patterns of behaviour that determine the commitment to, and the style and proficiency of an organisations health and safety programmes
Safety Management System (SMS)	-	Management of Safety to promote a strong Safety Culture and achieve high standards of safety performance.

List of Abbreviations

AHP	Analytic Hierarchy Process
AIChE	American Institute of Chemical Engineers
CCPS	Center for Chemical Process Safety
CI	Consistency Index
CIMAH	Control of Industrial Major Accident Hazards
COD	Critical Overview Document
COMAH	Control of Major Accident Hazards
CR	Consistency Ratios
EPC	Error-Producing Conditions
FTA	Fault Tree Analysis
GEMS	General Error Modelling System
HE	Human Error
HEI	Human Error Identification
HEIST	Human Error Identification in System Tools
HEP	Human Error Probability
HF	Human Factor
HFACS	Human Factors Analysis and Classification System
HFACS-OGI	Human Factors Analysis and Classification System for the Oil and Gas Industry
HFE	Human Factors Engineering
HFIT	Human Factors Investigation Tool
HRA	Human Reliability Analysis
HSE	Health and Safety Executive
IRA	Interrater Agreement
IRR	Interrater Reliability
ISD	Inherently Safer Design
IOGP	International Association of Oil & Gas Producers
IPSMS	Integrated Process Safety Management System
LOD	Lines of Defence
LOP	Layer of Protection
ORM	Operational Risk Management
OSHA	Occupational Safety and Health Administration
PIF	Performance Influencing Factors
PSC	Process Safety Culture
PSID	Process Safety Incident Database
PSMS	Process Safety Management Systems
RBPS	Risk Based Process Safety
RCPSC	Responsible Care Process Safety Code
RMP	Risk Management Plan
SC	Safety Culture
SCS	Safety-Critical System
SIS	Safety Instrumented Systems
SPE	Society of Petroleum Engineers
SRK	Skill, Rule, Knowledge
TA	Task Analysis
THERP	Technique for Human Error Rate Prediction

TRACEr	Technique for Retrospective and Predictive Analysis of Cognitive Errors
TRACEr-OGI	Technique for Retrospective and Predictive Analysis of Cognitive Errors the Oil and Gas Industry
U.S. CSB	U.S. Chemical Safety Board
U.S. EPA	U.S. Risk Management Plan
WOAD	World Offshore Accident Database

Chapter One

Introduction

This study seeks to develop Integrated Human Reliability Assessment Methods the oil and gas industry. To set the scene for the study, chapter one explored the evolution of a prevention culture and examined the development of human reliability assessment in other high risk industry. This chapter provides an overview of the research problem, research questions and operationalises these questions into short objectives. Finally, this chapter presents the structure of the Critical Overview Document (COD).

1.1 Background

The high rate of occupational accidents, injuries, diseases and fatalities that characterised the Industrial Age (the 1800s) (Cacha 1999) declined remarkably with the introduction of better engineering designs such as better controls, machinery processes, adherence to regulations, regular inspections and the use of appropriate personal protective equipment (Kim, Park and Park 2016; Hale and Hovden 1998). Safety in the technical age was concerned with the technical measures to guard machinery, stop explosions and prevent structures from collapsing simply by matching the individual to the technology (Hale and Hovden 1998). During this era, there was no "management system" other than the owner of an enterprise handling tasks such as planning, resource allocation, controlling, coordination and rewarding. The growing frustration with the health and safety idea of simply matching the individual to the technology and the increasing realisation that technical risk assessments and prevention measures could not solve all health and safety problems ushered in research related to human errors, human factors and performance influencing factors. A major "shift in concern for the human in a technological context occurred during the American Civil War" (Meister 2018: 147). However, the efforts at that time were to fit the man to the machine, but no efforts were made to design the machine to fit the characteristic of the human (Meister 2018). Although contributions of human factors to accidents were not fully captured during this age, it set the stage for the organisational age (Figure 1.1). The shift in understanding the influences of better engineering design and safety from technological to organisational factors led to improvements in systems safety and decreased the incidence of occupational accidents (OHSMS et al. 2001). The Organisational age saw the introduction of safety management systems which further decreased the incidence of occupational accidents, injuries, diseases and fatalities. Human factors and human errors emerged as an identifiable field of study around the 1970s (Glendon and Clarke 2015). The achievements of that period include the works of Hale and Glendon (1987), Petersen (1989), Reason (1990) and Glendon and McKenna (1995). Later, the impact of organisational safety policies, safety culture, risk identification and control were considered by companies and this further reduced the incidence of occupational accidents (Milczarek and Najmiec 2004; Kim, Park and Park 2016; Fennell 2017).

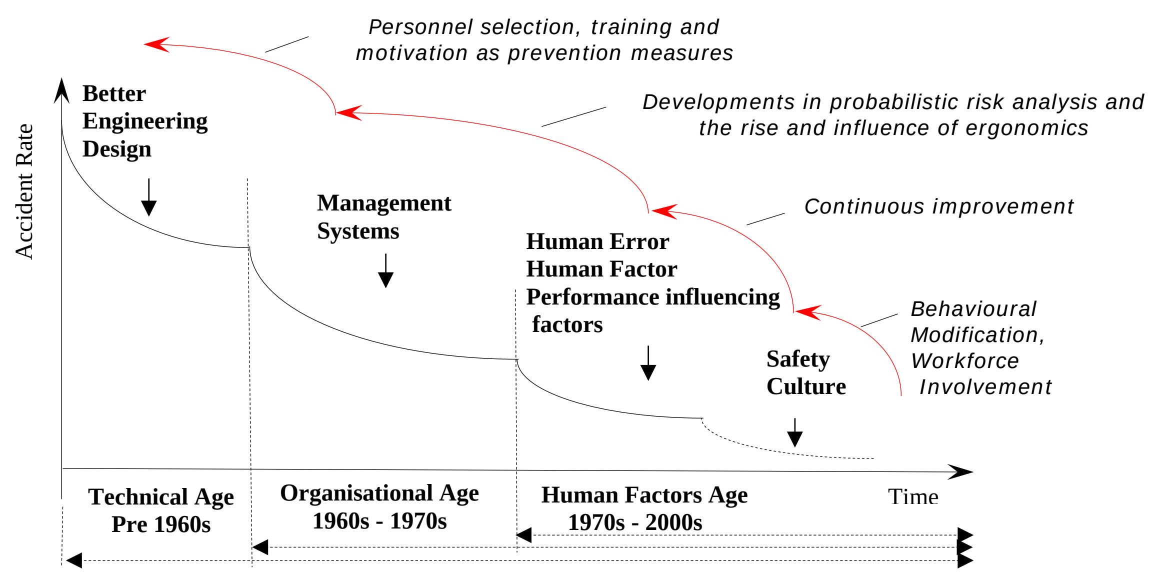


Figure 1. 1. Evolution to a prevention culture (adapted from Kim, Park, and Park 2016; Prado and Jasper 2015).

During the technical age, efforts to reduce the likelihood of incidents were traditionally concentrated on technology and operations management. However, evidence emerged that technologies such as automation and computerisation that should have reduced human errors by reducing human involvement have sometimes caused accidents because of problems with their design, their impact on the operator and the workflow (Karsh 2004), leading to an increased knowledge of human and organisational factors. This increased awareness of prevention measures that recognise human and organisational factors as major contributors to operational safety and the optimisation of process system performance in high-risk industry led to advancement in human factors engineering (Karsh 2004). Gradually, what could be termed holistic safety (Figure 1.2) emerged, concerned with an understanding of human capabilities. This awareness was then applied to the design of technologies that were usable (easy to use) and useful (improving job performance, efficiency, and/or quality), equipment, tools, systems and processes of work, without leading to prevalent organisational defects.

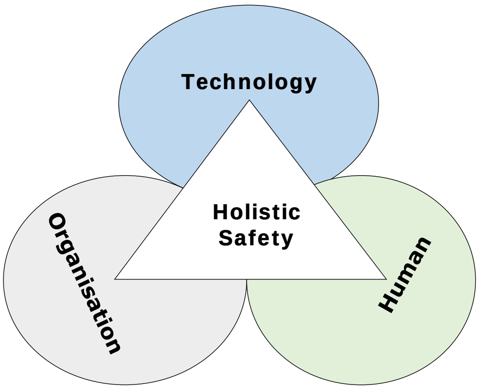
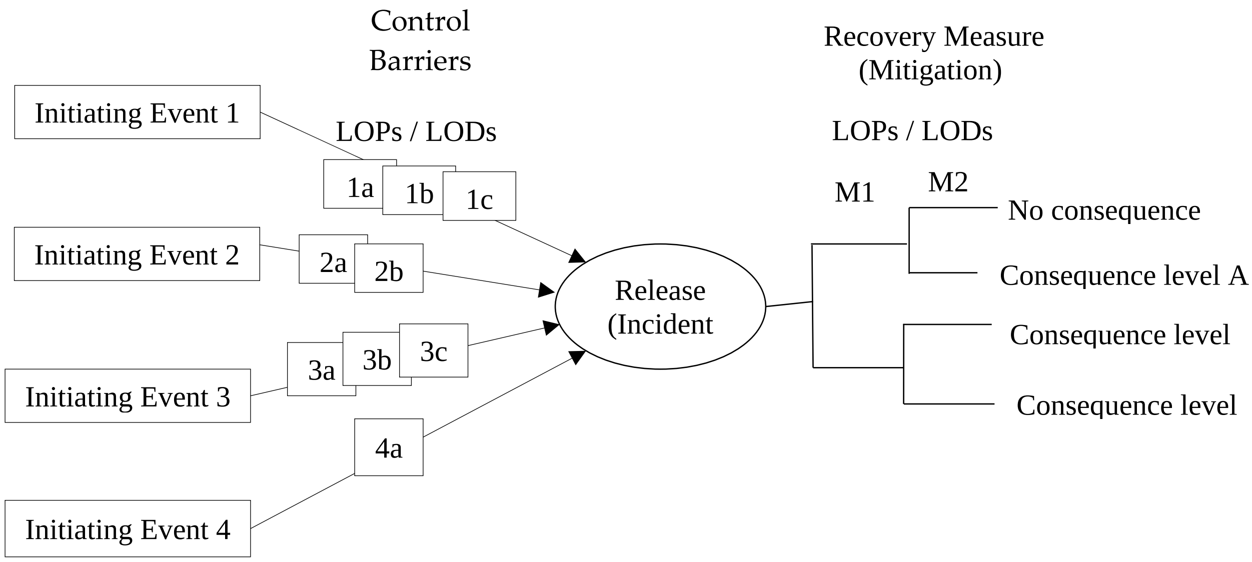


Figure 1. 2. Illustration of Holistic Safety (capturing technical, human and organisational factors in safety) adapted from ARPANSA (2017)

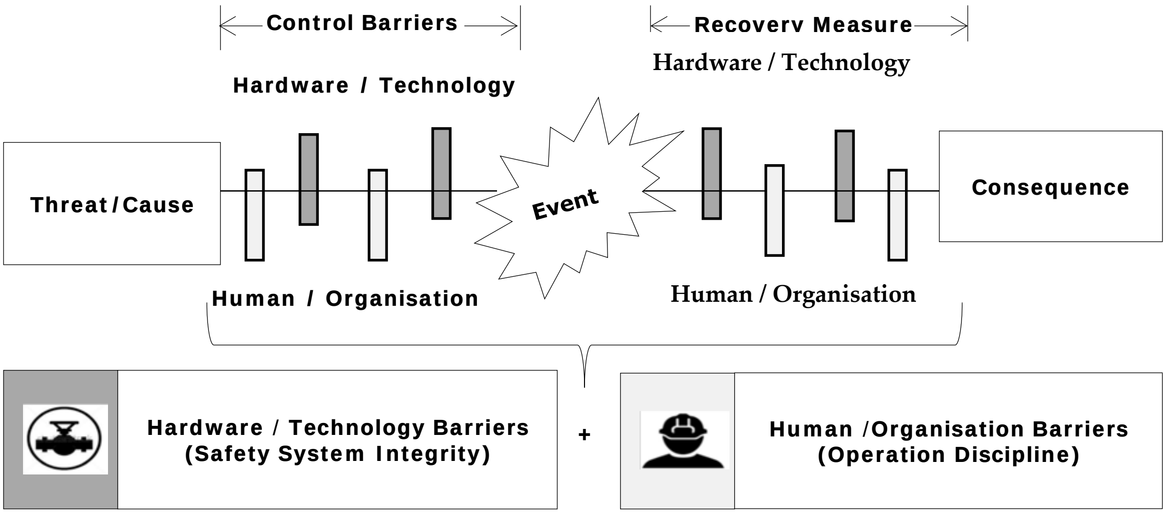
Plants in the technical age were designed to reduce harm and risk by simply adding protective equipment and following safe methods of working without attempting to eliminate the sources of the harm. Kletz, Amyotte and Amyotte (2010) defined a hazard as “a situation that can lead to harm”. Risk is the product of the probability that the harm will occur and the consequence of the occurence. Trevor Kletz in the late 1970s promulgated the concept of inherent safety based on common sense, which is to “remove or reduce the hazards” (Kletz Amyotte and Amyotte 2010). AIChE later defined inherent safety as “a concept, an approach to safety that focuses on eliminating or reducing the hazards associated with a set of conditions (AIChE 2009)”. This priciple is today applied to technological design processes as inherently safer technology (IST), or inherently safer design (ISD) (CCPS 2010: 1), to eliminate or reduce hazards and to avoid or reduce the consequences of incidents.

Process risk is measured in terms of likelihood and consequences of the occurrence of an incident. Whereas inherently safer design is commonly perceived to focus solely on reducing or eliminating the consequences, ‘layer of protection’ (LOP) or ‘lines of defence’ (LOD) is considered a form of inherently safer design (ISD) which reduces the likelihood of the initiating event leading to an incident (Franks 2017). Layer of Protection (Figure 1.3

A) is used to ensure that process risk events leading to an incident are successfully prevented and that consequences resulting from any eventual incident are mitigated to an acceptable level. Figure 1.3 B shows that these LOPs / LODs barriers can be human or hardware, for example, inherent safety devices, computer-based systems, safety-critical systems (SCS) and safety instrumented systems (SIS) and Technology (for example, information technology).



A Generic arrangement of layer of protection' (LOP) or 'lines of defence' (LOD) as part of inherently safer design



B Generic arrangement of hardware and human control barriers and recovery measures

Figure 1. 3. Generic arrangement of control barriers and recovery measures

1.2 Research Context and Justification

Significant advancements have been made in the direction of “engineering out” technological causes of accidents seen in the technology age (Figure1.1) (Lee and Harrison 2000). The hardware or technology aspects of control and recovery measures (Figure 1. 3 B) have advanced considerably. It is now arguable that human and organisational factors are behind the majority of the remaining major accidents seen in the process industry (Figure 1.3 A and Figure 1.3 B) (Lee and Harrison 2000; Rollenhagen 2010). As a result, the concepts of ‘human factor’ (HF), ‘human error’ (HE), ‘performance influencing factors’ (PIF), ‘process safety management system’ (PSMS) and ‘process safety culture’ (PSC) have evolved as a way of formulating and addressing these current foci (Kariuki and Löwe 2007; Manca and Brambilla 2012).

Notable accidents seen in the process industry include the Bhopal toxic release (1984) that resulted in over 2,500 fatalities and over 200,000 injuries; Ocean Ranger (1982) with 84 fatalities; Piper Alpha (1988) with 167 fatalities and Glomar Java Sea (1983) with 81 fatalities. These have all been investigated and found to be a result of both direct and indirect human and organisational failings (Singh et al. 2010; Mishra 2015; Pate-Cornell 1993; Gordon 1998). The accident model by the Disaster Management Institute (2010) shown in Figure 1.4 B below, traced the root causes of different accidents to human and organisational factors. It shows a schematic pathway from performance influencing factors (PIF), human factors (HF) and latent error (LE) leading to a likely adverse incident. Firstly, performance influencing factors influence jobs, organisations and personnel factors. Secondly, human factors that originate from top-level decisions proceed to unsafe acts committed by operators at the human-technology interface. Finally, latent error through an unsafe plant or conditions leads to an incident. Failure to recover from the incident leads to an accident and failure to mitigate determines the level of consequence resulting from the accident. Most human factors and human error investigation tools for most process industry sectors seek to break these causal sequences or reduce the influence of these contributors.

As the knowledge of management systems progressed (Figure 1.1), the concept of process safety management (PSM) practices was first considered in the 1970s, when company management began to introduce operational risk management, management of change, operating procedures and maintenance (Cummings 2009). It was focused towards the application of diverse practices to control the rate and extent of incidents involving hazardous chemicals and toxic substances release, structural collapse, as well as fires and explosions (Shimada, Kitajima and Takeda 2009; Knegtering and Pasman 2009a). This first model was the robust Responsible Care Process Safety Code (RCPSC) in 1984 (GPCA 2011). Later, the European Communities Seveso Directive (82/501/EEC) was implemented to curb the consequences of major accidents on both people and the environment; the Control of Industrial Major Accident Hazards (CIMAH) Regulations were enacted (1984) (Cassidy 2013). OSHA released the Federal Registry (55FR 29150) standard named the Process Safety Management of Highly Hazardous Chemicals on July 17, 1990 (U.S. Department of Labor 2000) to help combat accidents resulting from highly hazardous chemicals. The Control of Major Accident Hazards (COMAH) Regulations 1999 was also enacted to aid in the reduction of process safety accidents in the UK (UKHSE 2015). Other notable process safety management (PSM) models include the US EPA Risk Management Plan (RMP) Rule, the AIChE/CCPS Risk Based Process Safety (RBPS) Model, the Energy Institute High-Level PSM Framework, the DuPont Operational Risk Management (ORM) Model and the ILO PSM Framework. Today, process safety management (PSM) and human factors have become key factors in preventing exposure to both hazardous materials and major accidents in the process industry. However, Bridges, Tew and Lane (2010) argued that current PSM frameworks do not adequately address human factors elements. Moore et al. (2015) suggested that a key reason for this is the lack of a robust PSM system which integrates elements from every other PSM framework.

1.3 The Research Problem

Human Reliability Assessment (HRA*)* “involves the use of qualitative and quantitative methods to assess the human contribution to risk (Bell and Holroyd 2009).” Research is now geared towards human factor, human error, the effects of performance influencing factors (PIFs) and how PIFs influence the propagation of undesired occurrences in the processing industries (See points 1, 2, 3 and 4 in the circle in Figures 1.4A and 1.4B). Other current research areas are process safety culture and balanced organisational safety management strategies that are focused primarily on attitude and behaviour changes. This does not imply inherent safety design gains and the need for continuous improvements are neglected. Numerous generic HRA tools have been developed and some high risk industries have developed ‘bespoke’ HRA methods (Bell and Holroyd 2009). Notable examples of these ‘bespoke’ tools include the Human Factors Investigation Tool (HFIT) for Accident Analysis (Gordon et al. 2005), the Technique for Human Error Rate Prediction (THERP) (Boring 2012), the Cognitive Reliability Error Analysis Method (CREAM) (Hollnagel 1998), Human Factors Analysis And Classification System (HFACS) (Shappell and Wiegman 2003), the Predictive Analysis of Cognitive Errors (TRACEr) (Shorrock 2005; Shorrock and Kirwan 2002a) and many more. While there are ‘bespoke’ HRA tools for most process industry sectors, there are hardly any comprehensive, critical and robust tools designed precisely for the oil and gas industry. The Human Factors Analysis and Classification System (HFACS) and the Technique for Retrospective and Predictive Analysis of Cognitive Errors (TRACEr) developed for the aviation industry, are not sufficiently suitable for the oil and gas industry as presently constituted. HSE reviewed HRA tools and identified 72 tools (generics, bespoke, 1st, 2nd, and 3rd generation) mainly developed for the nuclear and aviation industries (none for the oil and gas industry). Human Reliability Assessment tools used in the oil and gas industry have remained generic, 1st generation tools: Hazard Operability (HAZOP) Fault tree analysis (FTA), Event Tree Analysis (ETA) and Hazards and Effects Management Process (HEMP). These were developed for the nuclear industry during the technical age and are mainly used for process hazard assessment. They are not very robust for assessing emerging complex qualitative and quantitative risks involved in the complex, ultra-deep frontier the industry has moved into. The core problem addressed by this thesis is twofold: a) assessing current ‘bespoke’ Human Reliability Assessment (HRA) tools used in the aviation industry for suitability in the oil and gas industry and b) adapting this method to make them suitable for the oil and gas industry.

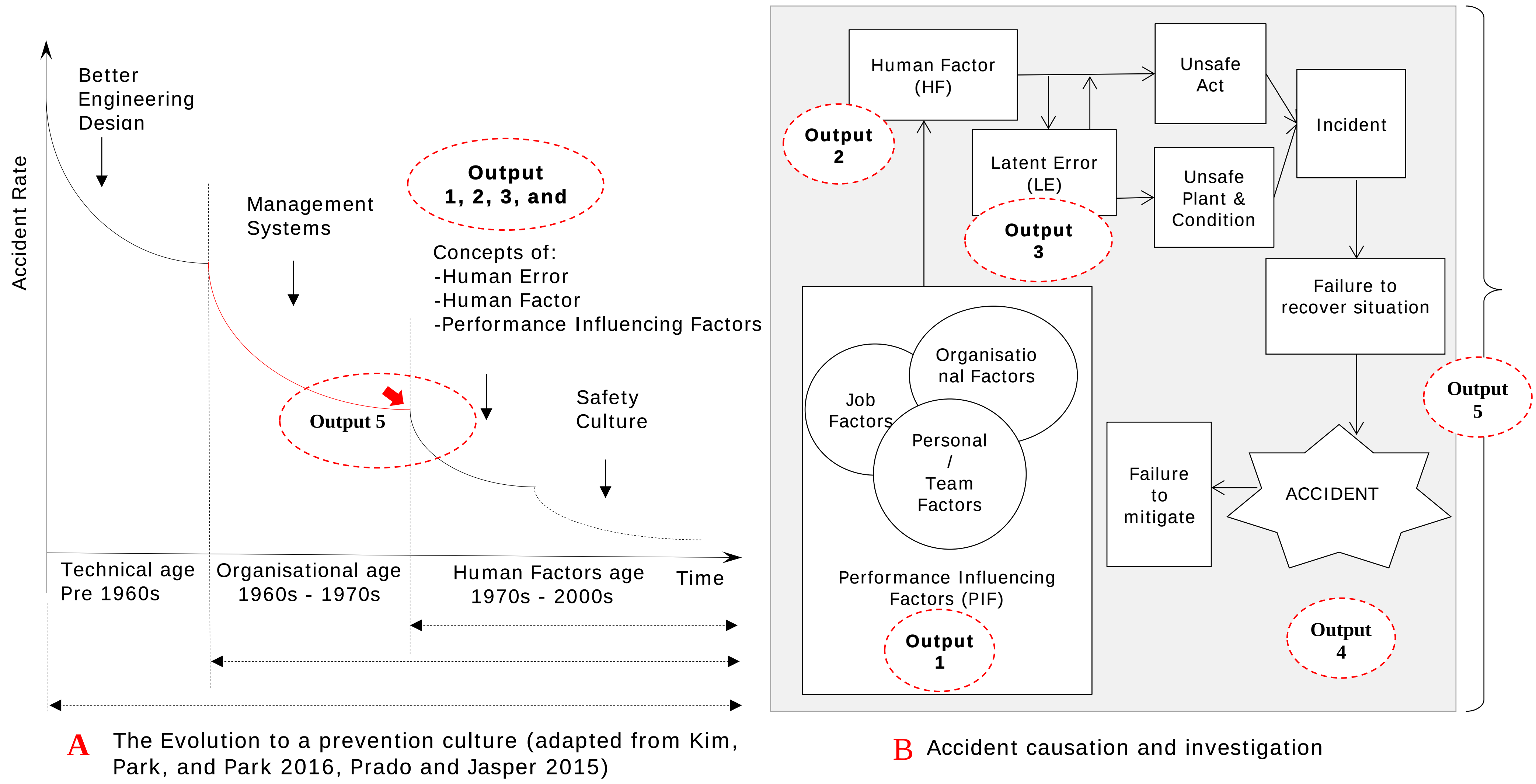


Figure 1. 4. Linking journal outputs included in the portfolio under a common theme. Numbers in circles indicate areas this research is focussed on.

1.4 Research questions

In addressing the above research problem, an attempt was made to provide answers to the following pertinent research questions:

I. How suitable for the oil and gas industry are the current human factor analysis and classification system (HFACS) frameworks developed for the aviation industry?

II. How suitable for the oil and gas industry is the current Technique for Retrospective and Predictive Analysis of Cognitive Errors (TRACEr) developed for the aviation industry?

III. What are the most common Human Factors (HFs) and Performance Influencing Factors (PIFs) contributing to major accidents in the process industry?

IV. Is it possible to develop a robust process safety management (PSM) system that integrates the missing human factor (HF) in the current management systems?

1.5 Aim and Objectives

The aim of the proposed study is to enhance existing Human Reliability Assessment (HRA) tools for the analysis of major accidents in the oil and gas industry. HRA tools specifically developed for the oil and gas industry will help accident investigators in the industry to make better sense of accident reports, proffer appropriate corrective measures to stop or reduces reoccurrence and save lives. It will also help oil and gas industry workers, policy decision-makers and regulatory agencies learn lessons which in turn will result in potential cost and time savings. The following objectives have been set to achieve this aim:

I. To develop a human factor analysis and classification system (HFACS) framework for the oil and gas industry (HFACS-OGI).

II. To develop a Technique for Retrospective and Predictive Analysis of Cognitive Errors for the Oil and Gas Industry (TRACEr-OGI).

III. To analyse the most common Human Factors (HFs) and Performance Influencing Factors (PIFs) in oil and gas industry accidents.
IV. To develop a robust process safety management (PSM) system that integrates human factor (HF) contributions to the current management systems.

1.6 Structure of the Critical Overview Document (COD)

This study seeks to develop Integrated Human Reliability Assessment Methods for Accident Investigation in the process industry with special consideration to the Oil and Gas Industry. This critical overview document (COD) comprises a coherent body of research publications which demonstrate personal and academic development around the analysis of performance influencing factors, human factors and human error contribution in accidents and the integration of human factor into process safety management system. It explores accident causation and provides sector-specific investigation models for the analysis of human and organisational factor contributions to accidents in the oil and gas industry.

This PhD critical overview document (COD) has two parts: **Part I**-Main COD report and **Part II** – Articles. To ensure clarity, in terms of what is covered in each part, brief explanations of the part are explained as follows:

Part I-Main COD report

This part of the COD, which is divided into five chapters, presents a critical overview that links the outputs in the portfolio, as demonstrated in Figure 1.4 above. It is a chronological description tracing the development of the portfolio of evidence.

Chapter one sets the scene for the COD. It presents the research background and context. It then proceeds to discuss the research problem and question. Finally, the aim and objectives of the COD are briefly summarised.

Chapter two gives an overview of literature on knowledge and theories relating human factor and human reliability assessment. This chapter is mainly a review of accident causation models, Human Factors (HFs), Human

Errors (HEs) and Performance Influencing Factors (PIFs) in process accidents. Chapter two also examines the problem of missing human factors in current process safety management system and examines the Integration of human factors (HF) into the process safety management system (PSM).

Chapter three provides a detailed exploration of the research design, the method used for data collection and subsequent analysis.

Chapter four provides a systematic and exhaustive analysis of the data collected aligning the results/outcome of the study to the set questions and objectives.

Finally, **chapter five** elucidate the study set objectives and what was achieved in short conclusions. Subsequently, recommendations were proposed for both academia and the health and safety industry.

Part II -Articles

This section consists of the main work and key contributions of the PhD including five journal papers published during the PhD project. Please refer to appendix B for a list of five selected publications used as the basis for this portfolio.

The journal articles (Outputs 1 to 5) included in the portfolio were designed to address each of the set objectives aligned with the coherent theme above. The portfolio is clear evidence of sustained independent effort, the exercise of critical analysis powers and a demonstration of a clear connection between the research outputs. Outputs 1 to 4 focused on the Human factors age (1970s - 2000s) with a view to developing a new Human Reliability Assessment (HRA) tool for the analysis of human errors, human factors, and performance influencing factors leading to major accidents in the oil and gas industry (Figure 4). Output 5 focussed on the missing human error element in existing Management Systems as safety transitioned from the Organisational age (1960s - 1970s) to the Human Factors age (1970s - 2000s).

Output 1 Output 1 introduces the application of Analytic Hierarchy Process AHP (a multi-criteria decision-making method) to examine PIFs which most influence the propagation of accidents in hydrocarbon processing industries with an illustrative case study. Output 1 deals with the development of a framework for identifying the most influential PIFs in a high risk industry. This framework considers the mutual influences that exist among the PSFs and how to assess their relative importance, considering their interactions in a specific context in influencing an operator’s performance. Furthermore, the proposed framework allows for quantifying the influence of PIFs.

Output 2 and Output 4

Output 2 introduces HFACS-OGI, a version of HFACS for the oil and gas industry, while Output 4 introduces TRACEr-OGI, a version of TRACEr for the oil and gas industry.

Output 3

In Output 4, HFACS was used to code upstream petroleum industry accidents in South and Central America from 2000 to 2014. It highlights the benefits of analysing an accident and incident database to extract information about human factors and latent errors leading to incidents in the oil and gas sector, to provide the decision maker with a reliable visualisation of the problem and decision-related opportunities.

Output 5

The concept of Continuous improvement means there is a clear need to integrate human factors elements and existing frameworks into a single, integrated process safety management system to ensure a holistic approach to control. To this end, Output 5, based on Shappell and Wiegmann’s Human Factors Analysis and Classification System (HFACS) (Shappell and Wiegman 2003), identified the missing human factors elements in current management systems and proposed an integrated process safety management system (IPSMS) model, adopting the PLAN, DO, CHECK and ACT framework for its implementation.

Chapter Two

Literature Review

The chapter reviews theories and central knowledge underpinning the human reliability assessment study. This involves, among many other activities, gathering data from peer-reviewed academic/journal papers, high risk industry reports and regulatory agency sources. Mainly, chapter two gives an overview of the literature on knowledge and theories relating accident causation models, Human Factors (HFs), Human Errors (HEs) and Performance Influencing Factors (PIFs) in process accidents. Chapter two also examines the problem of missing human factors in current process safety management system and examines and the ongoing attempt to integrate human factors (HFs) into the process safety management system (PSM).

2.1 Accident Causation Models

Hollnagel (2016: 5) defined an accident as "a short, sudden and unexpected event or occurrence that results in an unwanted and undesirable outcome. The short, sudden and unexpected event must directly or indirectly be the result of human activity rather than a natural event (Hollnagel 2016: 5)". The accident causation process is complex, involving many factors (Suraji, Duff and Peckitt 2001). Therefore, a comprehensive understanding of this complex process and its factors is necessary to develop strategies for accident prevention. The plethora of different conceptual causation models based on different perceptions (simple linear, complex linear and non-linear models) (Figure 2.1) is an attempt to understand the processes and factors involved and unravel the mysteries of accident causation (Al-Shanini, Ahmad and Khan 2014; Health and Safety Professionals Alliance 2012).

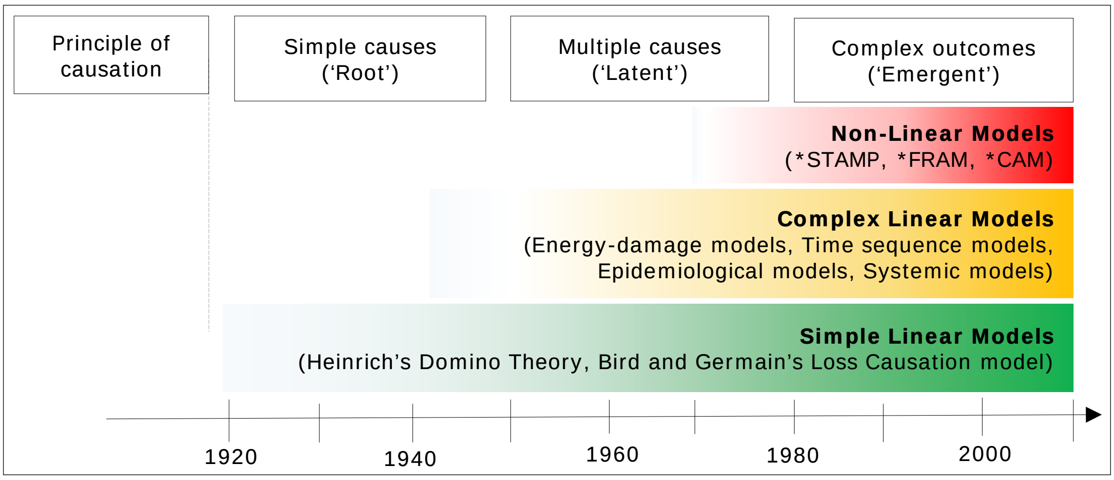


Figure 2. 1 Summary of a history of accident modelling.

Adapted from Hollnagel 2010, slide 7, cited in Health and Safety Professionals Alliance 2012). *STAMP - Systems-Theoretic Accident Model and Process, FRAM - Functional Resonance Accident Model, CAM - Complexity and Accident Modelling

2.1.1 Heinrich's Domino Theory

The realisation that technical risk assessment and prevention measures alone could not solve all health and safety problems ushered in human errors, human factors and performance influencing factors related research. Several theories emerged within the "Human factors age". Heinrich, seen as the pioneer of accident causation theories, developed the sequential accident model which is also known as the "five domino model" of accident causation (Figure 2.2). Using this model, Heinrich opined that an accident is avoidable by eliminating one of the dominoes, usually the central factors (also called unsafe acts or conditions).

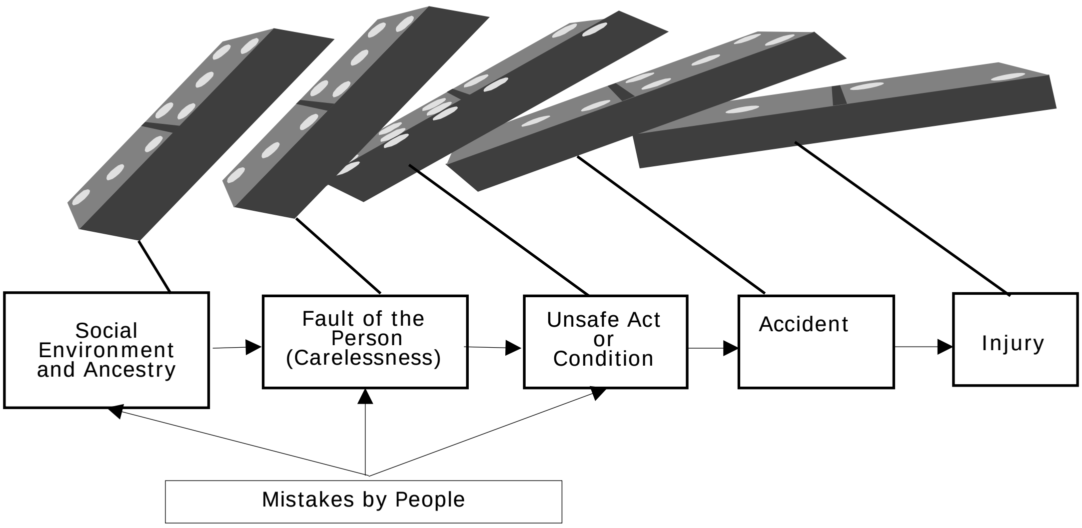


Figure 2. 2. Heinrich's Domino Theory Adapted from Heinrich (1931)

Heinrich's theory became the foundation for many management-based theories which recognised failures within the management system as the cause of accidents within the workplace. Weaver developed a theory based on Heinrich's domino theory with an emphasis on the role of a management system (Hosseinian and Torghabeh 2012). Weaver also introduced eight management aphorisms to guide decisions of supervisory management (Weaver 1971). Weaver's contributions shifted attention from the 'do's and don'ts' of safety, from the technological to the functional management of safety.

2.1.2 Bird and Germain's Loss Causation model

Bird and Loftus (1974) updated the "Domino theory" to reflect the role of health and safety management systems in accident causation (Figure 2.3). Bird and Loftus conducted an extended study of the application of Loss Control and pioneered auditing methods based on Heinrich's model (Hale and Glendon 1987; Hale and Hovden 1998; Bird and Loftus 1976).

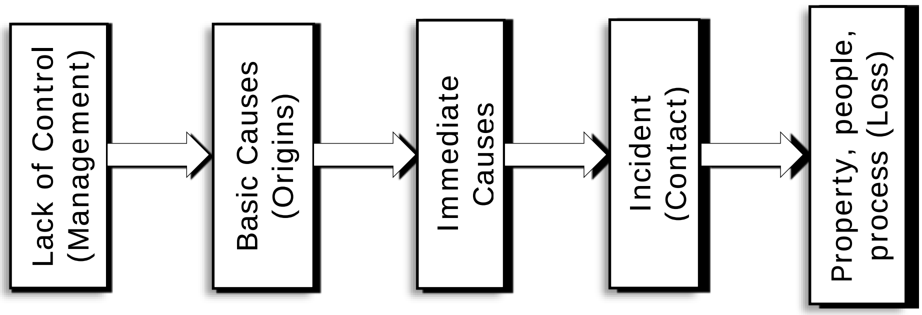


Figure 2. 3. Bird and Loftus' updated Domino Sequence of Accident Causation Theory (Bird 1974)

2.1.3 Petersen's multiple causation theory

Whereas Heinrich's domino theory is structured on the theory that an accident is caused by a single cause (Hosseinian and Torghabeh 2012), Petersen (1971) developed a model based on the management system. Petersen opined that rather than an individual cause, there are causes and sub-causes contributing to unsafe acts and unsafe conditions leading to an incident or accident (Figure 2.4).

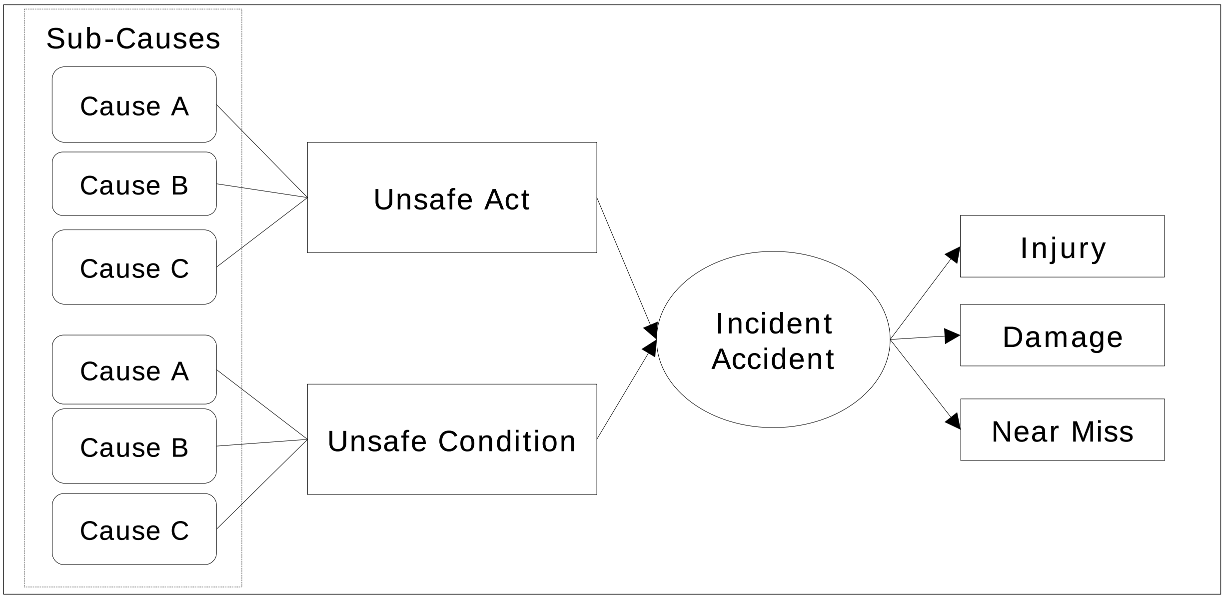


Figure 2. 4. Petersen's multiple causation theory

2.2 Human Factors and Human Errors in process accidents

Human and organisational factors are generally recognised as causes of the majority (up to 80%) of the major accidents seen in the process industry (Cox et al. 2016; Aas 2008). Gordon (1998) asserts that these accidents are a result of the interaction of human, organisational, technical, environmental and social factors and that they all affect the output of a very complex system. In most cases during investigation, errors are traced to organisational and supervisory failures, inappropriate inspections leading to preconditions for unsafe acts, structural and cultural failures (Pate-Cornell 1993). Hence, numerous models of accident causation have recognised the contribution of human factors and human errors in accident occurrence (O'Hare et al. 1994; Embrey 1992; Reason 1990). The most significant of these models is James Reason's widely accepted accident causation model (Figure 2.5), often referred to as the "Swiss Cheese Model" represented by rotating cheese slices (Reason 1997).

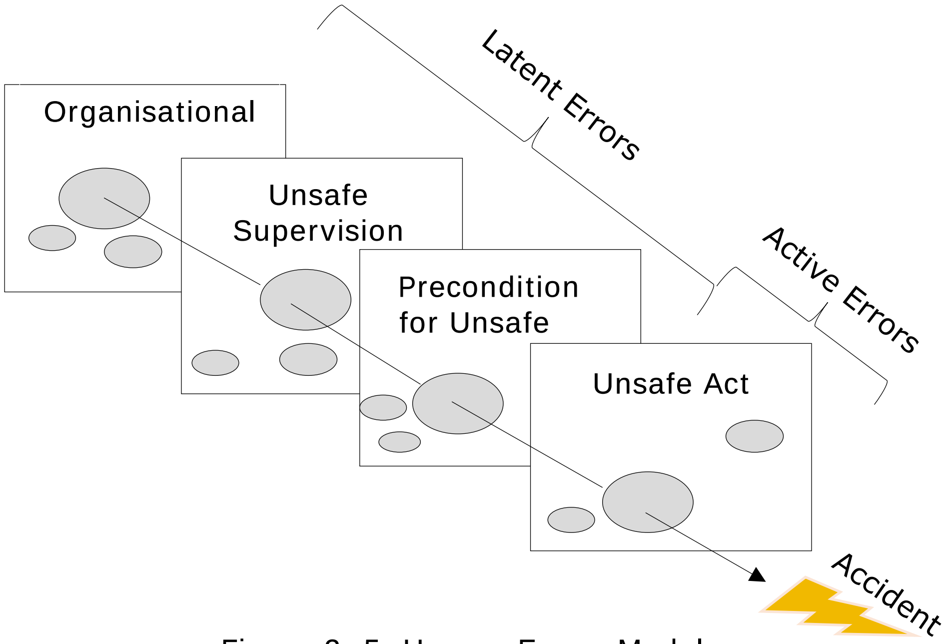


Figure 2. 5. Human Errors Model

The model defined two broad categories of errors: active errors (associated with the front-line operators of the system) and latent errors (associated with dormant adverse consequences within the system which become evident when they combine with other factors to breach the system's defences) (Reason, James 1990). When the threat (represented by an arrow) makes it all the way, from its origin, through aligned “cheese” holes (which represent control barrier and recovery measure), it materialises and accident happens. Provided any of the slices blocks the path, the threat cannot develop further to a mishap (Reason et al., 2006).

2.2.1 What is the Human Factor?

The Health and Safety Executive (HSE) refers to human factors as “environmental, organisational and job factors, and human and individual characteristics, which influence behaviour at work in a way which can affect health and safety” (HSE 2017). The International Association of Oil & Gas Producers defined human factors as “a term used to describe the interaction of individuals with each other, with facilities and equipment, and with management systems” (IOGP 2008). For the purpose of the thesis, human factors are defined as *a* “complex interplay of Personnel, Facilities and Equipment and Organisational and job factors which influence behaviour at work in a way which can affect health and safety” (Figure 2.6).

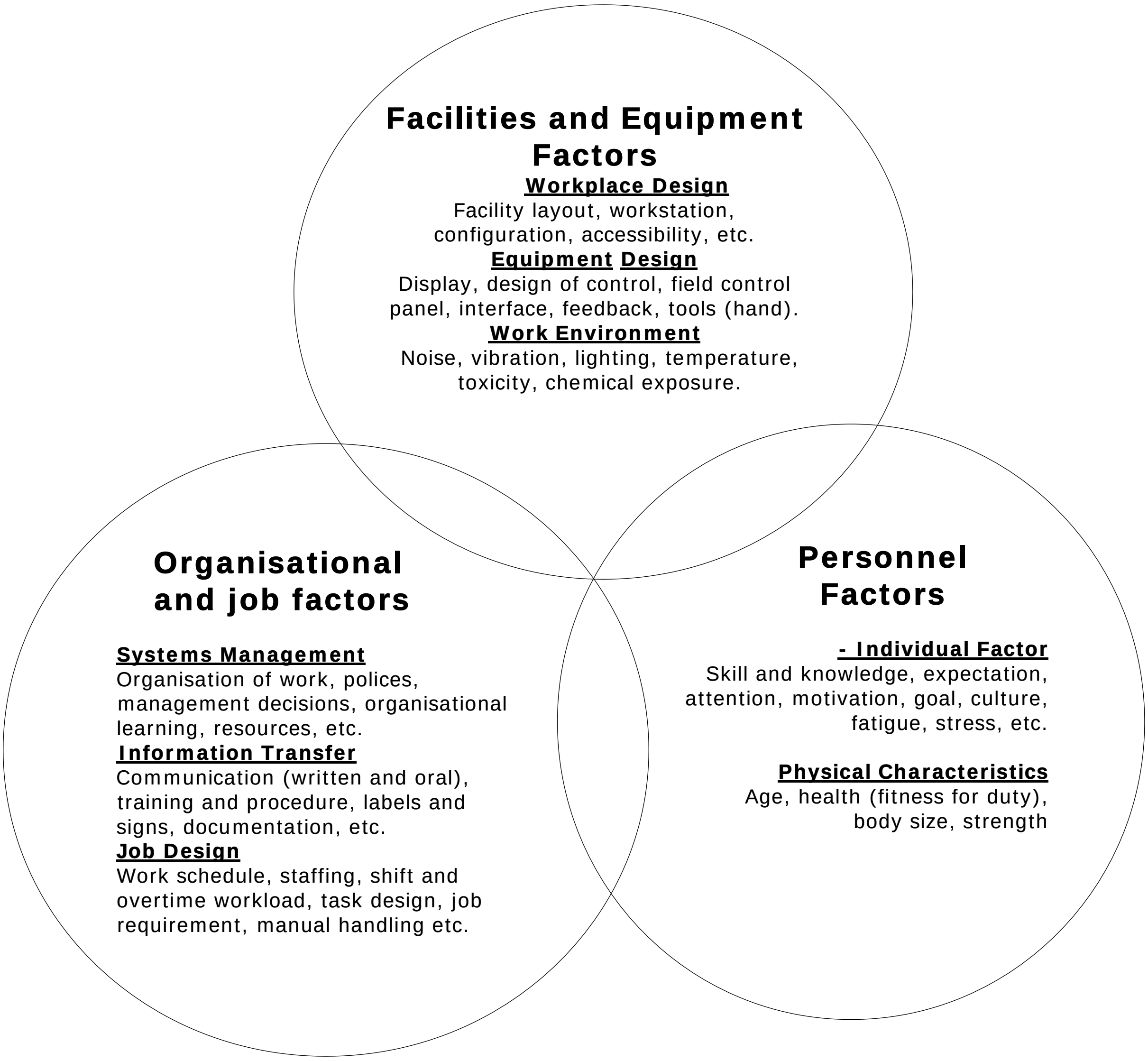


Figure 2. 6. The complex interplay of human factor subcategories

Human factors research is about eliminating or reducing human error (Russ et al. 2013). To prevent or reduce human factors contributions to incidents requires making the system more human factor tolerant (Baysari, McIntosh and Wilson 2008b). This can be achieved by putting a system or a technique into place that will reduce human factors contributions, ensure recovery from incidents and mitigate consequences (Cacciabue 2005).

2.2.2 What is Human Error?

Rothblum (2000) defined human error as “being one of the following: an incorrect decision, an improperly performed action, or an improper lack of action (inaction)” (Rothblum 2000). However, Reason (1990) defined error as “a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when failures cannot be attributed to the intervention of some chance agency" (Reason 1990: 9). Error is both normal and inevitable (Williamson et al. 1993), thus attempting to completely eliminate human imperfections is a futile goal.

Rasmussen (1983) developed a classification of different types of information processing involved in industrial tasks. The classification system, known as the Skill, Rule, Knowledge (SRK) based approach, is a useful framework for identifying types of errors (Rasmussen 1983; Woods 2009; Reason 1990). Reason extended the SRK approach to a General Error Modelling System GEMS, and identified three error types: Skill-based (and Lapses), Rule-based mistakes and Knowledge-based mistakes (Figure 2.7). Reason noted that errors may be a result of inadequate planning, failure in the execution of planned activities (slips) or failure in judgement (mistakes). Another form of error identified in Figure 2.7 is violation. The Health and Safety Executive (HSE) defined violation as "deliberate deviations from the rules, procedures, instructions and regulations drawn up for the safe or efficient operation and maintenance of plant or equipment" (HSE 1995: 3). Violations in these rules can be accidental, unintentional or deliberate. This thesis is concerned with the deliberate violation of rules and procedures. However, it is important to note that violations described here are made with explicitly good intentions, with no intention to cause harm (Jones, Phipps and Ashcroft 2018), Violation with the intention to cause harm is considered a criminal behaviour (Hudson and Verschuur 2000). Hudson and Verschuur (2000) identified three types of violation and the associated procedural problems (Figure 2. 7): "1) Routine violation -poor procedures that are not followed, 2) Situational Violation - special situations that are not or poorly covered in the procedures- and 3) Exceptional Violation - situations that are not covered by any procedure".

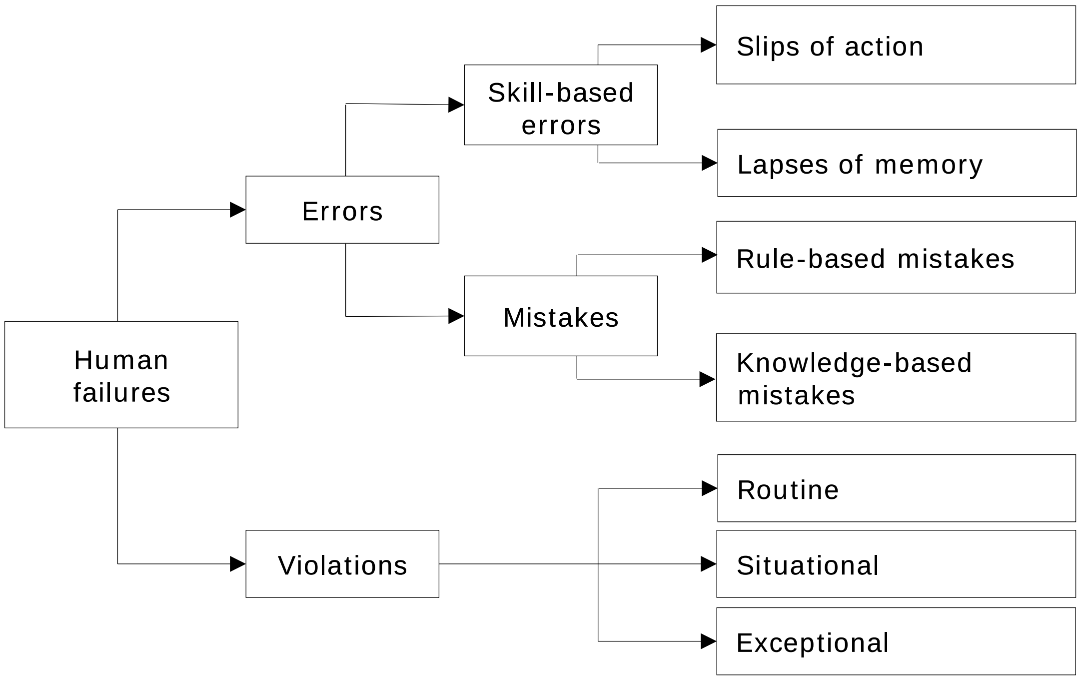


Figure 2. 7. Types of human failure (adapted from Reason 1990)

2.2.3 Human Factor Identification and Classification Systems (HFACS)

Errors are shaped and provoked by upstream workplace and organisational factors. Identifying an error is merely the beginning and not the end of the search for causes: "Only by understanding the context that provoked the error can we hope to limit its recurrence" (Reason 1997: 126, cited in Reinach and Viale 2006a). Human factors research aims to better understand the complex interplay of Personnel, Facilities and Equipment and Organisational and job factors (Figure 2.6) to design systems and tools that support the physical and cognitive abilities of humans that are resilient to unanticipated events (Russ et al. 2013, Saleem et al. 2009).

Human factor and human error identification use frameworks in accident investigation or analysis. The framework used is dependent on the adopted perspective or theoretical approach to human error (Baysari, McIntosh and Wilson 2008a). Two frameworks suitable for identifying a full range of human factors and human errors in a complex system are 1) the Human Factors Analysis and Classification System (HFACS) (Figure 2.8), developed by Shappell and Wiegman (2003) for investigating post-accident data in the aviation industry and 2) the Technique for the Retrospective and Predictive Analysis of Cognitive Error (TRACEr) in Air Traffic Management ATM (Figure

2.9), developed by (Shorrock and Kirwan 2002a). HFACS has no doubt remained the main method to date of investigating human factors and latent error contributions to major accidents (Baysari, McIntosh and Wilson 2008b). HFACS comprises four levels of taxonomy based on Reason's 'Swiss Cheese' model (Figure 2 5): 'Unsafe Acts'; 'Preconditions for Unsafe Acts'; 'Unsafe Supervision' and 'Organisational Influences' (Wiegmann and Shappell 2001; Shappel and Wiegmann 2000). Similarly, "One technique that has tried to harmonise active and reactive approaches to human error analysis (HEA) ... is 'TRACEr" (Shorrock 2002).

The original HFACS (Figure 2.8) and TRACEr (Table 2.1) frameworks were designed for the aviation industry (Shappell and Wiegman 2003; Shorrock and Kirwan 2002). Also, the original HFACS and TRACEr frameworks have been modified several times to suit different sectors where they are considered to be less effective as they are presently constituted. The current HFACS is sufficient for the analysis of most human factors related to organisational influences (Pasman et al. 2013), safety supervision (Theophilus and Shaibu 2014), operators' competency or lack of knowledge (Pasman et al. 2013; Knegtering and Pasman 2009b) and the technical failure of ageing equipment now apparent in the oil and gas industry. However, it cannot simultaneously analyse regulatory deficiencies (Committee 2014) emerging process safety issues relating to the Management of Change, Process Safety Culture, Contractor Environment and violation issues like sabotage. There is therefore a need to modify the current HFACS to make it suitable for the oil and gas industry. Output 2 provides a detailed theoretical framework for this modification and accident analysis using the new framework called HFACS-OGI. Similarly, TRACEr was initially developed for real-time accident analyses in air traffic control (Shorrock 2002) and has been successfully modified for other high risk industries such as railways and maritime (Baysari, McIntosh and Wilson 2008b) to make it suitable for their specific hazards. Output 3 attempts to modify the current TRACEr taxonomy to make it suitable and useful for the oil and gas industry's specific hazards as in other high risk industrial sectors.

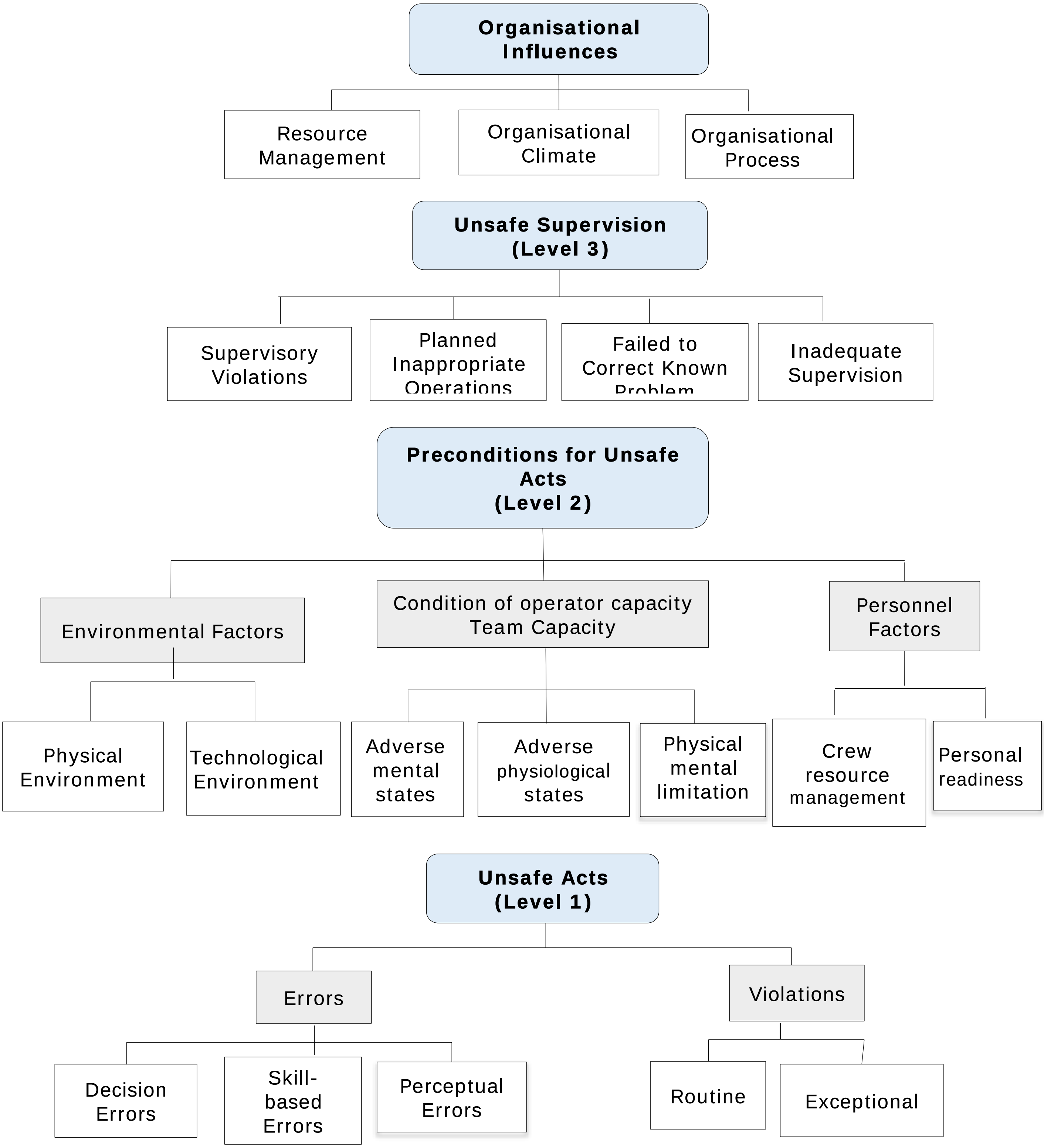


Figure 2. 8. Human Factors Analysis and Classification System (HFACS) (Shappell and Wiegman 2003)

Table 2. 1. Levels and subdivisions of the Technique for Retrospective and Predictive Analysis of Cognitive Errors (TRACEr) taxonomy (Shorrock and Kirwan 2002; Graziano, Teixeira and Guedes Soares 2016)

Major Divisions	Categories
Context of the incident	1. Task Error 2. Error Information 3. Casualty Level
Operator Context	4. External Error Mode (EEM) 5. Cognitive Domain I. Internal Error Mode (IEM) II. Psychological Error Mechanism (PEM) 6. Performance Shaping Factors (PSF)
Error Recovery	7. Error Recovery

2.3 Performance Influencing Factors (PIFs) in Process Accidents

Many authors have identified the job, the operator and the organisation as major factors affecting safety performance in high risk industries (Kariuki and Löwe 2007; Theophilus et al. 2018; Fabiano et al. 2004; HSE 2007; Khdair et al. 2011). There are specific characteristics of the job, the personnel and the organisation that influence human performance known as Performance Influencing Factors (PIFs) (Table 2. 2) (O'Reilly 1977; Sims and Szilagyi 1976; Hanafi 2016; Kim and Jung 2003; Bellenkes 1997; Ellis and Holt 2009; Kariuki and Löwe 2003; Theophilus et al. 2018). Different terms have been used to describe these factors: performance shaping factors (PSFs) (Park and Jung 1996) and error-producing conditions (EPCs) (Williams and Bell 2015). Performance influencing factors are seen as contributors to human factors, unsafe acts, unsafe plants and conditions and consequently, process accidents (Figure 1.4 B) (Kim and Jung 2003). Hence, optimising PIFs reduces the likelihoods of error occurrences (Bellenkes 1997; Ellis and Holt 2009).

Table 2. 2. Performance Influencing Factors Taxonomy adapted from (Kim and Jung 2003; Kariuki and Löwe 2003)

Human Factor Categories	Performance Influencing Factor Categories	Performance Influencing Factor
Personal factors	Individual factors	• Health • Emotional tension • Age • Gender
	Dependent factors	• Skill level • Knowledge and Experience • Motivation • Safety awareness • Competence • Supervision • Tiredness, Stress, and Fatigue • Discomfort • Workload
Job Factors	Anthropometry	• Basic layout of the working environment
	Working conditions	• Physical conditions like temperature, humidity, light, noise.
	Design of Human-Machine Interface (HMI)	• Positioning and layout of HMI • Usability • Quality of feedback
Organisational Factors	Employee-related factor	• Organisational Policies • Safety Culture • Inattention • Staffing (clearness in responsibilities) • Level of Training and instruction on work/task • Level of supervision
	Standard factor	• Standards, Rules, and Guidance • Task design

The 'influence' of performance influencing factors (PIFs) on human factors in the process industry and indeed the oil and gas industry is an area not yet well understood (Paradies et al. 1993; Groth and Mosleh 2012; Theophilus et al. 2016). Because PIFs can change the probability of a human error, the human probabilities (HEP) are estimated based on the PIF (PIFs) in many Human Reliability Analysis (HRA) models (Groth and Mosleh 2010). However, there is no defined set of PIFs used in these methods. Depending on the industry, the sets of PIFs relied upon by current HRA methods range from a few to over 50. Again, there is no defined method of accounting for or quantifying the influence of PIFs (De Ambroggi and Trucco 2011). Another challenge is how to deal with the types of influences that exist: 1) the influence of one PIF on another PIF (e.g. workload influence on stress); and 2) the influence of PIFs on human factors (HF) or human error probability (HEP) (e.g. the influence of stress on a team and the probability of human error) (De Ambroggi and Trucco 2011).

2.4 Integrating human factors (HF) into the process safety management system (PSM)

Before the 1970's, the impact of human factors on process safety management (PSM) was not considered. This started to change when companies began to introduce operational risk management, management of change, maintenance practices and operating procedures (Cummings 2009). However, industry activities and operational processes remained guided by very minimal legislation and regulations, leading to numerous fatal accidents (Nabhani et al. 2016; Lundteigen and Rausand 2007). In response to these fatal accidents, on July 17 1990, OSHA named the standard Process Safety Management of Highly Hazardous Chemicals in the Federal Registry (55FR 29150) (U.S. Department of Labor 2000). Similarly, to aid in the reduction of process accidents, the UK government enacted the Control of Major Accident Hazards (COMAH) Regulations 1999 (HSE 1999). Process safety management standards were concerned with the prevention of fires and explosions and unintended chemical releases in the process industries (Goh et al. 2015). The effectiveness of a company's process safety management system is assessed using several process safety indicators (PSI) The intended outcome of each assessment is to ascertain what is being done well and to learn lessons where necessary (Fearnley and Nair 2009).

As stringent legislations emerged, the concept of the process safety management system became a major concern within the process industry, as companies began seeking suitable and robust approaches to enhance their operational integrity. However, human factors contributions to major process accidents remain a major concern to date (Shappell and Wiegmann 2012). For example, in 2006, the US Chemical Safety Board (CSB) asserted that human factors deficiencies were a major contributor to most catastrophic accidents (Holmstrom et al. 2006). Also, human factors were blamed in a review of 148 US refineries released in 2010 (Holmstrom et al. 2006; Kaszniak 2010). Therefore, in a quest to deal with process accidents, companies have developed several process safety management models. However, process accidents have continued to happen with high human factor contributions. Bridges and Tew (2010) argued that most current PSM frameworks do not adequately address human factors elements. Moore et al. (2015) suggested that a critical reason for the continuation of process accidents with high human factor contributions was the lack of a robust PSM system which would incorporate all human factor elements. To this end, in Output 4, human factors were incorporated into the PSM framework based on Shappell and Wiegmann's proposal for a Human Factors Analysis and Classification System (Figure 2.8) (Shappell and Wiegmann 2012).

Chapter Three

Research Methodology and Approach

The credibility of finding answers to research questions posed in chapter one depend mainly on the quality of the research design, research method, data collection, data management, and data analysis. This chapter provided a description of the methodology and approach adopted to obtain the data and how they were analysed to draw up conclusions (Table 3.3).

3.1 Research Design

The research design sets out the framework of methods and techniques chosen for the various parts of the study so that the research questions are addressed. This study has relied mainly on retrospective accident data and the process of retrospective accident data analysis has been identified as belonging to post-positivism (Denzin and Lincoln 2011; Theophilus et al. 2016): ‘The problems studied by post-positivists reflect a need to identify and assess the causes that influence outcomes …It is also reductionistic in that the intent is to reduce the idea into a small, discrete set or test, such as a variable ….’ (Creswell 2013). However pragmatist research focuses on the 'what' and 'how' of the research problem which is also an aspect of this research. Therefore, the option of the post-positivist paradigm, the reductionist and the pragmatist approach in some aspects of the work cannot be overemphasised. As such, the research approaches are both qualitative and quantitative and include case study, correlational and descriptive research designs.

3.1.1 Case Study Research Design

The case study research method, sometimes referred to as the descriptive research method (Harrison et al. 2017), is one of the most widely used qualitative methods. The method is considered robust particularly when an in-depth, holistic investigation is required (Zainal 2007). The fundamental feature of case study research design is the examination of specific ‘instances of’ something that comprise the cases in the study (Yin 2003; Stake 1995). A case can be something reasonably concrete such as a group or a person, or something that is abstract such as an accident, a management system or a management of change programme. A case study research design may involve one or more cases (Yin 2003; Stake 1995; Baxter and Jack 2008). All the outputs in this COD were largely characterised by an in-depth examination of accident case studies (Outputs 1, 2, 3 and 4) and process safety management systems (Output 5), with a view to narrowing down on either the causal factors before statistical analysis or identifying missing human factors elements. This design was adopted because it is a valuable method for health and safety research to develop theory, evaluate programs and develop intervention tools (Baxter and Jack 2008).

3.1.2 Correlational (Archival) Research Design

Determining that one factor causes changes in another can be difficult (Privitera 2016). Correlational Research Design attempts to measure two factors (variables) and assess the statistical relationship (i.e. the correlation) between them with no attempt to control extraneous variables (Heiman 2001; Privitera 2016). Correlational Research Design presents the relationships among variables by using techniques such as correlations and cross-tabulation. Correlational designs were used in Output 2 and Output 4 to determine, for example, to what extent are HFACS Unsafe Supervision (Level 3) and Unsafe Act (Level 1) categories related by using historical accident records. This is considered archival research in the sense that it depended solely on examining historical records or data sets for relationships or patterns (Ventresca and Mohr 2017).

Descriptive designs

Descriptive research designs which can be either qualitative or quantitative (Nassaji 2015), "involves observing and describing the behaviour of a subject without influencing it in any way" (Nwokeafor 2015). It encompasses collections of quantitative data that can be tabulated in numerical form, or quantitative data that can be organised, tabulated and illustrated using visual aids such as graphs and charts to aid understanding (Glass and Hopkins 1984). Descriptive design was adopted in Outputs 2, 3, 4 and 5. Research questions were used to compare the usability and reliability of TRACEr and the developed TRACEr-OGI as a way of validating both tools.

Descriptive designs were adopted in Outputs 2, 3, 4 and 5. Research questions were used to compare the usability and reliability of TRACEr and TRACEr-OGI as a way of validating both tools.

3.2 Research Method

Research Methods can be categorised into three major clusters: 1) qualitative research (i.e. research based on, but not limited to, analysing narrative data or document contents (words)); 2) quantitative research (i.e. research based on, but not limited to analysing numerical data); and 3) mixed-methods research (i.e. research that combines features of quantitative and qualitative research approaches) (Venkatesh et al. 2013). The post-positivist, reductionist and pragmatist paradigm meant that the study adopted a mixed method approach. The mixed method was an ideal technique to assess complex accident scenarios. It was valuable in that it provided a mechanism to gain complementary views and a more complete picture in situations where existing theories and findings derived from one method did not sufficiently explain or offer significant insights into a phenomenon of interest.

3.2.1 Case Study Method

The case study research method, sometime referred to as the descriptive research method (Harrison et al. 2017), is one of the most widely used qualitative methods. It uses reports of past studies or accounts of events to investigate and understand complex situations. The method is considered robust particularly when an in-depth, holistic investigation is required (Zainal 2007). The researcher can adopt either a single-case or multiple-case design subject to the issue under investigation.

A single case study was examined in Output 1 while multiple-case studies were examined in Outputs 2, 3, 4 and 5. Each case was examined with the aim of improving the understanding of the event under consideration. Published limitations of the case study method recognise the use of a single case study as subjective, resulting in a lack of methodological rigour and external validity (Christie et al. 2000). However, through the application of mixed (qualitative and quantitative research) methods, this research was able to provide the empirically-rich results that were required.

3.2.2 Mixed-Methods Sequential Explanatory Design

The mixed-methods sequential explanatory design typically involves two phases: 1) an initial quantitative phase followed by 2) a qualitative data collection phase, which builds directly on the results from the quantitative phase (Wisdom and Creswell 2013). In this way, the quantitative results are explained in more detail through the qualitative data. Outputs 1, 2 and 4 needed the collection, collation and analysis of quantitative data followed by the collection and analysis of qualitative data to assist in explaining and interpreting the findings of the quantitative study. As such, the Sequential Explanatory mixed method was used.

3.2.3 Mixed-Methods Sequential Exploratory Design

The mixed-methods sequential exploratory design, like the explanatory design, involves two phases: 1) an initial qualitative phase which requires collecting and analysing qualitative data and 2) using the findings from the initial phase to develop a psychometric tool which is then administered to a sample of a population (Wisdom and Creswell 2013). This method was used in Output 3. Following the development of TRACEr-OGI, case study analysis was used to show the internal validity of the approach. Again, a total of initial phase was used to develop a psychometric tool which was used to rate 2 case studies by 25 respondents. These strategies were not only useful in developing and testing the new instrument, but was also necesssary for triangulation purposes to underpin policy recommendations or industrial implementation strategies for the process industry. The major limitations of this method were as follows: the research design was complex, it took much more time and resources to plan and implement the research and finally, at some point, it was unclear how to resolve some discrepancies in the interpretation of the findings.

3.3 Data Collection

3.3.1 Document Review and Analysis

Document review and analysis is a qualitative data collection method that involves reviewing existing reports or documents (Bretschneider et al. 2017). It involves deep-reading (thorough examination) and interpretation (Bowen 2009). The process combines elements of thematic analysis and content analysis. While content analysis is a systematic process of organising information or evidence into categories related to the central questions of the research (Bowen 2009), thematic analysis is a search for the identification of themes that emerge and which then become the categories for analysis (Fereday and Muir-Cochrane 2006).

Each output in this work began with a document review and analysis of academic literature and published reports. Limitations of this method include: subject coverage, date coverage, publication coverage and updates and timeliness. Therefore, the review was limited only to credible institutional publications. The review began by searching (for example) the World Offshore Accident Database (WOAD); the Process Safety Incident Database (PSID); the U.S. Chemical Safety Board (U.S. CSB) database; abstracts from Accident Analysis & Prevention publications and recent SPE International Conferences and Exhibitions on Health, Safety, Security, Environment, and Social Responsibility; published studies containing keywords, for example 'oil and gas safety', 'offshore oil and gas safety,' 'offshore accident analysis,' 'PIFs,' 'HFACS,' 'TRACEr,' 'incident reporting system,' 'human error taxonomy,' 'human factors taxonomy' and so forth. In most cases, each document's reference list was scanned for additional source materials.

Major offshore accident reports published by The International Association of Oil & Gas Producers (IOGP) were used for this research. The data used for Output 1 (HFACS-OGI) and Output 2 (TRACEr-OGI) were from the U.S. Chemical Safety Board (CSB) database and IOGP database, respectively. The major limitations experienced were ambiguities in the reports. It was difficult to confirm that the qualitative data were statistically significant or due to chance.

3.3.2 Data coding

The coding process is a form of document review process that involves identifying the human factors and human errors of the taxonomy associated with HFACS, HFACS-OGI, TRACEr and TRACEr-OGI that have contributed to the accident cases. If a given element is present, the value of the element is 1; if not, the value of the element is 0. The rule of assigning value as explained in Xi et al. (2010) is as follows and is illustrated in Table 3.1 below:

$$V_{ijk} = \begin{cases} 1, & \textit{if the factor is involved in accident} \\ 0, & \textit{if the factor is not involved in accident} \end{cases} \text{.................Equation. 3. 1}$$

Where combinations of several factors led to an accident, each particular unsafe act identified from the accident report was coded distinctly, considering all the subcategories of the tool (e.g. HFACS-OGI and TRACEr-OGI).

Table 3. 1. Illustration of the sequence of categories/taxa identified from the accident reports.

Year	No of Accidents	Categories			LEVEL 1	
		Taxa A Identified	Taxa B Identified	Taxa C Identified	TOTAL	
2000	1	1	0	1	3	
2000	1	1	0	0	1	
2000	1	1	0	1	3	
2000	1	0	0	0	0	
2000	1	0	0	0	0	

3.3.3 Questionnaire

Following the development of the TRACEr-OGI approach, there was a need to validate the approach. Details are available from Theophilus et al. (2017). Briefly and for the purpose of this COD, primary quantitative data were collected from 25 oil and gas industry respondents for the internal and external validity of TRACEr-OGI as part of the research forming Output 3. These were carried out by the author assisted by a research assistant.

Raters' data were subsequently analysed using SPSS software (see statistical test and analysis below). Please refer to appendix A for the approved CU ethics certificate. The only limitation was getting sufficient and robust data to explain complex HF and HE issues. This is one of the reasons why sequential explanatory and sequential exploratory mixed methods were used.

3.4 Data Analysis

3.4.1 Thematic Analysis

Thematic analysis is a qualitative approach for identifying themes within data (Braun and Clarke 2006). It is a method of encoding and organising qualitative data set in details (Boyatzis 1998). The catalogue of a process safety management system used in Output 5 was analysed using the six steps outlined by Maguire and Delahunt (2017) as follows: 1) become familiar with the data, 2) generate initial codes, 3) search for themes, 4) review themes, 5) define themes and 6) write up. Themes around the theoretical architecture, implementation strategy and subcategories within the strategies were identified using this method. All screened data were then reviewed and encoded before writing up.

3.4.2 Statistical analysis

Details of the statistical analysis are available in the outputs used for this COD. However, for the purposes of this COD, brief descriptions are provided. After coding, any categories that were not present in any of the accidents were excluded (see section 3.3.2 for the data coding process). The coded data were then cross-tabulated for statistical analysis with Excel in the case of TRACEr-OGI and were subjected to SPSS version 25 for Windows for HFACS-OGI. SPSS was used to calculate the Chi-square test of association and Fisher's exact test in order to determine the statistical association between the upper-level categories and the adjacent lower level categories (Chauvin et al. 2013; Hayes 2012; U.S. CSB 2008). In some instances, further analysis was conducted using Spearman's to measure the strength of the relationships between the different categories that showed significant relationships in the Chi-square and Fisher's exact test correlation (Holmstrom et al. 2006).

3.4.2.1 Chi-square test, Fisher's exact test and Spearman's correlation Test of Association

The Chi-square test, Fisher's exact test and Spearman's Test of Association are used to determine various statistically significant associations between two categorical variables. In this research, these tests were used to determine if relationships existed between elements of the same HFACS or HFACS-OGI level or between upper-level categories and the adjacent lower level categories of HFACS and HFACS-OGI.

The chi-square test statistic is calculated using the equation:

$$X^2 = \sum \frac{Observed - expected^2}{expected} \quad \text{...Equation 3. 2}$$

Where at 95% confidence level (5% chance of error)

$p \leq 0.05 \rightarrow$ statistically significant

$p > 0.05 \rightarrow$ not statistically significant

3.4.2.2 Interrater Agreement (IRA) or Interrater Reliability (IRR)

TRACEr and TRACEr-OGI are tools for judging accidents as part of an accident investigation. Therefore, agreement among raters is very important. In statistical analysis, interrater reliability is used to score the degree of agreement among raters. It is a measure of homogeneity or how much consensus exists among various judges. "The concept of IRA/IRR is fundamental to the design and evaluation of research instruments." (Gisev, Bell and Chen 2013) and was used to evaluate TRACEr and TRACEr-OGI. It is calculated as the number of times a set of ratings agree, divided by the total number of units of observation that are rated, multiplied by 100. Kappa calculations are the most common IRA/IRR indices. The kappa index (κ) can take any value between -1 and +1. Judgement values suggested by Landis and Koch (1977) are :< 0.00 (Poor), 0.00-0.20 (Slight), 0.21-0.40 (Fair), 0.41-0.60 (Moderate), 0.61-0.80 (Substantial), 0.81-1.00 (Almost perfect) and +1 indicates perfect agreement. However, a value of 1 cannot be achieved mathematically, except in extreme circumstances.

3.4.3 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) developed by Saaty (1980, 1990), is a methodical procedure that helps a decision-maker to make consistent judgements while separating physical factors from intangible factors to suit the decision maker's desired objectives (Saaty 2008). Given that there are numerous performance influencing factors that could potentially contribute to an accident, AHP was used to determine the most significant PIFs which influenced a catastrophic accident in the oil and gas industry, while ensuring consistency in judgments. Details of the five steps involved are explained in Theophilus et al. (2016a).

For this COD and for Output 3, an overview of the steps involved is provided.

Step 1: The objective was defined and structured. PIFs which influenced an oil and gas accident case study used in Output 3 were identified.

Step 2: A pairwise comparison (Matrix A) was obtained and PIFs leading to the accident (in Output 3) were compared between alternatives using the table proposed by Saaty (1980).

Step 3: Using Matrix A, priorities of each identified PIF were obtained and the final weight of each vector determined using Lambda Max (λmax)

Step 4: Consistency Ratios (CI) were determined.

Step 5: A weighted score and hence the quality index of the considered PIFs were obtained. Finally, the degrees of compliance were determined using the rating (Table 3.2 below).

Table 3. 2. Rating of Output 3 HF Subcategories and overall qualification of initiating event (Kariuki and Löwe 2007)

Explanation	Overall quantification of initiating event	Context of Use
Meets all/most required specification/standard practice	91% or more	Excellent
	76 -90%	Above average
	66 -75%	Good, Average
Fails to meet required specification/standard practice	56-65%	Below Average
	54% or below	Poor

Table 3. 3. Summary of research methodology and approach used in the COD

Objective	Research Design	Research Method	Data Collection Instrument	Data Analysis
Objective 1 To develop a Human Factor Analysis and Classification System (HFACS) Framework for the Oil and Gas Industry (HFACS-OGI).	Case Study Correlational (Archival)	Case Study Mixed-Methods (Sequential Explanatory)	Document review and analysis. This iteration process involves identifying and organising elements of HFACS and HFACS-OGI taxonomies into categories on Excel for statistical analysis.	Thematic analysis Statistical analysis - using Excel and SPSS
Output 2 To develop a Technique for Retrospective and Predictive Analysis of Cognitive Errors for the Oil and Gas Industry (TRACEr-OGI)	Case Study Descriptive →Qualitative (visual aids) →Quantitative (Questionnaire)	Case Study Mixed-Methods (Sequential Explanatory)	Document review and analysis. This iteration process involves identifying and organising elements of TRACEr and TRACEr-OGI taxonomies into categories on Excel for statistical analysis. Questionnaire	Thematic analysis Statistical Analysis (Excel and SPSS)
Output 3 Analysis of most common Human Factors (HFs) and Performance Influencing Factors (PIFs) in oil and gas industry accidents	Case Study Descriptive	Case Study Archival research	Document review and analysis. The iteration process involves using a checklist of HFs and PIFs to obtain a pairwise comparison (Matrix A) in which alternatives are later compared using the table proposed by Saaty (1980).	Thematic analysis Analytic Hierarchy Process as proposed by Saaty (1980). Statistical Analysis (Excel)
Output 5 Development of Integrated Process Safety Management System (IPSMS)	Case Study Descriptive	Case Study Archival research	Document review and analysis. The iteration process involves skimming existing process safety management systems using the HFACS taxonomy.	Thematic analysis

Chapter Four

Results and Discussion

This chapter presents the main results of this PhD published in five journal articles. In Chapter 1, section 1.3, four research questions were posed and operationalised into four objectives in section 1.4. These five published articles were aimed at providing answers to these questions and meeting the set objectives. The following subsections are summaries of major results of each article in line with the research questions and objectives.

4.1 Human factor analysis and classification system for the oil and gas industry (HFACS-OGI)

Question 1 - "How suitable for the oil and gas industry are the current human factor analysis and classification system (HFACS) frameworks developed for the aviation industry?"

Objective 1 - "To develop a human factor analysis and classification system (HFACS) framework for the oil and gas industry (HFACS-OGI)."

3.2.3 Analysis of HFACS-OGI

The result showed that the current HFACS as is currently constituted is not suitable for the oil and gas industry, hence the need to develop a human factor analysis and classification system (HFACS) framework for the oil and gas industry (HFACS-OGI). In July 2014 the SPE held a two-day summit and produced a technical report titled *The Human Factor: Process Safety and Culture* (SPE 2014), that explored the best way to address human factors affecting the oil and gas industry. The proposed HFACS-OGI (Figure 4.1) considered this technical report focused on preventing major accidents, particularly toxic releases, fires and explosions related to the Control of Major Accident Hazards (COMAH) regulations (O'Dea and Flin 2001).

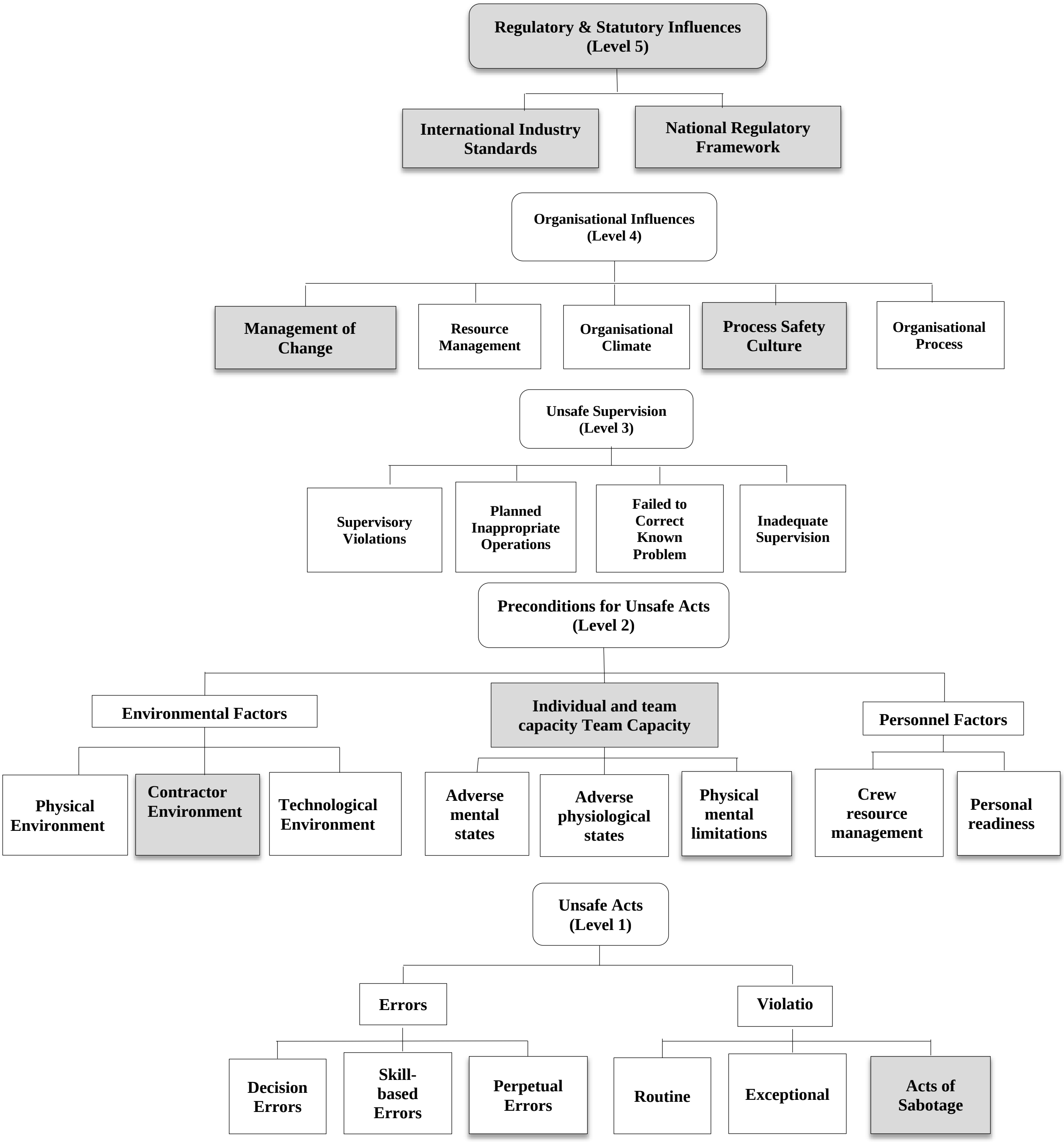


Figure 4. 1. Proposed Human Factor Analysis and Classification System for the Oil and Gas Industry (HFACS-OGI)

Following screening and analysis, the sub-categories (shown in gray) were added: to Level 1, the act of sabotage; to Level 2, Contractor Environment; nothing was added to Level 3; and to Level 4, Process Safety Culture and Management of Change. A new Level 5 called Regulatory and Statutory Influences was created, with International Industry Standards and National Regulatory Framework as sub-categories (Figure 4.1). The addition of level 5 was also supported by the frameworks developed for the marine industry (HFACS-MA) (Chen et al. 2013), machinery spaces on ships and shipping (HFACS-MSS and HFACS-FCM) (Schröder-Hinrichs et al. 2011; Soner et al. 2015), the railroad industry (Reinach and Viale 2006b) and the mining industry (HFACS-MI) (Patterson and Shappell 2010).

3.2.4 Comparative Analysis of HFACS and HFACS-OGI

HFACS and HFACS-OGI were assessed using 11 notable U.S. Chemical Safety Board (CSB) refinery accidents. Whereas only 54 causal factors leading to the occurrences of accidents were identified with the HFACS, a total of 80 were identified with HFACS-OGI. Organisational process (level 4) with a frequency of 10 each for both HFACS and HFACS-OGI, was identified as a contributing factor in 90% of the accidents. All oil and gas industry-specific causal factors which were difficult to identify with the HFACS were successfully identified using the HFACS-OGI. The contributing factors identified of the accidents include the newly added national regulatory framework (HFACS-OGI level 5) (Table 4.1) - industry standards (45%) and national regulatory framework (36%)(Table 4.2). A summary of results showing only the significant associations from the Chi-square and Fisher’s exact tests are shown in Tables 4.2, Table 4.3 and Table 4.4 below.

Table 4. 1. Breakdown of accident/incident contributing to HFACS categories

HFACS Level	Subcategory	Number of cases identified per contributing subcategory	*Percentage %
Level 4	Organisational process	10	90
	Organisational climate	6	54

Organisational influences	Resource management	6	54
Level 3 Unsafe supervision	Inadequate supervision	4	36
	Planned inappropriate operations	2	18
	Failed to correct a known problem	1	9
	Supervisory Violations	4	36
Level 2 Preconditions for unsafe acts	Physical environment	1	9
	Technological environment	2	18
	Adverse mental states	1	9
	Adverse physiological states	0	-
	Physical/ mental limitations	0	-
	Crew resource management	6	54
	Personal readiness	1	9
Level 1 Unsafe acts	Decision errors	5	45
	Skill-based errors	1	9
	Perceptual errors	1	9
	Routine violations	2	18
	Exceptional violations	1	9

*The column labelled percentage reflects the overall percentage among all cases. Note that the percentage will not equal 100%, because in many cases far more than one causal factor was associated with the accident

Table 4. 2. Breakdown of accident/incident contributing to HFACS-OGI categories

HFACS – OGI	Subcategory	Number of cases identified per contributing factor	*Percentage %
Level 5 Regulatory & Statutory Influences	Industry standards	5	45
	National regulatory framework	4	36

Level 4 Organisational Influences	Organisational climate	6	54
	Process safety culture	7	63
	Organisational process	10	90
	Management of Change	5	45
	Resource management	6	54
Level 3 Unsafe Supervision	Inadequate supervision	4	36
	Planned inappropriate operations	2	18
	Failed to correct a known problem	1	9
	Supervisory Violations	4	36
Level 2 Preconditions for Unsafe Acts	Physical environment	1	9
	Technological environment	2	18
	Contractor environment	5	45
	Adverse mental states	1	9
	Adverse physiological states	0	-
	Physical / mental limitations	0	-
	Crew resource management	6	54
	Personal readiness	1	9
Level 1 Unsafe Acts	Decision errors	5	45
	Skill-based errors	1	9
	Perceptual errors	1	9
	Routine violations	2	18
	Exceptional violations	1	9
	Acts of sabotage	0	-

*The column labelled percentage reflects the overall percentage among all cases. Note that the percentage will not equal 100%, because in many cases far more than one causal factor was associated with the accident

Table 4. 3. * Comparison of Chi-Square and Fisher's Exact Test Results between levels of HFACS framework

A significant association between the upper level and adjacent downward level categories in the HFACS framework.	Chi-square		Fisher's exact test	
	P-value	Significance P<0.05	P-value	Significance P<0.05

P-values less than 0.05 indicate a significant relationship between categories.					
Inadequate supervision	Technological environment	0.039	Yes	0.109	No
Inadequate supervision	Crew resource management	0.022	Yes	0.061	No
Planned inappropriate operations	Physical environment	0.026	Yes	0.182	No
Failed to correct a known problem	Physical environment	0.001	Yes	0.091	No
Physical Environment	Skilled Based Errors	0.001	Yes	0.091	No
Technological Environment	Perceptual Errors	0.026	Yes	0.182	No
Adverse Mental States	Perceptual Errors	0.001	Yes	0.091	No
Adverse Mental States	Routine Violations	0.026	Yes	0.182	No
Personal Readiness	Perceptual Errors	0.001	Yes	0.091	No
Personal Readiness	Routine Violations	0.026	Yes	0.182	No

Table 4. 4. * Comparison of Chi-Square and Fisher's Exact Test Results between levels of HFACS-OGI framework

A significant association between the upper level and adjacent downward level categories in the HFACS-OGI framework. *P-values less than 0.05 indicate a significant relationship between categories.*	Chi-square		Fisher's exact test	
	P-value	Sig P<0.05	P-value	Sig P<0.05

National regulatory framework	Organisational climate	0.022	Yes	0.061	No
Management of Change	Inadequate Supervision	0.006	Yes	0.015	Yes
Inadequate supervision	Technological environment	0.039	Yes	0.109	No
Inadequate supervision	Crew Resource Management	0.022	Yes	0.061	No
Planned inappropriate operations	Physical Environment	0.026	Yes	0.182	No
Failed to Correct Known Problem	Physical Environment	0.001	Yes	0.091	No
Physical Environment	Skill-Based Errors	0.001	Yes	0.091	No
Technological Environment	Perceptual Errors	0.026	Yes	0.182	No
Adverse Mental States	Perceptual Errors	0.001	Yes	0.091	No
Adverse Mental States	Routine violation	0.026	Yes	0.182	No
Personal Readiness	Perceptual Errors	0.001	Yes	0.091	No
Personal Readiness	Routine Violations	0.026	Yes	0.182	No

*Only Significant P-values are shown.

Chi-square test and Fisher's exact test was used to assess the significant association paths between the upper the level and adjacent downward level categories in the HFACS-OGI framework as illustrated in Figure. 4.2. The result shows there was a significant association between the national regulatory framework (level 5) and Organisational Climate (level 4) ($r = 0.022$, $p < 0.05$). Fisher's exact test was statistically significant ($r = 0.015$, $p < 0.05$). Spearman's correlation test between the national regulatory framework (level 5) and the Organisational Climate (level 4) showed a very strong positive association ($r = 0.690$, $p < 0.01$). However, though some categories were statistically significant in the Chi-square test of association, not all categories were significant in Fisher's exact test and Spearman's correlation. Spearman's correlation. Full details of the results are published in Theophilus et al. (2017) and available in part II of this COD.

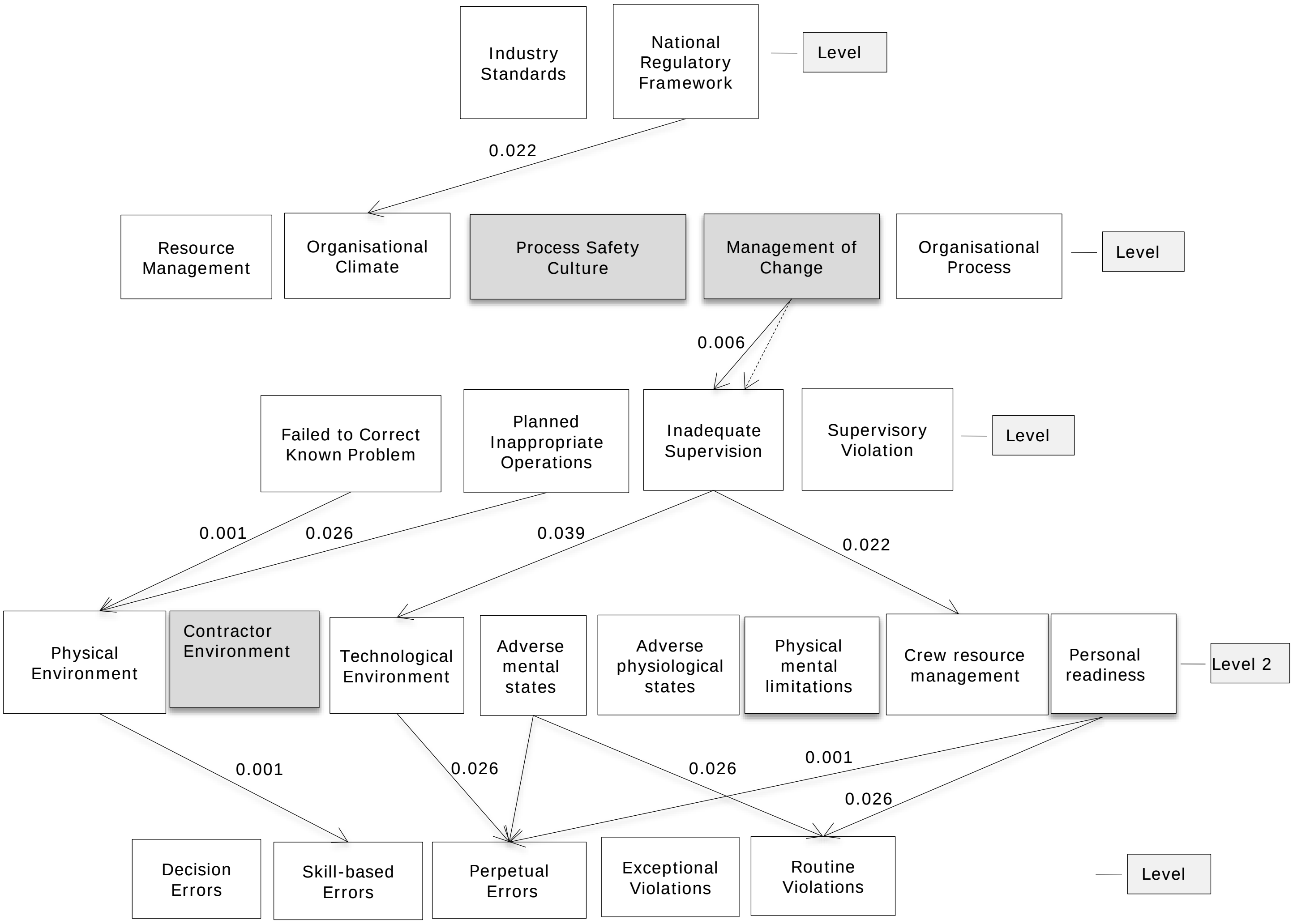


Figure 4. 2**.** Paths of associations between HFACS-OGI levels (Chi-square test Fisher's exact test).

4.2 Technique for the Retrospective and Predictive Analysis of Cognitive Errors for the oil and gas industry (TRACEr-OGI)

Question 2 –"How suitable for the oil and gas industry is the current Technique for Retrospective and Predictive Analysis of Cognitive Errors (TRACEr) developed for the aviation industry?"

Objective 2- "To develop a Technique for Retrospective and Predictive Analysis of Cognitive Errors for the Oil and Gas Industry (TRACEr-OGI)."

4.2.1 Analysis of TRACEr-OGI

The Technique for Retrospective and Predictive Analysis of Cognitive Errors for the Oil and Gas Industry (TRACEr-OGI) (Appendix D) was used to analyse 163 accident reports. It was shown that the tool was useful and effective in classifying task errors, major contexts in which these errors occurred and any causal factors. Results found that poor communication between drillers, roustabouts, crane operators, floor men, and other operators working on offshore platforms remains a major precursor to offshore accidents. Several injuries identified arose from a lack of communication between operators working simultaneously on drilling operations tasks.

The Operator's Context revealed major errors in perception. Overall, the major contributors to human error were the personal factor (*Competence*) and the organisational factor (*Training*). The predominant contributors to Error Recovery were failures in the functional barrier system

4.2.2 Reliability and Usability of TRACEr-OGI

The reliability and usability of the propose TRACEr-OGI are detailed in Theophilus et al. (2017). However, excerpts are provided in this section. The Technique for the Retrospective and Predictive Analysis of Cognitive Errors for the oil and gas industry (TRACEr-OGI) was developed to make it effective, less difficult to use and more comprehensive in identifying errors for the oil and gas industry. Therefore, TRACEr and TRACEr-OGI were assessed for reliability and usability. "Results for both taxonomies show the rater pairs with a substantial level of agreement, having a Cohen's kappa value ≥ 0.6. The Kappa value for TRACEr and TRACEr-OGI was found to be satisfactorily consistent as there was at least 83.9% agreement between the rater pair under consideration and all the values were significant at a level $p < 0.05$ (Table 4. 6 and Table 4.7). However, the overall percentage agreement for TRACEr-OGI was better. More raters found both TRACEr (78%) and TRACEr-OGI (83%) easy to use" (Theophilus et al. 2017). However, the majority of the raters found the TRACEr coding form easier to use than that of TRACEr-OGI (Table 4. 8). Similar to this study, Baysari et al. (2011) modified TRACEr-Rail (developed by the Rail Safety and Standards Board in the UK) to TRACEr-RAV (an Australian specific version of the tool) to more appropriately suit the Australian rail context. The tools were then compared for reliability and usability with poor inter-rater reliability observed. Baysari et al. (2011) noted that the poor inter-rater reliability observed was most likely the result of insufficient human factors, limited practice in using the tools and inadequate training.

Table 4. 5. Average percentage agreement from all participants using TRACEr and TRACEr-OGI.

Categories	% of Raters Who Found this Category to Be a Cause of the Accident	
	TRACEr	**TRACEr-OGI**
Task error	94	78
Error information	93	92
Equipment Error	-	72
External error modes	65	75
Cognitive domain	91	93
Internal error modes	77	83
Psychological error mechanisms	65	79
Performance shaping errors	89	80
Causality level	96	97
Control Barriers and Recovery Measure	-	90
Mean	67	84

Table 4. 6. The percentage agreement among raters for TRACEr-OGI.

Raters * (R)	Percentage Agreement	Kappa (*k*)*	*p*-Value	Percentage Agreement	Kappa (*k*)*	*p*-Value
	TRACEr-OGI			TRACEr		
R1 vs. R2	91.6%	0.746	0.00	86.7%	0.725	0.00
R1 vs. R3	92.7%	0.764	0.00	84.6%	0.679	0.00
R1 vs. R4	88.5%	0.644	0.00	83.9%	0.664	0.00
R2 vs. R3	91.6%	0.724	0.00	86.7%	0.723	0.00
R2 vs. R4	89.5%	0.669	0.00	87.4%	0.738	0.00
R3 vs. R4	92.7%	0.753	0.00	89.5%	0.779	0.00

* Only inter-raters with Kappa values ≥ 0.6 were renamed R1 to R4 and shown. Cohen suggested the Kappa result be interpreted as follows: values ≤ 0 as indicating no agreement and 0.01–0.20 as none to slight, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect agreement (McHugh 2012).

Table 4. 7. Participants rating of ease of use.

Questions	TRACEr	TRACEr-OGI
How easy did you find it while completing the steps?	78	83
Where the instructions/directions easy to follow?	78	89
Did you find the category descriptions easy to use?	78	83
Did the tool cover all of your errors/factors?	78	83
Were the categories independent?	56	61
Were the examples included helpful?	94	89
Was the recording form easy to use/follow?	100	94

4.3 Human Factors (HFs) and Performance Influencing Factors (PIFs) in Process Accidents

Question 3- "What are the most common Human Factors (HFs) and Performance Influencing Factors (PIFs) contributing to major accidents in the oil and gas industry?"

Objective 3- "To analyse the most common Human Factors (HFs) and Performance Influencing Factors (PIFs) in oil and gas industry accidents."

4.3.1 Analysis of HFs and PIFs contributions to process safety accident

The contribution of PIFs and in turn, human factors, to process safety cannot be overemphasised as process operations in process industries are highly technical and complex. The position of PIFs in the accident causation model (Figure 1.4b) shows that resolving their contribution at an early stage of the sequence remains the most optimal practice to preventing accidents and providing solutions to safety-critical issues in the oil and gas industry. Output 1 was designed to analyse the major performance influencing factors (PIFs) involved in a major process accident in the oil and gas industry. This output was to help to explain the role of human factors contributions to accidents in the oil and gas industry.

For the case study used, the most significant human factor was *Job Factors* at 41%, while *Individual Factors* and *Organisational Factors* were at 31% and 28% respectively. The percentage weighted score of PIFs in critical Event 1, 2 and 3 leading to the accident determined using analytical hierarchy process, the most performance influential factors (PIFs) that emerged were Procedures (41%) (Figure 4.3 A), Training (39%) (Figure 4.3 A) and Skills Level (25%) (Figure 4.3 C). The consistency index (CI) and consistency ratios (CR) affirmed consistency with the judgements of the study on PIFs.

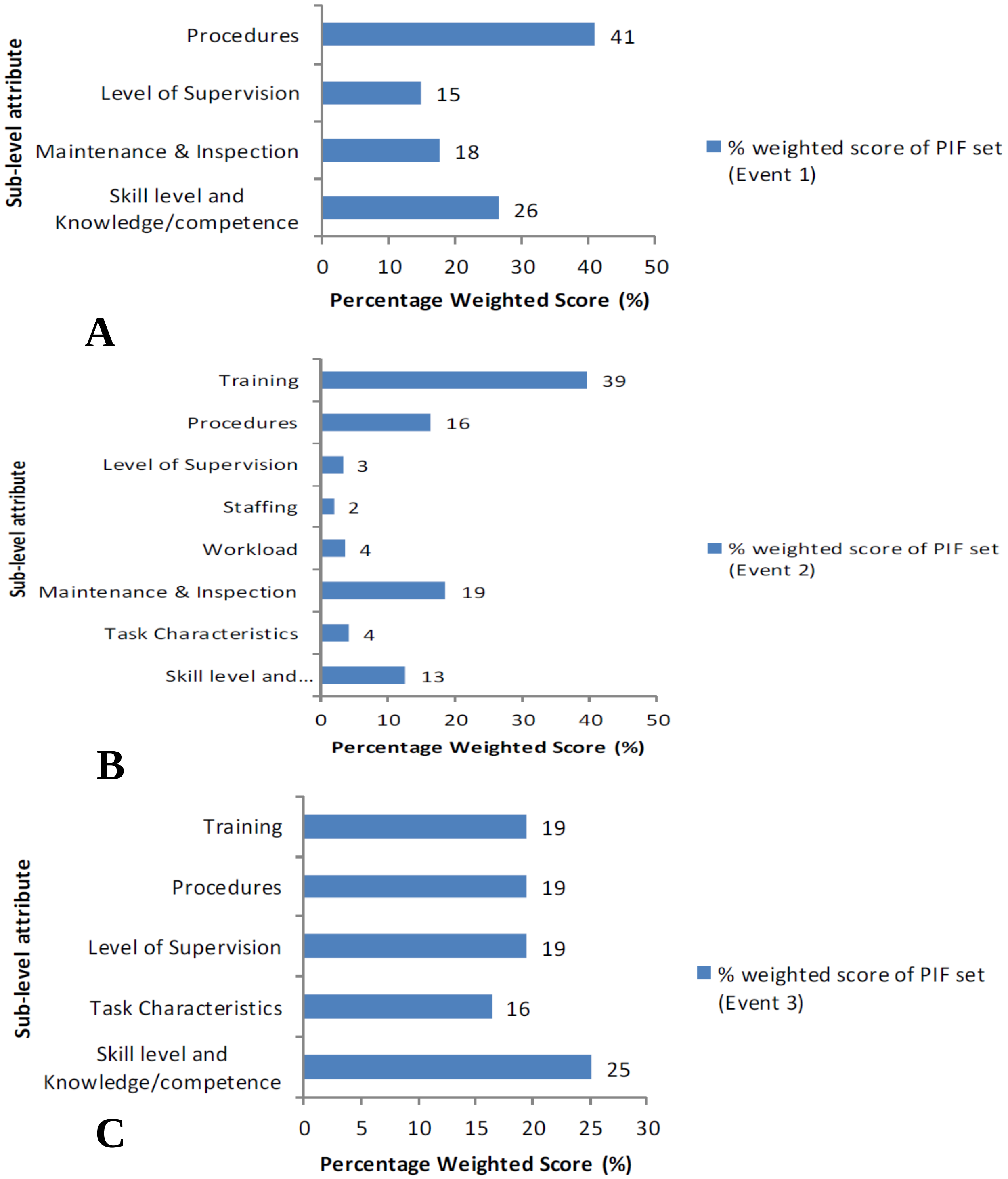


Figure 4. 3. Percentage weighted score of PIFs in critical Event 1, 2 and 3

Event 1 - Hazardous Non-routine cleaning activity; Event 2 Manual manipulation of isolation block valves and Event 3 Automated Start-up Operations

Analytic Hierarchy Process (AHP) was used in assessing human factor contributions to an accident. Results obtained following the steps outlined in section 3.4.3, (Table 4.8) showed that the consistency index CI and consistency ratios CR of the PIFs obtained affirmed consistency with the judgement of the study on PIFs selected for each critical event identified.

Table 4. 8. Consistency Index (CI) and Consistency Ratios (CR)

Event 1	Event 2	Event 3
0.174 and 0.193	0.170 and 0.120	0.037 and 0.033

Figure 4.4 is the percentage human factor quality index of considered PIFs. A score of 55% (Event 1) meant that the degree of compliance was below average in relation to the quality index range for the overall qualification of PIFs (Table 3.2) above. Event 2 with an overall qualification score of 35% is judged the event that may likely require major improvement. Event 3 with an overall qualification score of 64%, though the highest percentage for qualification of the HF quality index in the critical events assessed, also reflect a below average degree of compliance.

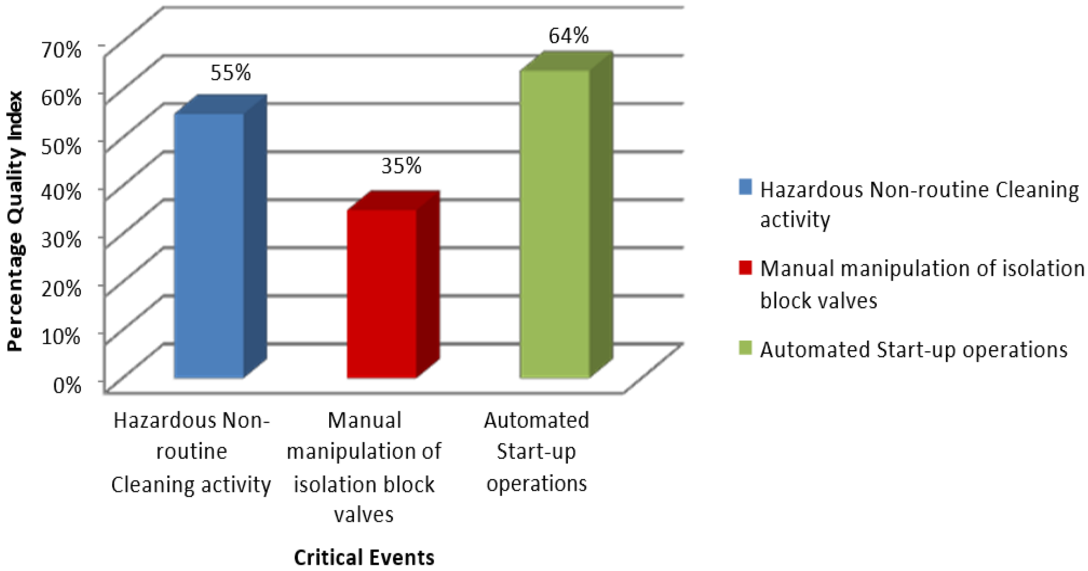


Figure 4. 4. Percentage Human Factors Quality Index behind each critical event

From these qualification values, we can deduce that the application of AHP will enable the assessor to quantify the contribution of human factor leading to the accident. Furthermore, it is possible to deduce that quite a lot of human factor related issues were not addressed and consequently shows that latent human-related failures eventually leading to the fatal incident were left exposed without appropriate attention and prevention. Finally, the process will inform prioritising remedial action hence an informed management decision-making process.

4.4 Integrating human factors, (HF) human error (HE) and performance influencing factors (PSF) into process safety management systems (PSM)

Question 4 – "Is it possible to develop a robust process safety management (PSM) system that integrates missing human factor (HF) in the current management systems?"

Objective 4- "To develop a robust process safety management (PSM) system that integrates missing human factor (HF) contributions to the current management systems."

Flowing logically from the previous outputs, Output 5 serves as an umbrella that addresses all performance influencing factors (Output 1) (Theophilus et al. 2016), human factors (Outputs 2 and 4) (Theophilus et al. 2017; Theophilus et al. 2016) and human error (Output 2) (Theophilus et al. 2017); as part of the process safety management system (SPE 2014; Mannan 2014; U.S. Department of Labor 2000). To achieve this, Output 5 used comparative analysis to draw a contrast between each existing process safety management framework, highlighting their features, differences, similarities and drawbacks. The results obtained show that the current process safety management frameworks are deficient in addressing all human factors, human error and the performance influencing factor elements. For example, the EI PSM framework did not address operator conditions, perceptual errors, physical environment, planned inappropriate operations among others and crew resource management. The DuPont PSM model also failed to address human factors like operator conditions, perceptual errors, routine and exceptional violations, physical environment, supervisory violations and crew resource management.

Following the comparative analysis, 26 matching elements were identified and were automatically incorporated into the new framework. All human factors elements required for exhaustive processes of risk management in the process industry were then included. These elements were divided into five categories in order of implementing the strategy as follows:

A. Job factor
B. Personnel factor
C. Organisational factor
D. Safety culture
E. External and internal influences.

To provide room for continuous improvement, Output 5 used the Deming's PLAN-DO-CHECK-ACT cycle as the theoretical framework for implementation (Figure 4 5). This was necessary to maintain high standards of process safety in a rapidly evolving petroleum industry (Chang and Liang 2009). Deming's PLAN-DO-CHECK-ACT cycle was also used as the theoretical framework for the robust Responsible Care Process Safety Code (RCPSC) included in the design of the AIChE/CCPS RBPS standard (Bridges and Tew 2010).

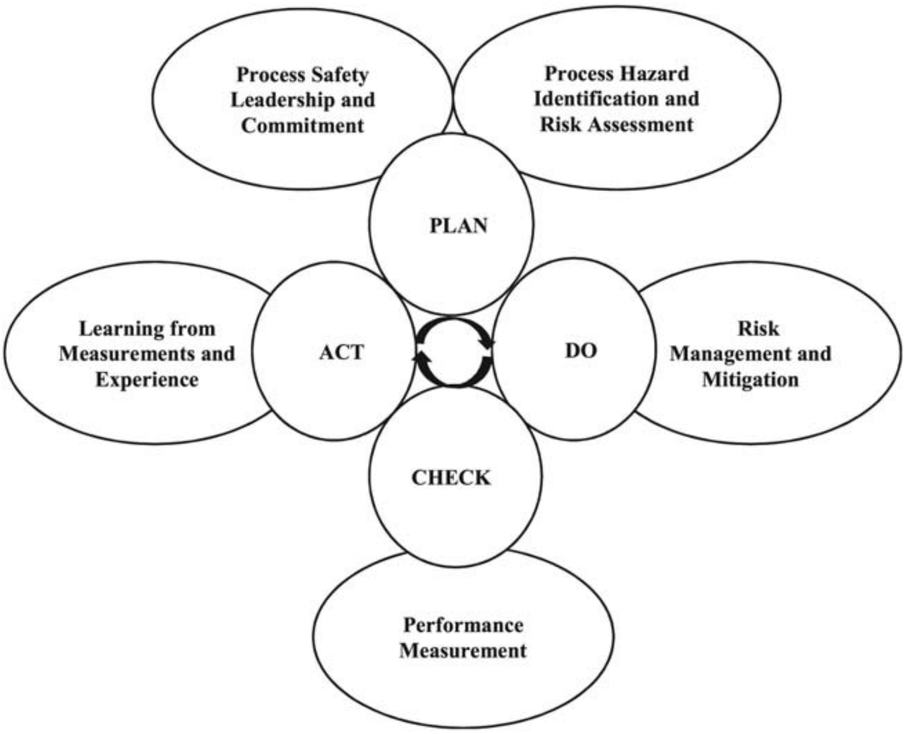


Figure 4. 5. Proposed Integrated Process Safety Management System model

Output 5 mirrors the International Ergonomics Association definition of ergonomics which is focused on 'designing machines, operations, and work environments so that they match human capabilities, limitations, and needs' (AIChemE 2007). There are two categories of PSM elements: those which deal with inherent safety culture amongst members of the organisation and those which address operational risks (Reniers et al. 2011). At the heart of these PSM elements are management commitment and operational discipline (Rains 2010). It could be inferred that there must be a good safety culture in an organisation for operational integrity to be assured and vice versa (Olive et al. 2006). Therefore, the proposed implementation strategy in Output 5 is based on the belief that operational discipline serves as a foundation for enhancing safety culture. This in turn acts as a central bevel gear for the advancement and continuous improvement of process safety management (Figure 4.6) (Lutchman et al. 2013; Theophilus et al. 2018).

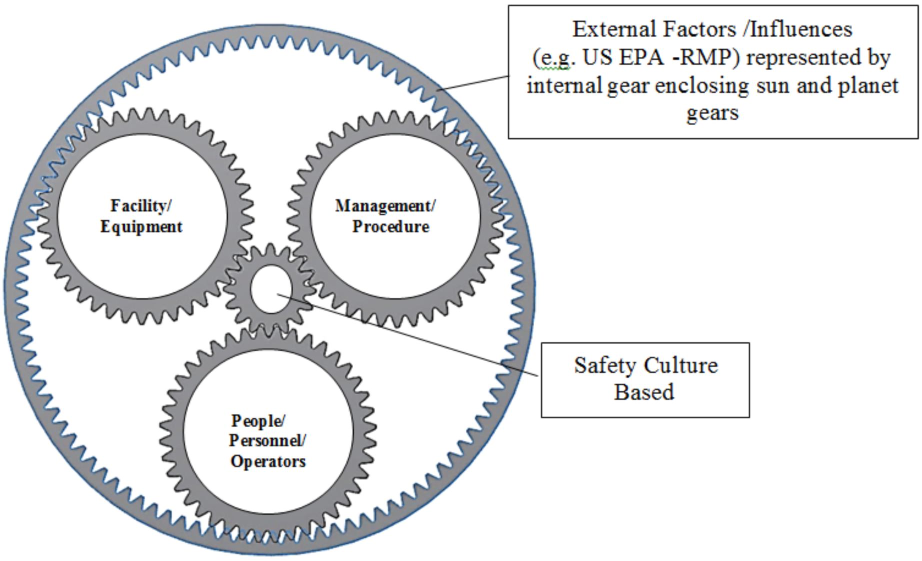


Figure 4. 6. Proposed Implementation Strategy for the IPSMS model

4.5 Evaluation of the Contribution to Knowledge

Professor Mark Jenkins of the Cranfield University School of Management asserted that *'the only way to get published is by making a unique and valuable contribution to the existing body of knowledge'* (Jenkins 2016). The outputs contained in this portfolio have been published and exposed to peer-review by notable journals in the field. This supports the fact that unique knowledge has been created and that valuable contributions have been made to the existing body of knowledge. This has been affirmed by a number of peers. The key contributions to knowledge of each output are highlighted using a matrix that was proposed by Professor Mark Jenkins and modified by Ifelebuegu (2013). 'The matrix is used to show the contribution that an output has made to knowledge by either confirming or replicating the findings of other researchers; contradicting or extending existing knowledge or making new contributions' (Ifelebuegu 2013) (Table 4.9 to 4.13).

4.5.1 Evaluation of Outputs

Output 1

Table 4. 9. "Application of Analytic Hierarchy Process to Identify the Most Influencing Human Factors (HFs) and Performance Influencing Factors (PIFs)" (Theophilus et al. 2016)

	Confirmed / Replicated Findings	Contradicted knowledge	Extended findings	Made New Contribution
Output 1	Confirmed the application of the Analytic Hierarchy Process (AHP), a multi-criteria decision-making process (Aragonés-Beltrán et al. 2014; Shi et	-	-	Successfully applied an Analytic Hierarchy Process (AHP) in the identification of the most influential human factors (HFs) and performance

	al. 2014; Singh and Nachtnebel 2016; Saaty 2008).			influencing factors (PIFs) in process safety accidents.
Citation	N/A			

This paper investigated human factors and performance influencing factors which influence the propagation of undesired critical events in the oil and gas industries. The application of Analytic Hierarchy Process AHP - a multi-criteria decision-making method - in identifying HFs and PIFs of critical events was demonstrated. It was also demonstrated that accident analysis could be narrowed down from the broad category of human factors to performance influencing factors (PIFs). Finally, PIFs were ranked using the Process Industry Safety Management PRISM human factor guidance.

The Tesoro refinery accident was used as an illustrative case study for this study. The findings showed that three critical events, namely Event 1 (non-routine operations), Event 2 (manual manipulation of several isolation block valves) and Event 3 (automated start-up operations of Naphtha Hydro-Treating unit) were the most critical leading to the accident. On the basis of HF, Job Factors had the most significant human factors at 41%; Individual Factors had 31%; while Organisational Factors had 28%. The ranking of PIFs revealed that Level of Supervision, Procedures, Skill Level and Task Characteristics were major influencing PIFs for the event. On the application of AHP, the consistency ratios (CR) and consistency index (CI) of the PIFs were 0.193 and 0.174 for critical Event 1; 0.120 and 0.170 for critical Event 2; and 0.033 and 0.037 for critical Event 3, respectively.

While there are a number of publications on human factors, they are mostly based on broad categories and rely largely on the experience and judgment of accident investigators. Moreover, they are subjective, introduce bias and are sometimes imitated in recommendations. Therefore, when retrospective accidents analyses are involved, there is the tendency to blame human factor for events where no sufficient organisational or technical errors are found.

The understanding from this paper would help accident investigators to sufficiently assess organisational or technical errors and PIFs involved in the human factor contribution. The need to distinguish the influencing factors from the direct cause of a fatal incident will enhance understanding of the latent action and hence improve recommendations. It will also help the decision maker involved in implementing recommendations to prioritise control measures. This result is similar to that reported by Erjavac et al. (2018) on the relationships between latent causal factors which are not usually obvious and obvious symptomatic factors. The findings of the Analytic Hierarchy Process application provided answers to some fundamental questions on the subjectivity and bias introduced by accident investigators' experience and judgment.

Output 2

Table 4. 10. "Human Factors Analysis and Classification System for the Oil and Gas Industry (HFACS-OGI)" (Theophilus et al. 2017).

	Confirmed / Replicated Findings	Contradicted knowledge	Extended findings	Made New Contribution
Output 2	Confirmed / Replicated human factors contributions to major accidents in the process industry and the oil and gas industry (Shappell et al. 2007;	-	Extended existing Human Factors Analysis and Classification System (HFACS) designed for the aviation industry to the oil and gas industry (Wiegmann and Shappell 2003).	Developed a new Human Factors Analysis and Classification System for the oil and gas industry (HFACS-OGI)

	Ergai et al. 2016)
Citations (see Appendix E)	

This paper moved on from PIFs to investigate Human Factors contribution to major accident in the oil and gas industry (Figure 1.4 B). Arguably, James Reason's ‘Swiss cheese’ model has become the most popular accident causation model for analysing errors and safety incidents (Underwood and Waterson 2014; Perneger 2005). The model explains the occurrence of accidents within a system at four levels: 1) Organisational failures, 2) Unsafe supervision, 3) Preconditions for unsafe acts and 4) Unsafe acts. Based on Reason’s ‘Swiss Cheese’ model, Shappel and Wiegmann (2000) developed the Human Factors Analysis and Classification System (HFACS) for the aviation industry. Although there have been several modifications of HFACS, there is no version that can, for example, analyse oil and gas industry-related regulatory deficiencies (O’Dea and Flin 2001; Kidam and Hurme 2013) and emerging violation issues.

The outcome of this output is a novel Human Factors Analysis and Classification System for the Oil and Gas Industry (HFACS-OGI). Level 5 was introduced to Shappel and Wiegmann's (2000) ‘4 levels classification’. Furthermore, HFACS-OGI was used to analyse 11 major accidents in the oil and gas industry. This output therefore extended James Reason's ‘Swiss Cheese’ model, and HFACS findings in accident analysis in the oil and gas industry.

The results show that in identifying human factors in the 11 reviewed oil and gas accidents, HFACS identified 54 categories of occurrences, but HFACS-OGI identified a total of 80. Moreover, HFACS-OGI successfully identified all industry-specific categories which were ordinarily difficult to identify with the HFACS. Furthermore, the novel HFACS-OGI system revealed that failures in level 5 (national and international industry regulatory standards) were not included but HFACS would be a precursor for accidents to occur. Also, there were significant relationships between level 5 (Industry Regulatory Framework) and level 4 (Organisational Climate). These findings demonstrate the applicability and efficiency of

HFACS-OGI as an important HSE tool for the analysis of accidents in the oil and gas industry. Since its publication toward the end of 2017, it has since been cited 9 times by notable journals in the nuclear and aviation industry (Diao and Ghorbani 2018; Erjavac et al. 2018b; Miranda 2018; Simpson 2018; Strand and Haskins 2018; Viramuthu 2017)

Output 3

Table 4. 11. “A Technique for the Retrospective and Predictive Analysis of Cognitive Errors for the Oil and Gas Industry (TRACEr-OGI)” (Theophilus et al. 2017).

	Confirmed / Replicated Findings	Contradicted knowledge	Extended findings	Made New Contribution
Output 3	Confirmed human errors’ contribution to major accidents in the process industry and in the oil and gas industry (Baysari, Caponecchia, and McIntosh 2011, Caponecchia, Baysari, and McIntosh 2012, Graziano, Teixeira, and	-	Extended the existing Technique for the Retrospective and Predictive Analysis of Cognitive Errors TRACEr designed for the aviation industry to the oil and gas industry (Shorrock and Kirwan 2002b)	Developed a new Technique for the Retrospective and Predictive Analysis of Cognitive Errors for the oil and gas industry (TRACEr-OGI)

	Guedes Soares 2016b, Schröder-Hinrichs et al. 2016).	

Most accident models show that human factors feed into a latent error (Figure 1.4 B) (Theophilus et al. 2017: 10). Consequently, 'human factors engineering' (HFE) is seen as the scientific and engineering discipline concerned with improving human performance and reducing human error in complex systems (Thomas et al. 2002). In this section of the research, the author moved on from HF investigation to explore Human Error contributions to major accidents in the oil and gas industry.

The analysis of 163 major retrospective accident cases that occurred between 2000 and 2014 revealed that it was difficult to code some latent errors within the industry with the three major divisions and seven categories of TRACEr. For example, since the tool is designed to identify human factors which feed into human errors, it is difficult to code equipment errors, regulatory errors and some administrative errors such as inspections and enforcement errors. The output therefore proposed a novel Technique for the Retrospective and Predictive Analysis of Cognitive Errors for the Oil and Gas Industry (TRACEr-OGI). The new taxonomy made the tool 1) less difficult to use; 2) more suitable and more comprehensive in identifying latent errors within the industry; and 3) easy to be applied more consistently (i.e., to show greater inter-rater reliability) in the oil and gas industry.

Output 4

Table 4. 12. “Fifteen-Year Accident Causation Assessment of the Petroleum Industry in South and Central America Using Statistical Correlations” (Theophilus et al. 2017).

	Confirmed / Replicated Findings	Contradicted knowledge	Extended findings	Made New Contribution
Output 5	Confirmed / Replicated human factors' contribution to major accidents in the process industry and in the oil and gas industry (Shappell et al. 2007; Ergai et al. 2016)	-	Extended the use of the Human Factors Analysis and Classification System (HFACS) designed for the aviation industry to the oil and gas industry (Wiegmann and Shappell 2003).	-

This paper carried out an extensive fifteen-year analysis of major retrospective accident cases in the oil and gas industry using a Human Factors Analysis and Classification System (HFACS).

It was found that inadequate supervision appeared to be the major human factor with 81% of the total accident cases analysed, while failure to correct action and organisational processes were at 65% and 62% respectively. Supervisory violation and exceptional errors were 52% and 39% respectively. This confirmed the findings of other investigators showing human factors as contributing factors at different levels of the organisation (Celik and Cebi 2009; Daramola 2014).
Furthermore, this Output confirmed the main types of causative events leading to accidents in the oil and gas industry are impacts at 36.25%, Collision at 13.75% and fall from a height at 10%. The outcome of this analysis revealed that ‘the current HFACS developed for the aviation industry, cannot be used to simultaneously analyse regulatory deficiencies and emerging violation issues, such as sabotage in the oil and gas industry’

(Theophilus et al. 2017: 167). Similar outcomes have been reported elsewhere in the literature (Chauvin et al. 2013; Zhou et al. 2017). Therefore, this analysis underpinned the proposal of a novel Human Factors Analysis and Classification System for the Oil and Gas Industry (HFACS-OGI). The human factors analysis and classification system (HFACS) designed for the aviation industry was therefore replicated and extended to the oil and gas industry

Output 5

Table 4. 13. “Human Factors (HF) into a Process Safety Management System (PSMS)’. Process Safety Progress” (Theophilus et al. 2018).

	Confirmed / Replicated Findings	Contradicted knowledge	Extended findings	Made New Contribution
Output 1	-	-	Extended existing Process Safety Management Systems by integrating missing human factor components (Center for Chemical Process Safety 1994)	Developed a new Integrated Process Safety Management System (IPSMS) Model Developed a new risk-based and culture-based approach to the implementation framework for process safety management.

This paper identified the missing human factors in the current process safety management systems. To do this ,all existing PSM frameworks were screened and a new integrated process safety management system (IPSMS) model proposed, which integrated the Human Factors Analysis and

Classification System (HFACS), while ensuring that the model adopted the PLAN, DO, CHECK, and ACT framework to provides both a theoretical and a practical framework with which to manage, measure and analyse process safety management systems. This paper extended the existing Process Safety Management Systems and provided answers to some fundamental questions on the missing human factors in the current process safety management systems.

This paper also developed a new implementation strategy for the IPSMS model with a risk-based and safety-culture-based approach. This strategy is based on three broad areas of human factor interaction and ergonomics: Management/Procedure, Facility/Equipment and People / Personnel / Operators.

4.5.2 Statements on the extent of the contributions

The author is the lead author of all the papers contained in this portfolio. Over 80% of the works included in this portfolio were carried out by the author. The individual contributions made by other collaborators and the extent of the collaboration from conception to write-up are shown in Table 4.14 below.

Table 4. 14. Summary of individual contributions and the extent of collaboration.

<table>
<tr><td colspan="8"></td></tr>
<tr><td rowspan="3">Output 1</td><td>Collaborators</td><td>Theophilus, S. C</td><td>Abikoye, O.G.</td><td>Arewa, A.O</td><td>Ifelebuegu, A.O.</td><td colspan="2">Esenowo, V.</td></tr>
<tr><td>% Contribution</td><td>80%</td><td>15%</td><td>2%</td><td>2%</td><td colspan="2">1%</td></tr>
<tr><td>Remarks</td><td colspan="6">The project idea was initiated by the author. Data collection and analyses were carried out by the author and Abikoye. The paper was 100% written by the author. The remaining other contributors reviewed parts of the finished work.</td></tr>
<tr><td colspan="8"></td></tr>
<tr><td>Output 2</td><td>Collaborators</td><td>Theophilus, S. C</td><td>Esenowo, V.N</td><td>Arewa, A.O</td><td>Ifelebuegu, A.O.</td><td>Nnadi, E.O.,</td><td>Mbanaso, F.U</td></tr>
</table>

	% Contribution	60%	35%	2%	1%	1%	1%
	Remarks	The project idea was initiated by the author. Data collection and analyses were carried out by the author and Esenowo. The paper was 60% written by the author. Esenowo wrote the remaining 40 % with the direction of the author. Other contributors reviewed parts of the finished work.					
Output 3	Collaborators	Theophilus, S. C	Ikpang E	Ifelebuegu, A.O.	Arewa, A.O.	Agyekum-Mensah	
	% contribution	80%	15%	2%	2%	1%	
	Remarks	The project idea was initiated by the author. Data collection and analyses were carried out by the author and Ikpang. The paper was 100% written by the author.					
Output 4	Collaborators	Theophilus, S. C	Bassey, B.O	Ajare, T.O	Baroni, A.S	Odigie, O.P.	Asogwa, D.
	% contribution	50%	40%	6%	2%	2%	2%
	Remarks	The project idea was initiated by the author. Data collection and analyses were carried out by Bassey Ajare Baroni and Odigie with the direction of the author. The paper was 100% written following the directions					
Output 5	Collaborators	Theophilus, S. C	Nwankwo, C.D	Acquah-Andoh, E	Bassey, E	Umoren, U	
	% contribution	80%	15%	1%	2%	2%	
	Remarks	The project idea was initiated by the author. Data collection and analyses were carried out by the author and Nwankwo. The paper was 60% written by the author. The remaining 40 % was written by Nwankwo with the direction of the author. Other contributors reviewed parts of the finished work.					

Chapter Five

Conclusion and Recommendations

5.1 Conclusion

There is empirical evidence that performance influencing factors (PIF), human factors (HF) and human errors (HE) are major contributors to process accidents. This thesis set out four clear objectives at the beginning which have mainly been achieved. The portfolio of evidence explained the development and application of new human reliability assessment (HRA) methods for the analysis of major accidents in the oil and gas industry. Firstly, it explained the application of the Analytic Hierarchy Process (AHP) to identify the most influential Human Factors (HFs) and Performance Influencing Factors (PIFs) in Process Safety Accidents. Secondly, the contributions of human factors and human errors in Process Safety Accidents were analysed. Thirdly, two human reliability assessments (HRA) tools (HFACS-OGI and TRACEr-OGI) were proposed. Finally, the research proposed and integrated a process safety management (IPSM) system that integrates the missing human factor (HF) element into the current process safety management system.

The portfolio of evidence presents a clear and logical trail linking the research together. The following are short excerpts of conclusions.

1. *To develop a human factor analysis and classification system (HFACS) framework for the oil and gas industry (HFACS-OGI).*

The developed HFACS-OGI identified significant themes that could not be identified by the original HFACS. "Some of the significant themes include the national regulatory framework, industry standards, management of change, the contractor environment and the process safety culture". These findings demonstrate the applicability, robustness and greater efficiency of HFACS-OGI for the oil and gas industry.

2. *To develop a Technique for Retrospective and Predictive Analysis of Cognitive Errors for the Oil and Gas Industry (TRACEr-OGI).*

From it result it was discovered that "TRACEr-OGI was not only able to identify human errors aligned to job context, organisational/facility context and operator context, it was also able to capture equipment error. It was shown therefore that TRACEr is sufficiently flexible and adaptable for the O&G industry". The results of the developed TRACEr-OGI made marginal difference in usability and reliability. However, it enhanced percentage rater agreement.

3. *To analyse the most common Human Factors (HFs) and Performance Influencing Factors (PIFs) in oil and gas industry accidents.*

Performance influencing factors typically comprise human and organisational factors which make human failure detectable. The case study of the Tesoro refinery accident can be likened to an organisational accident, as latent organisational and cultural failures, as well as other conditions, have been most instrumental. Managing the failure of these performance influencing factors lies in the responsibility of the organisation's management system, culture and operational structures in place.

4. *To develop a robust process safety management (PSM) system that integrates human factor (HF) contributions to the current management systems.*

The developed IPSMS model offers a structured way of implementing a Process Safety Management System in the process industry. Given that the development and maintenance of a process safety management system in any organisation involves various different interactions between jobs, personnel and organisational factors, this model facilitates the integration of all of these into a PLAN DO CHECK ACT model, which enhances continual improvement.

5.2 Recommendations

- This research has demonstrated the application of AHP in the identification of most influencing PIFs and HFs. Further investigation, however, will be required to demonstrate the application of AHP in the identification of the most influencing human factors and human errors in accident investigation.

- The work has developed a novel integrated process safety management (IPSM) system that integrates the missing human factor (HF) element into the current process safety management system. This needs to be further investigated to ascertain the cost implications of implementing the system and the impact on incident and accident reduction over at least three years.

5.3 Claim for the PhD

In bringing together this substantial body of research, it is believed that PhD equivalence has been achieved.

- The research papers presented in this portfolio are clear evidence of sustained independent research, originality and contribution to knowledge, having been published in refereed journals of an international standard with high impact factors.

- They are evidence of significant, continuous and coherent contributions to the subject of accident causation and prevention in the process industry.

- The portfolio is a testament to the author's critical and in-depth knowledge of the appropriate topic and related literature.

- The portfolio chose and used some analytical methods that were appropriate to the area of study. This is clear evidence of training in research methods including human reliability assessment (HRA) tools, surveys, qualitative and quantitative data analysis and interpretation, the Analytic Hierarchy Process (AHP) and the Statistical Package for the Social Sciences (SPSS).

References

Aas, A. (2008) ‘The Human Factors Assessment and Classification System (HFACS) for the Oil & Gas Industry’. in *Proceedings of International Petroleum Technology Conference*, ‘International Petroleum Technology Conference’ [online] held December 2008. Society of Petroleum Engineers. available from <http://www.onepetro.org/mslib/servlet/onepetropreview?id=IPTC-12694-MS&soc=IPTC> [2 June 2019]

AIChE (ed.) (2009) *Inherently Safer Chemical Processes: A Life Cycle Approach*. 2nd ed. A CCPS concept book. New York : Hoboken, N.J: Center for Chemical Process Safety ; Wiley

AIChE (ed.) (2007) *Guidelines for Risk Based Process Safety*. Hoboken, N.J: Wiley-Interscience

ALNabhani, K., Khan, F., and Yang, M. (2016) ‘The Importance of Public Participation in Legislation of TENORM Risk Management in the Oil and Gas Industry’. *Process Safety and Environmental Protection* 102, 606–614

Al-shanini, A., Ahmad, A., and Khan, F. (2014) ‘Accident Modelling and Analysis in Process Industries’. *Journal of Loss Prevention in the Process Industries* 32, 319–334

APRIL Indonesia (2013) *Sustainability Report - 6.4 Health and Safety* [online] Growing our Future. Sustainability Report. Indonesia. available from <https://www.aprilasia.com/sr2012/sustainability-report-2012/6-0-employees/6-4-health-and-safety.html> [10 June 2019]

Aragonés-Beltrán, P., Chaparro-González, F., Pastor-Ferrando, J.-P., and Pla-Rubio, A. (2014) ‘An AHP (Analytic Hierarchy Process)/ANP (Analytic Network Process)-Based Multi-Criteria Decision Approach for the Selection of Solar-Thermal Power Plant Investment Projects’. *Energy* 66, 222–238

Baxter, P. and Jack, S. (2008) *Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers*. 18

Baysari, M.T., Caponecchia, C., and McIntosh, A.S. (2011) ‘A Reliability and Usability Study of TRACEr-RAV: The Technique for the Retrospective Analysis of Cognitive Errors – For Rail, Australian Version’. *Applied Ergonomics* 42 (6), 852–859

Baysari, M.T., McIntosh, A.S., and Wilson, J.R. (2008a) ‘Understanding the Human Factors Contribution to Railway Accidents and Incidents in Australia’. *Accident Analysis & Prevention* 40 (5), 1750–1757

Baysari, M.T., McIntosh, A.S., and Wilson, J.R. (2008b) ‘Understanding the Human Factors Contribution to Railway Accidents and Incidents in Australia’. *Accident Analysis & Prevention* 40 (5), 1750–1757

Bell, J. and Holroyd, J. (2009) *Review of Human Reliability Assessment Methods* [online] RR679. Research Report. Derbyshire: Health and Safety Executive. available from <http://www.hse.gov.uk/research/rrpdf/rr679.pdf> [10 June 2019]

Bellenkes, C.A.H. (1997) ‘Guidelines for Preventing Human Error in Process Safety by Center for Chemical Process Safety 1994, 390 Pages, $140.00 New York: American Institute of Chemical Engineers ISBN 0-8169-0461-8 ,
Guidelines for Preventing Human Error in Process Safety by Center for Chemical Process Safety 1994, 390 Pages, $140.00 New York: American Institute of Chemical Engineers ISBN 0-8169-0461-8’. *Ergonomics in Design* 5 (1), 32–33

Bird, F.E. and Loftus, joint author.), Robert (1976) *Loss Control Management* [online] Loganville, Ga. : Institute Press. available from <https://trove.nla.gov.au/version/12792176> [12 May 2019]

Boring, R.L. (2012) ‘Fifty Years of THERP and Human Reliability Analysis’. in *Proceedings of the Probabilistic Safety Assessment and Management and European Safety and Reliability Conference (PSAM 11 & ESREL 2012)* [online] held 2012. available from <https://inldigitallibrary.inl.gov/sti/5680968.pdf> [8 October 2016]

Bowen, G.A. (2009) ‘Document Analysis as a Qualitative Research Method’. *Qualitative Research Journal* 9 (2), 27–40

Boyatzis, R.E. (1998) *Transforming Qualitative Information: Thematic Analysis and Code Development*. SAGE

Braun, V. and Clarke, V. (2006) ‘Using Thematic Analysis in Psychology’. *Qualitative Research in Psychology* 3 (2), 77–101

Bretschneider, P.J., Cirilli, S., Jones, T., Lynch, S., and Wilson, N.A. (2017) *Document Review as a Qualitative Research Data Collection Method for Teacher Research* [online] 1 Oliver’s Yard, 55 City Road, London EC1Y 1SP United Kingdom: SAGE Publications Ltd. available from <http://methods.sagepub.com/case/document-review-qualitative-research-data-collection-method-teacher> [27 June 2019]

Bridges, W. and Tew, R. (2010) ‘Human Factors Elements Missing from Process Safety Management (PSM)’. in *6th Global Congress on Process Safety and 44th Annual Loss Prevention Symposium, San Antonio, Texas* [online] held 2010. 22–24. available from <http://www.p-i-i-i.com/_downloads/Human_Factors_Elements_Missing_from_PSM.pdf> [11 April 2016]

Bridges, W., Tew, R., and Lane, W. (2010) *Human Factors Elements Missing from Process Safety Management (PSM)*. 24

Cacha, C.A. (1999) *Ergonomics and Safety in Hand Tool Design*. CRC Press

Caponecchia, C., Baysari, M.T., and McIntosh, A.S. (2012) ‘Development, Use and Usability of TRACEr-Rav: The Technique for the Retrospective Analysis of Cognitive Errors-for Rail, Australian Version’. *Rail Human Factors around the World: Impacts on and of People for Successful Rail Operations* 85

Cassidy, K. (2013) *CIMAH, Safety Cases and the Fine Chemcial Industry*. in [online] held 2013. IChemE. available from <https://www.icheme.org/communities/subject_groups/safety%20and%20loss%20prevention/resources/hazards%20archive/~/media/Documents/Subject%20Groups/Safety_Loss_Prevention/Hazards%20Archive/X/X-Paper-13.pdf> [20 March 2017]

CCPS (2010) *Definition for Inherently Safer Technology in Production, Transportation, Storage, and Use* [online] The American Institute of Chemical Engineers. available from <https://www.aiche.org/sites/default/files/docs/embedded-pdf/ist_final_definition_report.pdf> [23 May 2019]

Celik, M. and Cebi, S. (2009) ‘Analytical HFACS for Investigating Human Errors in Shipping Accidents’. *Accident Analysis & Prevention* 41 (1), 66–75

Center for Chemical Process Safety (1994) ‘Case Study in Implementing Process Safety Management’. in *Guidelines for Implementing Process Safety Management Systems* [online] John Wiley & Sons, Inc., 197–212. available from <http://onlinelibrary.wiley.com/doi/10.1002/9780470938218.oth/summary> [27 July 2016]

Chang, J.I. and Liang, C.-L. (2009) ‘Performance Evaluation of Process Safety Management Systems of Paint Manufacturing Facilities’. *Journal of Loss Prevention in the Process Industries* 22 (4), 398–402

Chauvin, C., Lardjane, S., Morel, G., Clostermann, J.-P., and Langard, B. (2013) ‘Human and Organisational Factors in Maritime Accidents: Analysis of Collisions at Sea Using the HFACS’. *Accident Analysis & Prevention* 59, 26–37

Chen, M., Wang, K., Guo, H., and Yuan, Y. (2019) ‘Human Factors of Fire and Explosion Accidents in Petrochemical Enterprises’. *Process Safety Progress* [online] 0 (0). available from <https://onlinelibrary.wiley.com/doi/abs/10.1002/prs.12043> [28 February 2019]

Chen, S.-T., Wall, A., Davies, P., Yang, Z., Wang, J., and Chou, Y.-H. (2013) ‘A Human and Organisational Factors (HOFs) Analysis Method for Marine Casualties Using HFACS-Maritime Accidents (HFACS-MA)’. *Safety Science* 60, 105–114

Christie, M., Rowe, P.A., Perry, C., and Chamard, J. (2000) *Implementation of Realism in Case Study Research Methodology*. held 2000

Committee, T.R. (2014) *The Human Factor: Process Safety and Culture*. [online] available from <https://www.onepetro.org/general/SPE-170575-TR> [6 July 2016]

Cox, K., Black, J., Grand-Clement, S., and Hall, A. (2016) *Human and Organisational Factors in Major Accident Prevention: A Snapshot of the Academic Landscape* [online] RAND Corporation. available from <http://www.rand.org/pubs/research_reports/RR1512.html> [2 June 2019]

Creswell, J.W. (2013) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. US Only edition. Thousand Oaks: SAGE Publications, Inc

Cummings, D.E. (2009) ‘The Evolution and Current Status of Process Safety Management Metrics’. *Process Safety Progress* 28 (2), 147–155

Cummings, D.E. (2009) ‘The Evolution and Current Status of Process Safety Management Metrics’. *Process Safety Progress* 28 (2), 147–155

Daramola, A.Y. (2014) ‘An Investigation of Air Accidents in Nigeria Using the Human Factors Analysis and Classification System (HFACS) Framework’. *Journal of Air Transport Management* 35, 39–50

De Ambroggi, M. and Trucco, P. (2011) ‘Modelling and Assessment of Dependent Performance Shaping Factors through Analytic Network Process’. *Reliability Engineering & System Safety* 96 (7), 849–860

Denzin, N.K. and Lincoln, Y.S. (eds.) (2011) *The SAGE Handbook of Qualitative Research*. 4 edition. Thousand Oaks: SAGE Publications, Inc

Diao, H. and Ghorbani, M. (2018) ‘Production Risk Caused by Human Factors: A Multiple Case Study of Thermal Power Plants’. *Frontiers of Business Research in China* 12 (1), 15

Disaster Management Institute (2010) *Human Factors vs Accident Causation* [online] Edition 1. InWEnt-gtz-ASEM Capacity Development Programme for industrial Disaster Risk Management (iDRM). available from <file:///F:/a-Coventry%20University/aa0%20Coventry%20University%202018-2019/3.%20-PhD/PhD%20by%20Publication%20-Folder/2.%20-Stephen%20Theophilus%20%20(2017)/PAPERS/Disaster%20Management%20Institute%20(Accident%20causation%20and%20investigation%20models).pdf>

Ellis, G.R. and Holt, A. (2009) *A Practical Application of ‘Human-Hazop’ for Critical Procedures*. (155), 6

Embrey, D.E. (1992) ‘Incorporating Management and Organisational Factors into Probabilistic Safety Assessment’. *Reliability Engineering & System Safety* 38 (1), 199–208

Ergai, A., Cohen, T., Sharp, J., Wiegmann, D., Gramopadhye, A., and Shappell, S. (2016) ‘Assessment of the Human Factors Analysis and Classification System (HFACS): Intra-Rater and Inter-Rater Reliability’. *Safety Science* 82, 393–398

Erjavac, A.J., Iammartino, R., and Fossaceca, J.M. (2018a) ‘Evaluation of Preconditions Affecting Symptomatic Human Error in General Aviation and Air Carrier Aviation Accidents’. *Reliability Engineering & System Safety* 178, 156–163

Erjavac, A.J., Iammartino, R., and Fossaceca, J.M. (2018b) ‘Evaluation of Preconditions Affecting Symptomatic Human Error in General Aviation and Air Carrier Aviation Accidents’. *Reliability Engineering & System Safety* 178, 156–163

Fabiano, B., Currò, F., and Pastorino, R. (2004) ‘A Study of the Relationship between Occupational Injuries and Firm Size and Type in the Italian Industry’. *Safety Science* 42 (7), 587–600

Fearnley, J. and Nair, S.R. (2009) *Determining Process Safety Performance Indicators for Major Accident Hazards Using Site Process Hazard Information*. (155), 5

Fennell, D. (2017) *Explaining the Growth of Effective Safety Systems---- Model* [online] available from <https://www.cos-mag.com/safety-leadership-culture/columns/explaining-the-growth-of-effective-safety-systems-----model/> [10 June 2019]

Fereday, J. and Muir-Cochrane, E. (2006) ‘Demonstrating Rigor Using Thematic Analysis: A Hybrid Approach of Inductive and Deductive Coding and Theme Development’. *International Journal of Qualitative Methods* 5 (1), 80–92

Filho, A.P.G., Souza, C.A., Siqueira, E.L.B., Souza, M.A., and Vasconcelos, T.P. (2019) ‘An Analysis of Helicopter Accident Reports in Brazil from a Human Factors Perspective’. *Reliability Engineering & System Safety* 183, 39–46

Franks, A. (2017) *Lines of Defence/Layers of Protection Analysis in the COMAH Context* [online] Health and Safety Executive. available from <http://www.hse.gov.uk/research/misc/vectra300-2017-r02.pdf>

Glendon, A.I. and Clarke, S. (2015) *Human Safety and Risk Management*. Third edition. Boca Raton: CRC Press

Glendon, A.I. and McKenna, E.F. (1995) *Human Safety and Risk Management*. 1st. publ. in paperback. London [u.a.]: Chapman & Hall

Goh, Y.M., Tan, S., and Lai, K. (2015) ‘Learning from the Bhopal Disaster to Improve Process Safety Management in Singapore’. *Process Safety and Environmental Protection* 97, 102–108

Gordon, R., Flin, R., and Mearns, K. (2005) ‘Designing and Evaluating a Human Factors Investigation Tool (HFIT) for Accident Analysis’. *Safety Science* 43 (3), 147–171

Gordon, R.P.E. (1998) ‘The Contribution of Human Factors to Accidents in the Offshore Oil Industry’. *Reliability Engineering & System Safety* 61 (1–2), 95–108

GPCA (2011) *Process Safety Code* [online] Responsible Care: Our Commitment to Process Safety GPCA-RC-C06. Responsible Care. available from <http://www.gpca.org.ae/wp-content/uploads/2014/05/06-process_safety_code.pdf> [12 April 2016]

Graziano, A., Teixeira, A.P., and Guedes Soares, C. (2016) ‘Classification of Human Errors in Grounding and Collision Accidents Using the TRACEr Taxonomy’. *Safety Science* 86, 245–257

Groth, K. and Mosleh, A. (2010) ‘A Performance Shaping Factors Causal Model for Nuclear Power Plant Human Reliability Analysis’. in *10th PSAM International Conference on Probabilistic Safety Assesment and Management · PSAM 2010*, ‘PROBABILISTIC SAFETY ASSESSMENT AND MANAGEMENT. INTERNATIONAL CONFERENCE. (PSAM10)’. held 2010 at Seattle, Washington, USA. 12

Groth, K.M. and Mosleh, A. (2012) ‘A Data-Informed PIF Hierarchy for Model-Based Human Reliability Analysis’. *Reliability Engineering & System Safety* 108, 154–174

Hale, A.R. and Glendon, A.I. (1987) *Individual Behaviour in the Control of Danger*. Individual behaviour in the control of danger. New York, NY, US: Elsevier Science

Hale, A.R. and Hovden, J. (1998) ‘Management and Culture: The Third Age of Safety. A Review of Approaches to Organizational Aspects of Safety, Health and Environment’. in *Occupational Injury Risk, Prevention And Intervention* [online] 1st Edition. CRC Press, 129 to 165. available from <https://books.google.co.uk/books?hl=en&lr=&id=9dhP7wJtotsC&oi=fnd&pg=PA129&dq=Management+and+culture:+the+third+age+of+safety.+A+review+of+approaches+to+organizational+aspects+of+safety,+health+and+environment&ots=qMy3WhHEuW&sig=qO8oZsDg1uPN69F3-TVrs8CpERM#v=onepage&q=Management%20and%20culture%3A%20the%20third%20age%20of%20safety.%20A%20review%20of%20approaches%20to%20organizational%20aspects%20of%20safety%2C%20health%20and%20environment&f=false> [11 May 2019]

Hanafi, A. (2016) ‘Influence of Individual Characteristic and Organization Climate on Job Satisfaction and Its Impact on Employee Performance’. *Sains Humanika* [online] 8 (4). available from <https://sainshumanika.utm.my/index.php/sainshumanika/article/view/843> [4 July 2018]

Harrison, H., Birks, M., Franklin, R., and Mills, J. (2017) ‘Case Study Research: Foundations and Methodological Orientations’. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research* [online] 18 (1). available from <http://www.qualitative-research.net/index.php/fqs/article/view/2655> [27 June 2019]

Hayes, J. (2012) ‘Operator Competence and Capacity – Lessons from the Montara Blowout’. *Safety Science* 50 (3), 563–574

Health and Safety Professionals Alliance (2012) *The Core Body of Knowledge for Generalist OHS Professionals*. Tullamarine, Vic.: Safety Institute of Australia

Heiman, G.W. (2001) *Understanding Research Methods and Statistics: An Integrated Introduction for Psychology, 2nd Ed*. Understanding research methods and statistics: An integrated introduction for psychology, 2nd ed. Boston, MA, US: Houghton, Mifflin and Company

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

Hollnagel, E. (2016) *Barriers and Accident Prevention*. Routledge

Hollnagel, E. (1998) ‘Chapter 9 - The Quantification of Predictions’. in *Cognitive Reliability and Error Analysis Method (CREAM)* [online] Oxford: Elsevier Science Ltd, 234–261. available from <http://www.sciencedirect.com/science/article/pii/B9780080428482500099> [8 October 2016]

Holmstrom, D., Altamirano, F., Banks, J., Joseph, G., Kaszniak, M., Mackenzie, C., Shroff, R., Cohen, H., and Wallace, S. (2006) ‘CSB Investigation of the Explosions and Fire at the BP Texas City Refinery on March 23, 2005’. *Process Safety Progress* 25 (4), 345–349

Hosseinian, S.S. and Torghabeh, Z.J. (2012) ‘Major Theories of Construction Accident Causation Models: A Literature Review’. *International Journal of Advances in Engineering & Technology* Vol. 4 (2), 53–66

HSE (2017) *Human Factors: Human Factors in Accident Investigations*. 4

HSE (1999) *A Guide to the Control of Major Accident Hazards Regulations 1999*.

HSE (1995) *Improving Compliance with Safety Procedures: Reducing Industrial Violations*. London: HSE Books

HSE, (Health and Safety Executive) (ed.) (2007) *Reducing Error and Influencing Behaviour*. 2. ed., reprinted. HSG 48. Sudbury: HSE Books

Hsieh, M.-C., Chiang, P.-Y., Wang, E.M.-Y., Kung, W.-C., Hu, Y.-T., Huang, M.-S., and Hsieh, H.-C. (2019) 'The Investigation of Human Error Analysis in Adverse Drug Events in Taiwan—From the Perspective of Causality Assessment'. *Human Factors and Ergonomics in Manufacturing & Service Industries* [online] 0 (0). available from <https://onlinelibrary.wiley.com/doi/abs/10.1002/hfm.20791> [28 February 2019]

Hudson, P.T.W. and Verschuur, W.L.G. (2000) *Bending The Rules: Managing Violation in the Workplace* [online] EP2000-7001. Exploration and Production Newsletter. The Hague: Shell InternationalExploration and Production. available from <https://www.naris.com/wp-content/uploads/2016/10/Bending-the-rules.pdf>

Hulme, A., Stanton, N.A., Walker, G.H., Waterson, P., and Salmon, P.M. (2019) 'What Do Applications of Systems Thinking Accident Analysis Methods Tell Us about Accident Causation? A Systematic Review of Applications between 1990 and 2018'. *Safety Science* 117, 164–183

Ifelebuegu, A.O. (2013) *Removal of Endocrine Disrupting Chemicals in Wastewater Treatment Applications* [online] Coventry University. available from <https://core.ac.uk/download/pdf/30617940.pdf> [4 August 2017]

Ifelebuegu, A.O., Martins, O.A., Theophilus, S.C., and Arewa, A.O. (2019) 'The Role of Emotional Intelligence Factors in Workers' Occupational Health and Safety Performance—A Case Study of the Petroleum Industry'. *Safety* 5 (2), 30

IOGP (2016) *Standardization of Barrier Definitions. Supplement to Report 415* [online] 544. International Association of Oil & Gas Producers (IOGP). available from <http://www.enform.ca/files/pdf/process_safety/OGP_Barrier_Definitions_Supp_to_RP415_2016.pdf> [16 June 2017]

IOGP (2008) *Human Factor. A Mean of Improving HSE Perfomance* [online] available from <http://www.ogp.org.uk/pubs/368.pdf> [13 April 2016]

Jones, C.E.L., Phipps, D.L., and Ashcroft, D.M. (2018) 'Understanding Procedural Violations Using Safety-I and Safety-II: The Case of Community Pharmacies'. *Safety Science* 105, 114–120

Kandemir, C., Celik, M., Akyuz, E., and Aydin, O. (2019) 'Application of Human Reliability Analysis to Repair & Maintenance Operations On-Board Ships: The Case of HFO Purifier Overhauling'. *Applied Ocean Research* 88, 317–325

Kariuki, G. and Löwe, K. (2003) *INCORPORATION OF HUMAN FACTORS IN THE DESIGN PROCESS*. 7

Kariuki, S.G. and Löwe, K. (2007) 'Integrating Human Factors into Process Hazard Analysis'. *Reliability Engineering & System Safety* 92 (12), 1764–1773

Karsh, B.-T. (2004) 'Beyond Usability: Designing Effective Technology Implementation Systems to Promote Patient Safety'. *Quality and Safety in Health Care* 13 (5), 388–394

Kaszniak, M. (2010) 'Oversights and Omissions in Process Hazard Analyses: Lessons Learned from CSB Investigations'. *Process Safety Progress* 29 (3), 264–269

Khdair, W.A., Shamsudin, F.M., and Subramanim, C. (2011) 'IMPROVING SAFETY PERFORMANCE BY UNDERSTANDING RELATIONSHIP BETWEEN MANAGEMENT PRACTICES AND LEADERSHIP BEHAVIOR IN THE OIL AND GAS INDUSTRY IN IRAQ: A PROPOSED MODEL'. in *2011 International Conference on Management and Artificial Intelligence IPEDR Vol.6 (2011),* 'International Conference on Management and Artificial Intelligence'. held 2011 at Bali, Indonesia. IACSIT Press, 9

Kidam, K. and Hurme, M. (2013) 'Analysis of Equipment Failures as Contributors to Chemical Process Accidents'. *Process Safety and Environmental Protection* 91 (1–2), 61–78

Kim, J.W. and Jung, W. (2003) ‘A Taxonomy of Performance Influencing Factors for Human Reliability Analysis of Emergency Tasks’. *Journal of Loss Prevention in the Process Industries* 16 (6), 479–495

Kim, Y., Park, J., and Park, M. (2016) ‘Creating a Culture of Prevention in Occupational Safety and Health Practice’. *Safety and Health at Work* 7 (2), 89–96

Kletz, T.A., Amyotte, P., and Amyotte, P. (2010) *Process Plants : A Handbook for Inherently Safer Design, Second Edition* [online] CRC Press. available from <https://www.taylorfrancis.com/books/9780429092428> [23 May 2019]

Knegtering, B. and Pasman, H.J. (2009a) ‘Safety of the Process Industries in the 21st Century: A Changing Need of Process Safety Management for a Changing Industry’. *Journal of Loss Prevention in the Process Industries* 22 (2), 162–168

Knegtering, B. and Pasman, H.J. (2009b) ‘Safety of the Process Industries in the 21st Century: A Changing Need of Process Safety Management for a Changing Industry’. *Journal of Loss Prevention in the Process Industries* 22 (2), 162–168

Landis, J.R. and Koch, G.G. (1977) ‘The Measurement of Observer Agreement for Categorical Data’. *Biometrics* 33 (1), 159–174

Lee, T. and Harrison, K. (2000) ‘Assessing Safety Culture in Nuclear Power Stations’. *Safety Science* 34 (1), 61–97

Liu, J., Schmid, F., Zheng, W., and Zhu, J. (2019) ‘Understanding Railway Operational Accidents Using Network Theory’. *Reliability Engineering & System Safety* 189, 218–231

Lundteigen, M.A. and Rausand, M. (2007) ‘Common Cause Failures in Safety Instrumented Systems on Oil and Gas Installations: Implementing Defense Measures through Function Testing’. *Journal of Loss Prevention in the Process Industries* 20 (3), 218–229

Lutchman, C., Evans, D., Maharaj, R., and Sharma, R. (2013) *Process Safety Management: Leveraging Networks and Communities of Practice for Continuous Improvement.* CRC Press

Maguire, M. and Delahunt, B. (2017) *Doing a Thematic Analysis: A Practical, Step-by-Step Guide for Learning and Teaching Scholars.* 8 (3), 14

Mannan, S. (2014) ‘Chapter 29 - Offshore Process Safety’. in *Lees’ Process Safety Essentials* [online] Oxford: Butterworth-Heinemann, 519–524. available from <http://www.sciencedirect.com/science/article/pii/B9781856177764000294> [13 February 2017]

Maturana, M.C. and Martins, M.R. (2019) ‘Technique for Early Consideration of Human Reliability: Applying a Generic Model in an Oil Tanker Operation to Study Scenarios of Collision’. *Journal of Offshore Mechanics and Arctic Engineering* 141 (5), 051607

McHugh, M.L. (2012) ‘Interrater Reliability: The Kappa Statistic’. *Biochemia Medica* 22 (3), 276–282

Meister, D. (2018) *The History of Human Factors and Ergonomics* [online] 1st edn. CRC Press. available from <https://www.taylorfrancis.com/books/9781410601919> [10 June 2019]

Milczarek, M. and Najmiec, A. (2004) ‘The Relationship Between Workers’ Safety Culture and Accidents, Near Accidents and Health Problems’. *International Journal of Occupational Safety and Ergonomics* 10 (1), 25–33

Miranda, A.T. (2018a) ‘Understanding Human Error in Naval Aviation Mishaps’. *Human Factors* 60 (6), 763–777

Miranda, A.T. (2018b) ‘Understanding Human Error in Naval Aviation Mishaps
, Understanding Human Error in Naval Aviation Mishaps’. *Human Factors* 0018720818771904

Mishra, K.B. (2015) ‘CFD Model for Large Hazardous Dense Cloud Spread Predictions, with Particular Reference to Bhopal Disaster’. *Atmospheric Environment* 117, 74–91

Moore, D.A., Hazzan, M.J., Heller, D.M., and Rose, M.R. (2015) ‘Enterprise PSM Development, Implementation, and Auditing’. *Process Safety Progress* 34 (1), 94–99

Nassaji, H. (2015) ‘Qualitative and Descriptive Research: Data Type versus Data Analysis’. *Language Teaching Research* 19 (2), 129–132

Nicoletti, L. and Padovano, A. (2019) ‘Human Factors in Occupational Health and Safety 4.0: A Cross-Sectional Correlation Study of Workload, Stress and Outcomes of an Industrial Emergency Response’. *International Journal of Simulation and Process Modelling* 14 (2), 178–195

Nwokeafor, C.U. (2015) *Information Communication Technology (ICT) Integration to Educational Curricula: A New Direction for Africa*. University Press of America

O’Dea, A. and Flin, R. (2001) ‘Site Managers and Safety Leadership in the Offshore Oil and Gas Industry’. *Safety Science* 37 (1), 39–57

O’HARE, D., WIGGINS, M., BATT, R., and MORRISON, D. (1994) ‘Cognitive Failure Analysis for Aircraft Accident Investigation’. *Ergonomics* 37 (11), 1855–1869

OHSMS, Gallagher, C., Pearse, W., and Bluff, L. (eds.) (2001) *Occupational Health & Safety Management Systems: Proceedings of the First National Conference*. Melbourne: Crown Content

Olive, C., O’Connor, T.M., and Mannan, M.S. (2006) ‘Relationship of Safety Culture and Process Safety’. *Journal of Hazardous Materials* 130 (1–2), 133–140

O’Reilly, C.A. (1977) ‘Personality—Job Fit: Implications for Individual Attitudes and Performance’. *Organizational Behavior and Human Performance* 18 (1), 36–46

Paradies, M., Unger, L., Haas, P., and Terranova, M. (1993) *Development of the NRC’s Human Performance Investigation Process (HPIP)* [online] NUREG/CR--5455-VOL.1. Nuclear Regulatory Commission, System Improvements, Concord Associates. available from <http://inis.iaea.org/Search/search.aspx?orig_q=RN:25032074> [4 July 2018]

Park, J., Baek, J.-B., Lee, Jun-won, Lee, Jin-woo, and Yang, S. (2018) ‘A Study on the Analysis of Human-errors in Major Chemical Accidents in Korea’. *Journal of the Korean Society of Safety* 33 (1), 66–72

Park, K.S. and Jung, K.T. (1996) ‘Considering Performance Shaping Factors in Situation-Specific Human Error Probabilities’. *International Journal of Industrial Ergonomics* 18 (4), 325–331

Pasman, H.J., Knegtering, B., and Rogers, W.J. (2013) ‘A Holistic Approach to Control Process Safety Risks: Possible Ways Forward’. *Reliability Engineering & System Safety* 117, 21–29

Pate-Cornell, M.E. (1993) ‘Learning from the Piper Alpha Accident: A Postmortem Analysis of Technical and Organizational Factors’. *Risk Analysis* 13, 215–215

Patterson, J.M. and Shappell, S.A. (2010) ‘Operator Error and System Deficiencies: Analysis of 508 Mining Incidents and Accidents from Queensland, Australia Using HFACS’. *Accident Analysis & Prevention* 42 (4), 1379–1385

Perneger, T.V. (2005) ‘The Swiss Cheese Model of Safety Incidents: Are There Holes in the Metaphor?’ *BMC Health Services Research* 5, 71

Petersen, D. (1989) *Techniques of Safety Management*. New York: Aloray

Prado, A. and Jasper, F. (2015) ‘Evolution of Paradigms in Aeronautical Occurrences Investigations’. *Revista Da UNIFA* [online] 28 (37). available from <http://www2.fab.mil.br/unifa/images/revista/pdf/v28n37/404.ing.pdf> [13 May 2019]

Privitera, G.J. (2016) *Research Methods for the Behavioral Sciences*. Place of publication not identified: Sage Publications

Rains, B.D. (2010) *Operational Discipline: Does Your Organization Do the Job Right Every Time?* 3

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

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

Reason, J.T. (1997) *Managing the Risks of Organizational Accidents* [online] 1st Edition. Routledge, London. available from <http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=1166101> [5 July 2018]

Reinach, S. and Viale, A. (2006) ‘Application of a Human Error Framework to Conduct Train Accident/Incident Investigations’. *Accident Analysis & Prevention* 38 (2), 396–406

Reniers, G.L.L., Cremer, K., and Buytaert, J. (2011) ‘Continuously and Simultaneously Optimizing an Organization’s Safety and Security Culture and Climate: The Improvement Diamond for Excellence Achievement and Leadership in Safety & Security (IDEAL S&S) Model’. *Journal of Cleaner Production* 19 (11), 1239–1249

Rollenhagen, C. (2010) ‘Can Focus on Safety Culture Become an Excuse for Not Rethinking Design of Technology?’ *Safety Science* 48 (2), 268–278

Rothblum, D.A.M. (2000) *Human Error and Marine Safety*. in ‘National Safety CouncilCongress and Expo’ [online] held 2000 at Orlando. 9. available from <http://www.bowles-langley.com/wp-content/files_mf/humanerrorandmarinesafety26.pdf>

Russ, A.L., Fairbanks, R.J., Karsh, B.-T., Militello, L.G., Saleem, J.J., and Wears, R.L. (2013) ‘The Science of Human Factors: Separating Fact from Fiction’. *BMJ Quality & Safety* 22 (10), 802–808

Saaty, T.L. (2008) ‘Decision Making with the Analytic Hierarchy Process’. *International Journal of Services Sciences* 1 (1), 83–98

Saaty, T.L. (1990) ‘Desicion Making by the Analytic Hierarchy Process: Theory and ApplicationsHow to Make a Decision: The Analytic Hierarchy Process’. *European Journal of Operational Research* 48 (1), 9–26

Saaty, T.L. (1980) *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. McGraw-Hill

Saleem, J.J., Russ, A.L., Sanderson, P., Johnson, T.R., Zhang, J., and Sittig, D.F. (2009) ‘Current Challenges and Opportunities for Better Integration of Human Factors Research with Development of Clinical Information Systems’. *Yearbook of Medical Informatics* 48–58

Schröder-Hinrichs, J., Graziano, A., Praetorius, G., and Kataria, A. (2016) ‘TRACEr-MAR?Applying TRACEr in a Maritime Context’. in *Risk, Reliability and Safety: Innovating Theory and Practice* [online] 0 vols. CRC Press, 120–126. available from <http://www.crcnetbase.com/doi/abs/10.1201/9781315374987-21> [20 June 2017]

Schröder-Hinrichs, J.U., Baldauf, M., and Ghirxi, K.T. (2011) ‘Accident Investigation Reporting Deficiencies Related to Organizational Factors in Machinery Space Fires and Explosions’. *Accident Analysis & Prevention* 43 (3), 1187–1196

Shappel, S.A. and Wiegmann, D.A. (2000) *The Human Factors Analysis and Classification System–HFACS* [online] US Federal Aviation Administration, Office of Aviation Medicine. available from <http://www.flighttestsafety.org/images/stories/workshop/2009Apr/Shappell-HFACS-HFIX.pdf> [3 December 2016]

Shappell, P.S.A. and Wiegmann, P.D.A. (2012) *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System*. Ashgate Publishing, Ltd.

Shappell, S., Detwiler, C., Holcomb, K., Hackworth, C., Boquet, A., and Wiegmann, D.A. (2007) ‘Human Error and Commercial Aviation Accidents: An Analysis Using the Human Factors Analysis and Classification System’. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 49 (2), 227–242

Shappell, S.A. and Wiegman, D.A. (2003) *A Human Error Analysis of General Aviation Controlled Flight Into Terrain Accidents Occurring Between 1990-1998*.

Shi, L., Shuai, J., and Xu, K. (2014) ‘Fuzzy Fault Tree Assessment Based on Improved AHP for Fire and Explosion Accidents for Steel Oil Storage Tanks’. *Journal of Hazardous Materials* 278, 529–538

Shimada, Y., Kitajima, T., and Takeda, K. (2009) ‘Practical Framework for Process Safety Management Based on Plant Lifecycle Engineering’. in *Proc. of 3rd International Conference on Integrity, Reliability & Failures, IRF*. held 2009. 501–502

Shorrock, S. (2002) ‘The Two-Fold Path to Human Error Analysis: TRACEr Lite Retrospection and Prediction’. *Safety Systems* [online] 11 (3). available from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.519.5899&rep=rep1&type=pdf>

Shorrock, S.T. (2005) ‘Errors of Memory in Air Traffic Control’. *Safety Science* 43 (8), 571–588

Shorrock, S.T. and Kirwan, B. (2002a) ‘Development and Application of a Human Error Identification Tool for Air Traffic Control’. *Applied Ergonomics* 33 (4), 319–336

Shorrock, S.T. and Kirwan, B. (2002b) ‘Development and Application of a Human Error Identification Tool for Air Traffic Control’. *Applied Ergonomics* 33 (4), 319–336

Shortz, A.E., Mehta, R.K., Peres, S.C., Benden, M.E., and Zheng, Q. (2019) ‘Development of the Fatigue Risk Assessment and Management in High-Risk Environments (FRAME) Survey: A Participatory Approach’. *International Journal of Environmental Research and Public Health* 16 (4), 522

Simpson, P. (2018) *Relationship Between Airline Category, Geographical Region, and Safety Performance*. 163

Sims, H.P. and Szilagyi, A.D. (1976) ‘Job Characteristic Relationships: Individual and Structural Moderators’. *Organizational Behavior and Human Performance* 17 (2), 211–230

Singh, B., Jukes, P., Poblete, B., and Wittkower, B. (2010) ‘20 Years on Lessons Learned from Piper Alpha. The Evolution of Concurrent and Inherently Safe Design’. *Journal of Loss Prevention in the Process Industries* 23 (6), 936–953

Singh, R.P. and Nachtnebel, H.P. (2016) ‘Analytical Hierarchy Process (AHP) Application for Reinforcement of Hydropower Strategy in Nepal’. *Renewable and Sustainable Energy Reviews* 55, 43–58

Soner, O., Asan, U., and Celik, M. (2015) ‘Use of HFACS–FCM in Fire Prevention Modelling on Board Ships’. *Safety Science* 77, 25–41

SPE (2014) *The Human Factor: Process Safety and Culture*. [online] available from <https://www.onepetro.org/general/SPE-170575-TR?sort=&start=0&q=The+Human+Factor%3A+Process+Safety+and+Culture+&from_year=&peer_reviewed=&published_between=&fromSearchResults=true&to_year=&rows=10#> [11 April 2016]

Stake, R.E. (1995) *The Art of Case Study Research*. 1 edition. Thousand Oaks: SAGE Publications, Inc

Strand, G.-O. and Haskins, C. (2018) ‘On Linking of Task Analysis in the HRA Procedure: The Case of HRA in Offshore Drilling Activities’. *Safety* 4 (3), 39

Suraji, A., Duff, A.R., and Peckitt, S.J. (2001) ‘Development of Causal Model of Construction Accident Causation’. *Journal of Construction Engineering and Management* 127 (4), 337–344

Theophilus, S.C., Abikoye, O.G., Arewa, A.O., Ifelebuegu, A.O., and Esenowo, V. (2016a) *Application of Analytic Hierarchy Process to Identify the Most Influencing Human Factors (HFs) and Performance Influencing Factors (PIFs) in Process Safety Accidents*. [online] available from <http://archives.datapages.com/data/africa-energy-and-technology-conference-2016/001/001001/pdfs/41.htm> [27 June 2018]

Theophilus, S.C., Bassey, B.O., Ajare, T.O., Baroni, A.S., Odigie, O.P., and Asogwa, D. (2016b) *Fifteen-Year Accident Causation Assessment of the Petroleum Industry in South and Central America Using Statistical Correlations*. in ‘SPE African Health, Safety, Security, Environment, and Social Responsibility Conference and Exhibition’ [online] held 4 October 2016. Society of Petroleum Engineers. available from <https://www.onepetro.org/conference-paper/SPE-183602-MS> [9 December 2016]

Theophilus, Stephen C., Ekpenyong, I.E., Ifelebuegu, A.O., Arewa, A.O., Agyekum-Mensah, G., and Ajare, T.O. (2017) ‘A Technique for the Retrospective and Predictive Analysis of Cognitive Errors for the Oil and Gas Industry (TRACEr-OGI)’. *Safety* 3 (4), 23

Theophilus, Stephen Chukwubuikem, Esenowo, V.N., Arewa, A.O., Ifelebuegu, A.O., Nnadi, E.O., and Mbanaso, F.U. (2017) ‘Human Factors Analysis and Classification System for the Oil and Gas Industry (HFACS-OGI)’. *Reliability Engineering & System Safety* 167, 168–176

Theophilus, S.C., Fubara-Manue, T.L.., and Anifowose, B. (2016) ‘Application of Analytic Hierarchy Process for Analysis of Impact Significance in EIA of Oil and Gas Industry’. in *Proc. of the Fourth Intl. Conf. Advances in Bio - Informatics, Bio - Technology and Environmental Engineering - ABBE 2016*, ‘Advances in Bio - Informatics, Bio - Technology and Environmental Engineering’ [online] held 2016 at Birmingham City University, City North Campus, Birmingham, United Kingdom. Institute of Research Engineers and Doctors, USA, 59-63. available from <http://www.seekdl.org/nm.php?id=7466> [26 July 2016]

Theophilus, S.C., Nwankwo, C.D., Acquah-Andoh, E., Bassey, E., and Umoren, U. (2018) ‘Integrating Human Factors (HF) into a Process Safety Management System (PSMS)’. *Process Safety Progress* 37 (1), 67–85

Theophilus, S.C. and Shaibu, J.H. (2014) *Assessing Leadership and Employee Safety Participation in Managing Health and Safety: A Case Study of K-Refinery and Petrochemical Companies (K-RPC)*. in [online] held 16 December 2014. 69–79. available from <http://library.witpress.com/viewpaper.asp?pcode=ESUS14-006-1> [6 July 2016]

Thomas, J., Baker, C.C., Malone, T.B., Malone, J.T., Hard, C.L., Rezende, I.C.L., Caruana, S., and Witten, M. (2002) *Application of Human Factors in Reducing Human Error in Existing Offshore Facilities*. in ‘2 nd International Workshop on Human Factors in Offshore Operations’ [online] held 2002 at Houston, Texas USA. Working Group 3 – HFW2002, 45. available from <https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1033&context=usdot>

UKHSE (2015) *The Offshore Installations (Offshore Safety Directive) (Safety Case Etc) Regulations 2015: Guidance on Regulations.* First edition. L154. Health and Safety Executive

Underwood, P. and Waterson, P. (2014) ‘Systems Thinking, the Swiss Cheese Model and Accident Analysis: A Comparative Systemic Analysis of the Grayrigg Train Derailment Using the ATSB, AcciMap and STAMP Models’. *Accident Analysis & Prevention* 68, 75–94

U.S. CSB (2008) *Valero – Mckee Refinery Propane Fire* [online] 2007-05-I-TX. Investigation Report. U.S. Chemical Safety and Hazard Investigation Board. available from <http://www.csb.gov/valero-refinery-propane-fire/> [12 April 2016]

U.S. Department of Labor (2000) *Process Safety Management*. available from <https://www.osha.gov/Publications/osha3132.pdf> [3 December 2016]

Venkatesh, V., Brown, S.A., University of Arizona, Bala, H., and Indiana University (2013) ‘Bridging the Qualitative-Quantitative Divide: Guidelines for Conducting Mixed Methods Research in Information Systems’. *MIS Quarterly* 37 (1), 21–54

Viramuthu, V.A. (2017) *Human Factors Engineering HFE: A Review of Human Elements That Have Contributed in the Occurrence of Major Accidents in Process Industries and Total Abu Al Bukhoosh TABK Means of Engineering Effective Mitigations*. in ‘Abu Dhabi International Petroleum Exhibition & Conference’ [online] held 13 November 2017. Society of Petroleum Engineers. available from <https://www.onepetro.org/conference-paper/SPE-188287-MS> [23 November 2018]

Wang, Q., Zhang, L., and Hu, J. (2019) ‘An Integrated Method of Human Error Likelihood Assessment for Shale-Gas Fracturing Operations Based on SPA and UAHP’. *Process Safety and Environmental Protection* 123, 105–115

Weaver, D.A. (2006) ‘Symptoms of Operational Error’. *Professional Safety* 51 (4), 48

Weaver, D.A. (1971) ‘Symptoms of Operational Error’. *Professional Safety* 104 (2), 39–42

Wiegmann, D.A. and Shappell (2001) *A Human Error Analysis of Commerical Aviation Accidents Using the Human Factors Analysis and Classification System (HFACS)*.

Wiegmann, D.A. and Shappell, S.A. (2003) *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System*. Aldershot, Hants, England ; Burlington, VT: Ashgate

Williams, J.C. and Bell, J.L. (2015) ‘Consolidation of the Error Producing Conditions Used in the Human Error Assessment and Reduction Technique (Heart)’. *Safety and Reliability* 35 (3), 26–76

Williamson, J.A., Webb, R.K., Sellen, A., Runciman, W.B., and Van Der Walt, J.H. (1993) ‘Human Failure: An Analysis of 2000 Incident Reports’. *Anaesthesia and Intensive Care* 21 (5), 678–683

Wisdom, J. and Creswell, J.W. (2013) *Mixed Methods: Integrating Quantitative and Qualitative Data Collection and Analysis While Studying Patient-Centered Medical Home Models | PCMH Resource Center* [online] 13-0028-EF. AHRQ Publication. Agency for Healthcare Research and Quality, U.S. Department of Health and Human Services. available from <https://pcmh.ahrq.gov/page/mixed-methods-integrating-quantitative-and-qualitative-data-collection-and-analysis-while> [27 June 2019]

Woods, D. (2009) ‘Rasmussen’s S-R-K 30 Years Later: Is Human Factors Best in 3’s?’ *Human Factors and Ergonomics Society Annual Meeting Proceedings* 53 (4), 217–221

Yin, R.K. (2003) *Case Study Research: Design and Methods*. SAGE

Zainal, Z. (2007) ‘Case Study As a Research Method’. *Jurnal Kemanusiaan* [online] 5 (1). available from <https://jurnalkemanusiaan.utm.my/index.php/kemanusiaan/article/view/165> [27 June 2019]

Zhou, A., Wang, K., and Zhang, H. (2017) 'Human Factor Risk Control for Oil and Gas Drilling Industry'. *Journal of Petroleum Science and Engineering* 159, 581–587

Appendix A

Certificate of Ethical Approval

Certificate of Ethical Approval

Applicant:

Stephen Theophilus

Project Title:

Integrated Models for Human Factors Accident Analysis in the Oil and Gas Industry

This is to certify that the above named applicant has completed the Coventry University Ethical Approval process and their project has been confirmed and approved as Low Risk

Date of approval:

19 October 2018

Project Reference Number:

P76810

Appendix B

A List of five selected publications used as the basis for this portfolio

Theophilus, S.C., Abikoye, O.G., Arewa, A.O., Ifelebuegu, A.O., and Esenowo, V. (2016) *Application of Analytic Hierarchy Process to Identify the Most Influencing Human Factors (HFs) and Performance Influencing Factors (PIFs) in Process Safety Accidents*. in 'SPE/AAPG Africa Energy and Technology Conference' [online] held 5 December 2016. Society of Petroleum Engineers. available from <https://www.onepetro.org/conference-paper/SPE-AFRC-2571952-MS> [29 December 2016]

Theophilus, Stephen Chukwubuikem, Esenowo, V.N., Arewa, A.O., Ifelebuegu, A.O., Nnadi, E.O., and Mbanaso, F.U. (2017) 'Human Factors Analysis and Classification System for the Oil and Gas Industry (HFACS-OGI)'. *Reliability Engineering & System Safety* 167, 168–176

Theophilus, Stephen C., Ekpenyong, I.E., Ifelebuegu, A.O., Arewa, A.O., Agyekum-Mensah, G., and Ajare, T.O. (2017) 'A Technique for the Retrospective and Predictive Analysis of Cognitive Errors for the Oil and Gas Industry (TRACEr-OGI)'. *Safety* 3 (4), 23

Theophilus, S.C., Bassey, B.O., Ajare, T.O., Baroni, A.S., Odigie, O.P., and Asogwa, D. (2016) *Fifteen-Year Accident Causation Assessment of the Petroleum Industry in South and Central America Using Statistical Correlations*. in 'SPE African Health, Safety, Security, Environment, and Social Responsibility Conference and Exhibition' [online] held 4 October 2016. Society of Petroleum Engineers. available from <https://www.onepetro.org/conference-paper/SPE-183602-MS> [9 December 2016]

Theophilus, S.C., Nwankwo, C.D., Acquah-Andoh, E., Bassey, E., and Umoren, U. (2018) 'Integrating Human Factors (HF) into a Process Safety Management System (PSMS)'. *Process Safety Progress* 37 (1), 67–85

Appendix C

Environment remediation publications (not included in this portfolio)

1. Investigation of the effects of slow-release fertilizer and struvite in biodegradation in filter drains and the potential application of treated water in the irrigation of road verges.
2. Impact of Slow-Release Fertilizer and Struvite in the Enhancement of Biodegradation of Hydrocarbon in Filter Drains to Prevent Groundwater Pollution.
3. Environmental effects of crude oil spills on the physicochemical and hydrobiological characteristics of the Nun River, Niger Delta.
4. The fate and behaviour of steroid hormones in wastewater sludge anaerobic digestion at mesophilic and thermophilic temperatures.
5. Potential of Pervious and Macro-Pervious Pavements as Harvesting Systems for the Irrigation of Adjacent Lawns and Flower Beds.
6. Mechanistic evaluation of the sorption properties of endocrine disrupting chemicals in sewage sludge biomass.
7. Application of an Analytic Hierarchy Process for the analysis of impact significance in the area of the oil and gas industry.

Appendix D

Levels and subdivisions of TRACEr for the O&G industry (TRACEr-OGI) taxonomy (Theophilus et al. 2017).

Major Divisions	Category	Subdivisions Example (Not Exhaustive)
Context of the incident	1. Task Error	Task error relate to I. What is the task performed unsatisfactorily by, (e.g., the drilling supervisor, drilling engineer, mud engineer, driller, etc.) (Supervision, Standard Operation, Handover/Takeover, well testing, crane operations, electrical/mechanical operations, job hazard analysis and material and equipment?). I. Where was the task performed (e.g., fixed platform, floating production storage and offloading, fixed platform, floating II. production storage and offloading, FPSO, helidecks, etc.)? III. Who performed the task (e.g., the drilling supervisor, drilling engineer, etc)?
	2. Error Information	Error Information relates to: I. Equipment involved (e.g., drilling string, blow out preventer (BOP), alarm system, control system, surveillance system, etc) I. Information not taken into account (size, dimension, etc).
	3. Equipment Error	Equipment Error relates to: I. Mechanical integrity (e.g., design error, installation error, operational error, corrosion, poor maintenance, inadequate inspection, etc.)
	4. Casualty Level	This defines the level of causal contribution. I. Minor II. Major III. Catastrophic
Operator Context	5. External Error Mode (EEM)	This is potential external error. This is majorly: I. Error of omission I. Error of commission I. III. Extraneous error
	6. Cognitive Domain I. Internal Error Mode (IEM) II. Psychological Error Mechanism (PEM)	The subdivision relates to the five cognitive domains originally proposed by Shorrock and Kirwan (Shorrock and Kirwan 2002b) and the addition of the sixth, called sabotage. It focuses on the cognitive framework that potentially applies to the error code. The cognitive domains are:

		I. Perception II. Memory III. Decision-Making IV. Action V. Violation VI. Sabotage In the first four categories the error is non-intentional, while in the last two categories, 'Violation' and 'sabotage, the error is considered an intended violation of the rules. These two (IEM and PEM) represent the cognitive function that failed. For example: I. risk recognition failure II. poor decision-making III. III. no decision
	7. Performance Influencing Factors (PSF)/Human Factors	Relates to factors that influence the performance of the crew. The PSF categories for TRACEr-OGI are based three key areas involved in the oil and gas industry, as follows IOGP (IOGP 2008): I. Personal/Team factors II. Job factors III. Organisational factors
Control Barriers and Recovery Measure	8. Hardware Barriers	Relates to 'primary containment, process equipment and engineered systems designed and managed to prevent loss of primary containment (LOPC) and other types of asset integrity or process safety events and mitigate any potential consequences of such events. These are checked and maintained by people (in critical activity/tasks)' (IOGP 2016). The categories of hardware barriers implemented by the oil and gas industry are (IOGP 2016): I. Structural Integrity II. Process Containment III. Ignition Control IV. Detection Systems V. Protection Systems, including deluge and firewater systems VI. Shutdown Systems, including operational well isolation and drilling well control equipment. VII. Emergency Response VIII. Life-saving Equipment, including evacuation systems
	9. Human Barriers	Relates to 'barriers that rely on the actions of people capable of carrying out activities designed to prevent LOPC and other types of asset integrity or process safety events and mitigate any potential consequences of such events' (IOGP 2016). Categories of human barriers

		implemented by the oil and gas industry are (IOGP 2016): I. Operating in accordance with procedures, e.g., isolation of equipment overrides and inhibition of safety systems, shift handover II. Surveillance, operator rounds, and routine inspection III. Authorization of temporary and mobile equipment IV. Acceptance of handover or restart of facilities or equipment V. Response to process alarm and upset conditions VI. Response to emergencies

Appendix E

HFACS-OGI Citations

(Chen et al. 2019)	Chen, M., Wang, K., Guo, H., and Yuan, Y. (2019) 'Human Factors of Fire and Explosion Accidents in Petrochemical Enterprises'. *Process Safety Progress* [online] 0 (0). available from <https://onlinelibrary.wiley.com/doi/abs/10.1002/prs.12043> [28 February 2019]
(Diao and Ghorbani 2018)	Diao, H. and Ghorbani, M. (2018) 'Production Risk Caused by Human Factors: A Multiple Case Study of Thermal Power Plants'. *Frontiers of Business Research in China* 12 (1), 15
(Erjavac, Iammartino, and Fossaceca 2018b)	Erjavac, A.J., Iammartino, R., and Fossaceca, J.M. (2018) 'Evaluation of Preconditions Affecting Symptomatic Human Error in General Aviation and Air Carrier Aviation Accidents'. *Reliability Engineering & System Safety* 178, 156–163
(Filho et al. 2019)	Filho, A.P.G., Souza, C.A., Siqueira, E.L.B., Souza, M.A., and Vasconcelos, T.P. (2019) 'An Analysis of Helicopter Accident Reports in Brazil from a Human Factors Perspective'. *Reliability Engineering & System Safety* 183, 39–46
(Hsieh et al. 2019)	Hsieh, M.-C., Chiang, P.-Y., Wang, E.M.-Y., Kung, W.-C., Hu, Y.-T., Huang, M.-S., and Hsieh, H.-C. (2019) 'The Investigation of Human Error Analysis in Adverse Drug Events in Taiwan—From the Perspective of Causality Assessment'. *Human Factors and Ergonomics in Manufacturing & Service Industries* [online] 0 (0). available from <https://onlinelibrary.wiley.com/doi/abs/10.1002/hfm.20791> [28 February 2019]
(Hulme et al. 2019)	Hulme, A., Stanton, N.A., Walker, G.H., Waterson, P., and Salmon, P.M. (2019) 'What Do Applications of Systems Thinking Accident Analysis Methods Tell Us about Accident Causation? A Systematic Review of Applications between 1990 and 2018'. *Safety Science* 117, 164–183
(Ifelebuegu et al. 2019)	Ifelebuegu, A.O., Martins, O.A., Theophilus, S.C., and Arewa, A.O. (2019) 'The Role of Emotional Intelligence Factors in Workers' Occupational Health and Safety Performance—A Case Study of the Petroleum Industry'. *Safety* 5 (2), 30
(Kandemir et al. 2019)	Kandemir, C., Celik, M., Akyuz, E., and Aydin, O. (2019) 'Application of Human Reliability Analysis to Repair &

	Maintenance Operations On-Board Ships: The Case of HFO Purifier Overhauling'. *Applied Ocean Research* 88, 317–325
(Liu et al. 2019)	Liu, J., Schmid, F., Zheng, W., and Zhu, J. (2019) 'Understanding Railway Operational Accidents Using Network Theory'. *Reliability Engineering & System Safety* 189, 218–231
(Maturana and Martins 2019)	Maturana, M.C. and Martins, M.R. (2019) 'Technique for Early Consideration of Human Reliability: Applying a Generic Model in an Oil Tanker Operation to Study Scenarios of Collision'. *Journal of Offshore Mechanics and Arctic Engineering* 141 (5), 051607
(Miranda 2018b)	Miranda, A.T. (2018) 'Understanding Human Error in Naval Aviation Mishaps , Understanding Human Error in Naval Aviation Mishaps'. *Human Factors* 0018720818771904
(Nicoletti and Padovano 2019)	Nicoletti, L. and Padovano, A. (2019) 'Human Factors in Occupational Health and Safety 4.0: A Cross-Sectional Correlation Study of Workload, Stress and Outcomes of an Industrial Emergency Response'. *International Journal of Simulation and Process Modelling* 14 (2), 178–195
(Park et al. 2018)	Park, J., Baek, J.-B., Lee, Jun-won, Lee, Jin-woo, and Yang, S. (2018) 'A Study on the Analysis of Human-errors in Major Chemical Accidents in Korea'. *Journal of the Korean Society of Safety* 33 (1), 66–72
(Shortz et al. 2019)	Shortz, A.E., Mehta, R.K., Peres, S.C., Benden, M.E., and Zheng, Q. (2019) 'Development of the Fatigue Risk Assessment and Management in High-Risk Environments (FRAME) Survey: A Participatory Approach'. *International Journal of Environmental Research and Public Health* 16 (4), 522
(Simpson 2018)	Simpson, P. (2018) *Relationship Between Airline Category, Geographical Region, and Safety Performance*. 163
(Strand and Haskins 2018)	Strand, G.-O. and Haskins, C. (2018) 'On Linking of Task Analysis in the HRA Procedure: The Case of HRA in Offshore Drilling Activities'. *Safety* 4 (3), 39
(Wang, Zhang, and Hu 2019)	Wang, Q., Zhang, L., and Hu, J. (2019) 'An Integrated Method of Human Error Likelihood Assessment for Shale-Gas Fracturing Operations Based on SPA and UAHP'. *Process Safety and Environmental Protection* 123, 105–115