<u>"Risk and the Designer"</u>

Subtitle:

"An investigation into what affects risk-taking and errors in the design of hazardous offshore installations using an experience sampling methodology."

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Abstract

This exploratory piece of work has disclosured certain predictive affects associated with a designer's use of risky protocols ('Risky') and cognitive error ('Error'). The implication of this organisational study on risk and cognitive error (Simon, Hillson & Newland, 1997) rests in the potential for theory development in the role of the offshore designer. The focus of this research has been to investigate how designers of hazardous installations, in particular offshore platforms, might influence the design end users' safety performance.

The risk paradigm provided the conceptual framework for making sense of the designer's attitude to risk. This exploratory research investigates if individual personality differences and the individual perception of risk and other constructs affect cognitive error and the use of certain risky design protocols. This study has extended the use of the Experience Sampling Methodology (ESM) into the complex design enivironment.

A sample population of 167 design engineers from 55 design teams was assessed in situ, up to four times per day over four working weeks. The sample that participated in this organisational study was drawn from industrial sectors that involved the high hazard nuclear and offshore oil and gas industry. This research has been conducted in a number of stages, applying both conventional questionnaires and the novel electronic diary based techniques.

Questionnaires were used to measure stable factors through individual maturity, such as personality, and an experience sampling methodology, using personal digital assistants that were used to record momentary data. The stable factors were analysed using exploratory factor analysis to derive 14 emergent factors from the six constructs examined. Multilevel hierarchical linear modelling, using HLM6, was applied to these factors and the momentary diary data. Whilst the research was primarily interested in the individual designer, there were certain interactions between the sample units that characterised the multilevel structure of the investigation. The momentary data nested within individuals, and within design teams showed that personality is significant in predicting cognitive error reports and the use of risky design protocols. Analyses indicated that emotionally stable individuals commit fewer errors, whereas extraverted, open and agreeable personality traits and the key job characteristic of job autonomy and the organisational safety climate are significant predictors in the use of risky design protocols.

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Abbreviations and Definitions

Abbreviations

ACSNI: Advisory Committee on the Safety of Nuclear Installations

AFC: Approved for Construction

AFD: Approved for Design

ALARP: As Low As Reasonably Practicable

CAD: Computer aided Design

CAE: Computer Aided Engineering

CFQ: Cognitive Failure Questionnaire

df: Degrees of freedom

DFA: Discriminator function analysis

DCS: Demands-Control-Support (model)

DSE: Display Screen Equipment

EC: European Community

EFA: Exploratory Factor Analysis

EPIC: Executive-Process/Interactive Control

EPSRC: Engineering Physical Sciences Research Council

ESM: Experience Sampling Methodology

ETSC: European Transport Safety Council

HAZID: Hazard Identification

HAZOP: Hazard and Operability (study)

HLM: Hieararchical Linear Modelling

HSE: Health and Safety Executive

HTA: Hierarchical Task Analysis

IAEA: International Atomic Energy Agency

INPO: Institute of Nuclear Power Operations

INSAG: International Nuclear Safety Advisory Group

ISO: International Standards Organisation

LTI: Lost Time Incident

LTIF: Lost Time Incident frequency

MBTI: Myers-Briggs Type Indicator

MTC: Medical Treatment Case

OLS: Ordinary Least Squares (regression)

PDA: Personal Digital Assistant

PFD: Process Flow Scheme

PHEA: Predictive Human Error Analysis

P&ID: Process & Instrumentation Diagram

PRP: Psychological Refractory Period

QRA: Quantitative Risk Assessment

RIDDOR: Reportable Injuries, Diseases and Dangerous Occurrence Regulations

sd: Standard deviation

SOAR: State Operator and Result

SOS: Safety Observation Score

TRCF: Total Recordable Case Frequency

TRIF: Total Recordable Incident Frequency

UTD: Utility Flow Diagram

WHO: World Health Organisation

Definitions

Cognitive Error: A cognitive error is described as a breakdown in cognitive functioning that results in a cognitively based mistake or error in task execution that either a person or groups of individuals would normally be expected to be capable of accomplishing;

(Design) Error: A feature of a design which makes the design feature unable to perform according to its specification;

SOAR: is a computational theory of human cognition that takes the form of a general architecture (Laird, Newell and Rosenbloom, (1987), Newell (1990), Rosenbloom, Laird and Newell (1992). SOAR is a major exemplar of the architectural approach to cognition;

"There's nothing more practical than a good theory"

(Credited to Kurt Lewin, psychologist.)

Acknowledgements

There are many whom I wish to thank for giving me encouragement and support and marvelling at my commitment to take this amazing journey. Making this happen has involved many individuals and organisations. A very big thank you must go to Loughborough University for turning this 'brain-wave' of an idea into reality and in particular, to two very special friends, who have overseen my work right from the very start. Without their guidance, patience and endless discourse none of this work would ever have materialised. So my immense gratitude and thanks are extended to Professor Kevin Daniels and Dr. Alistair Cheyne. I've also worked my way through a couple of Directors of Research in the time it's taken me to write up the thesis. Professor Geoff Chivers and John Loan-Clark made the panel sessions something to look forward to.

Heeding advice from Kevin "that it is never a good idea to risk humour in science", all the quirky quotes and personalised commentary have been scrubbed from the thesis. There has been plenty of other good advice given to me along the way. Paul van den Heuvel, suggested back in 2003, that I "Take a look at Wagenaar; we've done some work with this guy". So there it started. Off I went to Leiden University to meet up with Professor Patrick Hudson, a colleague of Wagenaar, who I'd been introduced to the previous year whilst attending a conference in Kuala Lumpur.

Around about the same time, Ed Terry, a friend of many years standing, suggested that I might be interested in the work of the Risk Perception network, initially operating out of the University of Bath and latterly from Lancaster University. Meeting with like minded

people every six months or so, at different academic institutions throughout the country, proved inspirational, and was something that sustained my efforts with new ideas, so many thanks must go to Ruth and Jerry.

Looking at risk within a specific industrial sector meant that gaining access to designers from that sector suddenly became a really important issue. I guess it goes without saying that a big thank you must go to my employer AMEC, and for a number of reasons. Firstly, for agreeing the terms of a sabbatical that allowed me to take time-out from the day job and undertake this important work. Secondly, for granting access to designers under the EPSRC funded research project, EP/D04863X. In particular, thanks must go to Nina Schofield, Jim Wright, Dave Dryer, Bob Austin, Tony Hinton, and John King and from outside of the AMEC organisation, to my old friend, Paul van den Heuvel at the Heerema Group at Zwijndrecht and Theo Driever at IV Oil and Gas. Everyone involved provided wonderful support to this project.

A year in Canada during 2005 and the success of gaining the EPSRC grant EP/D04863X and the two years at Loughborough University that have followed, have made everything all the more worthwhile. It was during this time that I realised that the daily commute into London, which I had subjected myself to for far too long, was going to become a thing of the past. What I hadn't anticipated was that I would end up completing the thesis, living albeit for only a few months, back in Canada at the start of 2008.

It almost goes without saying that there are others who have suffered throughout this thesis, so thanks to Lynda McGroggin, my chief proof reader who now knows more about SPSS than I do.

Finally, I wish to thank my wife, Julie for all her love and unwavering support throughout this whole episode and to my kids, Rachel and David, who with Julie have wondered whether I was ever going to finish. Julie now has grave concerns as to how I'm going to fill my time now that my mistress has gone!

The results of the research project Pilot Study have been peer-reviewed and presented to the American Society of Safety Engineers (Middle East Chapter) Professional Development Conference and Exhibition (Bahrain) in March 2006, (Beesley, Cheyne, & Daniels, 2006); The British Psychological Society Division of Occupational Psychology conference 2007 (Wimalasiri, Beesley, Cheyne & Daniels, 2007); The British Chemical Engineering Contractors Association (BCECA) 2006 Safety, Health Environmental and Security quarterly committee meeting (Beesley, Cheyne, & Daniels, 2006) and the European Association of Work and Organisational Psychology (EAWOP) 2007 Conference in Stockholm; (Daniels, Beesley, Cheyne & Wimalasiri, 2007).
The results from the Pilot Study have been published in Human Relations Volume 61 (6) 845-874 (Daniels, Beesley, Cheyne & Wimalasiri, 2008).

The Main Study results have been presented at the 2008 Safety Symposium of The British Psychological Society Division of Occupational Psychology (2008) annual conference (Beesley, Cheyne, Daniels & Wimalasiri, 2008). A paper for presentation has been prepared for the British Academy of Management 2008 (Wimalasiri, Beesley, Cheyne & Daniels, 2008). The results from the Main Study interview analysis are to be published in Journal of Engineering Design by Taylor and Francis (Wimalasiri, Beesley, Cheyne & Daniels, 2008).

Foreword

The contribution made by this exploratory piece of work resides in its disclosure of certain predictive effects associated with a designer's perception of risk and cognitive error. There has been much interest in cognitive error and its disclosure outside of the clinical setting described in the works by Broadbent, Cooper, Fitzgerald and Parkes (1982). This study takes the definitions of cognitive error, as described by Broadbent et al (1982), and has applied them to offshore designers in their design setting. This application of the everyday lapses in attention, memory and perception has been made in a similar fashion to the work conducted by Wallace and Chen (2005). The wider benefit of this study is in the understanding cognitive error and risk (Simon, Hillson & Newland, 1997) to the role occupied by the offshore designer with its subsequent potential for theory development. The statistically significant and the non-significant effects attached to the findings have been differentiated and commentary added in support of theory. This helps to explain why the cognitive error and risk effects revealed in this study may have occurred. This study also extends the use of an electronic Experience Sampling Methodology (ESM) into the design environment arena.

Kinnersley and Roelen (2007) and Drogoul, Kinnersly, Roelen and Kirwan, (2007) indicate that risk management in the design phase of a project is recognised as a highly regulated episode. Offshore designs involve the preparation of the design and operational safety cases for acceptance by the Regulator. However, there still remain a proportion of accidents that have their root causes embedded in the design process (Kinnersley & Roelen, 2007). The discussion on risk and design error considers these implications alongside the Government's Policy on the Management of Risk (HL Paper 183-I, 2006). The Government Policy on the Management of Risk examines whether there was significant evidence to support the widely held view[1] that the UK had become an increasing risk-averse society.

This thesis considers the potential design contribution to the safety performance of the end user when checks fail or are overlooked. The industrial sector participating in this organisational study involves the high hazard nuclear and oil and gas offshore industry. Analyses of systems failures that affect safety performance often conclude that human error was a key factor in causing these failures (Rasmussen, 1990). If human error is a significant root cause that can be attributed to erroneous designs then the evidence from accident investigations appear to be strongly dependent upon what constitutes design error. Hale, Kirwan and Kjellan (2007) attempted to pin this down by questioning whether design error was where:

- The system failed to meet the specification (See Taylor [2007] at pg 60);
- Safer design decisions could have been taken;
- Design errors picked up during the design review processes e.g. HAZOP were not corrected by changes in the design.

Such evidence points researchers towards the findings of investigations into such catastrophic incidents as Piper Alpha (HMSO, 1990), Chernobyl (Joint

[1] Speech by the Rt Hon Tony Blair M P, delivered at the Institute of Public Policy Research, May 2005.

EC[2]/IAEA[3]/WHO[4] report, 1996) and most recently Texas City (Baker, 2007) where all of the above design failure categories have, in a measure, been recorded. The Health and Safety Executive (2006) suggest that up to 90% of accidents in these forms can be attributed to human error. Kinnersley and Roelen (2007) indicate that:

> "50-60% of the root causes of (all) accidents arise in the design stages" (at pg 31-32)

Consequently, the area of human error has attracted a wealth of research, much of it focused on the end-users' interactions with new technology (Sharit, 1998). Research also suggests that safety behaviour ultimately comes to affect the safety performance outcome, where poor safety performance corresponds with poor safety behaviours (Griffin & Neal, 2000; Neal & Griffith, 2002; Parker, Turner & Griffin, 2003).

This investigation into human error started with a preliminary investigation that involved a first-hand accident root cause analysis. The accident was traceable to some pre-conditional states associated with a design feature. The diagnostic technique adopted in the accident investigation involved the use of the commercially available software package Tripod β (Shell, 1997). This method involved the identification of active failures, pre-conditional states, latent failures and failed checks. This study considered the circumstances under which these checks were made and what might have prompted the designer to make them. This understanding is important because it reaffirms the link

[2] EC: European Community
[3] IAEA: International Atomic Energy Agency
[4] WHO: World Health Organisation

between certain characteristics of the designer and his job and brings together the designer's risk perceptions and cognitive error into the accident arena.

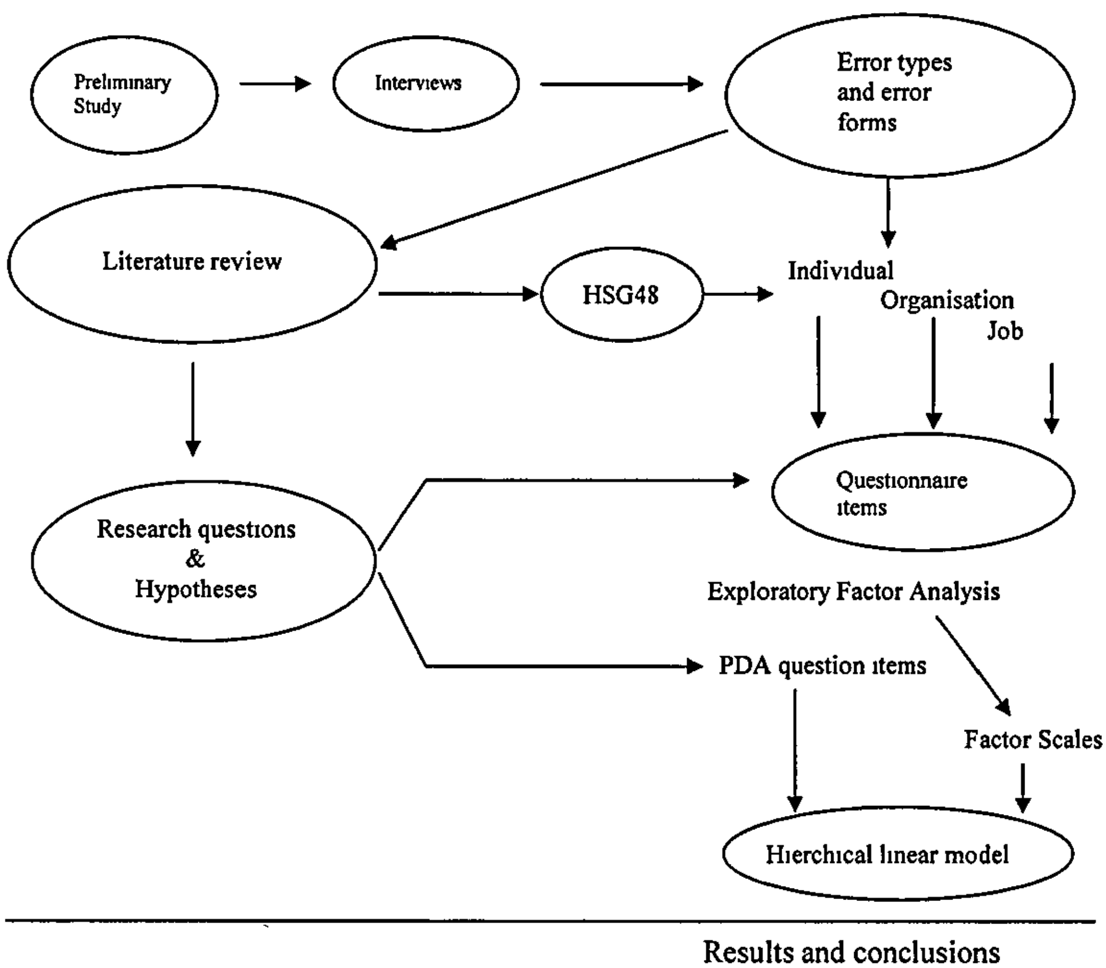
Consequently this thesis has been guided into taking a human-centred approach in order to investigate the way that the designer responds at a personal level through perceptions and cognitive error and at a group level through job characteristics and team working. The group level investigation has been conducted because the designers are nested within different design teams. The methodological approach to sampling designers, design teams and hazardous projects has necessitated an approach that has coupled the conventional with the novel. The design activities examined in this study takes place within an intrinsically dynamic organisational structure. The conventional approach reflects the early use of interview techniques to establish the types of design errors made by designers and the application of a questionnaire. The questionnaire was used for data gathering and measurement of the stable personal factors. Whereas, the highly dynamic effects attached to tracking the designer's cognitive errors ('Error') and their use of certain risky design protocols ('Risky') over time has been gathered using Personal Digital Assistants (PDAs).

Structure

This thesis has been divided into four sections. The first section contains the literature review and sets the scene for the research through outcomes informed by the early Preliminary Study. The Preliminary Study pointed the way to a relationship between accidents and a design contribution. Figure 1.1 maps the overall process.

Figure 1.1: Structure of the research investigation

Key stages of the research development **Research process outcomes**



Section one contains seven chapters, which represents the body of the literature review. An early preliminary investigation informed the literature review. These chapters have been arranged to correspond with the HSE model for human factors, HSG 48.

The second section commences by recapping some of the gaps that exist within the literature sources and develops the research question and advances some workable hypotheses. The research methodology provides a suitable instrument to apply to the designers on the offshore projects.

Section Three details the field research work and presents the Main Study and its results. These results are written in three parts. The first part describes the Main Study exploratory factor analysis and contains seven sections. The first five sections are dedicated to detailing the principal components factor analysis (PCA) attached to the five constructs examined by way of the research questionnaire. The remaining two sections describe the emerging factors through a Pearson correlations matrix and a two-level hierarchical linear regression derived from the new scales generated in the exploratory analysis. The second part includes a description of the PDA observations and their analysis using hierarchical linear modelling and the results are presented.

A designer population of n =167 completed the Main Study questionnaire and completed the weekly PDA trials. The PDA trials involved a series of four five-day trials spread over an intervention period of about six months. All projects in the Main Study provided

HAZOP[5] reports to assist the researcher in understanding the degree of design risk and the depth of design complexity.

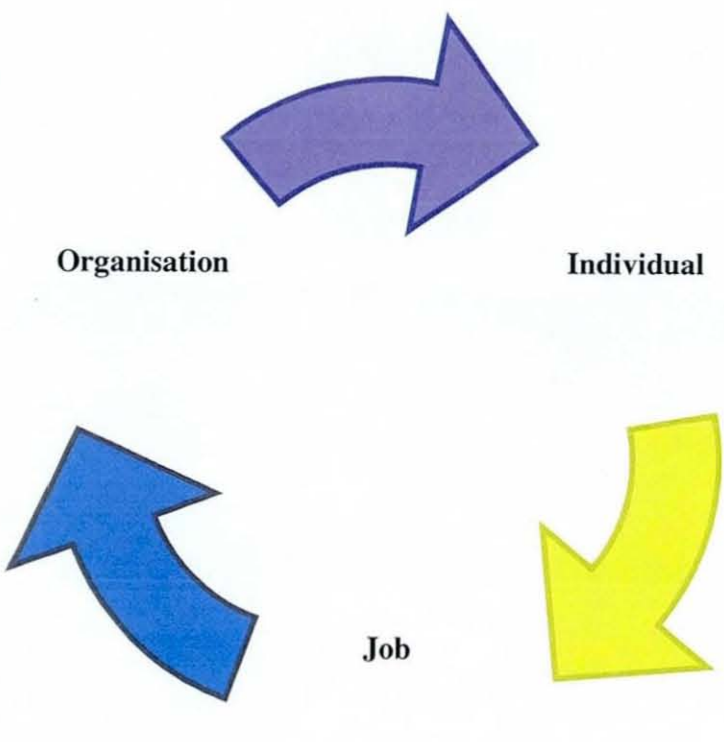
Section Four provides the discussion on the results and a narrative on the hypothesis testing. The final part provides an overall discussion on the research. It draws conclusions and implications for the designer and the present and future role in hazardous offshore designs and describes the contribution and limitations of this work.

[5] HAZOP: Hazard and Operability study

The approach to the Literature Review

The contribution made to this thesis by the literature review has been to reveal gaps in the chosen literature sources. These gaps represent opportunities for this thesis to explore how best these gaps may be closed through hypothesis testing. The selected model that has been used in this process is an adaptation of the HSG 48 model (Figure 1.2). This model promotes three interlinked aspects that effect human factors in the design environment firstly, the 'Individual', secondly the 'Job' and finally the 'Organisation'.

Figure 1.2: Relationship between the individual and the job in the design environment



(*After Human Factors in Occupational Health and Safety see HSG 48*)

Chapter One reviews the literature associated with the design process, which is the overarching process connecting these three constructs.

The Individual

Chapter Two represents the first section on the 'Individual' component of the HSG 48 model and concerns itself with cognitive ergonomics and the significant part it plays in the reporting of human error. Chapter Two investigates several models that could explain designer error following the outcomes from the preliminary investigation and the interview study.

Chapter Three represents a key area of the research as it focuses upon individual personalities and provides coverage of the major explanatory variables examined in this study. The power of personality theory rests in its ability to contribute to an understanding, relative to other influences, as to why designers may commit design errors and take risks. This aspect is the main focus of this research. Chapter Three goes on to acknowledge the work by Cattell (1950) and Esyenck (1947) and outlines some adjectives that illustrate the personality characteristics in context.

Some broader issues associated with individual perceptions are tackled in Chapter Four. Chapter Four addresses some of the foremost issues surrounding societal risk-taking. This section includes a discussion on the work of Slovic, Fischoff and Liechtenstein (1982) and their examination of risk and uncertainty.

The Job

The next aspect of the HSG 48 model is associated with the Job. Chapter Five deals with the primary job characteristics and provides a brief examination of the job characteristics that might be important and relevant to this study. These are job autonomy and social support, role clarity, demands and skill use.

The Organisation

The final aspect of the HSG 48 model deals with the Organisation and this has been addressed in two parts. In the first part, Chapter Six, addresses social cultures by investigating Douglas' anthropological theory (1982) and suggests some of the reasons why the risk-taking behaviours, revealed in this theory, may provide clarifications in the case of an offshore designer.

The second part addresses organisational safety climate. An effective organisational culture has a need to operate within a positive safety climate ('Revitalising Health and Safety' Strategy Statement, DETR, 2000). A discussion on the meaning of safety culture and safety climate is provided. Various literature sources (see Clarke, 2006; Cox & Cheyne, 2000; Flin, Mearns, O'Connor & Bryden, 2000) examine this topic. This part of the chapter devotes itself to examining the benefits of safety climate, as a means to gaining safety improvements in the design process.

Table 1.1 details the structure of the literature review sections.

Table 1.1: Literature Review sections

<table>
<tr><th>Outcome Variables</th><th>Workplace Setting</th><th>Explanatory Constructs
(See HS G 48)</th><th colspan="2">Related construct characteristics examined in this study</th></tr>
<tr><td rowspan="13">Risk-taking ('Risky') and Cognitive Error ('Error')</td><td rowspan="13">Designers and the Design Process
(Chapter 1)</td><td rowspan="5">Individual</td><td colspan="2">Cognitive Ergonomics and Human Error
(Chapter 2)</td></tr>
<tr><td colspan="2">Individual Personality differences
(Chapter 3)</td></tr>
<tr><td rowspan="3">Risk Perception
(Chapter 4)</td><td>Sub-category</td></tr>
<tr><td>Dread</td></tr>
<tr><td>Unfamiliarity</td></tr>
<tr><td rowspan="6">Job</td><td rowspan="6">Job Characteristics
(Chapter 5)</td><td>Sub-category</td></tr>
<tr><td>Job Autonomy</td></tr>
<tr><td>Job Support</td></tr>
<tr><td>Role Clarity</td></tr>
<tr><td>Job Demands</td></tr>
<tr><td>Skills</td></tr>
<tr><td rowspan="2">Organisation</td><td colspan="2">Social Culture
(Chapter 6)</td></tr>
<tr><td colspan="2">Safety Climate
(Chapter 7)</td></tr>
</table>

The first chapter of section one now considers the role occupied by the designer in the design process and introduces some of the common issues that form the circumstances where design errors may occur.

Section One: The Literature Review

CHAPTER 1

Designers and the Design Process

1.1. Overview

This first chapter outlines the design process and assesses certain key organisational practices. These practices include the application of design logic and why it fails to correspond to the end users' logic. The design logic considers such protocols as the reuse of proven designs, rules and procedures, and intervention methods such as HAZOP. The HAZOP aims to reveal the hazards and hazardous operations that are inherent within a particular design, at a stage when the designer still has the ability to develop suitable remedies (Kletz, 1972). The origins of the HAZOP method are evidenced by some early work undertaken by Elliott and Owen (1968).

Didelot (2001) highlighted the fact that the incorporation of safety in design might follow a sequential approach, not "an integrated one" (quoted in Fadier & Garza, 2006 pg 58). Whereas, the transportation sector (European Transport Safety Council (ETSC) 2003) declares that "(design) safety comes first" (at pg 11) and reports that safety design and engineering are seen as a major initial component of the work. These are important issues that this research has had to address.

1.2 Introduction

The focus of this research is into how designers of hazardous installations, in particular offshore platforms, might influence the end users' safety performance. An early Preliminary Study initially informed this research. The purpose of the Preliminary Study was to assess whether there were design contributions to accidents that could be traced back into the design process. It was considered to be a reasonable assumption to make at this stage, that designers' more prone to cognitive error, as defined by Broadbent et al (1982) and any undue risk-taking, should be more likely to embed some higher level of risk in a design. The level of risk would be higher than routinely expected and be experienced by others (fabricators and end-users) who are downstream of the design activity. To investigate this potential phenomenon a little further two design and construction organisations granted access to designers working at their fabrication facilities. A cross sectional sample from two European fabrication facilities, one in the UK and the other in the Netherlands, participated in the Preliminary Study (n = 82). The study was conducted between 2002 and 2004. The accident investigation work focused upon the UK facility.

The UK facility possessed a relatively small on-site design capability. A range of accidents was considered for the purposes of this evaluation. The Lost Time Incident (LTI) and Medical Treatment Case (MTC) categories of accident were evaluated to determine whether an element of designer error could be found to be associated with these accidents. The Tripod β (Shell, 1997) root cause analysis method was chosen and the Preliminary Study confirmed a design contribution to accidents.

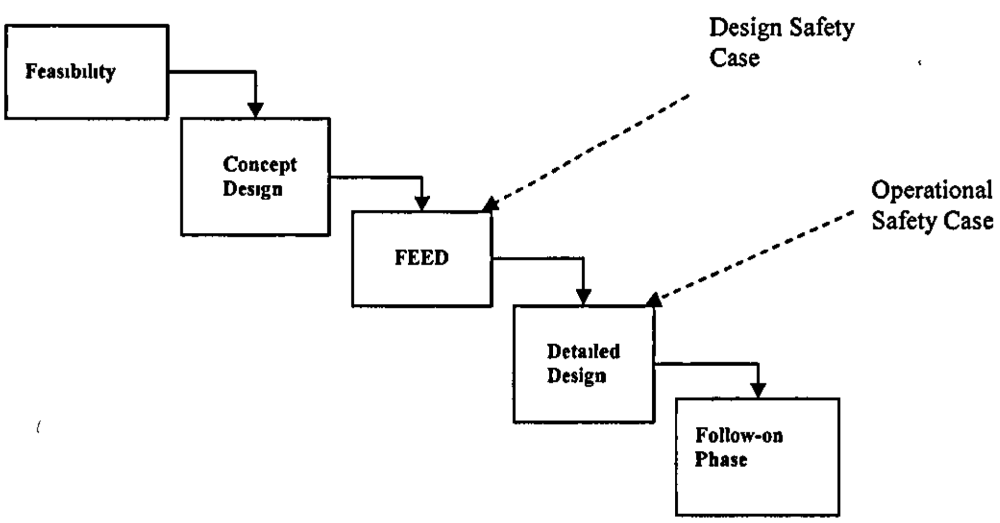
The evaluation of contemporary literature (Drogoul, Kinnersly, Roelen & Kirwan, 2007; European Transport Safety Council report, 2003; Kinnersley & Roelen, 2007; HSE 1992a; 1992b; 2005; Simon, Hillson & Newland, 1997) on the risk management in the design process, which applies to the high hazard aviation, offshore, railways and nuclear industries, appears to be practised within a standard framework. However, within this framework there are specific applications that are unique to the risks associated with the particular sector under consideration. For example, the offshore sector practice comprises of a number of evolved best practices, each of which involve the use of formal risk assessment in order to determine the appropriateness of the safety measures (Roberts & Gargano, 1990).

This chapter investigates how the design tasks are linked and if they can be matched to the end user's design performance criteria. This performance criterion takes into account the internal measurement points that are applied to almost all designs. The degree of assumption-making is assessed primarily as an input to a causation model for design errors. A designer's assumption-making is considered through the use of certain heuristics (Tversky & Kahnemann, 1974; Kahnemann, Slovic & Tversky, 1982; Busby & Payne, 1998). The next section starts off this review by considering the measurement points that are taken in the design process.

1.3 Measurement points

Design engineering is a creative process (Wang & Ruxton, 1998) that is sometimes compromised by the poor diagnostic abilities of designers in other functions. These occur at recognised stages in the design process (Busby, 1999b) and by designated personnel e g. the design checker. The measurement points occur at key stages in the design of a hazardous installation and appear reflective of the level of engineering definition present within the design at that time. Figure 1.3 shows this cascading effect as the degree of detail increases over time.

Figure 1.3: Waterfall diagram of the design process showing the key safety stages



The measurement points appear to be used by the designer in a number of ways. They are a measure that reflects upon the robustness of the designer's assumption-making in order to minimise designs with missing data. They are used as points that tie together the design logic and the end users' logic. Fadier and Garza (2006) consider that any gap or misalignment in this logic should be considered as a "most important source of risk" (at pg 56). The design logic is used to allow the formal transfer of complete data from one discipline team to another. This data is therefore used to verify the quality of the design and bracket the progression of a design from one layer to the next. These recognised stages (Simon, Hillson & Newland, 1997) and their content are described in Table 1.2

Table 1.2: The key stages of a design project

Design stage	Typical design deliverables
Feasibility	Exploitation scheme including reservoir mapping, geology, and evacuation route to existing/new infrastructure, risk model addressing schedule, installation impacts in a level 1 plan.
Conceptual	Outline philosophies and key functional specifications for major equipment, process flow scheme, HAZID[6] & level 2 plan
Front End Engineering Design (FEED)	More detailed philosophies and key functional specifications especially for long lead items, detailed PFD[7] and UFD[8] showing control loops, revisit HAZID and key stage HAZOP, & certain documents to AFD[9], early procurement
Detailed Design	Design deliverables to AFD and AFC[10], procurement activities, detailed design HAZOP selection of fabrication facilities and the release of fabrication work. Factory acceptance tests and shipping activities.
Follow-on support of fabrication and start-up to operations	Close out documentation, pre-start-up HAZOP and raise key deliverables to as-built/as-installed status; mechanical completion at site, pre-commissioning and commissioning activities and system hand-over to end user operator.

Whilst the designer of offshore installations is taking design decisions throughout the lifetime of an engineering project, the AFD and AFC phases appear as two key stages in

[6] HAZID. Hazard Identification
[7] PFD: Process Flow Diagram
[8] UFD. Utility Flow Diagram
[9] AFD: Approved for Design
[10] AFC: Approved for Construction

the project lifecycle where measurements are always taken. The completion of AFD and AFC stages release new areas of engineering activity. Achieving AFD status releases equipment procurement activities and helps to finalise the major equipment layouts. By this stage the design has usually participated in the HAZOP process. Achieving AFC status permits the engineering fabrication work to commence. The AFC stage would certainly have involved the HAZOP process. The relevance of the HAZOP test on the designs is to detect errors and conform to a design-for-safety approach.

1.4 Testing the relationships in the design

Busby, Chung and Wen (2004) indicate that:

> "The difficulty for the designer in predicting behaviour is that the natural sequence of design is from a functional specification" (at pg 821)

The concept behind this construct is to ensure the integration of the functional specifications in the design so as to meet the end users' requirements. This functionality provides the designer with the best opportunity to consider the technologies that satisfy the end users' needs. The uniqueness of each task activity, in order to fulfil this functionality, creates a complex pattern of interlinked relationships.

A test method developed by Bender (2003) has been used to assess designs and designers. This process is very similar to that used in empirical psychology and is outlined in the following passages. Bender's (2003) test involved determining the designer's response to such factors as current design status, the accommodation of a design change and task revision. This test appears adaptable to how offshore designers react during task execution.

The application of a scientific procedure to investigate the way that individuals react, points the way to how the offshore designer may respond when confronted with a difficult problem to solve. The approach taken by Bender (2003) was to address these types of issue in a similar manner to the one performed by Lienert and Raatz (1994).

Lienert and Raatz (1994) examined changes in performance and the corresponding changes in personality characteristics over a pre-defined period of time. In this instance the empirical research on design activity did not aim to test individual design proficiency, rather it analysed the tests and compared the results. Lienert and Raatz (1994) set out their objectives in both a cross sectional and longitudinal form. The cross sectional approach determined individual status and any differences between individuals concerning their design performance was noted. The longitudinal approach addressed changes in personal characteristics over time. These changes were observed over a pre-defined period of time that neatly corresponds with the types of issues driven by the hazardous projects just-in-time schedules. These findings into design activity were categorised by combining the outcomes of psychological tests on personal characteristics and cognitive performance (Lienart & Raatz, 1994).

The study (Lienart & Raatz, 1994) concluded that cognitive performance changed over time. This thesis will return to this issue in the development of the research methodology that has been applied to measure the designer's experiences over time and specifically their risk-taking (labelled as 'Risky') and cognitive error (labelled as 'Error').

1.5 Designing to a just-in-time schedule

Designers rarely experience the adverse affects linked with their designs even though they are responsible for the complex processes that derive them (Dekker, 2005). Busby and Hibberd (2002) illustrated that the design of complex and hazardous installations is vulnerable to designers designing in a way that impedes the end users' operational intentions. This contrast between the design and end users' operational expectations are captured in the way that space is normalised by the designer and the end user.

Perrow (1983) illustrated that 'good' design logic, exemplified in the case of the modern offshore platforms, are seen as being good by the designers, if they are designed to be compact and maximise space utilisation. Good design logic therefore appears to contrast with what the end users' logic requires from these designs. The end user requires space and engineering systems that provide easy access. For designs to be successful this bi-directional perspective of non-alignment is an important issue to resolve. Vincente (1999), Darses, Detienne, and Visser (2004) and Falzon (2006) agree that it is more useful to work on issues to do with space and consequently define the space constraints based upon a workable solution rather than just simply adopt a process that is limited by normative rules. Space has been used to highlight this potential logic indiscretion, although there are other features such as power generation and energy consumption that also fall into this same category. Gephart (1984) suggests that any non-alignment of design and end user logic can be very influential and induce organisational disruption. These circumstances occur when the designers have imposed upon their design logic what they perceive to be contradictory measures. Busby (2001) explains the influence that these factors can have in shaping the way that designer's tasks are performed. An example of these influences includes functional requirements that are contradictory to the technology that is available. It is suggested that this situation creates time pressure issues through the designers being forced to take decisions on complex problem-solving in order to meet prescribed deadlines. It is postulated that to resolve this type of issue results in the designer making unwarranted assumptions.

The emphasis on rapid completion of projects can insulate the designers from the consequences of these types of assumptions. This may even induce designers to give less consideration to factors relating to ease of operation and safety. The engineering of offshore installation projects tend to occur in smaller numbers. These smaller numbers of designs occur with large processing variances (after Busby & Payne, 1998). These variations are also reflected in the size or use of space, construction method and installation method of the offshore structures. The designs for all but the smallest installations tend to occur in less repeatable circumstances (OTC, 2000a). The repeatability of proven designs has in the past been used to confirm that an off-the-shelf design can provide for better systems of operation (Perrow, 1983). The reuse of proven designs in a new application has been revealed as an obvious way of reducing the effort and risk attached to these large variances (Busby & Payne, 1998). Vicente (1999) concurs with this point by outlining the strong constraints that generally involve a reduction in the field of creation that encourage the reuse of old solutions. These constraints involve specifications, standards and legislation. However, the reuse concept (ODE report 4381-B-A-002) is very rarely adopted in the design of the offshore platform. It is suggested, in OTC (2000b), that these circumstances arise because of the progressive need for the industry to optimise their past designs with the use of new technologies.

Explicit models of the normative reuse process have been developed (Duffy, Duffy & MacCullum, 1995) which concentrate on high levels of computational support. The use of these computational practices can help inform the designer on how designs can resemble (or differ) from an existing design. Computational methods can also help the designer to try and validate their assumption-making processes to meet the project's functional needs before a design is issued for use. Understanding the assumption-making processes invites an explanation into why design logic errors occur when reusing an existing design in a new application (Busby, 1999a).

A HSE report (2003) 'Mutual misconceptions between designers and operators of hazardous installations' posed three main questions about the designer's role in the design process. None of the following propositions create the circumstances that could be considered to be unknown for an experienced and competent designer.These questions also have an extended application in the discussion surrounding logic alignment:

1. 'Are you (the designer) conscious that your knowledge is provisional and (therefore) subject to doubt' (at pg 29);
2. 'How susceptible misconceptions (non-alignments) are to being corrected'(at pg 29),

3. 'If you (the designer) knew someone else was harbouring a misconception (non-alignment) and you could do something about it, should you do something about it'? (at pg 29)

The first question is addressing how the designer deals with assumption making. The question invites consideration as to how the designer develops design solutions. Procedural aids are important tools. Whilst procedures and rules underpin the whole design and the design assurance process (ISO[11] 9001), evidence shows that procedural rules are not always followed. The Three Mile Island incident (Rogovin & Frampton, 1980), Chernobyl (Joint EC/IAEA/WHO report, 1996) and Piper Alpha (HMSO, 1990) are three high profile examples where the rules set in the high hazard sector were not followed. Failure to follow design rules and procedures are far less obvious.

Sagan (1993) suggests that procedures dealing with problem-solving practices when applied during the course of a design can be perceived by designers to be an organisational decoy. By this Sagan (1993) is suggesting that the procedures are not always followed. Rule compliance allows the regulator and the general public to retain confidence in the outcomes of hazardous project designs. In that when the designs are placed into service they can be operated safely.

Regulatory focus received detailed attention in an article by Higgins (1997). Higgins (1997) discusses the critical characteristic of self-regulation and its attempt to reduce discrepancies between current states and the desired end state. For designers, the current state can be interpreted to mean a state achieved through their 'design logic', whereas the

[11] ISO. International Standards Organisation

desired end-state reflects upon the end users expectations. The regulatory focus for designers is therefore important. Designer's in a state of vigilance, for example aiming to avoid mismatches between the design and end users' logic, is viewed as one of prevention. Prevention focus is of particular concern because of its emphasis on protection, safety and individual responsibility in order to avoid certain types of design error.

A number of empirical aspects of Sagan's (1993) work involved case histories[12] within high reliability industries. High reliability and normal accident views presented Sagan with a number of theoretical contradictions. Sagan (1993) proposed that explicit in the normal accident accounts was a process that undermined the rationality of the so called safer institutional designs. Safer institutional designs are a feature of the high reliability industries of which the offshore oil and gas industry is one and aviation and nuclear are others. However, according to Sagan (1993) these safer designs were being undermined through procedures that allow ill-structured problem solving, undue complexity and organisational politics to take place. Sagan (1993) challenged whether organisational learning was a feasible design goal in practise.

The second question posed in the HSE Report (2003) is about the designer's role in the design process and states:

> 'How susceptible are misconceptions to being corrected (at pg 29)?'

[12] Sagan's case study addressed the US nuclear weapons command and control system, which fulfils the criteria of a high reliability organisation where safety was given priority, adequate resources to safety were provided, a strong organisational culture existed and there were opportunities to learn from mistakes.

The designers reported that they were either not aware of the expectations that were being placed upon them or that these expectations had not been built into the design logic. The conclusions drawn in the report (HSE, 2003) suggest that the designers' difficulty is as follows:

> ".. people (the designers) are not aware of their (the end user's) expectations or the expectations built into the way they (the designers) work" (at pg 39)

This research investigates the compliance that designers have to following organisational rules and procedures to specifically address this issue and the one raised by Sagan (1993). There is clearly an obvious and compelling argument for resolving Sagan's (1993) issue if future designers are not to fall into the same trap. The next section considers how vulnerable the designer and end user logic's are to organisational rules and procedures and what safeguarding remedies are available.

The third prime question relating to misconceptions (HSE report, 2003) was:

> 'If you (the designer) knew someone else was harbouring a misconception and you could do something about it, should you do something about it?' (at pg 29)

This process relies upon a design protocol that recognises the presence of design error types. These are mistakes that are made either unknowingly (omission) or in complicity (commission). It is conceivable that for every form of misconception quoted in the HSE Report (2003) to be detected requires each category to be thoroughly worked through.

However, it is highly debateable whether the rapid schedules attached to a hazardous installation design would permit such a remedy.

1.6 Design and the HAZID / HAZOP

The HSE Report (2003) developed a model that was predicated on the basis that both the designers' and end users' *modus operandi* were always based upon an incomplete representation of their own world of activities. Busby and Payne (1998) point to incorrect judgement as a contributor as to why incompleteness exists and is often not corrected. This situation often occurs because the applied interpretation, as Busby and Payne (1998) point out, is based upon experiences that are in themselves found to be flawed.

In the majority of cases the correction of logic non-alignment has been shown to generate the wrong result (Busby & Hibberd, 2002). So ensuring that only the right design elements are incorporated into the overall design clearly requires a high degree of design knowledge. This design knowledge needs to be held at the individual designer level, within design organisations (Reason & Mycielska, 1982; Rasmussen, 1986).

This approach to managing designs does not imply that the designer's conceptions about the designs should automatically be deemed as being faulty. However, it does place added importance upon such formal processes as the HAZID and the HAZOP to detect any mistakes. These two processes set out with the intent to reveal those mistakes that have serious safety consequences prior to the design leaving the designer. To be effective, the scheduling of these events needs to be done when access to the designers is still available. This arrangement permits the implementation of suitable correction strategies and enables any design error to stand the best chance of being remedied before requiring the end users' improvisation.

This issue draws an important distinction between the potential active and latent nature of failures described by Reason (1990). It immediately highlights the traceable contribution of the end user to active failures through what are seen to be the end user's corrections of design mistakes. Reason's (1990) pre-conditional failure states go back into the design process to include such latent aspects as poor design decisions.

Historically, designers of complex and hazardous installations appear to discover what design errors they have made from the end user (HSE, 2003). However, this exchange of information appears to occur at a stage when the design has been completed. This implies that determining any shortcomings of a design and any assumptions that have been made cannot be done until there is some form of "catastrophic" failure (Petroski, 1994). So to avoid the "catastrophic" failures of the type described by Petroski (1994), the safety processes need to be undertaken on two levels. Firstly, by testing the designer and secondly through tests undertaken at an organisational level. Testing the designs at an organisational level requires a thorough and in-depth understanding of the design process (Perrow, 1983). Testing the designer needs a human performance model that discloses when judgements are shown to be deficient (Norman, 1981).

1.7 Designers' assumption-making

Lawson's (1990) perspective of the designer's work is that their designs are never complete, and to a degree this is supported by Weill-Fassina, Raberardel and Dubois (1993). Weill-Fassina et al (1993) describe this facet to be a design that is never completely implemented. When the recognised outputs of the design are not known or, where there is no stopping rule to indicate when the design task is finished, the designer appears to continue to implement change (Lawson, 1990). In other words, to avoid a state of change each facet of a design model needs to be perceived as being very simple. This approach allows the designer to identify the end state of a finished design. Under these terms simplicity means designs that are so simple that they are generally lacking in any contingencies.

These designs have to be stripped of any interdependencies and are therefore only used to solve one particular problem at a time. Simplifying assumptions are one way in which designers can reduce the complexity of designs and so finish them with greater ease.

1.8 Design heuristics and errors

Heuristic theory (see Kahneman, Slovic & Tversky, 1982) is valuable in explaining how a designer may arrive at a completed design. For the designer, two reported types of heuristic appear to lead to decisions through assumption making, the process heuristic and the outcome heuristic (Busby & Payne, 1998). Both these types of heuristic represent assumptions that are attached to planning judgement and refer to the use of past rules. An example of a past rule is re-using an old design in a new application.

The process heuristic uses these past rules, as rules of thumb, to build-up procedural models that act as *aide memoires.* The designer then uses the *aide memoire* to specify all the activities in their design tasks. The tendency appears to be to base judgements on easily recalled data, or the so called "availability heuristic" (Tversky & Kahnemann, 1974). The "availability heuristic" suggests that the use of easily recalled or imagined data may be the more frequently applied *aide memoire.*

The outcome heuristic is applied to limit the repetitious use of trial and error techniques through a straightforward simplification mechanism. In this case the simplification method only adopts features of successful past designs. Therefore the designer appears at liberty to process their design decisions through assumption-making providing they can relate them to what they perceive to be successful outcomes.

In order to verify this state, it is necessary to understand what form of heuristics are generally applied and then record their usage. Advancing such an approach permits the generation of the assessment model that can include the self reporting of assumptions.

1.9 Design engineering and discovering design errors

The design-for-safety approach (Wang & Ruxton, 1998) is a concept that has been regularly promoted throughout the accident history of the high hazard industry (Flixborough 1980; HMSO, 1990). Wang and Ruxton (1998) conclude that many accidents, even those involving individual design error, could be prevented with greater attention to safety in the initial design stages. Wang and Ruxton (1998) also suggest the use of suitable design models. Approaching the same issue from a slightly different perspective, Busby, Chung and Wen (2004) illustrated that the designer could reason how risk in a system could be reduced by addressing the concept of (design) barriers to accident sequences. Whereas, Falzon (2006) and Hollnagel, Woods and Leveson (2006) advocate an added level of resilience to the design concept in order to control risks. Several articles (for example Gauthier & Charron, 1995) have suggested the use of decision-making models to improve the attention given to safety during design. Fadier and Garza (2006) suggests the reasons for these 'catastrophic' accidents:

> "...will <u>not</u> be found in (the) search for a combination of technical failures and human error" (at pg 57).

The attraction of a systematic method of design evaluation is the intrinsic capacity that the design-for-safety approach has in limiting the designer's ability to make unsafe decisions (Busby & Strutt, 2001a). Busby and Strutt (2001a) reflect upon the application of a systematic approach by stating:

> "The drawback is that they (the use of prescribed design processes or decision-making methods, rules and procedures) can also constrain the designer, and could either make the design process less responsive to specific circumstances of particular cases or run the risk of encouraging violation" (at pg 118).

The existing hazardous industry practice appears to be based upon conceptualising correction themes that are attached to reoccurring error types. For example, recording in the HAZOP a missing piece of data and then applying the correction theme (Lees, 1980). In order to adopt correction strategies for the error types revealed by this method it is necessary to know what to look for and how to correct the design.

The hazardous industries apply this universal identification and correction method that is HAZOP based upon the Chemical Industries Association (1977) practice. The HAZOP identifies potential deviations to the design specification and extends it beyond just component reliability that is suggested by Fadier and Garza (2006). The HAZOP considers unsafe design decisions. It remains important for the design organisations and the end users alike to be able to anticipate whether errors are embedded in designs, which require correction through different solutions. The opportunity to apply the HAZOP technique in a non-classical manner, beyond considering say the loss of containment, has also been reported by Swuste (1997).

If potential latent error failures exist within the design through a designer's design mistakes, then theory (Reason, 1990) indicates that these failures only arise when the conditions, in which they operate, are being externally tested. The failure opportunity is a result of the complex interaction between latent failures and a variety of local triggering events described in Reason's Swiss cheese model (1990). Reason (1990) hypothesised in the Swiss cheese model that most accidents can be traced to one or more of four levels of failure:

1. Managerial failures;
2. Psychological precursors;

3. Local triggers representing intrinsic defects, and
4. The unsafe acts.

In the Swiss cheese model, an organisation's defences against failure are modelled as a series of barriers, represented as slices of Swiss cheese. The holes in the cheese slices represent weaknesses in individual parts of the system. The system as a whole produces failures when a hole in each slice momentarily aligns.

The external test considered here is when the end user makes active changes or corrections. Therefore to meet the external test a design needs to include contingencies. These contingencies represent complex and not simple design outcome heuristics. As such, this examination avoids the very misleading position that places the end user as the 'sole locus of (design) failure(s)' (HSE, 2003).

1.10 Defences in the design

The designer's perspective of the causal paths of accidents (Reason, 1990) is constrained by their limited view of a design. These limitations are likely to induce a particular exhibition of behaviour. It is suggested that these behaviours appear reflective of the mistakes in events that may lead to an accident. Therefore the designer's correction strategies need to address not only the circumstances surrounding how the mistakes are revealed but go beyond this stage and consider how their avoidance could be achieved. Crowe and Higgins (1997) found that those in a promotion-focus condition, in other words, those seeking achievement in their work had a risky bias for saying yes to meet task execution. Whereas, those with a prevention-focus condition have a more conservative approach, and as Higgins (1997) suggests these individuals, in a vigilant state from a prevention focus point of view, would want to avoid errors. These individuals would be more likely to retain or repeat perceived past successes in a design. This approach reduces the likelihood of mistakes being made. This contrasts with those in a promotional state where alternative criteria would apply. The regulatory focus difference in strategic tendencies should produce differences in design task problem-solving.

1.11 Testing the Design

Through a process of examination and analysis of design projects, Bender (2003) recognised the need for the inclusion of some form of testing process that validated the adopted method (and content) of designs. The method had to be able to distinguish between good performance and bad performance; as well as good designs and bad designs. Bender (2003) recognised that such reference points needed to be readily available if workable solutions to rectify bad design performance were to be made a reality. These measurements are made of design organisations and have to be compared with the design's operational performance at a later date. The design's operational performance can also be captured as empirical data (see Busby & Strutt, 2001b). Capturing a design's performance has in the past been acceptable because of the high number of detailed work procedures associated with the design's preparation. These detailed work procedures permit designs to be accurately reinterpreted. The drawback with this approach is that there are such a large number of detailed design codes (for example The American Petroleum Institute codes: API 2A, API 2SK and API 14 J, British Standards, regulations, and codes).

The experimental setting test method employed in the Bender (2003) investigation failed to recognise these real world circumstances surrounding the derivation of design solutions. Bender's (2003) investigation also failed, to a certain extent, to recognise the relevance of the test methods. The opportunity for the designer to innovate and revise tasks within periods of design change still resulted in design deliverables being issued. These design issues include good data in a prevention-focus condition, as well as flawed or missing data when the designer is in a promotional-focus. Bender (2003) acknowledged that it was necessary to have a methodology that could be consistently reapplied to designs in equivalent circumstances.

In the analysis of design activity, De La Garza (2004) confirmed that the objectives of safety appeared to be grafted onto a design, almost like an external entity, in a more or less opportunistic way. The development of suitable test methods has in the past been an issue because of the limited research linking designers with accidents (Dekker, 2005). It has however been shown that by making the designs more predictable delivers outcomes that are safer (Swain & Guttman, 1983).

1.12 Summary

The search for a design solution should not ignore the experimental trial and error method in a vain attempt to eliminate design uncertainties and the unknown. Fadier and Garza

(2006) indicate that the designers knowledge, arising from experimentation, more or less official feedback from operational situations or from personal experiences appears to be the way that safety and ergonomics are integrated into designs. The practical problem with trial and error is that the evaluation of the predictive limits of the problem takes time. Time is often the commodity that the designer has the least of to devote to exhaustive problem-solving in this way. Tversky and Kahnemann (1974) suggest the availability heuristic is more frequently used, but the use of the process heuristic is intriguing. The literature accounts suggest that design mistakes appear to be attached to these heuristic states.

The evaluation of these heuristic states will be part of determining whether there is an already suitable and reusable model available for assessing designer's risky decision making by considering the following protocols. Each protocol should require an 'approver' to check the suitability of the content before they could be applied because risk maybe embedded:

- Assumptions about missing pieces of data;
- The use of a previous design that has not been updated;
- Applied solutions that have worked well in the past;
- Added a design feature fit-for-purpose but others need to decide if it's correct.

Finally, Soane and Chmiel (2005) suggest the influence of personality and other factors including risk perception may be linked to certain decisions and judgements.The next chapter advances the construct of error with personality and other factors.

CHAPTER 2

Cognitive Ergonomics and Human Error

2.1 Overview

The objective of this chapter is to start the debate on the merits of the different accounts of error within the HSG 48 model. These accounts are reviewed in the forthcoming chapters for their applicability to designers because of the way that other aspects, such as personality, may make the designer more vulnerable to a particular form of design error. This process was stimulated by a qualitative interview study. The interviewees were asked to reflect upon the types of mistakes and errors that designers make in order to help direct this literature search into human error.

The majority of the participants were designers (n = 17) with design end users (n = 3) and the Regulator (n = 1) making up the balance of the interviewees. The dissimilarity in the sample size reflects the researcher's particular interest in role occupied by designers. The sample reported that designers do make errors and that these design errors appear to map onto theory (Reason, 1990). Given that design assumption-making was reported to be common place within design organisations, its presence satisfies one of the key components of this study which is to measure assumption-making, as part of the designer's use of risky design protocols.

Chapter One discussed the congruence between the designer's decision-making over time and the tempo at which hazardous projects appear to be conducted. The interviewees referring to the project schedules and their working to tight deadlines reinforced this feature. Finally the important discovery relating to the end users' expectations of the design appears to be a crucial factor. The design end users expect changes to have to be made after receipt of the final design deliverables. These changes may range from clearing "HOLDS" from design documents through to adding design features arising from the HAZOP process, either way the end user appears to be having to make changes after the design is completed.

This chapter is structured in three parts and begins by linking the theme of the 'Individual' with personality and cognitive error.

2.2 Introduction

The seminal work in the field of human error was published by Reason (1990) and is reported by Gray, Sabnani and Kirschenbaum (1993) to be one of the most important works into the study of human error types. Reason's (1990) work brings the study of error into the realms of normal cognition.

Reason's (1990) theory advances error types and error forms that are firmly rooted in a generic performance model of human cognition. The implication of bringing Reason's (1990) hypothesis to the design community is that design errors should be capable of being modelled in a theoretically coherent fashion. Whilst there is a substantial body of well-publicised work that addresses how operators of complex plant are sometimes prone to making critical errors, the same cannot be said for designers. If this study of designer cognitive error is to make a useful contribution to a reduction in design errors, then it must be able to offer some workable generalisations that can eventually be modelled.

To date, little progress has been made in understanding how individual differences affect the safety behaviour of the designer. However, the next chapter starts this process by characterising the content of the Big Five personality traits in terms of potential designer safety behaviour. It is perhaps useful at this stage to define the terms for a design error, since it is rare that a design fails under all envisaged circumstances (Taylor, 2007):

> "A feature of a design which makes it (the design feature) unable to perform according to its specification" (at pg 62)

Taylor (2007) suggests that there are some problems with this definition since for many systems the initial end user specification appears to be inadequate which represents a major hurdle for the designers. However, if the implicit or indirect background of the design specifications do themselves contain mistakes which results in the designer's diverging even further away from the end users' true intentions, the results is that design itself represents a discrepancy between what was intended and what was achieved (Busby, 1999b).

2.3 Generic Error Models

The Norman-Shallice model (Norman & Shallice, 1980) represents a collection of action theories that form the basis for Norman (1981), Reason and Mycielska (1982), and

Reason (1984) to develop further work in this field. The Norman-Shallice model was mainly derived from clinical observations of cognitive errors. The starting point for the Norman-Shallice model is that an adequate theory of human behaviour must address correct performance. Therefore certain more predictable variations in human behaviour are needed in order to derive deviations that correspond to certain types of errors. There have been many attempts to go beyond this statement and build a framework that represents a true pattern of all types of human error.

Historically, human error performance represents a significant component of error types, accounting for nearly 44% of all error forms in the Institute of Nuclear Power Operations (INPO) analysis of 182 root cause events and, 52% of operator errors in 387 root cause events. These root cause events were recorded at nuclear installations between 1983 and 1984. The balance of the root cause events relates to design deficiencies, manufacturing deficiencies, and external causes. To further highlight this issue approximately one third of reported human error incidents in aircraft maintenance activities were as a result of a design deficiency (Daly, Corrigan & McDonald, 1997; McDonald, Corrigan, Daly & Cromie, 2000).

One of the aims of this research has been to affirm that some of the same cognitive qualities found within the work of Norman, Rasmussen, Reason, and Shallice is exhibited by offshore designers. Three surveys (Rasmussen, 1987a; 1987b; INPO 1984) have indicated that simple errors of omission constituted the single largest category of human performance problems. In maintenance-related activities these lapses include those attached to memory and attention. Procedural violations also account for certain types of errors (Daly, Corrigan & McDonald, 1997). Procedural violations are errors that appear to be most closely associated with excursions from prescribed methods.

Reason's (1990) work presents a short taxonomy of virtually all error types and error forms. Reason's conclusion was that these errors are firmly rooted in a generic model of human cognition. Reason's work has also successfully been related to other work in this field (see Rasmussen, 1987a; 1987b). These error types have been considered as outputs from this process that are suitable for consideration in this research. Two error types are described as, errors of omission or forgetting to do something (Reason, 1990), and errors of commission or doing something incorrectly (Sanders & McCormick, 1993; Higgins, 1997). The error of commission category has been further subdivided into three additional groupings, errors of repetition, transmission and substitution.

Table 2.1 Error types and error forms

<table>
<tr><th colspan="2">Error types</th><th>Model reference</th><th>Narrative</th></tr>
<tr><td colspan="2">Errors of Omission</td><td>Reason (1979,1990)</td><td>This error represents a risky protocol because it is the omission of a design feature that would normally be expected to be incorporated The design requirements are embodied in industry codes and standards This form of error can occur when an assumption is incorporated in a design and the designer fails to attach an essential facet of the assumption The initial missing piece of data requiring the assumption is necessary for the design to be considered 'complete'.</td></tr>
<tr><td colspan="2">Errors of Commission</td><td>Sanders & McCormick, (1993); Higgins (1997)</td><td>The incorporation of a design feature that is deemed to be fit-for-purpose but unproven in the new envisaged application is also a risky protocol The designer reuses the previous design that has not been updated to the new application with a strategy of achievement. This usage requires others to check for industry code and standards compliance</td></tr>
<tr><td rowspan="4">Sub groups of Errors of Commission category</td><td colspan="3">Sub groupings</td></tr>
<tr><td>Errors of Repetition</td><td>Busby & Payne (1998)</td><td>A previously successful design feature transposed inaccurately This error form can occur due to the poor exploitation of a designer's skills during periods of under employment and more probably in time-pressure situations</td></tr>
<tr><td>Errors of Transmission</td><td>Kirwan, (1994)</td><td>A design feature added by the designer where the end user needs to be heedful of the risk contained in the design The risk maybe attached to an assumption made by the designer. This form of assumption refers to how equipment will be fabricated and operated. The risk involves incorrect or incomplete interpretation of a design feature. It may include an added design feature that represents a risky protocol because it is a fit-for-purpose solution where interpretation is made by others to decide whether it is correct in the particular application</td></tr>
<tr><td>Errors of Substitution</td><td>Hollnagel, (1993)</td><td>A design feature that is proven but in this case is used in a new way. Applying solutions that are inappropriate but which have worked well in the past also fall within a risky protocol and substitution category</td></tr>
</table>

Reason (1990) provides a powerful examination of all error forms with a clear definition of the various error types and error forms. Reason states that the:

> "Recurrent error forms have their origins in fundamentally useful psychological processes." (at pg 1)

Reason's model presents a very convincing argument that human error generally results from normal cognitive processes and nothing else. Laird, Newell and Rosenbloom (1987) adapted a model based upon similar multiple-task behaviours and mapped these behaviours with human performance. These multi-task behaviours and human performance have been explored in other models. The State Operator and Result (SOAR) (Newell, 1990) and the Executive-Process/Interactive Control (EPIC) models (Meyer & Kieras, 1997a) are two examples. SOAR is a computational theory of human cognition that takes the form of a general architecture Laird, Newell and Rosenbloom (1987), Newell (1990), Rosenbloom, Laird and Newell (1992). SOAR is a major exemplar of the architectural approach to cognition.

Meyer and Kieras (1997b) report considerable success in developing a production rule-based model in the psychological refractory period (PRP) procedure. The PRP paradigm is a basic but important form of information processing where two stimuli are presented either concurrently or in very quick succession. Meyer and Kieras (1997b) indicate that the human response to the first stimuli is generally unimpaired. However, Meyer and Kieras report cognitive error with the second stimuli. Wallace and Chen (2005) argue that individuals prone to experiencing this form of cognitive failure might possess poor self-regulatory skills which allows for the occurrence of interference in dealing with intervening and concurrent stimuli. Heckhausen and Beckmann (1990) had previously argued that in circumstances where concurrent stimuli are received the lack of intervention processes may be responsible for the way that the interference is dealt with by the recipient. However, error types triggered within the PRP appear to form common error types. Reason (1990) had concluded that there are only a limited number of error types that are tied to an underlying, non-error producing cognitive stage. Reason considered two types of error in this form. These error types correspond to the similarity matching error and frequency bias error. Frequency biasing is known to give predictable shape to human behaviours in a wide variety of activities and situations (Norman, 1980; Reason & Mycielska, 1982; Rasmussen, 1982). Examples include errors attached to using designs that have worked well in the past.

The psychological literature quoted in Reason (1990 at pg 98) is replete with descriptions of the frequency bias error form representing: "conventionalisation" (Bartlett, 1932), "sophisticated guessing" (Solomon & Postman, 1952), "strong association substitution" (Chapman & Chapman, 1973), and "capture errors" (Norman, 1981). Bartlett (1932) found that individuals tend to ignore or re-interpret information that contradicts their current understanding. Irrespective of whether or not the consequences are erroneous, the tendency therefore appears to be in favour of gambling on the high frequency alternatives. This approach appears to be a generally acceptable adaptive strategy (Reason, 1990).

This strategy appears relevant in order to deal with issues that contain both a great deal of regularity and in some cases a large measure of uncertainty (Reason, 1990). The Kahneman and Tversky (1979) model of decision-making under risk conditions concludes that individuals tend to underestimate the outcomes that are merely probable compared to outcomes that are obtained with certainty. This tendency is called the 'Certainty Effect'. Kahneman and Tversky's (1979) model is one that contributes to the adoption of a risk cautious position when choices involve sure gains and to risk seeking in choices that involve sure losses. These considerations concerning risk, risk perception and risk modelling are discussed in more detail in Chapter Four.

Behaviours associated with risk-taking may be more complicated than Kahneman and Tversky's simple model implies. For example, a review of other early research on error (Isen & Nehemai, 1987) indicate that where the consequences of failure are rated as high, then individuals who are in a positive mood require a high probability of success in order to take the risk. Whereas, when the consequences of failure appear to be low, then a positive mood appears to be sufficient to increase an individual's option to be a risk-taker.

A usable model of information processing to allow an investigation of behaviour in the risk-taking paradigm is described by Wickens (1980; 1992). Wickens' model involves a series of stages or mental operations. The operations occur between the information initially being received by the individual and the individual actually processing the information. Wickens' (1992) model characterises four discrete stages of information processing namely, Perception, Memory, Decision-making, and Actions and Problem-solving. The third stage and the subsequent ability to take actions at the fourth stage in the Wickens model (1992) constitute a part of the problem-solving model that was also developed by Rasmussen and Jensen (1974) and Rasmussen (1987). Acquainting the available cognitive responses satisfies the approach to the fourth stage and decision-making. Overall, the process represents a search into the core skill-rule-knowledge framework detailed in the following passages (Rasmussen, 1987a; 1987b).

Reason (1990) had argued for a three-fold classification of error types. These were established on a skill-based (action) slip, rule-based mistakes and knowledge-based mistakes basis. This classification neatly corresponded to the three levels in the Rasmussen (1987a & 1987b) framework. Reason's (1990) notion of action slips is fundamentally the same to what Broadbent et al (1982) had named as cognitive failures. A narrative of these three levels is described as follows:

- **Skill-based level**: Human performance is governed by stored patterns of pre-programmed instructions represented by analogue structures in a time-space dimension. Errors made by designers at this level can be related to the intrinsic variability of their work tasks and activities;
- **Rule-based level**: The rule-based level is applicable to tackling familiar problems in which solutions are governed by stored rules of the rule type *diagnostic* or the rule type *remedial*. Here, errors made by designers are typically associated with the

misclassification of situations leading to the repetition of the wrong rule or with the incorrect recall of the right rules and procedures.

- **Knowledge-based level**: The knowledge-based level comes into play in novel situations for which actions must be planned using conscious analytical processes and stored knowledge. Errors made by designers at this level can arise from application of incomplete and substitution of incorrect knowledge.

Rasmussen's major contribution was charting the types of shortcuts that human decision-makers take in real life situations (Rasmussen, 1981). Following Rasmussen (1981), Rouse (1981) distinguished two kinds of problem-solving rules that could also be applied: symptomatic and topographic. These problem-solving rules follow the form *'if'* (as experienced in a situational reality), *'then'* (what to do) is the action to be applied (also see Higgins, 1997). These rules link two schematic components: a stored pattern of information relating to a given problem and the program that is appropriate for governing the corrective action. In this way, the use of learning and performance mechanisms represents a way to explain how errors types can be related in the field of cognitive theory.

For design errors that arise out of the normally adaptive psychological processes it is tempting to argue that slips and mistakes arise from quite different cognitive mechanisms. Reason (1990) asserts that:

> "Slips could be said to stem from the unintended activation of largely automatic procedural routines however, mistakes arise from failures of the higher order cognitive processes involved in

judging the available information, setting objectives and deciding upon the means to achieve them." (at pg 54)

The presentation of data represents exactly the same type of frequency-bias arguments that were derived and supported by Wickens (1992).

Reason (1990) had picked up on this aspect by pointing out that a design error should not be seen as the accident or failure in itself. Reason argued that these types of error precede the actual accident or failure event. The error can become an 'active failure', whose effects are felt almost immediately, as well as a 'latent failure', that are subject to certain pre-conditional states (see Figure 2.1 and the explanations contained in Chapter 1 regarding Reason's Swiss cheese model). The latent failures are adverse consequences that may lie dormant within the system for long periods of time.

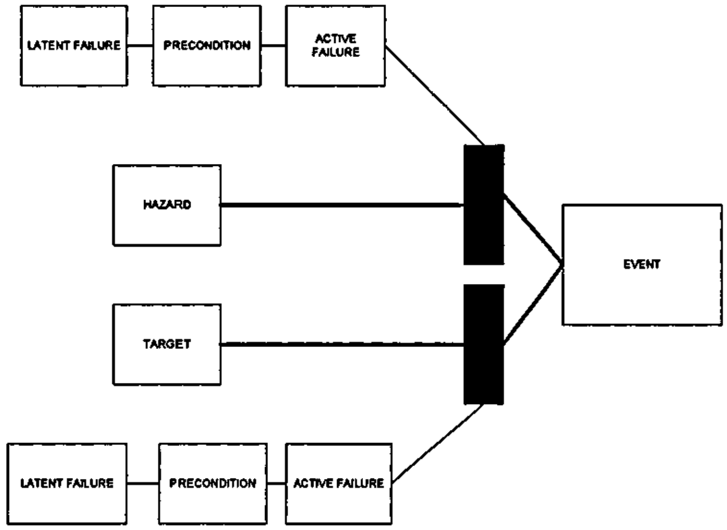


Figure 2.1: The relationship between an accident event and latent errors

These latent failures only become evident when they combine with other factors to each the system defences (Rasmussen & Pedersen, 1984). Reason (1990) maintained that active failure was usually associated with the performance of 'front-line' operators, for example control room operators. Whereas the latent failure was most often generated by individuals displaced from the operational system.

Errors at the skill-based action level, typically take the form of unintended deviations from a pre-planned course of action. The error at the rule-based level can take the form of either a misapplication of a good rule or the straightforward application of a bad rule. The bad rule typically being the one that failed to encode the appropriate stimuli or embrace the appropriate actions that were required or expected. At the knowledge-based level, the performance errors have been shown to include the selective processing of task information by both designers and the end user.

This application is therefore relevant to both the application of design logic and the end users' logic. At this level the inability to examine all the relevant facts within the conscious workplace gives undue emphasis to data that comes readily to mind such as the availability heuristic (Tversky & Kahnemann, 1974). Under these circumstances, the actual route to a solution becomes a missed opportunity creating the greater likelihood of a logic misalignment. Norman (1981) points out that error data examination revealed that errors can be categorised and thus fall into recognised patterns. However, this categorisation and Norman's (1981) subsequent interpretation was shown to be theory dependent and would need to be validated in the case of the designer.

The following table summarises the error models referred to in this Chapter.

<u>Table 2.2: A definition of the Error model</u>

Error model	Reference	Definition
Information processing model	Wickens (1980, 1992)	Characterised by 4 stages of information processing· Perception, memory, decision-making and actions and problem solving
Skill-rule-knowledge framework	Rasmussen and Jensen (1974), Rasmussen (1987).	Skill based actions typically take the form of unintended deviations from a pre-planned course of action Rule-based actions take the form of misapplication of a good or straightforward application of a bad rule. Knowledge-based actions include the selective processing of task information
Three fold classification model	Reason (1990)	Skill-based errors, rule-based errors and knowledge-based errors Latent and active failure types also see Rasmussen and Pedersen, 1984 Active failures are usually experienced by front-line operators and latent failures can occur in design
Learning and performance model	Rouse (1981)	Symptomatic and topographic forms based on situational reality.
SOAR	Laird, Newell and Rosenbloom (1987), Newell (1990), Rosenbloom, Laird and Newell (1992)	SOAR is a major exemplar of the architectural approach to cognition It is a computational theory of human cognition and has an application to explaining why designers may take certain decisions
EPIC (Executive-Process Interactive Control)	Meyer and Kieras (1997a)	Considerable success in developing a production rule-based model of the Psychological Refractory Period

The implications of reappling any of these error models is that the application should be capable of yielding results that provide an extension of an already accepted human performance model. In addition, cognitive errors associated with such factors as multi-tasking, concern and boredom have also been shown to affect self-regulatory style as an outcome of risk related behaviour (Robertson, Manly, Andrade, Baddeley & Yiend, 1997). Kanfer and Ackerman (1996) related the regulatory skill perspective to workplace cognition in order to reflect the component of task behaviour. Off-task cognition and behaviour demonstrated by Kanfer, Ackerman, Murtha, Dugdale and Nelson (1994) were shown to divert attention away from the task and hence work specific cognitive errors were shown to be highly significant with the off task activity.

An approach built upon the methodology employed by Card, Moran and Newell (1983) can also provide a general workable solution. Card et al (1983) used a methodology in a similar way to how design information handling processes are addressed. The Card et al (1983) methodology can also be applied and draw upon the benefits of the HAZOP intervention method (Kletz, 1972; Lees, 1980). Different types of error have been related to human attention and sustaining attention, memory, intervention and certain organisational routines. These routines have not only been considered in an application of technical systems (Reason, 1990; Wagenaar, Hudson & Reason, 1990) but to broader and more diverse applications.

The presence of the error types appears to occur through the designer anticipating how the end users should adapt to new technology (Sharit, 1998). Sharit's observation reinforces the discrepancy already noted in Chapter One between design logic and the end user logic. Busby, Chung and Wen (2004) suggest that the designer may tend to emphasise dispositional explanations rather than situational ones when explaining such discrepancies. This attribution suggests bias and the greater salience of information about people than information about situations (which follows on from Feldman, 1981). This notable conclusion was also drawn by Kvitrud, Ersdale and Leonhardsen (2001). Kvitrud et al, (2001) indicate that designers tend to under estimate actual failure rates because they ignore or neglect to account for a component that is human error.

2.4 Summary

This chapter has investigated several human error models summarised in Table 2.1 and 2.2. The explanation provided by Reason (1990) three fold classification models appears to offer the most theoretically sound basis upon which describe the latent nature of design error types. The next chapter, Chapter Three, focuses upon individual personality differences and the rationality attached to certain behaviours and how they may account for mistakes and errors.

CHAPTER 3

Personality traits and other factors influencing Safety Behaviour

3.1 Introduction

In Chapter Three the themes of personality and individual differences are introduced and discussions on the leading theories and definitions of personality are made. A review of design process literature discloses that certain personality differences (e.g. agreeableness and conscientiousness) are related to the design behaviours of conceptualisation and elaboration by engineers (Peeters, 2006), when the engineer is placed in a organisational setting (Baird, Moore & Jagodzinsky, 2000; Peeters, 2006; Valkenburg, 2000), and by engineering students being evaluated for their design team performance (Madara & Gul, 2006) when set in an educational environment.

There are a number of influential models that have evaluated individual personality differences when forming engineering design teams and the evaluation of the engineers design performance (Shen, Prior, White & Karamanoglu, 2007). These instruments include the Keirsey Temperament Sorter II (KTS II) and the Myers-Briggs Type Indicator (MBTI). There is another model that is significant in providing a comprehensive account of individual personality differences and this is Goldberg's Big Five (1999). Shen et al (2007) analysed the sixteen MBTI personality types and concluded that only eight types were best suited to the area of engineering. These included the fields of creativity, intuition and learning styles that are all captured in the adjectives describing the Big Five (Goldberg, 1999). There are other competing models that assess personality differences which include the NEO-PI-R (Costa & McCrae 1992), 16PF (Conn & Rieke, 1994), and the HPI (Hogan & Hogan, 1992). The Big Five (Goldberg, 1999) has already been used by other researchers, in particular Wallace & Chen (2005), into explaining how cognitive error and the differences between those individuals who are more or less likely to be accident involved maybe due to their cognitive errors. This chapter holds implications for designers, design teams and particularly significant in predicting certain design behaviours, such as commiting design errors and risk-taking in the design process, due to individual personality differences.

3.2 Three factor or five factor personality

The theoretical debate surrounding personality traits and individual differences can trace their origins back to the influential works of two Twentieth Century researchers, Eysenck and Cattell. Eysenck (1947) and Cattell (1950) presented analytical techniques for modelling personality traits. Generally, most personality researchers accept that personality has three basic components (Krahe, 1992) namely that:

1. Personality reflects individual uniqueness;
2. Personality in adulthood is enduring and therefore relatively stable;
3. Personality and its reflection in behaviour are determined by dispositions assumed to reside within the individual.

Underpinning these theoretical constructs of personality are three general features (Krahe, 1992):

1. In order to capture the uniqueness of an individual's personality, it is necessary to identify and seek consistent differences between individuals. These differences should apply across different situations and over time;
2. To demonstrate the stability and endurance of personality, evidence of intra-individual consistency is required;
3. To explain individual behaviour, as residing within the individual, it is essential that the disposition can be shown to shape behaviour consistently and reliably in different situations.

Thus, personality appears to be linked to consistency. This consistency is mainly determined by stable enduring inherited qualities, referred to as internal factors, and experience or external factors such as childhood experiences (see McCrae & Costa 1987; Saucier & Goldberg 1998). Determining whether it is these internal or external factors that characterise a hazardous installation designer's behaviour should enable a degree of theory development to take place in this study. Eysenck, Arnold and Meili (1975) provide, in the following passage, a workable definition of personality that is a reference point for this thesis:

> "Personality is the relatively stable organisation of a person's motivational dispositions, arising from the interaction between biological drives, and the social and physical environment. The term usually refers chiefly to affective-connative traits, sentiments, attitudes, complexes and unconscious mechanisms, interests and ideals, which determine man's characteristics or distinctive behaviour or thought" (Volume 2 of 3, at pg 383).

For the purposes of this study a trait is defined as a temporally stable, cross-situational individual difference (Kassin, 2003). Kassin (2003) also refers to personality as the emotions, thoughts, and behaviour patterns that distinguish the individual. This section investigates whether these behaviour patterns have dimensions that can be used to predict, not only important life outcomes, but in the context of this research, certain behaviours in the designer and their proneness to cognitive errors and design mistakes. Lajunen (2001) already suggests that different dimensions of personality, for example conscientiousness are associated with safe behaviour, but not necessarily with risk-taking and accident history. Peeters (2006) and Peeters, Rutte, van Tuijl and Rymen (2008) suggest that agreeableness and conscientiousness is significantly related to generic design behaviours and the realisation of a design's technical goals.

A three factor typology developed by Eysenck, (1947) proposed a basis for understanding certain dimensions of personality. The relations between the Eysenck's three dimensions of extraversion, emotional stability and tough-mindedness have been reported in other subsequent studies that include the work of Costa and McCrae (1980), Kendell, Mackenzie, West, McGuire and Cox (1984), Kirkcaldy (1984), Emmons and Diemer (1986) and McCrae and Costa (1987). Eysenck's theory is based upon the examination of behavioural habits and argues that individual differences emerge from our genetic inheritances.

An alternative model comprises of the five dimensions of extraversion, emotional stability, agreeableness (reverse of tough mindedness), conscientiousness and openness-to-experience (see Goldberg, 1999). The debate between three and five factor approaches (see Goldberg, 1999) to understanding personality has been, perhaps the largest in all individual difference research, and for a good reason. These two particular approaches are in many ways identical. Both the three factors and five factor approaches use hierarchical factor analysis and the traits themselves are described as continuous, bipolar dimensions of personality. Questionnaires are used to capture the essence of the Big Five traits, where the emphasis is on taxonomy yet the differences between these two approaches, the three factor and five factor models, are subtle ones.

Contrasts can be made between the answering style in the respective questionnaires, the organisation and number of the lower-order factors. The emphasis of Eysenck's three factor approach is that it condenses more into less. However, perhaps the most marked difference between Eysenck's approach and the five factors is that of causality. The five factor approach focuses on taxonomy and suggests that both nature and nurture are important causal factors. By contrast, the three-factor approach assumes the differences arise from physiology that is defined by our genetics. For individual differences, the five factor approach is probably operationally better. It assumes the existence of more liberal causal factors which are necessary when considering the comparatively small sample population of designers of hazardous installations in this study. However, such a selection would never have been possible without the work into the three factor approach conducted by Eysenck (1947). The five factors were derived from factor analysis of a large number of self-reports and peer-reports on personality-relevant adjectives and questionnaire items (see Goldberg, 1999). Table 3.1 describes the five personality dimensions and offers some prototypical characteristics that maybe attached to designers, their associated characteristics and expected demonstrations of behaviour. This list also includes some illustrative adjectives that are associated with the general types of safety behaviour associated with designers (McCrae & Costa, 1989; Mount, Barrick, & Strauss, 1994; Hogan, 1991; Goldberg, 1999). Table 3.1 presents the five major personality types: 'conscientiousness', 'extraversion ', 'agreeableness, 'emotional stability' and 'openness-to-experience' and section 3.3 expands some of the tabled definitions in further text in order to elaborate on the concise listing in Table 3.1. In consideration of these illustrative characteristics that are attached to the five personality dimensions there are certain characteristics attached to other recognised behaviour patterns.

Table 3.1: Dimensions of personality and their characteristics

Dimension	Prototypical Characteristics	Illustrative Adjective	Cognitive correlates	Safety Related Behaviour correlates
Conscientiousness	Responsible Dependable Able to plan and organised	Organised; Systematic, Thorough; Hardworking; Neat, Compliant	Low in conscientiousness focuses on satisfying immediate needs and failure to follow rules, suggesting individuals are more vulnerable to cognitive failures	Low scores on conscientiousness are significantly associated with accidents and poor safety behaviour
Extraversion	Sociable Assertive Active Tendency to experience positive emotions	Gregarious, Energetic,	High extraversion results in a reduction in task performance under monotonous or repetitious conditions	Individuals with high extraversion have significantly lower in levels of vigilance, less involved in task execution and more liable to take risks
Agreeableness	Co-operative Trusting	Sympathetic; Warm; Tactful, Considerate	Low agreeableness implies an inability to cooperate effectively increasing likelihood of failures	Low agreeableness is associated with increased accident involvement
Emotional stability	Calm Secure	Relaxed; Stable, Confident, Effective,	Low emotional stability results in acute reactions to stressors, decreasing cognitive resource and increased error probability	There is a positive relationship between distract-ability and increased accident liability
Openness to Experience	Imaginative Intellectual Need for variety	Intellectual, Creative, Artistic; Imaginative, Original, Curious	High in openness the imaginative, curious and unconventional individual may be more liable to experimentation and improvisation	High in openness involving tasks where safety compliance is critical individuals may be more liable to rule violations

3.3 Individual Personality Differences

The personality literature (McCrae & Costa, 1989; Mount, Barrick, & Strauss, 1994; Hogan, 1991; Goldberg, 1999) provides a fuller description of the five major personality dimensions of conscientiousness, extraversion, agreeableness, emotional stability and openness-to-experience; these are presented in the following sections. The discussion includes a critique of the associated safety behaviours and accident prone characteristics that have been correlated with the individual difference types. These narratives develop the basis of an interpretation into what high or low scores in each trait may mean. These narratives also aid the interpretation of the exploratory factor analysis (EFA) results that are presented in Chapter Nine.

3.3.1 Conscientiousness

Conscientiousness concerns the way in which an individual controls, regulates, and directs certain impulses. Previous meta-analyses (Barrick & Mount, 1991) show a tendency for individuals with high scores in conscientiousness to report consistently well across certain job performance for example safety performance. There is also evidence reported by Clarke and Robertson (2005) that suggests conscientiousness has a role to play in safety performance (Arthur & Graziano, 1996; Cellar, Nelson, York & Bauer, 2001). The benefits of high levels of conscientiousness in a high hazard industry are obvious. Conscientious individuals avoid trouble and achieve high levels of success, through purposeful planning and persistence in completing tasks. These individuals tend to be positively regarded by others as intelligent and reliable. On the negative side, they can be compulsive perfectionists and workaholics, that goes some way to explaining the persistence of the high hazards sector to using the just-in-time schedule to complete work tasks (Lienert & Raatz, 1994). Other definitions attached to conscientiousness include a number of different aspects involving competence, order, dutifulness, achievement and deliberation.

As a personality dimension, conscientiousness reflects dependability, personal organisation and compliance and has been shown to predict job performance in a variety of different occupations (Stewart, 1999). There is evidence from several relevant personality trait studies that relate low scores in conscientiousness to be significantly associated with accident involvement (Wallace & Vodanovich, 2003; Wallace & Chen, 2005). Designers more prone to cognitive errors and less likely to take design risks should record the same low conscientiousness scores.

3.3.2. Extraversion

Extraversion is marked by pronounced engagement with the external world. Several empirical studies have supported a positive relationship between extraversion and accidents (Powell, Hale, Martin & Simon, 1971). Powell, Hale, Martin and Simon (1971) indicate that the differential affect attached to the extravert accounts for the difference between a shy and quiet individual and those who are their more out-going counterparts. Extraverts enjoy being with people, they are full of energy, and often experience positive emotions. In groups, the extravert likes to talk, draw attention and assert themselves. Conversely, introverts lack the exuberance, energy, and activity levels of the extravert. The introvert tends to be quiet, low-key and deliberate and appear less dependent on the social world. This lack of social engagement should not be interpreted as shyness or depression; they simply need less stimulation than the extravert. According to Arthur and Graziono (1996) the extravert is significantly more accident involved, although Clarke and Robertson (2005) report that other studies that have found just the opposite effect to exist (Pestonjee & Singh, 1980; Roy & Choudhay, 1985). The mechanism by which extraverts may have a higher accident liability is unclear. Eysenck (1962) offered an explanation that rests in the extravert's potentially lower level of vigilance. The extravert may also be less involved in task execution and therefore more liable to make mistakes that lead directly to their involvement in accidents. In particular, there is evidence to support a reduction in task performance under monotonous or repetitious conditions. Translating these behaviours into those likely to be demonstrated by the extraverted designer suggests that they maybe more prone to errors and mistakes and more likely to take significant design risks.

3.3.3 Agreeableness

Agreeableness reflects an individual difference that involves co-operation and the aim within agreeable individuals to achieve social harmony. Agreeable individuals value getting along with others and are seen as considerate, friendly, generous, helpful, and willing to compromise their interests. There is some empirical evidence to support a negative relationship between agreeableness and accident involvement (Cellar, Nelson, York & Bauer, 2001), although other studies have shown no such association (Arthur & Graziano, 1996).

Agreeableness is most salient in situations that involve interaction or co-operation with others (Barrick & Mount, 1991). Agreeable individuals are seen as having an optimistic view of human nature. The agreeable individual believes people are basically honest, decent and trustworthy. The disagreeable individual places self-interest above getting along with others. These individuals are generally unconcerned with others' well-being, and therefore are unlikely to extend themselves to assist others. Occasionally the disagreeable individual is sceptical about others' motives, causing them to be suspicious, unfriendly and uncooperative. Agreeableness is obviously advantageous for attaining and maintaining popularity. Agreeable people are better liked than disagreeable people. On the other hand, agreeableness is not useful in situations that require tough or absolute objective decisions. Overall, the literature implies that aspects of low agreeableness are associated with increased accident involvement. The agreeable designer is likely to take fewer risks and commit fewer errors.

3.3.4 Neuroticism and emotional stability

A large number of studies have shown that there are clear associations between neuroticism and measures of negative affect e.g. anxiety (Costa & McCrae, 1980; Emmons & Diener, 1985, 1986a, 1986b; Tellegen, 1985; Warr, Barter, & Brownbridge, 1983; Watson & Clark, 1984, 1992). For example, Costa and McCrae (1980) found that neuroticism predicted negative affect in everyday life, and that these associations were held over extended periods. On the basis of this relation Costa and McCrae (1980) and others, have proposed that neuroticism represents the trait of the temperamental personality dimension as one that predisposes the individual to negative affectivity (McCrae & Costa, 1991).

Neuroticism, also known inversely as Emotional Stability, refers to the tendency to experience negative emotions. Individuals who score high on neuroticism may experience primarily one specific negative feeling such as anxiety, anger or depression. They are more likely to experience several of these emotions. Individuals high in neuroticism are emotionally reactive. Research shows that individuals high in neuroticism will be more accident involved (Eysenck, 1970). They respond emotionally to events that would not affect most people and their reactions tend to be more intense than normal. The neurotic is more likely to interpret ordinary situations as threatening, where even a minor frustration appears hopelessly complicated and difficult. These negatively emotional reactions tend to persist for unusually long periods of time, which means they are often found to be in a bad mood. These problems in emotional regulation can diminish the neurotic's ability to think clearly, make decisions and cope effectively with stress. At the other end of the scale, individuals who score low in neuroticism are less easily upset and are less emotionally reactive. They tend to be calm, emotionally stable and free from persistent negative feelings. Freedom from negative feelings does not necessarily mean that low scorers experience a lot of positive feelings. The frequency of positive emotions is a component of the extraversion domain.

Hansen (1989) suggests that the increased accident liability of neurotics maybe due to their distract-ability. Further explanation of this mechanism linking emotional stability to low accident rates may be related to a response to stress. Acute reactions to stress include higher levels of anxiety and fatigue. The result of higher levels of anxiety and fatigue mean decreased cognitive and performance capacities, such as reaction times and judgement. Higher levels of anxiety and fatigue also mean an increased probability of errors being made (Steffy, Jones, Murphy & Kunz, 1986). Correspondingly, the designer scoring high levels of emotional stability should be less prone to taking high risks and making mistakes.

3.3.5 Openness-to-Experience

Meta-analyses (Barrick & Mount, 1991; Salgado, 1997) have supported a relationship between openness and training proficiency. This implies that individuals scoring high in openness are associated with a positive disposition to learning (Clarke & Robertson, 2005). Within the high hazard industry, where safety compliance is critical, the imaginative, curious and unconventional individual may be more liable to rule violations, experimentation and improvisation. Openness is heritable, although Bandura (1997) suggests that one environmental cause of increased openness appears to be through exposure to tertiary education. Openness-to-Experience describes a dimension of personality that distinguishes imaginative, creative people from conventionalists. Open people are intellectually curious, appreciative of art and sensitive to beauty. The open individual tends to hold unconventional and individualistic beliefs, although their actions may be more conformist.

Individuals with low scores on Openness-to-Experience tend to have narrow, common interests. They prefer the plain, straightforward and obvious over the complex, ambiguous and subtle. They may regard the arts and sciences with suspicion, regarding these endeavours as abstruse or even of no practical use. Closed people prefer familiarity over novelty, they are conservative and resistant to change. Therefore theory suggests that designers scoring high levels of Openness-to-Experience are more likely to experiment when problem-solving (Costa & McCrae, 1980). Experimentation may involve the use of trial and error techniques. Although it is unclear whether an individual demonstrating these traits are good decision makers, there appears merit in testing this idea in the design setting to establish the safety implications that trial and error carries.

3.4 Summary

The personality traits are known to exist because they are the highest-level factors of a hierarchical taxonomy. This is based upon the statistical technique of factor analysis. The resulting factor analysis on lower-order traits appears to be product of a factor analysis on habits. These habits appear to exist because of an individual's behaviours. Indeed, such methods produce factors that are continuous, bipolar and can be distinguished from other states that describe individual differences (Goldberg, 1993). The three factor and five factor approaches used self reporting questionnaires to try and capture the top-level factors by means of the lower level habits. There are organisational differences between the two models. The three factor model has the three top-level factors that are intended to be orthogonal (Eysenck, 1990). An explanation of the orthogonal rotation method is presented in Chapter Nine. Eysenck (1992a) argued that fewer factors were superior to a larger number of partly related ones. The five factor model has been criticised for corrupting the orthogonal relationships by allowing the five factors to correlate (Block, 1995; Draycott & Kline, 1995), but remains the model of choice for this study. Thus, the two approaches are comparable because of the use of factor analysis to construct hierarchical taxonomies.

Chapter Four

The Individual perceptions of risk

4.1 Overview

The aim of this chapter is to examine some of the foremost issues surrounding the underlying factors of risk-taking. These discussions are orientated around the Slovic, Fischoff and Liechtenstein (1982) examination of risk and uncertainty.

4.2 Introduction

Almost all previous major studies on acceptable risk have fallen within a framework that offers two points of view (HSE, 1989a; 1989b; 1992; Ministry of Housing, Land Use Planning and Environment, 1988; Schofield 1993; 1998). One view relates to when the individual decides to undertake an activity by weighing the risk against their direct and indirect personal benefits. The alternative point of view is the collectivist view where society decides whether the same risk-benefit trade-off should be acceptable to society as a whole (Vrijling, van Hengel & Houben, 1998; Jonkman, van Gelder & Vrijling, 2003).

There is one axiom that underlies any design for uncertainty which states:

> "There exists a serious trade-off between designs aimed at preventing failure and designs that respond and survive when that failure occurs (Holling & Clark, 1975)" quoted in Holling (1978 at pg 138).

To conduct such a risk-benefit trade-off and remove any vagueness from the process requires the application of the classical positivist view of risk. This exists through the objective measurement of risk. This position is one that contrasts with the Bayesian view where the risk paradigm is seen as just another way of expressing uncertainty (Shrader-Frechette, 1991; Schofield, 1998).

There are three classes of uncertainty to be considered in any evaluation risk (Schofield, 1998). Firstly, where there are direct effects with a known probability of occurrence. Secondly, where the effects are imaginable and are at least partially describable, for example the outcomes of a nuclear failure, and finally where the process is both unknown with unknown outcomes.

This research considers the notion that risk is indeed informed within such a framework of objective measurement informed by social attitudes and perceptions. If this process treats the social attitudes to risk as just a simple functionalistic extension of societal opinion, does it envisage alignment to the ones held within everyday social institutions? Examples of the types of social institutions in question include those associated with housing and employment. This level of functional attainment being as the theorist Montesquieu (1689-1755) had suggested, as one where the social institutions are moulded by social histories, and reasoned that this included social order. From the Montesquieu perspective social order sustained people's attitudes.

Moulding the present day designer's views of risk are their perceptions of the modern day risks. These perceptions should be based upon the likely threat from the technologies that they employ and treated as a reaction to the widely publicised views expressed as public opinion. Turner (1991) already considers culture to possess a technical aspect and thereby regarding the design environment in socio-technical terms rather than in a pure social or psychological application.

4.3 Characterising risk using cultural preference models

The study of Starr's (1969) work on the social benefit and the technological risk issue represents, in many ways, a view on the economic theories of choice. Starr's tenet is that in establishing the equilibrium between risk and its benefits the process becomes an iterative one, subject to many trials and tribulations. By its very nature, the process of trial and error becomes a utility of social agreeableness. The mechanisms attributed to social agreeableness are used to reveal the groups, who are engaged in the trial and error process, and their social preferences. By establishing exactly what the actual level of acceptable risk should be, the designer can then take the right decision on how to tackle risk through applying these social preferences. Establishing the levels of risk also determines which technologies are appropriate to the application. The investigation into such implicit preferences associated with risk saw Starr (1969), seeking to demonstrate, that risk acceptance differed between individuals.

Firstly, that for the hazards to which lay people, in this case members of the public, are involuntarily exposed, a comparison needs to be made with those who take the same risk voluntarily. The choice appears to be either a fundamentally socio-political one (Lindblom, 1977) or a socio-economic (Williamson, 1975) representation.

Furthermore, if theoretical and actual differences between the perceptions of risk can be shown to exist between the groups of designers, then agreement on what risk-decisions need to be taken should be demonstrable. The development of mental models of risk perception, with their associated benefits, can improve the understanding of risks and add clarity to this debate (see Jungermann, Schutz & Thuring, 1988; Bostrum, Fischhoff & Morgan 1992; and Bostrum, Altman, Fischhoff & Morgan, 1994).

Any investigation into risk should examine the repeatability of some already established findings that have been made in the same or a similar context. Work on risk perception by Pidgeon, Hood, Jones, Turner and Gibson (1992) provides this backdrop. The work by Pidgeon et al (1992) lent heavily on earlier work conducted by Slovic, Fischoff and Liechtenstein (1982). Slovic et al (1982) work addressed the social attributes of risk decision making. The psychometric tradition and cultural treatment of risk attached in these works by both Slovic et al (1982) and Pidgeon et al (1992) are unified in the social amplification framework that was later developed by Kasperson (1987, 1992).

Kasperson's model indicated that an adverse event, such as a major accident, for example Piper Alpha (HMSO, 1990), acts as a trigger to individuals and groups of individuals engaged in identical pursuits in either the same or an equivalent sector of industry. This triggering effect then results in a correspondingly large increase in the perceptions of risk. The issues surrounding risk judgement lead onto the relevance of the key findings in the original work undertaken by Slovic et al (1982).

Slovic et al (1982) revealed that people denied uncertainty and misjudged risk by either an over or underestimate. This situation occurred when their views were being compared with those opinions held by experts. The studied population (according to Slovic et al, 1982) also demonstrated unwarranted confidence in their perception of the facts. This misplaced confidence was recognised by Slovic et al (1982) as the cause of the over or underestimate of risk. Slovic et al (1982) found two dimensions of risk. The dimensions, in terms of technological risk, were measured through reactions to the concepts of dread and unfamiliarity. The first factor 'dread' was labelled by Slovic et al (1982) so as to relate to judgements on scales that included uncontrollability, fear and the involuntariness of the exposure and the inequitable distribution of risks. Other adjectives that can be attached to 'dread' include immediacy, control, newness, scale, psychological pressure and severity.

The second factor, 'unfamiliarity', Slovic et al (1982) related to judgements on the observability of risks. This aspect covered whether the effects were delayed or not, the general knowledge of the risks and any overall familiarity with the risk. Pidgeon et al (1992) concluded that the 'dread' factor was more important because the respondents in Slovic et al (1982) work were not satisfied with the principle behind the risk benefit trade-off mechanism. This trade-off had been assumed by Slovic et al (1982) in their revealed preferences approach. Slovic (1987) later noted that the expert assessments were similar with their earlier reported results in Slovic, et al (1982).

There were significant correlations reported between the factors being measured in the Slovic et al (1982) model. These correlations were attached to the views held by the expert and lay person. Liechtenstein, Slovic, Fischoff, Layman, and Combs (1978) conducted a survey on 40 different hazards and asked lay persons to judge the annual mortality frequency attached to these hazards against the anchor point of motor vehicle deaths. The motor vehicle mortality rate was supplied. The respondents overestimated the number of deaths from infrequent causes and underestimated the number to deaths from frequent causes. The lay persons corresponding perceptions of the risk emerged alongside how they related risk to the likely benefits that they were to receive. This illustrates that the differences and similarities between expert and lay perceptions might be more subtle than at first thought.

The simplest interpretation to apply would reflect upon whether the risk construct generates different attitudes towards risk from different designers. Therefore, examining risk perception in terms of the designer sample group is hard to ignore. Other research into the influence that situational factors have upon risk-taking has been based upon the important prospect theory (Kahneman & Tversky, 1979). Mowrer (1960) proposed that the fundamental principle underlying motivated learning was regulatory anticipation by approaching the desired end state and avoiding the undesired state. Kahnemann and Tversky (1979) considered these desired (gains) and undesired (losses) and their model of risk decision-making concludes that individuals tend to underestimate the outcomes that are merely probable, compared to outcomes that are obtained with certainty. Kahneman and Tversky (1979) have illustrated that decision-making behaviour was influenced by relative perceptions of loss and gain. For example, people take or avoid risks to achieve goals that are seen as consistent with their character. To further illustrate this point, Zuckermann (1994) highlights extraverts as being risk-takers because of a generalised need for sensation.

Kahneman and Tversky's (1979) model is one that contributes to the adoption of a risk cautious position when choices involve sure gains and to risk seeking in choices that involve sure losses. These risk-taking positions have been discussed by Johnson and Tversky (1983) and Stallen and Tomas (1988), where experts were shown not to be immune from biases of judgment, for example over confidence in their own predictions.

Kates (1971) discovered that experience of past events seemed to exert the most influence on the personal persuasion or accuracy of perception and hence personal confidence in the ability to predict future events. Linking threat reduction with prior experience may reflect upon the designers' desire to recall perceived 'good' practices that have worked well in the past.

In summarising this literature, the search suggests that there is a suitable mental model which risk decision-making can be made. The entry point for determining the designer's risk decision-making in this mental model involves understanding the process attached to the rationality for adopting risk.

4.4 The Engineering approach

The risk analysis process is used to support and inform the designer's decision-making throughout a hazardous installations design (Lees, 1980; HSE 1992a; 1992b; 2005). The analyses cover hazard identification, cause analysis and consequence analysis. In cases where there is significant uncertainty attached to either the cause or consequence in the analysis, it is not unusual for the risk treatment to include either a cost-benefit or cost-effectiveness assessment of the options under consideration (HSE, 1992a & 1992b).

The aim of this cost related measure is to ensure that the modified risk is being considered within an appropriate framework. In this framework, the designer judges the individual and collective implications of avoiding, reducing, transferring and retaining risk. This judgment is based upon certain institutional determinants. These institutional factors are placed within a framework that involves the social preferences described by Starr (1969) and the modern day hazards discussed by Aven and Kristensen (2005). Engineering risk judgment therefore appears to be complicated by social culture. The following table details five of the most familiar models for determining the acceptable levels of risk that are applied to engineering designs.

Table 4.1: The Risk model through five stages of acceptability

Risk Model	Commentary
Nationally acceptable level of risk	The determination of the socially acceptable level of risk starts from an assumption that the accident statistics reflect the result of a social process of cost-benefit appraisal. If these statistics reveal the preferences, then a standard can be derived from them. To establish the norm for the acceptable level of risk for engineering structures, it is more realistic to base the probability of a fatality due to a non-voluntary activity, for example upon a member of the public. Relatively frequent small accidents appear more easily accepted than one single rare accident with large consequences (Slovic, Lichtenstein, and Fischoff, 1982).
Socially acceptable level of risk	The basis of this framework with respect to societal risk is an evaluation of risks from certain activities that are conducted at a national level. The risk at a national level is an aggregation of all the risks attached to the activities at the local level where local people are impacted. It therefore seems preferable to start with risk criteria set at a national level, and then evaluate the opinions at a local level by considering the total population of hazardous installations and people in close proximity to them.
Personally acceptable risk	The smallest component of the socially acceptable level of risk is the personal cost-benefit assessment The fact that the actual personal levels of risk connected to various activities have been shown to be statistically stable over the years (HSE and DETR 2000) and that in the UK the majority are approximately equal to that of the rest of Western society indicates a consistent pattern of preferences
Locally acceptable level of risk	This perspective is viewed as the translation of the nationally acceptable level of risk for one single installation being dependant upon the distribution of casualties arising from the full range of accident events experienced by these types of installation and the likelihood that they will be repeated
Economically optimal level of risk	The problem associated with the acceptable level of risk can be formulated as an economic problem. The expression of the safer systems can be equated with the gains made by decreasing the present value of risk.

By considering the roles delegated by society to the national policy makers, these models inform the public's expectations on risk. These models also illustrate how the risks are to be managed at different stages and at different levels. Therefore, in terms of item development within a model describing risk perception, exploring individual reactions to dread and unfamiliarity appears to be appropriate in relation to social preferences.

Chapter Five

Control variables of Job Characteristics

5.1 Overview

In the context of project structures it has been noted that Joyce and Slocum (1984) insist upon some consensus amongst employees about certain organisational factors in order to make task completion more successful. This research has related these organisational factors to be the designer's job characteristics

5.2 Introduction

In order to set the orientation of this section, it is appropriate to describe why job characteristics are being considered in relation with the design of hazardous installations. Whilst there are a large number of different job characteristics, this study has focussed on those that have been most extensively researched, are more clearly understood and hence are more generally accepted (Barnett & Brennan, 1995; Breaugh, 1985; Caplan, Cobb, French, Van Harrison & Pinneau Jnr., 1975; Daniels & Guppy, 1995; Hackman & Oldham, 1975; Kahn, Wolfe, Quinn, Snoek, & Rosendahl, 1964). The primary characteristics that have been selected are an adaptation of Warr's (1987) factors. These emerged as important factors because of the way that the work domain influences job performance (Warr, 1987).

Warr's (1987) job categories included a variety of factors that provide the opportunity for control, the opportunity for skill use, meeting demands, and attaining role clarity. Leadership (Dieterly & Schneider, 1974), organisational climate (Campbell, Dunnette, Lawler & Weick, 1970) and job design (Hackman & Oldham, 1976) have also been considered because they represent plausible aspects to mediate design error and the designer's use of risky design protocols.

5.3 Job Autonomy

Hackman and Oldham (1975) define autonomy as:

> "The degree to which the job provides substantial freedom, independence and discretion to the individual in scheduling the work and in determining the procedures to be used in carrying it out" (at pg 162)

The importance of job autonomy, as a key job characteristic, is supported not only by the traditional organisational literature (Griffin, 1981; Sutton & Rousseau, 1977) but also by several experiments where job characteristics have been modified (Cummings & Molloy, 1977). Cummings and Molloy (1977) found that the most frequently altered of all the organisational variables was job autonomy. Kiggunda (1983) revealed the importance of being able to differentiate between job autonomy and independence. Kiggunda (1983) also demonstrated that there is value in distinguishing between job autonomy and task interdependence and independence. The benefits reflect the theoretical improvements that can occur when the facets of job autonomy are clearly distinguished and decision latitude is available.

Turner and Lawrence (1965), Hackman and Oldham (1975), Sims, Szilagyi and Keller (1976) have all discussed job autonomy in terms of distinguishable features such as work schedule and work procedures. Since job autonomy appears to reflect the ability to independently set the work schedule and the work procedures, it is important to consider if designers retain this mode of self determination. Breaugh (1985) focused specifically on measurement issues relating to job autonomy by considering two common instruments (Hackman & Oldham, 1975; Sims, Szilagyi & Keller, 1976) and their construct validity. Breaugh (1985) determined that job autonomy appeared delineated in terms of three distinct facets. These facets include scheduling work, work procedures and work acceptance criteria.

Sutton and Rousseau (1977) link job autonomy with these important variables that encapsulate job performance, and relate them to work satisfaction and behaviour. Others (Dieterly & Schneider, 1974) viewed autonomy, not only in terms of a work schedule and procedures, but in terms of work criteria, for example performance standards, goals and objectives. For designers scheduling represents planning and the design logic links that bind their work program with the end users acceptance criterion. The designer's procedures are built upon design guides, rules and procedures and the quality and compliance tests that meet with the requirements of codes and standards. The use of criteria within job autonomy applies when setting the design logic and the conditions under which decision-making takes place. Chung (1977) discussed autonomy in terms of the individual being able to determine their own work method, rate of task completion, and their control over schedule.

Whilst solving design problems involves a degree of uncertainty, the best solution to a problem may not become clear until more than one solution has been tried. In this sense, complex problem-solving demands involve an element of operational uncertainty (Wall, Cordery & Clegg, 2002). Under these conditions, it has been suggested that not only does job control allow designers the flexibility to implement novel solutions, but in turn it increases aspects of 'on-the-job' learning and most essentially, increased degrees of team support (Wall et al., 2002). From the cases examined in Chapter One, the job design tasks range from simple and repetitive activities up towards an orientation where the individual needs to respond to much more intricate problem solving.

From the present review of literature (Hackman & Oldham, 1975; Kiggunda, 1983; Turner & Lawrence, 1965) specifying autonomy as an explanatory variable may lead to further theory development and aid the organisational intervention efforts already described by Breaugh (1985). Theory development being achieved in this instance by placing job autonomy in context, and in particular the role afforded to the designer in fulfilling the expectations attached to the design of hazardous installations. Breaugh's (1985) work has been considered in the item development of the questionnaire section addressing job autonomy and in particular the issues relating independence and schedule in specific areas of design.

5.4 Job Support

Daniels and Guppy (1995) report that one of the most important constructs consistently identified as being related to well-being in the workplace is support (Cassell, 1976;

Kaplan, Cassell & Gore, 1977; House, 1981). It is the beneficial effects attached to job support and control in problem-focused coping, where the demands-control-support model (Karasek & Theorell, 1990) may have as its explanation for potentially improving design safety. Job support provides designers with support networks.

In addition, support appears associated with other more discrete promotional effects that are embedded in organisational outcomes, for example reputation (cf. Parker, Turner, & Griffin, 2003). Reputational issues go hand-in-hand with rule compliance and the confidence attached to more successful designs. At the heart of the demands-control-support model is the idea that job support and control are more effective in problem-solving, which in turn satisfy the specific work demands (Karasek & Theorell, 1990; Parker et al., 2003; Wall et al, 2002).

In the context of this study, support is described as the level of helpful social interaction between a designer and fellow designers who are all members in a design team (Guzzo & Dickson, 1996). The notion of support also extends to include support given through leadership by the lead engineer or project management (after Karasek & Theorell, 1990). Daniels and Guppy (1995) reported that working long hours and frequently working to deadlines were major sources of tension that may upset the balance provided through job support. Generally, the design schedules of hazardous installations reflect these two aspects, where working long hours and progressing along a just-in-time schedule appear quite common place. Haskins, Baglioni and Cooper (1991) also reported that role and organisational structure, work overload and interpersonal relations were all factors affected by degrees of support. Despite support being important in predicting well-being amongst design teams virtually no evidence exists that examines the relationship between support and the execution of work tasks in hazardous installation designs.

Job support, as reported by Daniels and Guppy (1995), can be operationalised through the integration of an individual into a social network or in this case a design team. Design teams form part of the occupational environment and are seen as a social grouping (Waring, 1992, 1993 & 1996). The design teams are relatively small groups that are interdependent because of the nature of the tasks that they perform (Guzzo & Dickson, 1996). The design teams appear embedded in one or more larger social systems. These social systems perform tasks that affect other groupings. In this case, the group relates to a particular design team and the larger social system can represent the global hazardous project. For hazardous projects, where the need for compliance is very high, problem-solving (Karasek & Theorell, 1990) needs to undertaken whilst retaining a particular non-risk taker focus (Parker, Turner, & Griffin, 2003; Unsworth & Parker, 2003; Wall et al, 2002).

At a higher level, beyond the completion of simple and repetitive activities, team support appears to be a more important factor. The need for support appears to occur when the designer is confronted with developing strategies that address complexity and the testing complex designs (Lienart & Raatz, 1994). Designers are also working to the deadlines of a just-in-time schedule, where job support appears critical, therefore team support appears to be worthy of inclusion within the item questionnaire development of this study.

5.5 Role Clarity

The concept of role clarity has been operationalised in two ways. Firstly, it refers to the presence or absence of adequate role relevant information due to a restriction in the circulation of this information and secondly, it can be due to variations in the quality of this information (Lyons, 1971). Kahn, Wolfe, Quinn, Snoek, and Rosendahl (1964) found that ambiguous role expectations were also associated with greater tension, resulting in less job satisfaction. This was compared to the circumstances where role clarity was high. Some early work by Raven and Rietsema (1957) indicated that clarity in group goals were also associated with greater satisfaction and levels of personal achievement. Conversely, greater tension was reported when goals were reported to be unclear. Role ambiguity has also been reported to be related to poor team and individual performance (Torrance, 1954) due to either the unclear situations referred to above or unclear group structures.

Kahn et al (1964) suggest three general organisational conditions that significantly contribute to role clarity. These are:

1. organisational complexity;
2. organisational change and
3. management or leadership communication;

Kahn et al (1964) reported increased ambiguity during periods of organisational change. This was due in part to certain re-organisational factors that included technological change. Technological change requires change in the social structures or at the very least the method in the way that the tasks are performed. This in turn may require changes in personnel.

Many of Kahn et al (1964) findings relate to change orientation, which should aim to enhance both personal and organisational effectiveness. Change orientation also makes a contribution in cases of individual initiative, especially when devising suitable work strategies are required for use in complex problem solving. Therefore understanding the contribution made by role clarity represents a significant step towards controlling why certain errors in the design process may occur when these work strategies are not followed.

Job autonomy accompanied by high levels of role clarity also appears to be important as this implies minimal conflict during problem solving. When taken in context with other factors, such as a personality type that is high in conscientiousness, the job characteristic of role clarity can become reflected in a designer's positive safety behaviour (Parker, 2000). Therefore, the designer's role clarity appears to be a clear factor worthy of further evaluation through its inclusion in questionnaire item development and establishes a potential link between job characteristics and safety climate.

5.6 Job Demands and skills

Demands are defined in psychological terms by such aspects as exposure to time pressure and difficult and complex work. This is typified in trying to control a design schedule and work process that is orientated around computer display screen equipment (DSE). This is the case with design engineering tasks and their use of computer aided design (CAD) and engineering (CAE) methods. CAD and CAE demand a high level of vigilance (Van Cott, 1985). Fault prevention and active diagnosis of errors formed (Alder & Borys, 1989; Buchanan & Bessant, 1985; Dean & Snell, 1991; Walton & Susman, 1987) requires an enhancement to the designer's problem-solving techniques.

Bandura (1997) indicates that a variation in an individual's ability to cope with demands maybe a function of their intelligence, experience, education and perceptions. For design processes involving the use of advanced technologies, it is argued that the general level of cognitive skill needs to be higher because the new technologies absorb the routine information-processing aspects of the designer's job (Walton & Susman, 1987). However, very high attention demands are also likely to have a negative impact on the designer's well being and thus affect their ability to cope. This impact contrasts with problem-solving demands that add challenge to the job (Parker & Wall, 1998). Therefore matching the individual designer's skills with just about the right level of demands appears to be important and highly relevant aspect to ensuring a well designed product and a motivated designer.

DeVaro, Li and Brookshire (2007) evaluated skill and task variety and defined them as the extent to which a task utilises or challenges an individual's skills and abilities. Karasek and Theorell (1990) refer to skill discretion to be the extent to which individuals can utilise their skills and abilities at work. Verhofstad, Witte, and Omey, (2007) report that with a failure to match these combined effects (skills and abilities) susceptible individuals maybe vulnerable to experiencing tension and delivering poor job performance (Kahya, 2007). Jobs that are low in skill discretion for example, variety, challenge and opportunities to learn and low in decision authority have been associated with tension (Kohn & Schooler, 1973; Karasek & Theorell, 1990). In this context 'tension' refers to any characteristic of the job environment that would pose a psychological condition for example stress or anxiety.

Two types of job deficiency may threaten the individual. Firstly, demands which they may not be able to meet, for example demands that are imposed by an unrealistic work schedule and secondly through having insufficient skills to meet the particular demands. Skills appear to provide a buffering effect to high job demands (Caplan, Cobb, French, Van Harrison & Pinneau Jnr., 1975). Measuring job demands and individual skills therefore appears to be an attractive proposition in order to evaluate whether the skill sets of the designer are matched to the job demands that are being made upon them.

Table 5.1 summarises some of these key elements of the designer's job characteristics.

Table 5.1: Job Characteristics and their relationship to errors

Job characteristics	Illustrative adjectives	Error types
Job Autonomy Dieterly and Schneider, (1974), Hackman and Oldham (1975) Kahn, Wolfe, Quinn, Snoek, and Rosendahl (1964), Parker, Wall and Jackson (1997), Sutton and Rousseau (1977),	Job autonomy reflects the ability to set work schedules and work procedures Self determination Work satisfaction leading to positive behaviours	Low levels of job autonomy during periods of problem-solving, working to deadlines and improvisation of procedures have the potential to lead omissions, and substitution errors
Job Support Daniels and Guppy (1995), Unsworth and Parker, (2003) Turner and Parker (1998)	Promotes well-being, Discrete promotional effects such as reputation; Positive team support delivers more effective problem-solving	The level of helpful social interaction between an individual designer and the other team members may help minimise errors by sharing problem solving However, the likelihood is that where poor networking and support exists then inadequate attention will be given to problem solving resulting in the use of inappropriate methods. Poor or negative levels of support affect coping to high demands
Role Clarity Goodman (1979), Lyons (1971) Kahn, Wolfe, Quinn, Snoek, and Rosendahl (1964),	Role clarity is provided through role relevant information; Ambiguous role expectations result in less job satisfaction and lower levels of personal achievement, Change orientation aims to enhance personal and organisational effectiveness	Safety affected through errors of commission and rule violation due to unsatisfactory resolution of assigned roles in design The absence of adequate role relevant information due to either a restriction in the circulation of this information or variations in the quality of this information may invite designers to make assumptions Role conflict may affect on innovative proposals to complete tasks and the potential for errors of omission
Job demands and skills Caplan, Cobb, French, Van Harrison, and Pinneau (1975), Goodman, Devadas, Griffith-Hughes (1988)	Demands are defined in psychological terms e g time pressure, difficult and complex work and the need to have demands matched with skills; Skills provide the buffer to higher demands	Periods of re-design time pressure and resolving complex tasks need to be accompanied by an ability to match demands with skills Skills training can help to avoid errors of omission; Unrealistic work schedules and insufficient skills create the circumstances for errors of omission and commission

5.7 Summary

For design processes that involve the use of advanced technologies it is argued that the levels of cognitive skill need to be generally higher. Problem-solving demands add challenge to the job (Parker & Wall, 1998). Therefore matching an individual designers demand and skill levels appears highly relevant to ensuring a well designed product that could be mediated by the design safety climate which is known to be important. Job autonomy offers the designer the ability to set work schedules which enhances ob satisafaction and positive behaviours. Support also underpins job satisfaction and provides and environment for better problem-solving.

Chapter Six

Social anthropology and the cultural expressions of risk

6.1 Overview

The final element of the HSG 48 is the 'Organisation'. Two aspects of organisational working have been addressed in the following two chapters and these relate to social culture and safety climate as the measure of safety culture.

6.2 Introduction

The characterisations made by Douglas (1982) of the social cultures were undertaken on the basis of an anthropological view. Lave (1988) noted that Douglas' (1973) perspective introduced the context in which humans learn to execute tasks. Lave (1988) appears to be suggesting that as the human learns, and acquires more knowledge, especially that associated with risk, it allows them to make better informed decisions. This chapter considers how these processes affect risk.

6.3 Douglas' simple designations and their fit into the designers' worldview

Rohner (1984) suggests that no two individuals would ever hold precisely identical views, and therefore only the notion of equivalence emphasises the importance of approximate sharing. In other words, two individuals can agree on the term '*risk*' but disagree over its place on the scale between say negligible and intolerable.

Risk perceptions on the other hand are seen to lie upon a different line, polarised between the expert view and that of a lay person. Cultural theory has been seen as particularly interesting to some practitioners because of its ability to help explain certain decisions and choices that are based upon varying degrees of risk and its perception.

Sagan's (1993) treatment of culture claims that in a hierarchical setting, this form of culture is one that often stresses intense socialisation, discipline and control. It is also one which is frequently rejected by many organisations as being impractical. Paradoxically, all design engineering organisations that participated in this study appear set up in a hierarchical fashion. Turner, Pidgeon, Blockley and Toft (1989) recognised the use of other cultural possibilities to explain different perceptions of risk and not just the hierarchical ones.

Three prototypical cultural biases originally characterised by Hollings (1978) whilst formed in terms of ecosystems offer these different perspectives. This method appears contextually relevant to offshore engineering. Hollings' (1978) prototypical cultural biases related to three views of nature, namely nature benign, nature ephemeral and nature 'the practical joker', where things are deemed to happen unexpectedly or in bizarre sets of circumstances. Hollings' (1978) thinking was based upon individuals or organisations developing adaptive strategies that were embedded in both scientific and social processes and how best they could be applied. These processes inform management decisions at appropriate temporal and spatial levels.

Risk, and in particular risk perception, is a very complex topic that brings together cultural, social, physical, political and psychological factors (Starr, 1969; Rohner 1984; Wildavsky & Dake, 1990). It is thought possible to align Douglas' (1982) theory and certain risk perception models, for example Kahneman and Tversky (1979) and Slovic et al (1982) to the designer population.

6.4 What is the world view of risk?

Work undertaken by Thompson, Ellis and Wildavsky (1990), Adams (1995) and Mars (1996) examined the relationships between shared work and shared resources. This examination involved understanding how organisational cultures and team working engage individuals and in particular, socialising individuals. Douglas' (1982) theory outlined a five-fold typology that permits the placement of any individual within a unique cultural classification. Thompson et al (1990) have also argued that each of these states or ways of life was explained by these typologies. Thompson et al (1990) recognised that there were interdependencies within these five states that created an overall social balance. Whilst these five states are, in effect, in direct competition for adherents, that is to say that they will endeavour to try and attract like minded people, they also appear to be dependent upon each other. Each state needs something from its rivals to compensate for any social deficiencies that it may appear to inherit.

Douglas' (1982) original argument was based upon the recruit similar-to-me effect in order to populate each group with like-minded individuals. This effect operates quite comfortably when relationships are organised into a group pattern. The study of social culture has characteristically, as in this case, defined each state by emphasising its degree of uniqueness. Douglas (1982) argued that, for these varieties to be adequately represented the dimensions of each social state needed to be represented within some form of mathematical structure.

The structure of social relationships was thus captured within a pattern that reflects the social groups and their networks. Douglas states that the group reflects upon:

> " .The extent to which individuals were active within bounded units," (quoted in Thompson, Ellis & Wildavsky, 1990 at pg 5)

Graphically a two dimensional diagram depicts these group relationships (see Figure 6.1). However, several diagrams would be needed to fully depict an individual's network pattern. Douglas (1982) states that the group dimension builds upon the extent to which:

> "The individual's life is absorbed in and sustained by group membership" (quoted in Thompson, Ellis & Wildavsky, 1990 at pg 5)

However, the networks within which an individual operates are not constrained by group boundaries, thereby establishing a representation that recognises both groups and networks leads to their representation in Douglas' group-grid diagram. Douglas (1982) states that the grid denotes:

> ......'the degree to which an individual is circumscribed by externally imposed prescriptions' (at pg 5).

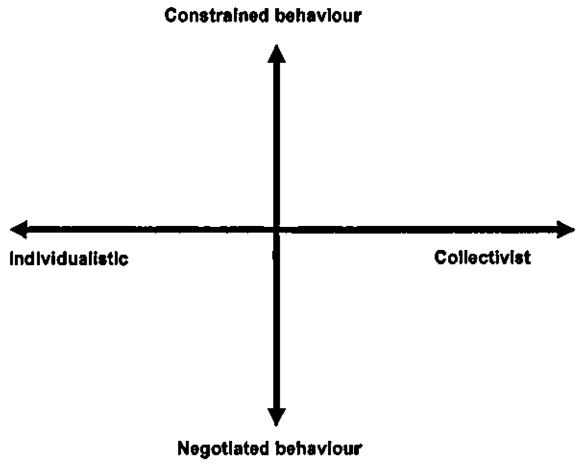
The term grid used by Thompson et al (1990) appears to represent a highly regulated scheme that reflects high social order. Douglas (1982) also appeared to signify this use through the statement that grids represent:

> "An explicit set of institutionalised classifications (that) keeps (individuals) apart and regulates their interactions" (at pg 5)

Modes of social control therefore appear to be the focal point in this two dimensional analysis.

It is proposed that this approach can be equally well used to explain risk decision-making if it can be shown to involve social control. Risk decision-making may be constricted by two different social control protocols. Firstly, through a protocol that requires the individual to be bound by the group decision from within a certain group. Secondly, by the protocol that demands that the individuals should follow the rules that accompany their station in life (social station). These boundaries appear to capture the fundamental mathematical distinction in the pattern of relationships of groups and networks used by Thompson et al (1990). The intersection points of the groups are representative of the networks. The relationship boundaries are illustrated in Figure 6.1. Movement along the horizontal axis reflects a continuum of relaxed personal choices (individualistic) or tighter team (collectivist) controls. These groups are contained in the root definitions for the egalitarian, hierarchic, individualist, fatalist and the socially autonomous or hermit group.

Figure 6.1: The grid-group matrix



Movement up and down the grid represents how individuals are expected to negotiate their own relationships with others. Attempts to operationalise the grid–group dimensions can be found (see Hampton, 1982; Gross 1982). Applying the grid–group dimensions to designers and assessing where the risk benefits may lay on this diagram is not obvious. The aim would be to determine where on the 'Individualistic-Collectivist' continuum the choice of the risk benefit should be positioned.

Some of the cultural correlations described by Douglas (1982) have been transposed by others (see Thompson, 1979). The transformations took the form of simple and straightforward descriptions of the common risk-taking attitudes adopted by the group typologies that were initially developed by Douglas (1982).

Douglas (1982) and Thompson et al (1990) views of these groups and networks have been supplemented with those subsequently expressed by Smallman (1998) and Adams (1995; 2004). This provides an account of the risk benefit representations within the boundaries of each typology that is suggested by Douglas (1982). These accounts also provide an opportunity to delve deeper into each typology. These descriptions are then just a short step away from providing a platform, upon which to assess the social cultures that may be attached to designers.

6.5 Cultural Correlations

The cultural correlations described in Douglas' theory were based upon a set of groups describing the characteristics of the egalitarian, hierarchic, individualist, fatalist and the socially autonomous person. The following sections describe some of the generic characteristics attached to these first four social states. The fifth group, the socially autonomous person is considered in Section 6.6 and the reasons for this placement explained.

6.5.1 Individualists

Individualists are found to be neither bound by group incorporation nor retain their prescribed roles. The Individualist is generally considered to be a self-made (or self-orientated) person, free to make their own decisions on aspects that they then seek to exert on others (Smallman, 1998). The Individualist is generally considered to be an optimist and a pragmatist. Adams (1995) suggests that Individualists have a tendency to focus on the rewards associated with risk.

6.5.2 Egalitarians

The Egalitarian operates within strong group boundaries with minimal prescriptions. According to Smallman (1998), Egalitarians prefer to be managed by leaders who tend to control and steer the Egalitarian. The technique that guides Egalitarians is the use of persuasion to align them with the team view. This may characterise the Egalitarian as risk adverse (Adams, 1995). Under these circumstances the Egalitarian bases the decision-making upon whether science has proved that a particular process or substance can be applied safely. In instances where this is not the case, then the Egalitarian's automatic response is to consider it a hazard and unsafe. This would tend to invoke the most appropriate of precautionary principles within the Egalitarian.

6.5.3 Hierarchic

Individuals according to Douglas (1982) who possess hierarchical views operate within a strong group boundary. The Hierarchic also has certain binding prescriptions. Everyone has a place and is graded to that place according to certain rules sets. According to Adams (1995) the Hierarchic when confronted with taking a decision tends to commission more research in order to ultimately elicit the most appropriate risk beneficial answer.

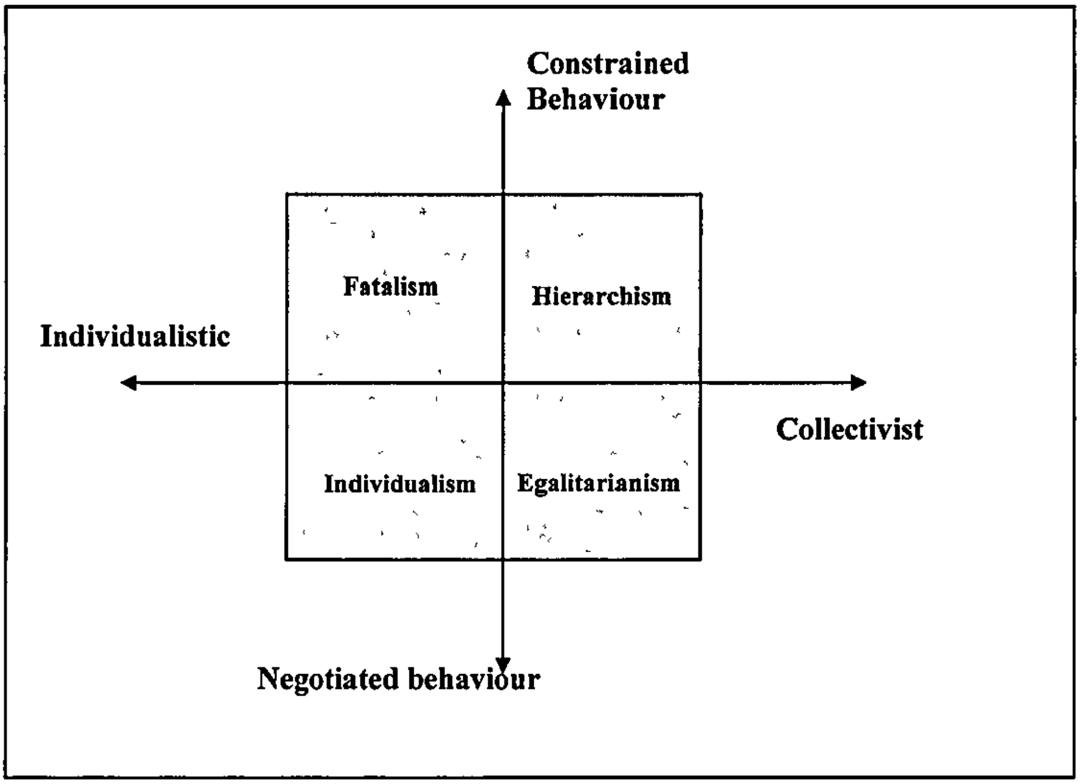
6.5.4 Fatalism

Douglas (1982) suggests that Fatalism is seen as having minimal control over their destiny and circumstances. Therefore Fatalists tend to live their lives by looking towards certain other binding prescriptions. These are possessed within the other groups.

However, Fatalists are denied access to group membership because of their cultural type. Consequently Fatalists appear to have little or no influence over rule making, and tend to be more isolated, and according to Smallman (1998) subordinate.

Figure 6.2 illustrates the placement of these four typologies described above within the grid-group framework discussed earlier in Section 6.3.

Figure 6.2: The positioning of the social cultures within the grid-group matrix



6.6 Deriving the designer's social cultural characteristics based upon their worldviews

The four levels of social risk-taking examined in Table 6.1 provide some straightforward interpretations on how designers with certain socio-cultural characteristics might be expected to respond and act when engaged in a risk decision-making process. Table 6.1 summarised these points in the risk and behaviour correlates.

Table 6.1: Dimensions of social culture and their definitions

Dimension	Prototypical characteristics attached to risk (Thompson, Ellis & Wildavsky, 1990)	Illustrative adjective	Designer behaviour correlates	Designer risk culture
Individualist	The individualist views risk as an opportunity, coupled with combinations of new technology to mitigate unforeseen consequences	Nature benign	Individualists are 'long' on uncompensated benefits	The extent to which the designer considers that the individual is best placed to regulate their exposure to risk
Egalitarian	Egalitarians are able to support their way of life and discount rival ways of accentuating the risks of technological & economic growth through negotiation	Accountable nature and nature ephemeral	Egalitarians do recognise risk and draw them to the attention of the risk generators This view maybe more synonomous with views held within a positive safety climate.	The extent to which the designer considers the collective team views are best placed to regulate risk and that no level of risk is acceptable
Hierarchic	The hierarchic sets acceptable risk at fairly high levels so long as these decisions are made by experts	Isomorphic nature	Reliance upon the views of others and expert opinion in particular These behaviours rely upon the prevailing Regulatory factors	The extent to which the designer considers organisational rules and procedures are best placed to reduce risk to acceptable levels
Fatalism	Fatalists do not knowingly take risks Fatalists believe that fate conspires against them to prevent them from improving their position in life	Nature capricious, fatalist passivity may result in others trying to impose unwanted dangers Unpredictable and almost unmanageable	Fatalists are 'long' on uncompensated risks and have a learned response to others who are distant and in charge;	The extent to which the designer considers that risks are impossible to regulate

The fifth state or bias from Douglas' descriptions contained in Section 6.3 is termed the Social Autonomous Person (or hermit group). This state relates to individuals who withdraw from social interaction and hence team working. The implication for persons possessing this attribute is that they are assumed to have been excluded from employment in offshore design teams.

6.7 Discussion on orientation of groupings

Cultural subsystems are distinguishable domains of belief and other meanings that encompass a range of socio-cultural systems (Rohner, 1984). Daniels, Harris and Briner (2002) reported their examination of what were labelled the four cultural cosmologies of 'fatalism', hierarchism', 'egalitarianism' and 'individualism'. From the subsequent analysis they found evidence of socio-cultural influences through cultural beliefs about work and group membership. Reporting on two scales termed "*Chance*" and "*Group Rules*" (HSE, 2002 at pg 73) the inferences drawn by Daniels, et al in HSE (2002) indicate that a subtle account of how differences in response to the psychological hazards were reported. The composition of these scales reflected fatalistic beliefs being associated with the '*Chance*' scale and individualistic and hierarchical group processes attached to the '*Group Rules*' scale. These influences maybe deeply rooted in personality differences and linked to the wider socio-cultural environment. Nevertheless this provides a recent marker relating to the impact of social culture in workplace events.

6.8 Summary

This chapter has examined some of the broader issues associated with risks, perceptions of risk and risk decision-making. It has briefly reviewed some of the underpinning theories that support the perceptions of risk and recognises that society cannot live entirely risk free. It has also looked at some empirical studies that have tested societal perceptions of risk. The conventional view of risk perception has been investigated and appears to be based upon either an individual's personal preferences or the wider societal view. These risk preferences also appear to be adjusted according to whether the social constructs of gain are reflected through individualism or in a principle embodied in the collectivist view. Therefore, a psychological analysis of individual personality differences and the collective of cultural and social states offer a way forward in the evaluation of the designer's risk-taking.

The next chapter considers safety climate as it applies to design organisations and investigates whether they have a moderating effect on mistakes, errors and the use of risky design protocols.

Chapter Seven

Safety Climate in design organisations

7.1 Introduction

The second aspect of the 'Organisation' has been to address the contemporary relevance of safety climate. Waring and Glendon (1998) approached organisational culture from two contrasting perspectives, both of which seem to dominate professional practice (Glendon & Stanton 2000). These approaches are described as functionalist (see Burrell & Morgan, 1979) and interpretive (see Smircich, 1983). The functionalist approach assumes organisational culture exists (Waring, 1992, 1993 & 1996) whereas, the interpretive approach surmises organisational culture to be an emergent and complex phenomenon of social groupings. The evidence of both these approaches to organisational culture appears to be created as building blocks by its members. Indeed, some have viewed organisational culture primarily as a set of theories, values and beliefs, and have denied that the policies of any organisation have any relevance to safety culture as a doctrine.

Glendon and Stanton (2000) report some confusion between the use of the terms 'culture' and 'climate' which has inevitably meant a degree of interchangeability. Denison (1996) discussed some of the differences and similarities between organisational culture and climate and concluded that the distinctions appear to be clearly defined. Schneider and Gunnarson (1996) applied the notions of expression, communication and socially constructed dimensions to their analysis of the psychology of the workplace. These dimensions are defined in terms of organisational climate and culture.

7.2 Safety climate, Safety culture and Safety behaviour

Some of the fundamental characteristics of safety climate are discussed and the various dimensions that are consistently reported within the literature have been reviewed (Cox & Cheyne, 2000; Neal & Griffin, 2002; Turner & Parker, 2004; Waring & Glendon, 1998; Zohar, 1980; Zohar & Luria, 2005). Significant progress has already been made in understanding some of the mechanisms by which safety climate might affect safety behaviour (Cox & Cheyne, 2000) and these have been added to this review.
The move towards a new approach to improving safety performance, through organisational aspects measuring the organisational climate appeared justified across several different industrial sectors, in response to different prevailing states. These include the responses to major accident events such as Piper Alpha (HMSO, 1990) and Chernobyl (Joint EC/IAEA/WHO report, 1996) or at times when accident rates appeared to plateau (Krause, 1994). This fresh approach provided an opportunity to interpret aspects of the organisation in a different way. This was in order to leverage the required impetus to improve an organisations design safety performance.

The offshore example of this initiative was handled by the Step Change for Safety program. The Step Change for Safety was delivered by the Cross Industry Safety Leadership Forum (1997) which aimed to deliver a 50% improvement in offshore safety performance over three years. These performance initiatives were focussed upon end user operators, offshore technicians and contractors. Step Change (1997) was also accompanied by initiatives that focussed upon engineering activities. The engineering activities involved technology selection and their use for which the designer and the design teams were responsible.

These measures were aimed at reducing the potential for fires and explosions and hence a repeat of Piper Alpha. By treating the design environment in a similar vein to the way that organisational activities became primed under the Step Change (1997) program provides the opportunity for this study to assess design teams in a contextually appropriate way. Neal and Griffin (2002), report on the relationship between safety behaviour and certain of these initiatives are used in support of the safety climate dimension.

In the aftermath of the 1986 Chernobyl disaster the International Nuclear Safety Advisory Group (INSAG) 1992 developed their particular definition for safety culture. Not surprisingly the INSAG definition of safety culture has a general application that extends beyond just nuclear installations but it is one that captures the essence of safety culture:

> "That assembly of characteristics and attitudes in an organisation that has an overriding priority (and where) nuclear plant safety issues receives the attention warranted by their significance." (ACSNI, 1998 at Pg 11)

Research has shown that aspects of organisational safety climate have a significant relationship with accident involvement across a wide range of industrial settings, and not just in the oil and gas sector (Cox & Cheyne, 2000). These other industrial setting include industrial manufacturing (Brown & Holmes, 1986; Zohar, 1980, 2000; Zohar & Luria

2005), construction (Duff, Robertson, Cooper & Phillips, HSE report 51, 1993), chemical and nuclear industry (Hofmann & Stetzer, 1996; Lee, MacDonald & Coote, 1993) and in the service industry (Barling, Loughlin & Kelloway, 2002). For the purposes of assessing the notion of safety climate within any design environment organisation, the measurement of safety climate should include the items that have been consistently reported in literature provided there is sufficient significance and validity for their inclusion.

The following passages report on some of the underlying features of safety climate. A review of historical safety performance between high and low accident rate organisations concludes, that in organisations where there is a strong management commitment to safety, their safety initiatives appear to be more successful at improving safety performance (Cohen, Smith & Cohen, 1975; Lee, 1998). This commitment is demonstrated in a number of ways. The most successful safety performing organisations involve conspicuous top management participation.

Cox and Flin (1998) identified organisational safety climate by investigating some emergent factors that included:

- management commitment to safety;
- personal responsibility;
- attitudes to hazards;
- compliance with rules and

- workplace conditions;

The derivation of organisational safety behaviour appears not only to rely upon a demonstration of leadership from within the organisation (Cox & Cheyne, 2000), but also upon the individual's attitude towards ownership of safety issues in a supportive environment (Alexander, Cox & Cheyne, 1994). Collinson (1999) found that managers in organisations supporting a safety climate worked extensively to imprint the same positive safety climate on their employees. However, negative stereotyping of managers attitudes by employees, has been reported as leading to mistrust amongst employees (HSL, 2002). Such demonstrations of leadership qualities invite recognition of safety leadership and its communication of an organisations safety messages (Krimsky & Plough, 1988). Communication of safety issues appears to be a complimentary objective to meeting compliance needs and is one that runs alongside rules and procedure (Cox & Cheyne, 2000; Zohar & Luria, 2005).

Ryan (1991) identified effective communication as a means of relaying the critical importance of safety climate. Whilst Cohen, Smith and Cohen's (1975) research was conducted in the manufacturing sector (also see Brown & Holmes, 1986; Zohar, 1980, 2000; Zohar & Luria 2005) the validity of safety leadership claims to achieve employee buy-in and participation is a persuasive dimension that appears to be included in the vast majority safety culture literature sources.

One of the most enduring fundamental characteristics of a safety culture appears to be its commitment to sharing, through the participation of its adherents to a collective state that aims to enhance both safety and personal well being. Recognition of individual contribution to safety performance (Clevelend, Cohen, Smith & Cohen, 1978; Davis & Stahl, 1964) through organisational arrangements, such as reward and team support also appears to be related to an organisation's culture in this way. This concept contrasts with an approach that just adopts straightforward enforcement and admonition in order to meet an organisation's compliance needs yet fails to achieve a potentially long-term sustainable outcome. Gray (1982) observed that the approach to reward and non-punishment were effectively equivalent.

Cox and Cheyne (2000) report that in the offshore industry there is the potential for many different cultures to exist on the offshore installations that participated in their study, which was reported as stemming from the number of different contractor's that, are involved in offshore work. Such organisational fragmentation makes the task of cultural alignment a far more demanding exercise. However, the size and composition of design teams on a hazardous project does not involve the same number of different contracting entities (See ODE report 4381-B-A-002 at pg 7 & 8) thus making the task of achieving a positive safety climate within design teams a more straightforward exercise (c.f. Cox & Cheyne, 2000).

7.3 Climate for a Safe Design

Goodman (1979) discussed several mechanisms by which design might affect end user safety performance. Goodman, Devadas and Griffith-Hughes (1988) suggest that safer working could be enhanced through the greater use of training and through increasing awareness and knowledge. Theoretically, this training should be a feature accompanying any design work, especially error training where designers should be encouraged to develop their own mental models. Mental models of the system and the use of risky strategies to investigate and experiment are observed by Reason (1990) to be an important instruction. Reason (1990) asserts

> "Error training should form an integral part of the overall training process" (at pg 245).

However, strict compliance with design safety rules and operating procedures (see Cox & Cheyne, 2000; Zohar & Luria, 2005) suggest another reasonable basis upon which safety performance improvements might be achieved apart from specific forms of training. This approach to compliance may also suggest that a collective effect (team level) maybe achieveable within design organisations because of the importance that safety climate has within the oil and gas industry.

Designing for error minimisation (Lewis, 1986) through greater knowledge of the characteristics of the tasks, the task and its constraints, is a way that training could adapt the best possible design characteristics to the end user characteristics, thereby avoiding accidents downstream of the design (Vincente & Rasmussen, 1992). Turner and Parker (2004) have already investigated how 'working in teams (but not exclusively design teams) might help or hinder occupational safety'. Mearns and Flin (1995a) addressed the extent to which knowledge and information affects safety behaviour and concluded that attitudes to safety are constrained by values, norms, rules and regulations that the organisational system has put in place.

These values, norms and rules are a perfect example of the visionary qualities that reside at the heart of an organisation's safety policy and delivered through the safety management system (see HS (G) 65). An organisation's safety policy provides the public window onto an organisation's commitment to safety.

Turner (1991) considered climate to possess a technical aspect and is therefore an aspect that needs to be regarded in socio-technical terms rather than in a pure social or psychological context. Turner's (1991) approach directly engages the designer's safety philosophy when they are responsible for judging the merits of competing products or systems on the basis of safety. Cox and Cox (1991) were amongst the first to measure employee attitudes to safety, and in a later study, Alexander, Cox and Cheyne (1994) measured safety attitudes where prior accident involvement had been experienced. There is little published material recording the designer of hazardous installations views on 'management commitment to safety', their levels of 'personal responsibility' towards safety, the designers appreciation and 'attitudes to hazards', and issues relating to 'compliance with rules'. Although on this final point, the hazardous installations industry has adopted the universal method of testing designs using the HAZOP procedure. Therefore all designers should already be aware of compliance expectations associated with their design deliverables.

The offshore industry, through safety initiatives such as the Step Change for Safety (1997) has placed added importance at both an organisational and individual level to prioritising safety. This prioritisation certainly extended to an individual's safety in operations (Marehelal, 1985; Rundmo, 1992a; 1992b, Alexander et al 1994) in order to achieve the objective of the 50% improvement in safety performance over three years (Step Change for Safety, 1997). There appears to have been extensive work in the area of the offshore organisational culture and the effect of that safety climate, safety leadership and team support has within an organisation (Cox & Cheyne, 2000). However, only a limited amount of work has been conducted in the design environment which justifies the inclusion of measuring the climate for a safe design within the design teams.

7.4 Summary

From the safety culture literature, leadership and management emerge as key influences in the creation and maintenance of an organisation's safety culture (Thompson, 1997). The following table illustrates some of the principal features of safety climate and its relationship with errors and risky protocols when the safety climate is poor.

Table 7.1: Safety Climate and its relationship to errors and risk-taking

Safety Climate characteristics	Illustrative adjectives	Error types and risky protocols
Leadership Cohen, Smith and Cohen (1975), Cox and Cheyne (2000)	Conspicuous top management participation; Personal recognition for achieving safety goals; Senior management interventions to prevent accidents; Visible demonstration of commitment to safety	Design features added without adequate reference to others who 'need to check' the design feature
Team Support Clevelend, Cohen, Smith and Cohen (1978), Davis and Stahl (1964)	Increased levels of team support, safety awareness and knowledge improves safety performance; Individual responsibility for safety, Team ethics and shared learning; Freedom to raise safety concerns without recrimination	Poor levels of support will undermine safety expectations; Increased levels of risk transfer because there is a lack of willingness to achieve a safe design and someone else e g. HAZOP will solve the problem
Communications Schneider and Gunnarson (1996); Ryan (1991), Brown and Holmes (1986); Zohar (1980)	Effective communication enhances personal well-being and encourages individuals to take ownership of safety issues; Regular safety meetings increase awareness of technical issues; Reporting of unsafe design features	The lack of feedback as to whether designs that had worked well in the past have proven to be successful in a new application is a critical form of communication and networking;
Safety priorities Cohen, Smith and Cohen (1975); Cox and Cheyne (2000)	Safety initiatives in design appear effective at improving safety performance when they are not compromised by other aspects of the design process e g. schedule and cost; Cultural cohesion and a good safety climate avoid organisational failings because safety is the first priority;	End user fabricators and operational issues conflict with the designers safety goals leading to potential errors of substitution amongst the design teams
Safety rules and procedures Cox and Cheyne (2000)	A good organisational safety climate ensures compliance obligations are satisfied, Increased knowledge of the design rules and procedures increases overall safety awareness	The lack of any checking procedures introduces the opportunity for errors of omission, Checking is overlooked leading to errors of commission and the use of certain risky protocols

The organisations participating in this study include employees involved in activities associated within the end user workplace and design environment. Modelling safety climate appears to lean quite heavily on such constructs as safety priorities, the individual's perception of these priorities and their subsequent safety behaviour that should be reflective of the internal consistency of the safety climate. Whilst material recorded in this chapter generally relates to the physical workplace, the organisational setting that drives this investigation can be validated against existing scales.

Section One Summary

Section one of the thesis reports on how a measurement of the design contribution to safety performance may be derived from the way that design decisions are taken and how the design tasks are executed. So far the thesis has considered the types of errors that designers make and the circumstances under which these mistakes might be made and perhaps, what prompts the designer to make them. Exploring the attribution between individual personality differences and the levels of reported cognitive errors (Wallace & Chen, 2005) also reflects on human errors (Reason, 1990). This understanding is important in order to establish the potential link between the job characteristics of the designer; for example the degree of job autonomy that they enjoy, and different forms of cognitive error that are examined by way of hypotheses.

Section 2: Hypotheses and Methodology

Chapter Eight

Research Question and hypotheses

8.1 Research Questions

The literature sources in Section One have focussed upon the design process where the designer is central (Shen et al, 2007) and the elements described within HSG 48, namely the 'Individual', the 'Job' and the 'Organisation'. In consideration of the literature reviewed in Section One and the HSG 48 model the search uncovered a potential knowledge gap. This chapter develops a research question orientated around this knowledge gap and then proposes how to test the research question by way of hypotheses.

The literature sources indicate that there are important phenomena that need to be accounted for when studying risk. These include risky decisions taken by designers based upon individual personality traits and the influences of the environment in which the designer is working. The research question confronts these issues in order to evaluate whether personality, being all pervasive, contributes to the designer committing cognitive error and taking risks. The research question that this study addresses is:

1. How do individual personality differences account for cognitive errors and risk-taking in the design of hazardous installations?

Chapter One evaluated HSG 48 and considered how the designer is central to the design process. Chapter One also evaluated the relevant literature (Simon et al 1997; Drogoul et al 2007; Kinnersley & Roelen, 2007) associated with errors and the risk management in the design process. These sections of the chapter outlined the common error types, errors of omission (Reason, 1990) and errors of commission (Sanders & McCormick, 1993; Higgins, 1997) and the delineated error types of repetition (Busby & Payne, 1998); errors of transmission (Kirwan, 1994) and errors of substitution (Hollnagel, 1993) from within the error of commission. The designer's use of assumption-making (Kahneman, Slovic & Tversky, 1982) appears valuable in explaining how a designer may arrive at certain decisions.

Chapter Two discussed how the different types of error have been linked to human attention, sustaining attention, human interventions, psychomotor events and certain everyday routines such as answering email. These aspects have been considered in the application of technical systems where designers are involved (Reason, 1990; Wagenaar, Hudson & Reason, 1990). Reason's theory is an often cited theory in this field and has received particular attention in this research because it brings the study of error into the realms of normal cognition.

Chapter Three advanced Goldberg's Big Five (1999) to try and explain the link between personality and error and accident involvement, whilst acknowledging that other methods of evaluating personality are available. Wallace and Chen (2005) recognised that individual personality plays an important part in evaluating safety behaviour and cognitive error. According to Wallace and Chen (2005) cognitive errors appear to occur where the levels of conscientiousness were found to be low. Cognitive error also appears to have moderated the relationship between conscientiousness and individual safety behaviours. This research's application of Goldberg's Big Five through the IPIP 50 (see Goldberg, Johnson, Eber, Hogan, Ashton, Cloninger & Harrison, 2006 for a detailed account of IPIP) and an adaptation of Wallace and Chen's (2005) questionnaire, aims to reveal if a designer's individual personality can be attributable for cognitive error in the design process. Individual personality has been shown to be predictive of attitudes (Cattell, 1950) so presumably risk perception too, and therefore this examination will provide the direct test of whether individual personality differences can account for both cognitive errors ('Error') and risk-taking ('Risky').

The dominant views of risk described in Chapter Four, comes from work set in the social cultures (The Royal Society Study Group, 1992) and from within Douglas' (1982) theory. Individual personality effects have generally been ignored in these works which have focussed on other important phenomonan. The HSE approaches in HSG 48 treats risk reduction as a function of the job and safety climate across all sectors of industry, which include the psycho-social hazards and job characteristics, but where the individual is targeted as a source of intervention.

Chapter Five literature sources describe the typical characteristics of a designer's job. These determinants appear as facets of the designers' role orientation, and job responsibilities. These are coupled with the designer's ability to solve problems, without committing the mistakes attached to cognitive error and adopting the risky design protocols, which have been discussed Chapter One.

The literature sources in Chapter Six indicate that the social culture construct is brought about through personal beliefs, acknowledgement of the leadership values and the qualities of others. Social responsibility and the socialising of individuals within teams also appear to be critical in order to test any group effects associated with risk-taking.

Chapter Seven continues the theme of socialised working and group effects by describing the design organisation's safety climate within which hazardous designs are executed. Many of the characteristics described within safety climate are facets of the organisation and how designers' fit into an organisational structure. The evaluation of the design organisation's safety climate will be made through the adaptation of questionnaire items originally applied to an offshore workforce (Cox & Cheyne, 2000) and in an industrial setting by Zohar & Luria (2005).

The error types suggested as being responsible for the majority of bad designs have been described in Chapter One. The two classes of design error are recognisable as the mistakes most frequently committed by designers, namely errors of omission, as postulated by Reason (1990) and the errors of commission put forward Sanders and McCormick (1993) and Higgins (1997). These error states have been operationalised in two ways. Firstly, as errors that are intimate to the individual and specific to certain *a priori* conditions (see Wallace & Chen, 2005) and secondly through the designer's use of a risky design protocol. These design protocols relate to regularly making assumptions about missing pieces of data (errors of omission); the reuse of previous designs that have not been updated, applied solutions that have worked well in the past, and an added fit-for-purpose design feature that others need to check (errors of commission). These protocols are seen as risky because the data used is not necessarily from a finalised design. The cognitive error states relate to memory, having difficulty in remembering how to perform specific design tasks, attention including sustaining attention, for example being easily distracted by others and certain intrinsic psychomotor functions relating to the individuals accuracy in typing on a PC keyboard, writing or reading email. Therefore the thesis has concentrated upon individual personality differences to explain designer's cognitive errors ('Error') and use of risky protocols ('Risky').

8.2 Hypotheses

From the discussions in Section 8.1 several hypotheses have been developed to explore the research question attached to this study.

The hypotheses attached to the research question state:

1a). *Designers with high levels of extraversion should report higher levels of risky protocols* (Eysenck, 1962; Arthur & Graziono, 1996). Individuals with high extraversion have significantly lower in levels of vigilance, less involvement in task execution and are more liable to take risks;

1b). *Designers reporting low levels of emotional stability are more likely to report cognitive errors* (Costa & McCrae 1980; Eysenck, 1970). Theory suggests that low levels of emotional stability results in acute reactions to stressors, decreasing cognitive resource and increased cognitive error probability;

1c). *Designers reporting low levels of agreeableness are more likely to report cognitive errors* (Cellar, Nelson, York & Bauer, 2001). A low level of agreeableness implies an inability to cooperate effectively with others thereby increasing the likelihood of errors;

1d). *Designers reporting high levels of openness are more likely to use risky design protocols* (Costa & McCrae, 1980). Designers who are high in openness are imaginative, curious and unconventional and maybe more liable to experimentation and improvisation resulting in more risky protocols being used;

1e). *Designers who possess high levels of conscientiousness are less likely to commit cognitive errors and use less risky design protocols* (Arthur & Graziono, 1996; Cellar, Nelson, York & Bauer, 2001; Wallace & Vodanovich, 2003; Wallace & Chen, 2005). Designers with low scores on conscientiousness are significantly associated with errors, risk-taking, accidents and poor safety behaviour.

The designer's job characteristics are non-hypothesised constructs that will be added to the analytical model as important contextual variables. There inclusion is in order to examine the designer's job experiences in response to cognitive error events and the use of risky design protocols. Job characteristics are also important factors because of the way that the work domain evokes and influences performance (Daniels et al, 2006). Risk perception, the social cultures and safety climate have been treated in exactly the same way. The investigation into any affects that safety climate may have has been considered at two levels, at the individual level and at the team or group level.

The next section of this thesis contains the methodology chapter. The development of a suitable instrument to apply to designers on hazardous projects is proposed in Chapter Nine and reflects upon some of the practical as well as theoretical issues. This instrument provides the framework for the measurement of the constructs considered attributable to the designer and is therefore amenable to scientific study.

Chapter Nine

Methodology

9.1 Overview

This overview prepares the reader with an insight into the use of the qualitative and quantitative methods selected for this study. The overall methodological approach is described in the introduction, Section 9.2. Section 9.3 commences by entering into a general discussion into the questionnaire methodology that has been applied and the forms of daily diary methods that are available for general use in research of this type. Section 9.3.1 describes Stages One and Two which adopt these same approaches, albeit with slightly different objectives. The methodology in Stages One and Two makes use of experience sampling methods through the application of a daily diary method, together with the more traditional paper based questionnaire.

Stage One is the Pilot Study that was preceded by the development of initial questionnaire items. A review of the available scales supporting the Pilot Study item development is included in order to justify the item selections that are made. Stage One also applies the experience sampling method (ESM) by using personal digital assistants (PDAs). There are certain advantages that are afforded in an ESM by using a structured daily diary methodology over other more traditional methods, and these are described.

Questionnaire item development for stages one and two are contained in Section 9.4. Section 9.5 details the approach to the development, interpretation and validation of these study questionnaires by using exploratory factor analysis and hierarchical linear analysis.

Section 9.6 commences with a description of intervention protocols that have been adopted. This is followed by a description of some of the traditional limitations found when applying daily diary methods and proposals are included that describe how to overcome them in the sample population involved in this study. Section 9.7 describes the application of the exploratory factor analysis. The validity of the methods used, in terms of internal and external performance consistency is discussed in Chapter Twelve.

Section 9.8 describes the hierarchical linear modelling techniques for the two-level and three-level models with Section 9.9 displaying the results format.

The chapter concludes with a summary in Section 9.10.

9.2 Introduction

Dane (1990) reports that research of this type should set out to achieve a specific objective. Existing research undertaken into the practices associated with the organisational adoption of risk-taking implies that a difference has been demonstrated between the basic climate of the designer and that of the end user (Florman, 1976; Kunda, 1992). The acceptability of these circumstances in the design and operation of hazardous installations represents an intriguing proposition that was initially explored in the preliminary investigation. The methodology attached to this research has been developed to explore the hypotheses.

This chapter describes how the hypothesis testing has been approached through this combination of complimentary measurement techniques. The process of hypothesis testing at stages one and two is considered in the context of an extension of the experience sampling using daily diary methods already described by Daniels, Harris and Briner (2001) and Daniels, Hartley, Beesley, Boocock, Cheyne, and Holland (2006).

9.3 Methodological approach

For the organisational setting attached to this study Sekaran (1992) suggests that the research should be conducted to solve a particular problem. McGrath (1981) states that using multiple methods of investigation are not just a desirable approach but an imperative for building knowledge. Within management and organisational studies the quantitative approach is seen as being objective (Williams, 1998) and this has been followed. There are a number of key assumptions that have underpinned the research method, notwithstanding the many approaches that have been employed in this study into cognitive error ('Error') and the use of risky protocols ('Risky') in the offshore sector (Burrell & Morgan, 1979).

This research has taken a positivist approach which makes the following assumption, that the objective measurement of cognitive error and risk is achievable. This position is one that contrasts with the Bayesian view where for example the risk paradigm is seen as just another way of expressing uncertainty (Shrader-Frechette, 1991; Schofield, 1998). Also some of the early work in the preliminary investigation was based upon the 'The Cognitive Failure Questionnaire (CFQ) and its correlates' developed by Broadbent et al, (1982) which demonstrated three major categories of cognitive error:

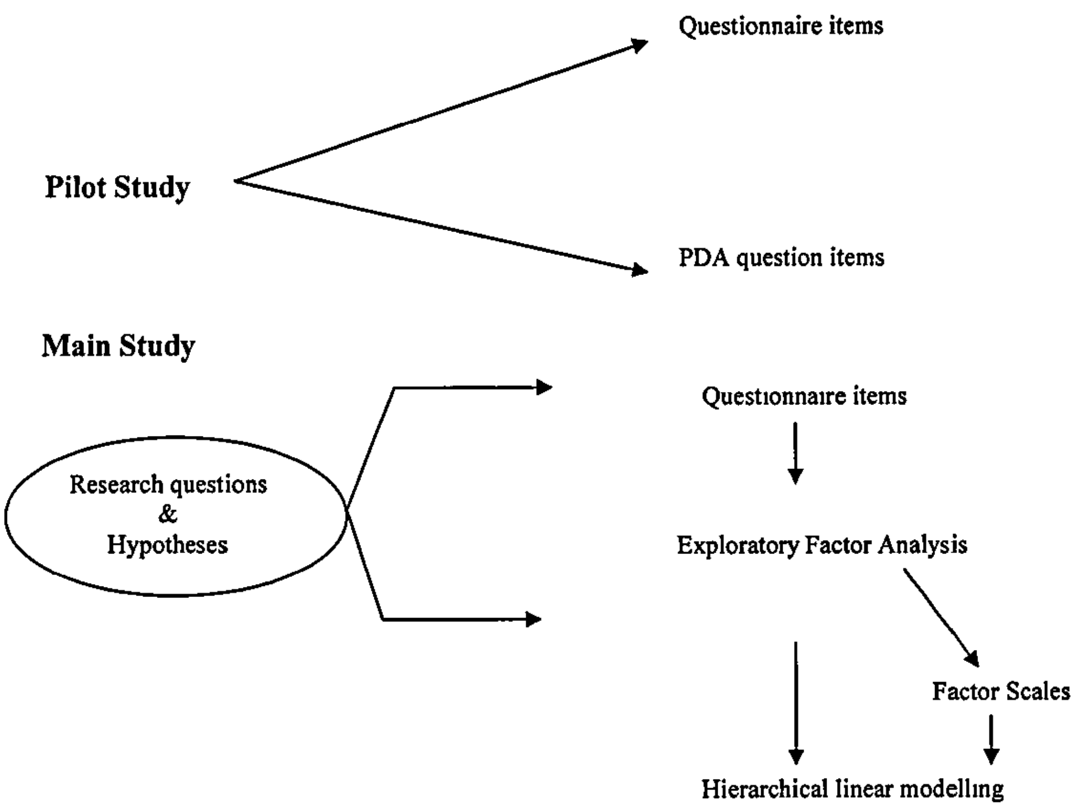
- Errors in the formation of intentions;
- Faulty activation of schemas and
- False triggering of actions.

In addition, similar scaling approaches have been taken to addressing individual personality (Conn & Rieke, 1994; Costa & McCrae 1992; Goldberg, 1999; Hogan & Hogan, 1992), job characteristics (Barnett & Brennan, 1995; Breaugh, 1985; Caplan, Cobb, French, Van Harrison & Pinneau Jnr., 1975; Daniels & Guppy, 1995; Hackman & Oldham, 1975; Kahn, Wolfe, Quinn, Snoek, & Rosendahl, 1964), safety climate (Cox & Cheyne, 2000; Neal & Griffin, 2002; Turner & Parker, 2004; Waring & Glendon, 1998; Zohar, 1980; Zohar & Luria, 2005), and the tradition of risky decisions (Kahneman, Slovic & Tversky, 1982; Norman, 1981; Norman & Shallice, 1980; Reason & Mycielska, 1982, and Reason, 1984 & 1990) where the strongly embedded view is that risky decisions are real things that can be observed.

9.4 Stage One and Stage Two methodology

This section details the Stage One Pilot Study and Stage Two Main Study methodologies. Firstly, the methodological approaches for these two stages are identical however, the purpose of the Pilot Study differs from that of the Main Study. The extent of analysis work on the questionnaire undertaken in the Pilot Study also differs from that in the Main Study. Figure 9.1 illustrates the different aims of the research methodology for the Pilot Study and the Main Study

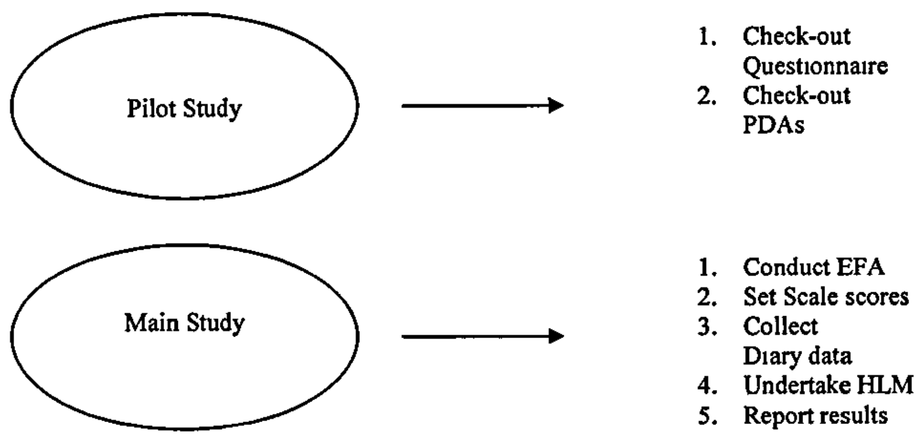
Figure 9.1: The aims of the research methodology for the Pilot Study and the Main Study



The Pilot Study investigates scale reliabilities defined by way of Cronbach's α (See Section 9.6) in order establish the internal reliability of the questionnaire items. The factored items in the Main Study are used to create new scales that are used in the hierarchical modelling. The Main Study also reports cognitive error and risk perception through a correlations matrix and a two level hierarchical linear regression.

Consistent with Miner, Glomb and Hulin (2005) the method of sampling for stages one and two have been carefully considered in order to gauge the appropriateness of the organisational context and the sample population. The questionnaire item development that was undertaken at the Pilot Study stage is fully described in the following passages. Rather than repeat these descriptions within the Main Study the thesis only reports the main study items by exception. All questionnaires appear in Appendix 1. The Pilot Study results are contained in Appendix 4.

Figure 9.2: Pilot Study and Main Study activities



9.5 Questionnaire item development

9.5.1 Pilot Study

There are five objectives attached to the pilot study:

1. Enrolling a sufficient but small number of participants from within an aligned hazardous industry, in this case the nuclear sector, compared to the one being studied in the Main Study;
2. To ensure that the organisational context of the Pilot Study was the same as the Main Study;
3. To confirm that the participants understood the questions being asked in both the questionnaire format and on the PDA handsets;
4. Assess the reliability over the range of scales in the categories of job characteristics, risk perception, safety climate, social culture and individual personality differences. The internal reliability of each scale is measured by calculating the internal statistic known as the Cronbach's α. This statistic refers to the homogeneity of the scale. The acceptable level for internal reliability is around 0.7 and above. A very low alpha indicates that the scale does match the items as intended and are not being answered in a consistent fashion;
5. Proving the robustness of the PDA handsets and reliability of the software over the one week trial period

The Risk and the Designer questionnaire used in the Pilot Study contain five sections. The first section addresses job characteristics in the section titled 'Your Work' (Barnett & Brennan, 1995; Breaugh, 1985; Caplan, Cobb, French, Van Harrison & Pinneau Jnr., 1975; Daniels 1996; Daniels & Guppy, 1995; Hackman & Oldham, 1975; Kahn, Wolfe, Quinn, Snoek, & Rosendahl, 1964). There are 35 questions that have been applied based upon the features that emerged from the literature review. Six of the job characteristic questions concern job autonomy (Breaugh, 1985), ten address support (Daniels & Guppy, 1995), seven deal with role clarity (Caplan et al, 1975), and six are formed in each of the categories attached to job demands (Caplan et al, 1975; Barnett & Brennan, 1995) and skills (Barnett & Brennan, 1995). Eight Risk Perception (Slovic, Fischoff & Liechtenstein, 1982) questions are also embedded in Section one, where four have been selected in each of the categories of dread and unfamiliarity. This brings the total number of questions in the first section of the questionnaire to 43. In the analysis, job characteristics and risk perception are reported separately.

Section Two of the questionnaire addresses 'Your Team Work' (Cox & Cheyne, 2000, Zohar & Luria, 2005) and contains 24 questions. The questions for this section have been adapted from the measurements addressing safety climate derived in an industrial workplace. These questions have simply been rephrased to suit a design environment. Five of these questions relate to safety communication, four concern safety priorities, seven address safety leadership, and four questions are placed in each of the support and safety rules categories.

The Social Culture questions in Section Three appear under the heading 'Your Attitudes to Work' and contain 24 questions. These questions are adaptations of the work conducted by Daniels, Harris and Briner and reported in HSE (2002) and concern associations with attitudes that reflect individualism, egalitarianism, hierarchism and fatalism and are randomly distributed throughout the section.

The psychological personality questions are the IPIP 50 (Goldberg, 1999) which appear in Section Four in the measurement of individual personality differences and are reflective of work that has been previously validated. Interspersed within this section are adaptations of Wallace and Chen's (2005) questions that deal with the constructs of attention and memory in relation to cognitive error. Individual personality differences and cognitive error are reported separately.

9.5.1.1 Job Characteristics

In complex problem solving, the demands usually involve an element of operational uncertainty (Wall, Cordery & Clegg, 2002). In these situations it has been suggested that job controls allow individuals the degree of flexibility to implement novel design solutions (Wall et al, 2002). The primary job characteristic measures are classified according to an instrument designed specifically for a population of designers. Warr's (1987) categories of control through job autonomy and clarity, skills and demands are described. Support was added because of the reference to teams, team support and organisational support recorded during the interviews. The attitude statements that are contained within Section 1 of the questionnaire cover aspects of a designer's working role and are co-mingled with a number of risk perception questions. All questions are set based upon a Likert scaling method where the respondents are asked to express their views according to the anchor points of 1 = disagreement or 5 = agreement.

Job autonomy is described as the degree to which the designer has control over how to complete work tasks and schedule work activities for example, how the designer can choose to do the job. The job autonomy question set is based upon work by Breaugh (1985). Job support items (Daniels & Guppy, 1995) describe the degree to which the designer can seek advice from colleagues, technical authorities within the engineering organisations in order to help solve technical problems, for example "Can you seek advice from other people about work problems?"

Role clarity items from Caplan et al (1975) represent the degree to which the designer is clear about their role, responsibilities and objectives within the design team within the execution of the hazardous project, for example 'Are you clear about your job responsibilities?' Work demands represent the degree to which the designer has to work to stringent just-in-time deadlines, extended hours, dealing with complex technical issues or on the completion of multiple tasks. These types of demands contrast with work activities that are simply straightforward tasks, repetitive tasks or work that occurs when the designer has plenty of time to do the work. An example of how these demands might be addressed is through controlling the sequence of work activities. These items have been adapted from Caplan et al (1975) and Barnett and Brennan (1995). Skills items have also been adapted from Barnett and Brennan (1995) to represent the degree to which the designer's skill utilisation matches their work demands.

The 43 questions that apply to this section are listed below and include the eight risk perception questions in items 5, 7, 12, 14, 19, 24, 28 and 31:

Table 9.1: Job Characteristics

1. Can you choose how you do your job?
2. Are your work objectives clearly defined?
3. Do you work to tight deadlines?
4. Can you talk to other people at work to decide what to do about work problems?
5. Do you work on projects with little scientific knowledge of the risks?
6 Do you receive feedback on your job performance?
7 Do you work on projects where the hazards pose a significant and widespread risk to the environment or the public?
8. Can you decide when to do particular work activities?
9. Are you clear about your job responsibilities?
10. Does your job require complex or high level skills?
11. Can you rely on other people at work when things get tough?
12 Do you work on projects where the consequences of any accident might not easily be controlled?
13. Do you work long hours?
14. Do you work on projects where the long-term outcomes of the risks are uncertain?
15 Are you given new tasks with little regard for work already in progress?
16. Are you able to modify your job objectives?
17. Are you clear about what others expect of you at work?
18. Can you seek advice from other people about work problems?
19. Do you work on projects where people might be exposed to risks they cannot control
20. Can you control the sequencing of your work activities?

21. Do you ever work for periods where you feel you have too little to do?
22. Are you allowed to decide how to get your job done?
23. Do you have a variety of tasks to perform?
24. Do you work on projects where the health and safety risks can be unpredictable?
25 Can you confide in other people at work?
26. Do you have too much work to do?
27. Do you work on difficult designs?
28 Do you work on projects where the hazards pose a significant risk to future generations?
29. Do you have to do a lot at work?
30. Do you have some control over what you are supposed to accomplish?
31. Do you work on projects where the risks cannot easily be observed by those exposed?
32 Does your job require detailed technical knowledge?

9.5.1.2 Risk Perception

The attitude statements contained within this section of questionnaire are also set based upon a Likert scaling method to measure the two major dimensions of dread and unfamiliarity (Slovic et al, 1982). The respondents are asked to express their views according to the anchor points of 1 = disagreement or 5 = agreement on the congruence attached to dread and unfamiliarity through their use of technology. These items were developed for this study.

The questions attached to each are described in Table 9.4:

Table 9.2: Risk Perception question set

Dread Risk Perception question
Do you work on projects where the hazards pose a significant risk to future generations of the general population?
Do you work on projects where the hazards pose a significant and widespread risk to the environment or the public?
Do you work on projects where the consequences of any accident might not easily be controlled?
Do you work on projects where others might be exposed to risks they cannot control?

Unfamiliarity Risk Perception question
Do you work on projects where the long-term outcomes of the risks are uncertain?
Do you work on projects where the health and safety risks can be unpredictable?
Do you work on projects where there is little scientific knowledge of the risks?
Do you work on projects where the risks cannot easily be observed by those exposed?

9.5.1.3 Safety Climate

To measure the dimensions of safety climate this section argues in favour of using simple and straightforward adaptations of readily available scales. This approach contrasts with engaging in a fundamentally exhaustive examination into how to derive original items for use in an environment that has had limited exposure. In particular, this section discusses whether the available instruments have the capability to be used to predict the effect of safety climate in mediating behaviour at an individual and design team level.

This section proposes how safety climate can be measured within the design function of the engineering organisations that participated in this study. Eldridge and Crombie (1974) identified the dimensions of climate to comprise of depth, breadth and progression. Depth relates to the way that climate is reflected in the values and policies held by the organisation. Climate breadth is the lateral co-ordination of different organisation components that are reflected in the internal consistency when measuring and reporting on safety climate. Progression refers to the time dimension attached to improvements in performance over time (Schein, 1990).

The adaptations made to the questions are reflective of the designers work environment. Through these adaptations it has become possible to capture the essence of the original questionnaire developed by Cox and Cheyne (2000) and Zohar and Luria (2005). This process involved setting out the questions in a way that reflected the degree to which the design teams were reliant upon the organisation and each other for assistance. This measure included defining their responsibilities for design safety issues and measuring the encouragement the designer receives to apply safe design practices. This process reflects the willingness of the designer's to revert to their team leaders.

Team leaders are expected to provide support at the team level. The team leadership issue corresponds with the degree to which those personnel in authority, in this case either the Lead Engineer or Engineering Manager, are perceived by their designers as willing to assist the design teams. This support reflects solving design problems with safety issues and the adoption of design safe practices. Section Two of the questionnaire addresses 'Your Team Work' (adapted from Cox & Cheyne, 2000, Zohar & Luria, 2005) and contains 24 questions. Five of these questions relate to safety communication, four concern safety priorities, seven address safety leadership, and four questions are placed in each of the support and safety rules categories illustrated in Table 9.4.

<u>Table 9.3: Safety Climate questions</u>

Safety Messages and Communication
1. There is good communication about safety issues.
2. Our team leader expresses satisfaction when I perform my job with safety as a priority.
3. Our team leader talks about the importance of safety.
4. Our team leader makes sure we receive appropriate recognition for achieving safety targets on the job.
5. We are strongly encouraged to report unsafe design features.

Safety Priorities
6. Sometimes, the team finds it necessary to assign safety as a lower priority to meet project deadlines.
7. Safety issues are assigned a high priority.
8. Our team leader encourages us to give safety a priority.
9. Operational concerns often conflict with design safety procedures.
Safety Rules and Procedure
10. Safety rules and procedures are carefully followed.
11. Some health and safety procedures and systems are not really practical for this design team
12. We find that some health and safety procedures do not need to be followed to get the job done.
13. Our team leader spends time advising me on how to make designs safer

Table 9.3: Safety Climate questions Continued)

Safety Leadership
14. Our team leader waits for things to go wrong before taking action.
15. Our team leader suggests new ways of making our designs safer
16. Our team leader does not intervene until safety problems become serious.
17. Our team leader spends time advising me on how to make designs safer
18. Our team leader shows determination to ensure our designs are safe
19. Our team leader behaves in a way that displays commitment to safe designs
20 Our team leader avoids making decisions that affect safety
Team Support
21. We often give to tips to each other to maximise the safety of our designs
22. We encourage each other to raise safety concerns
23. There are always enough people to get the design completed so it is safe.
24. Our team leader encourages me to express my ideas about safety in our designs

9.5.1.4 Social Culture

Chapter Six examined whether there is a gap or any potential conflict in Douglas' (1982) theory when it is applied to designers. This is in order to explore some of the concepts that collectively form the foundations of social culture. These views and beliefs combine in contributing to item development. These items are drawn from the investigation (Daniels, Harris & Briner, 2001; HSE, 2002) that populates the taxonomy of social cultures and their associated risk-taking beliefs captured from Table 4.3. Interpretation of these factors is a burden that has dogged previous investigations into quantitatively measuring the social cultures (see HSE report 2002).

Sjöberg's (1997) key criticism of Wildavsky and Dake (1990) and Mars and Frosdick (1997) concerned the validity of measures of cultural inclination that need to be in place to validate cultural theory.

Sjöberg states:

> "Cultural theory is simply wrong. Cultural biases are not major factors in risk perception, but only a ***very minor*** contribution to its explanation." (at pg 126)

Cultural theory is, according to Smallman (1998), an abstraction of nature and human kind and therefore beyond empirical validation. Sjöberg (1998) described cultural theory as a complex conceptual structure where much of the research has been conducted on a theoretical basis. A key weakness is the apparent impossibility of framing a testable hypothesis (Adams, 1995) in order to adequately explore cultural theory. The original analysis by Wildavsky and Dake (1990) involved the use of qualitative approaches to record the observed phenomena. As a predictive mechanism this test provides marginal statistical validation of cultural theory requiring further work to be undertaken, yet, as a test measure it appears to probe the existence of cultural theory (c.f. Smallman, 1998). Dake (1991) devised scales in a questionnaire format for measuring three of the major dimensions of cultural theory. These measurements included scales for egalitarianism, individualism and hierarchy. Some experimental methods were also developed for measuring fatalism. Wildavsky and Dake (1990) reported promising results with the use of similar scaling methods on the same set of classifications but within a different sample population. From the work undertaken by Thompson et al (1990), Adams (1995) and

Mars (1996) there have been past attempts to correlate cultural trend classifications within the scope of human risk and reasoning. The techniques used by these researchers incorporated interventional decision-making and are techniques that have been considered in support into this investigation into the designer's risk-taking.

9.5.1.4.1 Item development

Capturing views in an environment that is risk laden is considered highly salient to this study. Any investigation into risk needs to examine the repeatability of some already established findings that have been made in the same or a similar context. A number of factors that concern social attributes of risk decision-making are described by Slovic et al (1982) and risk preferences (Starr, 1969; Aven & Kristensen, 2005). The individual and collective views on dread and unfamiliarity (Slovic et al, 1982) and the implications of avoiding, reducing, transferring and retaining risk are seen as being highly relevant to this discussion. Other themes concern risk uncertainty and hence the acceptability of risk in designs according to the designer and the end user views.

Addressing each of these themes with the degree of freedom offered by the range of adjective narratives (in Table 4.3) permits the behaviours associated with the relationships individualist, hierarchic, egalitarian and fatalist to be embraced, tested and reported. The adoption based upon these adjectives also helps to provide a more meaningful interpretation of the analysis. The Social Culture questions in Section Three appear under the heading 'Your Attitudes to Work' (after Daniels, Harris & Briner, see HSE 2002) and contain 24 questions developed for this study.

Table 9.4: Social Culture questions

1. Designers should be responsible for the safety of fabricators and users.
2. Individual designers can bend some rules in order to get the job done.
3. No level of risk is acceptable in a design
4. All designs should be examined from every possible angle before being signed-off.
5. Designs do not always need thorough checking to be considered safe.
6. Responsible designers reduce risk.
7. Fabricators and users should be responsible for their own safety.
8 Risk in a design is inevitable
9. Members of a design project should work together to ensure the safety of their designs
10. Design team members should strive to reduce risk below the level set.
11. Risks are too uncertain to make detailed plans.
12. Members of a design team should all be happy the design is safe before it is signed off.
13. Senior managers in this organisation should be responsible for the safety of fabricators and users.
14 Rules and procedures are effective in preventing accidents
15. It is important to apply design safety procedures properly.
16. Fabricators and users should determine the level of risk they are willing to bear
17. The individual designer is the best person to know if a design is as safe as it can be.
18 Responsible behaviour by fabricators and users reduces risk.
19. Risks are too uncertain to be able to assign responsibility
20. Rules and procedures cannot prevent accidents.
21. Procedures ensure that risks are as low as possible.
22. Inevitably, some designs have to be modified during fabrication or use.
23 Whatever designers do have little bearing on eventual risk in a design.
24. Comprehensive planning and systems reduce risk.

9.5.1.5 Individual Personality Differences and the Development of Cognitive Error Scales

Different researchers often use different measures in multivariate prediction studies therefore obtaining access to true comparative validity studies is rare (Ashton & Goldberg, 1973; Goldberg, 1992; Johnson, 2000). Goldberg (1999) suggested placing a set of personality items into the public domain free from the constraints of copyrighted inventories hence the universal access to the International Personality Item Pool (IPIP). The format chosen for IPIP items is a short narrative phrase that is more contextualised than a single adjective, but more compact than items found in other inventories (see NEO-PI-R, Costa & McCrae 1992; 16PF Conn & Rieke, 1994; HPI, Hogan & Hogan, 1992). For example, the NEO PI-R model developed by Costa and McCrae (1989) has a 240-item inventory. The inventory describes not only the five factor dimensions, but also six other facets or subordinate dimensions for each of the five factor categories. The review of the literature provides strong evidence for the contextual application for certain personality traits to be associated with accident involvement and cognitive errors.

The personality trait dimensions together with the convergence model associated with the questionnaire-based research (Goldberg, 1992) provide a further comparison of three of the most frequently used instruments. These instruments have all recorded data with reliability and convergent validity.

Eysenck (1967, 1991) suggested that personality is reducible to three major traits, whereas others, McCrae and Costa (1987) for example, indicate that there are five factors. Developing a scientific means, using statistical techniques, such as a principal components factor analysis, indicates that personality is stable across different situations and therefore usable in a case where designers are the target population. There are other proponents that suggest there are more than five factors (see Cattell, 1970; Saucier & Goldberg, 1998)

At present there are hundreds of scales constructed from the IPIP items. The psychometric characteristics of the original scale, compared with the IPIP proxies, have been made and in general the co-efficient α reliability of the IPIP scale match or exceed the reliabilities of the original scales. Goldberg, Johnson, Eber, Hogan, Ashton, Cloninger, and Harrison (2006) provide a detailed discussion on this issue.

A further advantage of the IPIP 50 is the visibility of the items coupled with the wide range of the constructs measured by one or more of the IPIP scales. This provides an opportunity for the researcher to target the constructs of interest, although in this study all individual difference constructs are reported. Hence, this study is not constrained by the limited number of scales attached to any commercially available inventory (Ashton, 2005; Johnson, 2005).

To aid the interpretation of the factor analysis, it is relevant to consider research already performed in this field, although not necessarily work that has been applied in an identical context. Wallace and Vodanovich (2003) suggest that individuals who are low in conscientiousness are more vulnerable to cognitive errors, which in turn is predictive of workplace accidents. Some initiating work into relating safety behaviour with certain of the five factor constructs (Wallace & Chen, 2005), involved examining individual workplace cognitive errors. The first of these studies by Wallace and Chen (2005) developed and validated work-specific measures of cognitive error. The second study provided further criterion-related validity of safety behaviour. From these studies the personality traits of conscientiousness and emotional stability appeared significant.

Cognitive error positively and significantly related to emotional stability and unsafe behaviour. Negative and significant correlations were obtained between the aspects of cognitive error considered by Wallace and Chen (2005) e.g. memory, attention and action and the personality trait of conscientiousness. Arthur and Doverspike (2001) recorded that individuals low in conscientiousness exhibit behaviours where failure to follow the prescribed rules was the outcome.

Wallace and Chen (2005) did note that the majority of the previous research had used self-reported behavioural outcomes. The concern expressed by Wallace and Chen (2005) is that self reporting could have manipulated the actual relationship between the cognitive error being examined and the behaviours being recorded (Hofmann & Stetzer, 1996). In other words, the individual may have perceived more accidents due to common source variance, by as much as they perceived their own cognitive error. Wallace and Chen (2005) concluded that some task specific measures could be better predictors of work behaviour compared to assessing trait like measures (c.f. Phillips & Gully, 1997).

Wallace and Vodanovich (2003) investigated the effects of cognitive errors on safety and accidents and hypothesised that cognitive failure should directly predict safety behaviour and workplace accidents. These were predictors with outcomes over and above individual levels of conscientiousness. However, Wallace and Vodanovich (2003) also suggest that certain other individual differences may interact to produce differential effects. Overall, the conclusion from Wallace and Vodanovich (2003) is that cognitive error plays an important part in individual safety behaviour, especially where conscientiousness is found to be low. Cognitive error appears to have moderated the relationship between conscientiousness and unsafe behaviours and subsequent accidents.

Additionally, workplace cognitive error positively relate to emotional stability as these individuals are more prone experience stress, fear and disgust that may put them at a higher risk of engaging in certain off-task behaviours. These expectations are consistent with Kanfer and Heggestad (1997) who also argued that general achievement and anxiety tendencies were the best predictor components of self-regulation. It is therefore conceivable that if designers follow the same behaviour patterns defined by their personality, then those designers who are more prone to engaging in risky behaviour and committing cognitive errors are more likely to be the designer's responsible for allowing a design feature to pass through a design without the requisite degree of checking.

This section has examined individual differences, personality traits and other factors influencing safety behaviour and indicated that some factors that are attached to cognitive errors. The literature sources that have been reviewed demonstrate consistency in their treatment of the specific personality traits.

The literature review of the comparative studies undertaken by Wallace and Vodanovich (2003), Wallace and Chen (2005), Clarke and Robertson (2005) also provides evidence of a connection between personality traits and forms of cognitive error. Finally, contained in Chapter Three is the theoretical evidence that a model exists where the five factor taxonomy adequately accounts safety related behaviours.

Table 9.5: IPIP 50

Extraversion
I am the life of the party.
I don't talk a lot.
I feel comfortable around people
I keep in the background.
I start conversations
I have little to say
I talk to a lot of different people at parties
I don't like to draw attention to myself
I don't mind being the centre of attention
I am quiet around strangers

Table 9.5: IPIP 50 (Continued)

Agreeableness
I feel little concern for others
I am interested in people
I insult people
I sympathize with others' feelings
I am not interested in other people's problems
I have a soft heart
I am not really interested in others
I take time out for others
I feel others' emotions
I make people feel at ease
Conscientiousness
I am always prepared.
I pay attention to details
I make a mess of things
I get chores done right away
I often forget to put things back in their proper place
I leave my belongings around
I like order
I shirk my duties
I follow a schedule
I am exacting in my work

Table 9.5: IPIP 50 (Continued)

Emotional Stability
I get stressed out easily
I am relaxed most of the time
I worry about things
I seldom feel sad
I am easily disturbed
I get upset easily
I change my mood a lot
I have frequent mood swings
I get irritated easily
I often feel blue
Openness to Experience
I have a rich vocabulary
I have difficulty understanding abstract ideas.
I have a vivid imagination.
I am not interested in abstract ideas
I have excellent ideas.
I do not have a good imagination.
I am quick to understand things.
I use difficult words.
I spend time reflecting on things.
I am full of ideas.

Table 9.6: Cognitive Error questions

Cognitive Error		
Wallace and Chen, 2005	**Risk and the Designer (Section 4)**	**Category**
Cannot remember whether you have or have not turned off work equipment?	I often forget whether I have turned off work equipment, such as computers before I leave work	Memory
Fail to notice postings or notices on the facilities notice board(s) or the email system?	I often fail to notice postings or notices on the work email system	Memory
Forget where you have put something you use in your job (e g. tools)?	I often forget where I have put something I use in my job	Memory
Cannot remember work-related phone numbers?	I often find it difficult to remember work-related phone numbers	Memory
Cannot remember what materials are required to complete a particular task?	I often have difficulty remembering the things required to complete a particular task	Memory
Daydream when you ought to be listening to somebody?	I often daydream when I should be listening to somebody	Attention
Do not focus your full attention on work activities?	I often find it difficult to focus my full attention on work activities	Attention
Fail to recall work procedures?	I often fail to recall work procedures	Attention
Are easily distracted by co-workers?	I am often distracted by my co-workers	Attention

9.5.2 Main Study

The Risk and the Designer questionnaire used in the main study contains five sections as mirroring the Pilot Study. The first section addresses job characteristics in the section titled 'Your Work' (Barnett & Brennan, 1995; Breaugh, 1985; Caplan, Cobb, French, Van Harrison & Pinneau Jnr., 1975; Daniels 1996; Daniels & Guppy, 1995; Hackman & Oldham, 1975; Kahn, Wolfe, Quinn, Snoek, & Rosendahl, 1964). There are 43 questions addressing job characteristics with six of them concerning job autonomy, ten addressing support, seven dealing with role clarity, and six in each of the categories of job demands and skills. The Risk Perception (Slovic et al, 1982) questions as in the case of the Pilot Study are embedded in Section one with four in each of the categories of dread and unfamilarity. In the analysis, job characteristics and risk perception are reported separately.

Section Two of the main study questionnaire addressing 'Your Team Work' (Cox & Cheyne, 2000, Zohar & Luria, 2005) contains the identical set of question items as the pilot study. The Social Culture questions in Section Three appear under the heading 'Your Attitudes to Work' (after HSE, 2002) and contain 33 questions. Section 7.5.2.5 details the questions for each of these social cultures. Section Four of the Main Study questionnaire entitled 'Behaviours in general', addresses the psychological personality questions in the IPIP 50 (Goldberg, 1999) are all reflective of work that has been previously validated. The IPIP 50 question set has been directly imported into the Main Study questionnaire. Interspersed within this section were the same adaptations of Wallace and Chen's (2005) questions that deal with the scales of attention and memory in relationship to cognitive failure. Individual personality differences and cognitive error are reported separately. This section contains the same set of question items as the Pilot Study.

9.5.2.1 Job Characteristics

A number of changes were instigated as a result of some poor scale reliabilities in the Pilot Study. Items 1 through to 13 remain the same with the exception of item 11. The content of questions 11 and 15 has been changed because internal reliability was improved when they were deleted. Q16 was repositioned to become Q18 in the main study. A new support question was introduced as Q19 and a new role clarity question was added at Q20. Q21 introduces a new support question and Q22 is a new and more concise role clarity question to the one originally included in the Pilot Study. Q24 is a new support question and Q25 was originally Q20. Q26 has been reversed to read 'Do you ever work for periods where you have little to do?' from 'Do you have too much work to do?' Q27 is a new job autonomy question and Q30, Q34, Q35, Q36 and Q37 have all been slightly rephrased to assist in their comprehension. Q38 is a new demands question and Q39 was formerly Q32 in the Pilot Study. Q40, Q41 and Q42 are new questions in the support, job autonomy and demands categories.

The attitude statements that are contained within this section of the questionnaire covering aspects of work are still co-mingled with the risk perception questions. All questions were set based upon the same Likert scaling method where the respondents were asked to express their views according to the anchor points of 1 = disagreement or 5 = agreement. The 43 work related questions include the eight risk perception questions where the job characteristics are grouped into five categories as follows:

Table 9.7: Job Characteristics

Job Autonomy
Can you choose how you do your job?
Can you decide when to do particular work activities?
Are you able to modify your job objectives?
Can you control the sequencing of your work activities?
Are you allowed to decide how to get your job done?
Do you have some control over what you are supposed to accomplish?
Job Support
Do people at work help you get the things or information you need to do your job?
Do other people at work listen to your work problems?
Do people at work tell you that they value your contributions?
Is it easy to talk to other people at work about work problems?
Do other people at work make your work life easier for you?
Do people at work tell you that they have confidence in you?
Can you seek advice from other people about work problems?
Can you confide in other people at work?
Can you talk to other people at work to decide what to do about work problems?
Can you rely on other people at work when things get tough?
Role Clarity
Are your work objectives clearly defined?
Do you receive adequate feedback on your job performance?
Are you clear about your job responsibilities?
Are you clear about what others expect of you at work?
Are your performance criteria clear?
Are you clear about how to do your job?
Are your work tasks well defined?

Table 9.7: Job Characteristics (Continued)

Work Demands
Do you work to tight deadlines?
Do you work long hours?
Are you given new tasks with little regard for work already in progress?
Do you have too much work to do?
Do you work on many tasks in quick succession?
Is your job ever simple or repetitive?

Skills
Does your job require complex or high level skills?
Do you ever work for periods below your level of ability?
Do you ever work for periods where you have too little to do?
Do you have a variety of tasks to perform?
Do you work on complex designs?
Does your job require detailed technical knowledge?

9.5.2.2 Risk Perception

The statements contained within the Main Study questionnaire were exactly the same set as in the Pilot Study.

9.5.2.3 Safety Climate

This section of the Main Study contains exactly the same question set as the Pilot Study.

9.5.2.4 Social Cultures

The attitude statement of the design team is set based upon an 8 point Likert scaling method where the scale was asymmetric around the measurement point '3' because of the pilot study result and in order to provide more nuances to each item statement. The respondents are asked to express their views according to the anchor points of disagreement where '1' indicates the participant feels the attitude reflects no truth, '3' that the attitude is neither true nor untrue, '6' indicates the attitude mostly reflects the truth and '8' that the attitude reflects the truth completely as follows:

1. indicates the statement is not at all true;
2. indicate the statement is mostly untrue;
3. indicate the statement is neither true nor untrue,
4. indicates the statement is has some truth to it;
5. indicate the statement is somewhat true;
6. indicate the statement is mostly true;
7. indicate the statement is very true;
8. indicate the statement is completely true;

Additional questions had been added to the questionnaire since the pilot study. This provided additional opportunities for the researcher to improve the scales of social culture and risk and scale reliability. Additional questions were added following the pilot study in an attempt to improve the internal reliability of the social culture scales to a level where the alpha co-efficient was > 0.7. The additional questions in the final questionnaire were selected from the following:

Table 9.8: Social Culture additional questions

1.	Designs don't need to account for all risks
2.	Design standards do not act as barriers to safe designs
3.	Operator preferences help improve design safety
4	Sharing design problems will ultimately improve safety
5.	Safer designs rely upon sound engineering judgement
6	Designers should always see the job through to handover
7.	All designers know that the benefits of technology compromises Safety
8	Operators improvise to solve design problems
9.	A fit-for-purpose design makes good safety sense and is more profitable
10.	Checking and approval procedures always capture design mistakes
11.	Technology always improves your quality of life
12.	The danger from new technology is always considered to be unknown
13.	Risk is always seen as an opportunity

For the main study there are 13 individualistic questions, eight deal with egalitarianism, seven addressing hierarchism and five fatalistic questions. The complete list of the items is detailed below in Table 9.9:

Table 9.9: Social Culture Mian Study questions

Social Culture Question	Category
The best way to reduce risk is thorough and well-executed rules and procedures	**Hierarchy**
Thorough planning and well-executed procedures limit mistakes in fabrication and use	
Rules and procedures reduce risk to acceptable levels.	
Rules and procedures are effective in preventing accidents.	
Rules and procedures cannot prevent accidents	
Comprehensive planning and systems reduce risk.	
Checking and approval procedures always capture significant design mistakes.	
The individual designer is the best person to know if a design is as safe as it can be.	**Individualism**

Designs do not always need thorough checking to be considered safe.	**Individualism**
Fabricators and users should be responsible for their own safety	
Designers are not responsible for the behaviour of fabricators and users	
Fabricators and users should determine the level of risk they are willing to bear	
Rules can get in the way of efficient design	
Designs don't need to account for all risks	
Operator preferences help improve design safety	
Fabricators can always modify designs if they want to make them safer	
Responsible behaviour by fabricators and users reduces risk	
Safer designs rely upon sound engineering judgment	
All designers know that the benefits of technology compromise safety	
Operators improvise to solve design problems	
No level of risk is acceptable in a design	**Egalitarianism**
Design organisations should strive to eliminate risk.	
All designs should be examined from every possible angle before being signed-off.	
Members of a design team should all agree that the design is safe before it is signed off	
Fabricators and users should never be exposed to risk.	
Designers should always see the job through to handover	
Sharing design problems improves safety	
Safety in a design should never be compromised for profit.	
Risks are too uncertain, in order to make detailed plans.	**Fatalism**
No design can ever be free of risk.	
Inevitably, some designs have to be modified during fabrication or use.	
Whatever designers do have little bearing on eventual risk in a design.	
Risks are too uncertain in order to be able to assign responsibility.	

9.5.2.5 Individual Personality Differences and Cognitive Error items

This section of the Main Study contains exactly the same question set as the Pilot Study.

9.6 Analytical Approach.

9.6.1 Overview

The following sections describe the highly proceduralised methods for recording and analysing the questionnaire data and the diary data. This section has been prepared in three stages. Firstly, the exploratory factor analysis methodology is explained and the development of reliable scales is detailed. This is followed by a discussion on the daily diary methodology. The ESM methodology considers the use of PDA's for data gathering and the validity of this method in a new application. Finally, the section concludes with a description of the hierarchical linear modelling technique that has been used to consider the relationships between the outcome variables, nominated in the research hypotheses, and the explanatory variables that emerged in a Principal Components Analysis (PCA).

9.7 The Daily Diary methodology using Personal Digital Assistants

9.7.1 Overview

Considerable effort needs to be expended in any experience sampling research, as most sample sizes are modest by social science research standards (Hektner, Schmidt & Csikszentmihalyi, 2007). However, the richness of the data makes even studies with few participants reliable in simple statistical terms. This study has turned to the daily process paradigm in order to examine the relationship between daily experiences and the occurrence of the outcome variables.

9.7.2 Event Sampling Methods (ESM)

The diary method aims to record experiences as close as possible to the actual occurrence and thus reduce any retrospective biases (Reis & Gable, 2000). Past psychological and behavioural science research has devoted considerable resources to sampling people and variables but relatively less effort into sampling what happens over time and in everyday daily experiences (Ferguson, 2005). Reis and Gable (2000) further argue that diary studies offer an opportunity to develop and experiment with novel hypotheses, such as those presented in Chapter Eight.

Many of the phenomena described in the hypotheses associated with this research have a strong temporal component and relate to specific daily work experiences, for example being confronted with a design problem where the solution may rest in the adoption of one or more risky design protocols. Past diary studies have mainly focussed upon experiences in a social and clinical setting, where the effects of stress on dependent variables such as emotion, mood and well-being (see Stone & Neale, 1984; DeLongis, Folkman & Lazarus, 1988; Bolger, DeLongis, Kessler & Schilling, 1989), emotional reactivity to everyday problems (Bolger, DeLongis, Kessler & Schilling, 1989; Suls, Green & Hills, 1998), psychosocial antecedents of depressive symptoms (Stader & Hokanson, 1998), self esteem liability as a vulnerability factor for depression (Butler, Hokanson & Flynn, 1994) and physical symptoms (see Brown & Moskowitz, 1997) have all been recorded and measured. These measurements were taken in situ. Increasingly, the recording of experiences from other organisational and social settings (see Daniels & Harris, 2005; Butler, Grzywacz, Bass & Linney, 2005; Miner, Glomb & Hulin, 2005; Tschan, Rochat & Zapf, 2005) has extended the use of this methodology.

This research extends the organisational experience into a new field of interest by examining designers responsible for offshore designs. This in situ study addresses the designer's use of risky protocols and their particular attributions to cognitive errors. These experiences are correlated with a variety of other dependent variables such as, time of day and day of week in order to explore any affect associated with the temporal exponents. They are also related to the conceptually and empirically related constructs that emerged from the exploratory factor analysis.

The equipment used in studies of this type provides several proven alternatives. There are four available methods of data collection each offering something different. The most obvious method for this study is the pen and paper method which offers immediate familiarity to the designer but has the disadvantage for the researcher of confirming accurate compliance (see Guthert, Cohen and Armeli, 2002). Palm-top computers (PDA) provide novelty, a convenient medium for data storage, and accuracy of timings (Feldman Barrett, 2004; Feldman Barrett & Barrett, 2001; Oishi, 2002; Shiffman, 2000). Ferguson (2005) lists the main disadvantages of the PDA to be the need for a high level of technical support, the time commitment needed to train the participants in the use of the PDA, and the frequent contact that is needed between the researchers and the participants' for when things go wrong. Hektner, Schmidt and Csikszentmihali (2007) also indicate the restricted nature of ESM studies using PDA's because of the limited range of responses that participants can provide to the questions being asked, rather than writing down the responses in their own words. Obviously, as the technology improves then this may become a feature of future PDA studies.

The third method involves the use of computer diskettes (Nezlek, 2002). This method experiences the same set of advantages and disadvantages as the PDA. The final method involves the use of email and/or the mobile phone, whereby the participant is contacted with a daily file ready for their completion. Timings can be checked for accuracy and the disadvantages are similar to those associated with the PDA and computer diskette.

Thiele, Laireiter and Baumann (2002) suggest that any of these methods can be characterised through four different types of recognition mechanism. These relate to *object, mode, trigger* and *distance.* The terms applied in this study for *object* refers to the tests applied by way of hypothesis and *mode* refers to the method of data collection. *Trigger* is either the reaction to a particular event or as in this case, a request for a response at a pre-specified time interval. Finally, *distance* concerns the separation between the participants and the researcher, which in this study can be considered to be remote with the researcher physically detached from the participants' work environment following the initial contact.

There are three general classes of signalling schedule that exist (Reis & Gable, 2000; Scollon, Kim-Prieto & Diener, 2003; Wheeler & Reis, 1991). The available trigger methods are described as event-contingent, signal-contingent or interval-contingent methods. In the event-contingent method, participants are simply requested to complete a self report at the same time every day. The most typical type of ESM studies are reported by Hektner, Schmidt and Csikszentmihali (2007) to involve signal-contingent methods, where participants are signalled at random times over the course of several days. The selected technique for this study is the interval contingent method because it is still possible to record the participants' current experiences and general demeanour, as with the signal-contingent method, as well as observe the phenomena to be measured at regular intervals.

There are a number of conventional problems that this ESM study has had to address that possess a positive as well as negative impact. The ESM study enables everyday experiences to be taken at specific time intervals and should be achieved as unobtrusively as possible so as to account for the following affects:

1. Minimising retrospective bias (Reis & Gable, 2000);

2. A reduction in recency and memorability (Reis & Gable, 2000);
3. Establish a temporal precedence to strengthen the causal inferences that can be drawn from the ESM (Tennen & Affleck, 1996).

The frequency of occurrence of cognitive error and the use of risky design protocols was assumed to be occurring throughout the designer's working day and throughout their working week. So taking measurements at regular times, provided they matched with the designer's external co-ordinates, makes good sense. The external co-ordinates refer to the participants being at work, and are consistent with other similar work (see Daniels et al, 2006).

Recruiting participants to share their daily experiences has in the past proved difficult. Offer and Sabshin (1967) suggest that developing a sense of trust and collaboration between the researcher and participants has proved to be an effective strategy. In this study an orientation meeting was set up with groups of participants, in order to outline the importance of the research and describe the data entry and data recovery protocols. In this thesis the data included the participant's levels of cognitive error, measured on a five point scale and anchored at *1 = not at all* to *5 = very* and their use of risky design protocols that required a simple *yes/no* response; for example have you applied a risky design protocol (yes, select 1, 2, 3, 4). Thus acknowledging one of Hektner et al's (2007) concerns regarding the limited range of the available PDA responses however, the range of available self reported choices did strengthen the data entry and data coding procedure. This was achieved by eliminating the need to interpret input data by converting a respondents own written entry into a standard format and was a process that was double checked through the interview study. The self reporting of cognitive error and risky design protocols considered included:

Table 9.10: PDA 'Error' and 'Risky' question sets

Cognitive error (adapted from Wallace and Chen, 2005)	**Use of Risky Design Protocols developed for this study** (see Chapter 1)
In the past hour has it been difficult to remember how to perform specific design tasks,	In the past hour have you made assumptions about missing pieces of data
In the past hour have you been easily distracted from your work,	In the past hour have you reused a previous design that has not been updated
In the past hour has it needed effort to type, write or read	In the past hour have you applied solutions that have worked well in the past
	In the past hour have you added a design feature fit-for-purpose but others need to decide if it's correct

The key to any ESM is striking a balance between getting a representative sample of daily experiences, and not overburdening the participants. Delespaul (1992) suggests that longer sampling periods are more feasible only if the reporting forms that are used are short, for example they take less than two minutes to complete and the number of signals per day is low, for example less than six per day. One of the advantages of an ESM is that it is flexible and can be applied across a variety of research settings. Considerable effort has been expended in developing a question set for the PDA that is aimed at not overburdening the participants. The reporting forms are short, initially taking perhaps three to four minutes to complete but within the working week the respondents become more proficient and are able to complete the set in a much shorter period, say within 60 to 90 seconds. The number of requests for data is limited to four per day for each day of the working week.

Methods that involve the collection of data on more than one occasion are termed longitudinal. Longitudinal research allows an investigation to take place between individuals, between situations and allows a comparison to be drawn between the differences recorded to the same situations. Assessing the participant's reactivity to the phenomena and the situations being measured has been shown to alter the participants experience to the events being measured (Affleck, Zautra, Tennen & Armeli, 1999). Reis and Gable (2000) suggest that this problem is minimal, citing studies showing that diary studies do not account for different retrospective reports compared to non diary studies. However, retrospective recall has come under some criticism (Stone & Shiffman, 1992; Affleck & Tennen, 1996).

The experience sampling methods reported in this thesis captures data in context. The benefit of the selected method is that it minimises distortion due to the recall bias mentioned above and therefore enhances the causal inferences that can be drawn from the data (Bolger, Davis & Rafaeli, 2003). Administering data collection protocols through the

PDA's also has the added advantage of providing each entry with a time signature. This is critical because research shows that a significant proportion of samples can report misleading information about when protocols were completed, rendering time-based data uninterruptible (Stone, Shiffman, Schwartz, Broderick & Hufford, 2003).

Electronic momentary assessments afford greater accuracy in assessment of 'Risky' and 'Error' variables that can be obtained with other daily, weekly, or in other retrospective reports by recording data as close as possible to changes in an individuals personal experiences (Todd, Tennen, Carney, Armeli, & Affleck, 2004). For these reasons the ESM allows stronger inferences of causality to be made. This situation arises because temporal influences on explanatory variables, and the stable factors associated with the individual can all be controlled (Bolger et al., 2003; Tennen & Affleck, 2002).

Another criticism levelled by Rutter, Pickles, Murray and Eaves (2001) on time based data indicates that cross sectional data relies upon between-group analysis. In effect this means that differences in group characteristics are used to infer differences applied to individuals. However, the data collected over time from different individuals in different groups allows comparisons across time, between individuals and between design teams.

With several organisations participating in this ESM study the importance attached to maintaining a detailed register of the participants that is used to log each participant's questionnaire number and the associated PDA by trial wave cannot be over stressed. This is the first step in developing a codebook that will be necessary later in data entry.

Another key feature of this study is the repeat frequency and duration of the study. Ferguson (2005) suggests that the phenomenon under investigation needs to be considered when setting the repeat frequency and duration of the study. Stone, Smyth, Pickering and Schwartz (1996) consider that shorter intervals maybe more appropriate when studying mood related phenomenon and job performance. The PDA field work was conducted continuously over a 24 week period that included PDA administration, data recovery and uploading. The PDA's and their data were recovered onto iESP software immediately following the final signal on day five.

The aim of the diary study was for the participants to complete four one week trials over the 24 week period. In this case the interventions were staggered to occur about once every six weeks. This aim was achieved in six of the eight hazardous projects that agreed to participate in the study. The two remaining projects were closed-out prior to a third trial commencing. The sample size associated with this study should not be considered as small as a result, as both the number of participants and the number of observations recorded is large relative to other studies using this methodology (see Stone & Neale, 1984; DeLongis, Folkman & Lazarus, 1988).

It is essential that the variables under consideration in this study have some meaning and can be related to the theoretical reckoning of the research. The designer's experiences maybe influenced by a top-down (management influence) and bottom-up (team-working) approach and through social information processing or social networking routes (social constructs). Examining the causal hypothesis, that individuals with different personality traits are more or less susceptible to errors and risk-taking, engages Ferguson's (2005) suggestion that the temporal order in which the data is collected is theoretically critical. The empirical evidence surrounding the significance of non-compliance on the results appears inconclusive and perhaps even a little weak (see Gable, Reis & Elliot, 2000; Ferguson, 2005). It is important that attempts are made to ensure a high compliance rate even if the overall effects on the results are not immediately evident. Therefore a cut-off rate for compliance has been set at a rate of < 25% (see Stone et al, 2003) and participants falling below this rate were excluded.

This type of data is recorded in the register in order to help formulate the overall compliance rate. The register ultimately contains every participant's demographic details including their name, and design team in a unique code; questionnaire number and PDA number(s); temporal data including wave number, day of week and time of day and PDA data including error data and the use of risky protocols. A total of 55 design teams were sampled from the eight hazardous projects.

9.7.3 Limitations of the ESM

One of the advantages of applying a daily diary method that adopts the PDA as the recording medium is that time-based data is interpretable. There is no opportunity when using the PDA in this study for any of the participants to manipulate the data being recorded. Gable and Reis (2000) using a computerised system of data collection noted that two thirds of their sample recorded at least two days observations simultaneously when the request for data has not being recorded through a trigger mechanism. The programming of the PDAs eliminated any opportunity for participants to effect multiple completions of data. If an entry was missed at the time of an interval request, then the opportunity was missed and no data relating to that request is recorded and with no opportunity for the data to be added at a later stage. Similarly, there was no opportunity for a participant to skip days of reporting and then complete the data set in one sitting at a later time (c.f. Stone, Kessler & Haythornthwaite, 1991).

Reis and Gable (2000) considered that excessive researcher's time is taken up in administering these types of diary studies. This burden is caused by having to explain why the research is important, why participation is important, and the frequent follow-up contact that is necessary between the researcher and participants. Some of these aspects are addressed in a section of Chapter Eleven that discusses the researcher's experiences with the participants and their PDA's.

9.7.4 Validity of Method

It is important that theoretically orientated research demonstrate internal, construct and statistical validity as well as external validity. A major objective of this study is to isolate the cause and effect relationships experienced by hazardous installation designers. With its focus on particular everyday experiences, the ESM avoids low external validity and many of the internal validity issues appear to be resolved through the selected methodology. ESM is a methodology and a tool and it was important for the researcher to consider if there were any other explanations, apart from the participants experiences, that could account for the ESM data. Zuzaneck (1999) suggests that the immediacy of the

PDA questions eliminates recall bias and whilst the interval-contingent basis of the PDA requests may induce a reflexivity bias, there is little possibility of the participants to tailor their responses (See Kubrey, Larson & Csikszentimihalyi, 1996).

Making inferences about a larger population from a smaller sample population is a key driver for using the ESM (Hektner et al, 2007) in this study. This ESM is a longitudinal study and therefore introduces an additional form of data loss affecting the overall compliance rate other than through a poor response rate and/or a changing sample size, namely any attritional effects. Besides a shrinking sample size, due to absences, closure of projects and participants leaving the host organisation, data loss through refusal, non-response or attrition needs to be considered. There remains the possibility that the participant's may falsify or misrepresent their responses and this cannot be ruled out. However, this ESM study has been conducted on a voluntary basis, and the participants were instructed that their responses were confidential. Critics will point out that organised, diligent, conscientious and psychologically healthy individuals will always volunteer for ESM studies at a greater rate than others, thus rendering the study sample size unrepresentative of the organisation (Hektner et al, 2007). This potential effect is acknowledged and discussed in Chapter Twelve.

In summary, the strength of the ESM is that it produces multiple assessments of a single individual, allowing within person changes in subjective experiences to be measured over time. This compares with individual data that will not change over time such as age, ethnicity and gender, but which is nevertheless important data to record and consider in context. ESM has unsurpassed ecological validity because it allows the respondents to go about their daily work, allowing the researcher to capture their experiences before there is any chance for the response to be filtered by memory or self reflection. A strong utility in this ESM is the interval-contingent period and the overall schedule. The safeguarding of the daily diary data has also been achieved by limiting the duration of the PDA trial to a single working week and by conducting repeat trials with a six week break between the trials. A further measure to limit the possibility of self reflection has been to restrict the time available to make a response following a request for data. This period was limited to 60 seconds. With no response after 60 seconds the PDA switches off.

9.8 Exploratory Factor Analysis

9.8.1 Overview

Exploratory factor analysis can be distinguished from other forms of analysis at both a statistical and methodological level. Whilst there is a strong theoretical argument relating to several of the constructs attached to the questionnaire, it is fair to say that the sample population under investigation is probably being tested for the first time. Therefore an exploratory rather than confirmatory factor analysis has been conducted. In this research a specific form of factor analysis – Principal Components Analysis was used. This is one of the most frequently used forms of factor analysis.

9.8.2 The Exploratory Factor Analysis

The exploratory factor analysis has been conducted in order to predict the emergent factors that are deemed to be not directly observable. This form of analysis merely decomposes the original data into a set of linear variates. The data has been presented as a series of scores based upon a Likert scaling method (Likert, 1932). Likert scaling is a scaling method measuring either a positive or negative response to a statement. Likert scales maybe subject to distortion from several causes. Respondents may avoid using extreme response categories (central tendency bias) or agree with statements as presented (acquiescence bias) or they may try to portray themselves in a favourable manner (social desirability bias).

The aim of the decomposing technique is to then report the variates against a straight line against some theoretically predicted outcomes (Dunterman, 1989). This form of reporting is recognized as the most common form of reporting under such investigative circumstances (Dane, 1990). Comrey (1978) indicates that, where possible, a scientific basis for such an analysis needs to be established upon some form of theoretical structure which reiterates Dunterman's (1989) point. This allows the degree of hypothesis testing that is envisaged to be undertaken and then determine how similar the emergent structure, disclosed through the exploratory analysis, is to the one proposed by theory.

The Main Study questionnaire provides for the development and interpretation and the degree of theoretical structuring suggested by Comrey (1978). Aspects of the questionnaire for example 'Your Work' in Section One (Barnett & Brennan, 1995;

Breaugh, 1985; Caplan et al, 1975; Daniels 1996; Daniels & Guppy, 1995; Hackman & Oldham, 1975; Kahn et al, 1964), the adaptations to questions that created 'Your Team Work' in Section Two (Cox & Cheyne, 2000; Zohar & Luria, 2005), the psychological personality questions (Goldberg, 1999) and the cognitive error questions (Wallace & Chen, 2005) in Section Four are all reflective of work that has been previously been scaled and hence validated.

The exploratory factor analyses have also been conducted on the data sets where there have been no previous analyses, for example the Risk Perception questions in Section one (after Slovic et al, 1982). In the study of risk perception two constructs, dread and unfamiliarity, have been given very specific definitions to account for the designer's treatment of these features of technological risk. Dread has been used to represent the perception of the catastrophic potential, for example the threat posed by the technologies to the offshore workforce. Whereas, unfamiliarity accounts for the degree to which the designer perceives there is little scientific understanding of the risks associated with the use of these technologies. The other example in this class of appraisal relates to the Social Cultures contained in Section Three 'Your Attitudes to Work' (after HSE, 2002).

A basic factor model assumes that the observed variables reflect linear combinations of the underlying factors (Ferguson & Cox, 1993). The aim of the exploratory factor analysis is to identify the minimum number of common factors that are required to produce the initial output matrix (Ferguson & Cox, 1993; Glick & Fiske, 1996).

Exploratory factor analysis has therefore been conducted in four stages to produce the correlation matrix:

1. Error trapping to ensure that there are no incorrect data translations between the questionnaire records containing the Likert scores and the SPSS data file;
2. A data frequency check for any biases;
3. A check that the data is appropriate for an exploratory factor analysis involving skewed and non-skewed variables and kurtosis;
4. Application of either the Varimax or Direct Oblimin rotation methods. The Direct Oblimin method has been applied where there are expectations based upon theoretical reasoning and previous research and the Varimax method where limited expectations exist, for example in Section Three of the questionnaire.

Stages one and two require that the variables that are being investigated should, as far as possible, demonstrate univariate normality. This normality requires that the frequency curves show a normal distribution. The co-efficient of skewness and kurtosis determines whether the variables show this univariate normality. All aspects in Sections One (Your Work), Section Two (Your Team Work) and Section Four (Individual Personality differences) have been previously validated therefore the exploratory factor analysis included all variables, both skewed and no-skewed[13] as variables being suitable for inclusion within the analysis. No real guidelines exist on how to deal with varying

[13] It was recognized that scales ideally need to be free from contamination by skewness through social desirability responses (Kline, 1987). Social desirability is where the participant endeavours to present themselves in a preferable way rather than responding to the section of the questionnaire in an honest fashion (Cox and Ferguson, 1993).

degrees of skew and kurtosis with regard to an exploratory factor analysis. Ferguson and Cox (1993) indicate that Muthen (1989) and Muthen and Kaplan (1985) discuss the effects of skewness and kurtosis on the performance of a number of factor estimators. Three parameters emerged from the work by Muthen (1989) and Muthen and Kaplan (1985) as important determinants on the effects of skewness and kurtosis:

1. The absolute magnitude of skewness and/or kurtosis on each variable;
2. The number of variables affected by skewness and kurtosis;
3. The proportion of initial correlations within specified ranges (for example < 0.2 and > 0.5).

Muthen and Kaplan (1985) argue that some degree of skew and kurtosis is acceptable, for the <u>majority</u> of variables, if neither co-efficient exceed +/- 2.0[14]. The values of skewness and kurtosis and their respective standard errors are produced within SPSS. Dividing skew and kurtosis by its standard error produces a z-score. These z-scores can be compared against values that would be expected to be conferred by chance alone. An absolute value greater that 1.96 is considered significant at $p < 0.05$ and at > 2.58 is significant at $p < 0.01$ and absolute values above 3.29 are significant at $p < 0.001$. Large sample sizes will give rise to small standard errors and when sample sizes are large, significant values arise from even small deviations from normality.

In most samples it is acceptable to investigate values > 1.96 however, in small samples this criterion should be increased to 2.58. In very large samples approaching 200 or more,

[14] Where zero indicates there is no kurtosis.

because of the problem of small standard errors, no criterion should be applied. Field (2005) at pg 72 suggests that it is more important to look at the shape of the distribution and then consider the values of the skewness and kurtosis statistics rather than calculate their significance.

If necessary the deviant items can then be corrected to normalise the data. For example, this is achieved for skewness by taking the $\log_n$ of all high positively valued items in order to squash the right tail of the frequency distribution curve, and by squaring all negatively valued items to normalize the frequency distribution of the items back towards the centre.

However, what Muthen and Kaplan (1985) failed to define was exactly what they meant by '*majority*' in the number of variables, although Ferguson and Cox (1993) do suggest that '*majority*' may represent as many as 60% of the variables or even more (at pg 87). For the purposes of this exploratory factor analysis there becomes three possible scenarios described by Ferguson and Cox (1993) and supported by Field (2005), each possessing a separate correction strategy, which needs to be considered:

1. Leave all deviant items in the analysis;
2. Identify the most appropriate transformation option to correct the variables and return them to the analysis;
3. Remove all deviant items from the analysis.

The decision heuristic proposed for this stage of the exploratory factor analysis is designed to retain the maximum breadth of sampled variables, whilst recognising the possibility for creating potentially spurious results. Therefore strategy one has been applied but with the check attached to strategy two being applied to report on any significant degree of skewness and/or kurtosis extracted from the frequency statistics in order to qualify, where necessary, the final outcome. This check was conferred upon all data that was subjected to the Varimax rotation e.g. risk perception, the 'Your Attitudes to Work' section of the questionnaire and the exploratory factor analysis conducted on the PDA data for both 'Error' and 'Risky'.

As well as deciding upon the optimum number of factors to extract, a decision has to be taken on which of the available extraction algorithms to use. Ferguson and Cox (1993) report that the common practice is to use principal components factor analysis (PCA) as the extraction algorithm, in fact, Tabachnick and Fidell (1989; 2001) recommend it as a first step. The PCA output matrix reproduces eigenvalues as the measure of substantive importance associated with the revealed factors. Therefore only factors with large eigenvalues become the ones that are retained. The eigenvalue is the total variance accounted for by the particular factor. The eigenvalue is divided by the number of tests applied and the quotient is the proportion of the total variance that is accounted for by the factor. The first factor extracted has the largest eigenvalue, the second the next largest value and so on through to the n^{th} factor. The decision on which factors to retain rests upon a threshold value, which in this case is where the eigenvalues are greater than 1.000.

This approach derives a solution that is wholly consistent with other research (Kaiser, 1970).

Jolliffe (1972, 1987) reported that Kaiser's (1970) criterion was too strict and suggested that all factors with an eigenvalue ≥ 0.7 should be retained. The effect of retaining all items with eigenvalues ≥ 0.7 for this research would be quite dramatic, in that a large number of factors would be retained. Kaiser's (1970) criterion has been shown to be accurate when the number of variables is ≤ 30 and the resulting communalities after extraction are all ≥ 0.7 (Jolliffe, 1972; 1987). Kaiser's criterion has also been demonstrated to be accurate when the sample size exceeds 250 and the average communalities are ≥ 0.7. The communality of the variable is an expression that accounts for how much variance in a variable is accounted for by the factors that are extracted. This is achieved by simply squaring the factor loadings and then adding the values together. For example, variable X loads onto three factors; factors 1, 2 and 3. The factor 1 loading is 0.932; the factor 2 loading is 0.013 and the factor 3 loading is 0.250. Variable X is highly correlated with factor 1 but negligibly correlated to factors 2 and 3. How much variance is accounted for in variable X is accounted for by the expression: $(0.932^2 + 0.013^2 + 0.250^2) = 0.93129$. This value is termed the communality of the variable.

Cattell (1978) advocates a plot of each eigenvalue against the factor to which it is associated and this plot is referred to as a Scree plot. By presenting the eigenvalues as a graph the relative importance of each factor becomes apparent. The point of cut-off for selecting the number of factors is determined by the point of inflexion on the Scree plot curve. However, the identification of this break point on such plots has proved debatable. The use of the Scree plot centres upon its reliability. Glorfeld (1995) reported that the Scree test was only 57% accurate and overestimated in 90% of the cases where it was incorrect. Consequently a cautious approach regarding the number of factors being disclosed through the sole use of the Scree test has been adopted in the evaluation of the PCA results. Stevens (1992) considers that the Scree plot should only be used in conjunction with Kaiser's criterion when there is a sample size that is ≥ 200.

9.8.3 Factor Rotation methods

For the factors that are extracted in the PCA the degree to which they load onto these items is determined by the selected rotation method. The two types of rotation method have been considered in the PCA. The orthogonal rotation keeps the factors independent, unrelated and uncorrelated. In the oblique rotation method the factors are allowed to correlate. The initial choice of rotation method depends upon theoretical reasoning behind the structure of the questionnaire. This selection of method, based upon theoretical reasoning, avoids the presentation of results that may appear to be an opportunistic selection by only reflecting the best outcome.

The computer package SPSS makes the application of both of these rotation methods, Varimax and Direct Oblimin procedures to be very straightforward. Pedhazur and Schmelkin (1991) suggest that if the oblique rotation method using Direct Oblimin demonstrates a negligible correlation between the extracted factors, then it is reasonable to just report the orthogonally rotated solution (uncorrelated), Varimax procedure.

Conversely, if the oblique rotation reveals a correlated factor structure where a degree of correlation between the factors was initially assumed then, the orthogonally rotated solution maybe discarded. The Varimax rotation is used where there is no previous scale validity for example the social cultures, and the Direct Oblimin is used where scale validity has been previously demonstrated, for example in Goldberg's IPIP50.

In a Varimax rotation a pair-wise deletion of missing values has been used to maximise the numbers of cases in the analysis. This approach has been applied in all cases where the rotation method has been used. The case with the oblique rotation is more complex because correlation between factors is permitted. In this case the degree to which factors are allowed to correlate is determined by the value of a constant called delta. The default value for delta in SPSS (version 15) is zero. This value of default setting ensures that high correlations between factors are not permitted. Selecting a value for delta that is greater than zero would permit higher correlations between the extracted factors. For values that are less than zero then lesser correlations between the factors are reported. Therefore a default value of zero for delta (Pedhazur & Schmelkin, 1991) is recognized as the sensible choice and has been consistently been applied throughout the analysis (Field, 2005).

The extracted factors are therefore rotated according to a simple structure where each variable with a high loading on one of the factors and with a low or zero loading on the others are captured. Overall, a reduction in cases of social desirability has been achieved through the item selection method (Rotter, 1966). The reduction in social desirability was also achieved through the inclusion of some forced choice questions in Section 1 and in Section 3 of the questionnaire. Generally, the questions were formulated so as to account for the constituents of each construct and consequently a general factor for each section was not initially anticipated.

The correlation matrix for the principal components factor analysis needs to meet certain psychometric requirements (see Cyr & Atkinson, 1986). This is in order to demonstrate a systematic covariance amongst the variables under consideration, meaning that the variables correlate to each other because they are measuring the same thing. The first test used is the Kaiser-Meyer-Olkin (KMO) test of sampling adequacy that indicates the associations between the variables in the correlation matrix. This is achieved by creating a smaller set of factors for items that have an individual sampling adequacy greater than 0.5 (see Dziuban & Shirkey, 1974). The interpretation of the KMO indicates that there are discoverable relationships in the data above 0.7 and in excess of 0.8 they can be considered to be exceptional. Friel (2005) confirms that a KMO value of greater than 0.7 represents an acceptable degree of common variance and that KMO values between 0.9 and 1.00 are to be considered marvellous.

The second measure of suitability produced in the analysis is the Bartlett test of sphericity (or the homogeneity of covariance). The determinant of the matrix is converted to a chi-square statistic and tested for significance. Increasing the factor saturation loading to 0.400 for each variable is an option to consider rather than employ the default value of 0.300 (Velicer, Peacock & Jackson, 1982; Stevens, 1992). However, in this analysis

0.300 has been applied. Instances of cross loading, arising when a variable higher than 0.300 loads on two or more factors, indicates that the variable is related to more than one factor. The treatment of cross loading factors is dependent upon two aspects. Firstly, that the analysis has produced a number of clear and distinct factors and secondly that the deletion of any cross loading factors is based upon a difference in magnitude between the loadings. The deletion of the variable takes place where the difference on the cross loaded items is ≤ 0.200. However, if the discrepancy is large ≥ 0.200 then the variable is allowed to remain and is assumed to be loading onto the factor with the highest value (Ferguson & Cox, 1993). Following any item deletion through either cross-loading and where the difference on the cross loaded items is ≤ 0.200 or KMO values below 0.7 then the remaining items are subject to a re-calculation by applying exactly the same procedure. This process continues until only items loading on discrete factors remain.

This research has recognised the need to adopt a rigorous application of exploratory factor analysis techniques and secondly that this is reported through a detailed procedure. This detailing stems from the derivation of the items that have been used, the tests that have been applied, for example skew and kurtosis on untested variables, the selected extraction method and the theoretical justification for their use, the pattern matrix is also relevant, and ultimately the scale reliability.

The internal reliability of each scale is measured by calculating the internal statistic known as the Cronbach's Alpha. This statistic refers to the homogeneity of the scale. The acceptable level for internal reliability is around 0.7 and above. A very low alpha indicates that the scale does not hang together as intended. After the analysis of the questionnaire is completed and the emerging items considered, the emergent items can be summed and divided by the number of items to deliver a new scale for the construct under examination. Finally, Cromey (1978) stated that the structure of the factor results stabilise with samples of 2,000, but others have shown reliable results with sample sizes as low as 50. However, such results should be considered to be preliminary and caution used in interpreting the results (Guadagnoli & Velicer, 1988; Hutcheson & Sofroniou, 1999; Stevens, 2002).

The next section brings together the methodology used to explore the relationship between the construct scale scores which have been derived from the exploratory factor analysis and the uploaded daily diary data. The methodology used is a hierarchical linear modelling technique.

9.9 Hierarchical linear modelling in an exploratory data set.

9.9.1 Overview

Hierarchical data presents several problems in analysis. Behavioural and social data commonly have a nested structure. For example, if repeated observations are collected on a set of individuals and the measurement occasions are not identical for all persons, then the multiple observations are properly conceived as being nested within persons (Raudenbush, Bryk, Cheong, Congdon & du Toit, 2004). In this study it is already known who the groups of individuals are and it is the experiences of the designers, within these design team groups, that have been studied. This data is conceived to be nested within a hierarchical organisational structure. Within the hierarchical organisational structure encountered in this ESM each level of data structure (e.g. repeated observations recorded in daily diaries, within persons, and within teams) is formally represented as a series of sub-models. The outcome variables that are examined have been defined as 'Error' describing the occasions of cognitive error that may influence decision-making and 'Risky' describing the use of risky design protocols.

The equations describing these outcome variables are constructed from these sub-models. Establishing the significant effects between two or more explanatory variables and the outcome variable has been achieved by modelling all of the data structure correctly.

9.9.2 Hierarchical Linear models

Determining whether all the structure has been modelled correctly is not easy. Hofmann and Gavin (1998) have reviewed and discussed the theoretical implications of involving variables at different levels of analysis. Rousseau (1985) defined these cross-level models in terms of the effects that phenomena can have on variables at another level. The basic concept behind hierarchical linear modelling is that the outcome variable ('Error' and 'Risky') is predicted as a function of the linear combinations of one or more variables plus an intercept with any variance explained.

The HLM6 package has the capability to produce robust results and is suitable for use with diary studies where data is nested in different organisational levels (Daniels, 2007). Raudenbush et al (2004) describe the use of the HLM6 package for the statistical modelling of two-level and three-level data structures. This analysis model is a technique that is progressively built up to allow both between subject and within team observations to be treated as independent observations, whilst both categories are simultaneously analysed. Affleck, Zautra, Tennen and Armeli (1999) and Nezlek (2001) issue a cautionary warning about using this form of data when a complete data set has both individual and team observations within it. Affleck et al (1999) and Nezlek (2001) indicate that misleading results can emerge if both are not analysed. This study has used both the individual and team level observations thus safeguarding the results. The main problem for an ESM study of this type is that designers, within a team, tend to be more similar to each other than within a random population sample. This introduces a potential problem for the researcher when dealing with observations that cannot be considered to be entirely independent.

The strategy to address this concern, and that associated with population similarity, has been to bring the general level variables down to a daily level by averaging the scores. The model that has been created within HLM6 explicitly recognises that the daily level data gathered from designers over time may be more similar. However, as the hierarchical linear model data also recognises, the partial interdependence within the analysis needs to be addressed by using the appropriate modelling technique.

These multi-level relationships, which are involved in the design team organisation, are also termed cross-level, whilst at the same time being multi-level relationships. These circumstances occur because at a cross-level they involve characteristics that are nested at different levels of a hierarchy. Whilst this research is primarily interested in the individual designer, there are certain interactions between the sampled units that characterise the multi-levelled structure of the investigation. This approach permits meaningful cross sectional data comparisons to eventually be made with no loss of validity. These comparisons have been made in the two levels and three level modelling states.

The types of hazardous project, whilst being governed by certain defining characteristics, for example is the hazardous project related to either an offshore or onshore development, have been assumed to be randomly sampled from within a large population of similar hazardous projects. From the engineering population where the majority of this ESM's participants were enrolled, there were upwards of forty hazardous projects at different stages of development ongoing at the time of this study. These hazardous projects employ several thousand personnel[15] and involve permanent staff and contractor personnel. Therefore the term team variable is any variable that is constant for every designer within a given project, but is one that may vary across projects. The measurement of designers' views has included aspects of their work and job characteristics, risk perception, social culture and the safety climate which vary across designers within teams. In addition to these variables, the measurement of the individual difference dimensions, across all organisations, has been correlated with levels of cognitive error ('Error') and the use of risky design protocols ('Risky'). These may vary between occasions and between individual designers.

[15] Source. Private correspondence between the researcher and the British Chemical Engineering Contractors Association 26.06.2007

9.9.2.1 Analysis method of structured diary data

There are several theoretical implications for this research arising from using this ESM methodology. The thesis has already outlined the abundance of different demands placed upon designers, such as high work-pace or tempo, time pressure, and involvement in complex designs. The hypotheses aim to investigate whether when a mismatch occurs between the individual and these states then mistakes may arise. The designer's experience at work and decision-making are all modelled using HLM6.

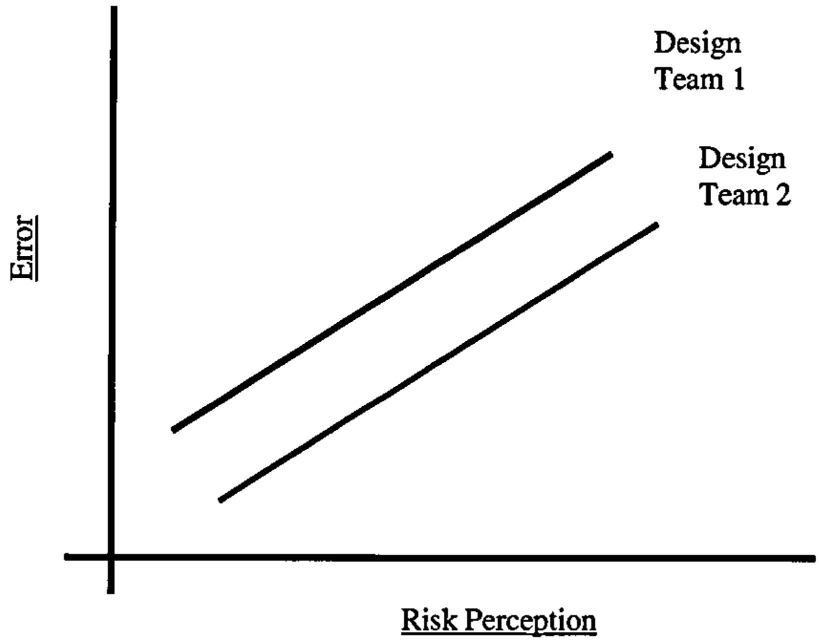
The questionnaire data and the PDA data were merged in HLM6. A register tallied the participant's questionnaire records and PDA data records. The data gathered was expressed in a form that is compatible with the modelling so as to permit the analysis by HLM6. Raudenbusch and Bryk (2002) at page 23 indicate that the simplest expression of a hierarchical linear model is equivalent to a one-way analysis of variance (ANOVA) with random effects, given by the expression:

$$y = \beta_0 + r_i;$$

Where each level 1 error r_i is assumed to be normally distributed with a mean of zero (e.g. +/- 1 standard deviation) and a constant variance and at level 2 by:

$$\beta_0 = \tau + u_i.$$

Figure 9.3: Varying intercepts, non-varying slopes

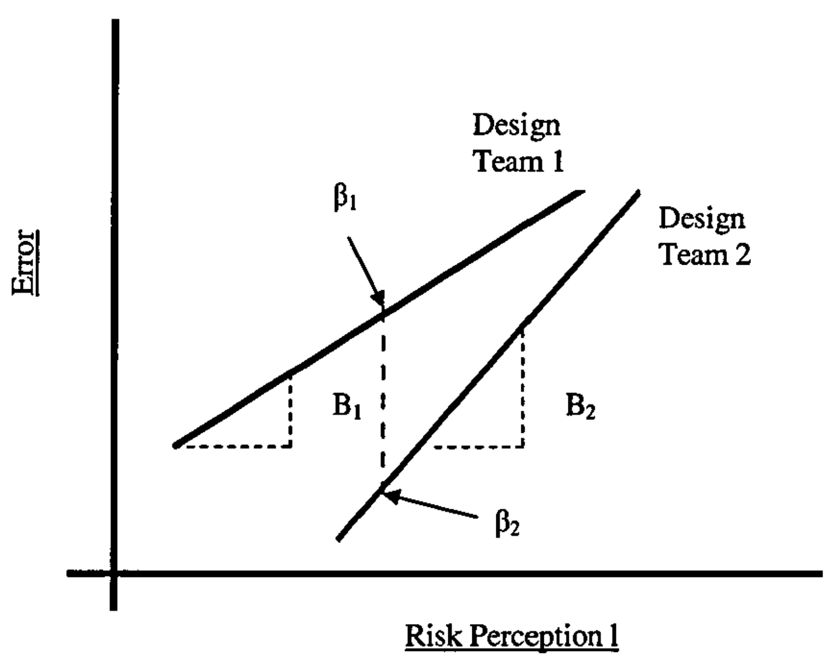


The level 2 model is a simplification. The starting point for this study is to consider if the chosen outcome variables can be fitted to an ANOVA model. This mathematical representation is an expression of the 'best-fit' slope that could be drawn through a scatter-plot of points derived from the relationship between the selected outcome variable, say 'Error' and any one of the 14 explanatory variables, which in the example represented in Figure 9.3 is risk perception.

The slope is given by the expression $y = \beta_0 + \beta_1 X_i + r_i$;

where β_0 is the intercept based upon say an individual level of 'error', β_1 is the gradient of the slope of the scatter-plot 'best-fit' line and r_i is the statistical error term, which represents a unique effect associated with person (i) and <u>should not</u> be confused with the term 'error' that is being described as the outcome variable. Typically, r_i is assumed to be normally distributed (see Raudenbush & Bryk, 2002 at pg 16 & 17). β_0 and β_1 can vary across the higher levels units, such that β_1 can be different for different teams reflecting the variability in the relationships. In Figure 9.3 β_0 is different in different teams (different intercepts) but β_1 is the same across different teams (same slope).

Figure 9.4: Varying intercepts, varying slopes within two hypothesised design teams



The two slopes in Figure 9.4 illustrate the way in which any two design teams differ. These differences are reflected in the two intercepts and the two slopes. Risk Perception has a weaker relationship with error in Design Team 1 compared to Design Team 2 as indicated by comparing the gradients of the slopes. When such variability exists in slopes it is important to model it, as in the case with the designer population in this study. However, if there is no variability, as shown in Figure 9.3, then there are clearly benefits in not modelling it. These benefits relate to the existence of fewer parameters to estimate and therefore gains to be obtained in statistical power.

Gains in statistical power are important because by examining what might remain to predict the outcome variable allows an estimate of variability in the regression co-efficient for both the intercept and the slopes to be made with adequate degrees of freedom remaining. Where the variability is very close to zero, then for reasons of statistical efficiency and computational stability it is sensible to set the slopes to zero.

It is useful to scale the explanatory variable, represented by the term X_i in the the expression $y = \beta_0 + \beta_1 X_i + r_i$, so that the intercept can be considered to be meaningful. The effect of centering depends upon the relationship in the data and the aims that have been set for the analysis. The practical purpose of centering the explanatory variable is to change the interpretation of the intercept. The explanatory variables can be centered on the basis of one of three alternatives. These centering options include the natural metric (un-centred), centred on the grand mean, and centred on the group mean for each individual. For this study and with the exception of the temporal variables, all independent variables have been centred on the grand mean. Centring on the grand mean is achieved by subtracting the mean score for all participants, as in the example of risk perception, from the individual score for risk perception to create a grand mean value. When the independent variables are centred in this way, the intercept represents the average across individuals.

Multilevel regression analysis is used to examine the hypotheses and test the research question RQ1. Multilevel regression is suitable on experience sampling data, as unlike the ordinary least squares (OLS) regression method it makes no assumptions concerning the independence of observations and allows the strength of relationship to vary across the participants. This approach permits the disaggregating effects of between-person differences to be made in sustained levels of reported 'Error' and reported 'Risky'. These are expressed in hypotheses and in research question RQ1. The distinctions are made between-person, from dynamic within-person fluctuations and are related more closely to time of day (see Raudenbush & Bryk, 2002). In instances where level 2 effects are thought to dominate the level 1 effects, then in this study, for example where the dimensions attached to the personality trait variables are thought to influence the temporal state variables, it is important to judge the significance of the level 2 functions and report them accordingly. These temporal effects are presented in 10.13.3 and discussed in Chapter Twelve.

9.9.2 2 Two-level and three-level models

The HLM6 package (Raudenbush et al, 2004) was used to create two hierarchical linear models, one as a two-level model and the other as a three-level model. The SPSS files saved the common variables at levels one, two and three for importing into the HLM6 package.

9.9.3 The two-level model

In this analysis the individual designer represents a sampling unit at the first level and the design team at the second level. The two-level model consists of two sub-models at level 1 and level 2. The first stage of the analysis was to define the outcome variable and this was termed 'Error' Note: this is the analysis of the questionnaire measure of error (Cognitive Error) which is related to memory, attention and/or action deficits. The two-level model was created to enable an investigation into the relationships and any significance between this outcome 'error' variable, and the dependent variables that emerged from the exploratory factor analysis PCA. The variables were entered in blocks and examined for variability in slopes. The level 2 data entry for Safety Climate was estimated by taking the aggregate for the whole sàmple population because theory suggests an individual and team level affect.

For the set of analyses in model 1 (see Table 9.11), an incremental, stepwise approach is applied when building equations (Snijders & Bosker, 1999). The stepwise approach is a variation on a forward regression. The standard approach is to build the regression model by plotting the outcome variable against the different explanatory variables. These variables are added one at a time beginning with the explanatory variable that has the highest co-efficient of determination. The stepwise approach tests each explanatory variable or block of variables as they are added.

At each step if any of the regression slopes that evinced no significant variation between individuals or teams for example $p \geq 0.200$ or they demonstrated poor reliability at < 0.05 (see Raudenbush & Bryk, 2002 at pg 125 for a fuller explanation)[16] then they were fixed to be invariant across participants e g. the slopes are set to zero. As a new variable is added to the model and the equation re-run, it became necessary to fix variables entered into the model at an earlier stage. If a slope was fixed, the step was run again to examine for further variation in slopes until only slopes with significant variation were left in the equation and all other slopes are fixed. This procedure ensured sufficient degrees of freedom to permit the analysis to be computed.

Results are considered significant if the p-value is < 0.05 (twin-tailed) for non-hypothesised relationships and one tailed for hypothesised relationships provided they are in the right direction. In each case, the magnitude of the relationship between 'Error' or 'Risky' protocols and another variable is gauged by the regression co-efficient β and the absolute value of the t-statistic. The t-statistic is a standardised statistic that indicates the relative size of the relationship between two variables. The greater the absolute value of the t-statistic, the greater the relationship. Positive values of the t-statistic indicate that as one variable increases then so does another. Negative values indicate that as one variable increases then the other decreases.

[16] Slope reliability is an index of variability of slopes between teams or between individuals

Table 9.11: Structure of the two-level hierarchical model

	Model 1 (grand-centred mean)
Level 1	Risk Perception; Social Culture Perceived Safety Climate individual score
	Individual Personality differences
	Job Characteristics
Level 2	Safety Climate (aggregated score)

9.9.4 The Three-level model

The diary entries represent the sampling unit at the first and lowest level. The designer has then been constituted at the second level, and the design teams at the third level. The additional features of the three-level model include the temporal variables. Whilst all stages of the analysis need to conducted with great care, the three-level hierarchical model is particularly sophisticated and built with increasing levels of complexity. The outcome variable 'Error' was initially defined at the top level. The HLM technique selected from the drop-down menu was the normal continuous variable distribution method. For 'Risky' the selected technique was a Poisson constant exposure distribution method was selected.

Constructing the first block of the model was completed by introducing the temporal variables at level one, compliance variable at level two[17] and aggregated safety climate at level three. The temporal variables are defined as time of day, day of week, and wave and are independent of one another and possess a restricted range. The temporal variables have been entered as un-centred variables. This method is appropriate because entry of the temporal variables with a mean value is not meaningful, and these variables had to be dummy coded, for example 0 or 1. The un-centred option supposes that the variable can only take on one of two values (see Raudenbush & Bryk, 2002 at pg 34).

The temporal variables, the day of week (Monday, Tuesday, Wednesday and Thursday), time of day (10.00, 12.00 14.00 and 16.00) and data entry waves (wave 1, wave 2 and wave 3) were transformed in the model as a series of dummy variables. The dummy variables take the form Monday = 1, not Monday = 0; Tuesday = 1, not Tuesday = 0; Wednesday = 1, not Wednesday = 0; Thursday = 0, not Thursday = 0; and morning (10.00) = 1, not morning = 0; lunchtime (12.00) = 1, not lunchtime = 0; afternoon (14.00) = 1, not afternoon = 0; and wave 1 = 0, not wave 1 =1, wave 2 = 0, not wave 2 = 1, wave 3 = 0, not wave 3 = 1.

In block two Emotional Stability, Extraversion and Conscientiousness are added at level two because of the strong theoretical expectations and the hypothesised reasoning attached to these traits. These variables are entered as grand centred variables. In the third block the associations between the dependant variable and the risk-related attitudes, are

[17] The cut-off rate for compliance has been set at a rate of <25% (see Stone et al, 2003) and participants falling below this rate were excluded.

again added as grand centred variables. These attitudes include risk perception and the social cultures. The two remaining hypothesised individual personality differences, Openness-to-Experience and Agreeableness were then entered into the model in block four, also at grand centered of their means. The final model, model five, assessed the associations between the job characteristics of job support, role clarity, autonomy and skills/demands and individual perceptions of safety climate. These variables were entered into the model as grand centered means, one at a time and the model re-run.

For each set of analyses from model 1 through to model 5 (see Table 9.12), an incremental, stepwise approach was again applied when building these equations (Snijders & Bosker, 1999).

The outcome variable is expressed by equation:

Level 1: $y = \pi_o + \pi_{1\,(Mon)} + \pi_{2\,(Tues)} + \pi_{3\,(Wed)} + \pi_{4\,(Thur)} + \pi_{5\,(Mor)} + \pi_{6\,(Lunch)} + \pi_{7\,(Aft)} + \pi_{8\,(Wav\,1)} + \pi_{9\,(Wav\,2)} + \pi_{10\,(Wav\,3)} + e$ (where e is the level 1 error term)................. (9.9.4.1.)

Level 2: $\pi_o = \beta_{00} + \beta_{1\,(Compl)} + \beta_{2\,(Group\ Culture)} + \beta_{3\,(Individualism)} + \beta_{4\,(Safety\ Climate)} + \beta_{5\,(Risk\ Perception)} + \beta_{6\,Emotional\ Stability)} + \beta_{7\,(Extraversion)} + \beta_{8\,(Openness)} + \beta_{9\,(Conscientiousness)} + \beta_{10\,(Agreeableness)} + \beta_{11\,(Role\ Clarity)} + \beta_{12\,(Skills)} + \beta_{13\,(Autonomy)} + \beta_{14\,(Support)} + r$ (where r is the level 2 error term)... (9.9.4.2.)

$\pi_{1\,(Mon)} = \beta_{10} + r_1,$
$\pi_{2\,(Tues)} = \beta_{20} + r_2,$
$\pi_{3\,(Wed)} = \beta_{30} + r_3,$
$\pi_{4\,(Thur)} = \beta_{40} + r_4,$
$\pi_{5\,(Mor)} = \beta_{50} + r_5,$
$\pi_{6\,(Lunch)} = \beta_{60} + r_6,$

$\pi_{7\,(Aft)} = \beta_{70} + r_{7},$
$\pi_{8\,(Wav\ 1)} = \beta_{80} + r_{8},$
$\pi_{19\,(Wav\ 2)} = \beta_{90} + r_{9},$
$\pi_{10\,(Wav\ 3)} = \beta_{100} + r_{10},$

Where r_n is the error term

Level 3 $\beta_{00} = \gamma_{000} + \gamma_{001\ (Safety\ Climate)} + u_{00}$ where u_{00} is the level 3 error term).......(9.9.4.3.)

$\beta_{01} = \gamma_{010} + u_{010},$	$\beta_{09} = \gamma_{090} + u_{090},$	$\beta_{30} = \gamma_{300} + u_{030},$
$\beta_{02} = \gamma_{020} + u_{020},$	$\beta_{010} = \gamma_{100} + u_{100},$	$\beta_{40} = \gamma_{400} + u_{040},$
$\beta_{03} = \gamma_{030} + u_{030},$	$\beta_{011} = \gamma_{110} + u_{110},$	$\beta_{50} = \gamma_{500} + u_{050},$
$\beta_{04} = \gamma_{040} + u_{040},$	$\beta_{012} = \gamma_{120} + u_{120},$	$\beta_{60} = \gamma_{600} + u_{060},$
$\beta_{05} = \gamma_{050} + u_{050},$	$\beta_{013} = \gamma_{130} + u_{130},$	$\beta_{70} = \gamma_{700} + u_{070},$
$\beta_{06} = \gamma_{060} + u_{060},$	$\beta_{014} = \gamma_{140} + u_{140},$	$\beta_{80} = \gamma_{800} + u_{080},$
$\beta_{07} = \gamma_{070} + u_{070},$	$\beta_{10} = \gamma_{100} + u_{10},$	$\beta_{90} = \gamma_{900} + u_{090},$
$\beta_{08} = \gamma_{080} + u_{080},$	$\beta_{20} = \gamma_{200} + u_{20},$	$\beta_{100} = \gamma_{1000} + u_{100},$

Table 9.12: Structure of the three level hierarchical linear model.

	Model 1 (Temporal variables)	Model 2 (Model 1 +)	Model 3 (Model 2+)	Model 4 (Model 3+)	Model 5 (Model 4+)
Level 1 (un-centred mean)	Monday Tuesday Wednesday Thursday Morning Lunchtime Afternoon Wave One Wave Two Wave Three				
Level 2 (grand-centred	Compliance	Emotional Stability, Extraversion, Conscientiousness	Risk Perception; Social Culture	Openness-to-Experience, Agreeableness	Job Characteristics Safety Climate-(individual score)
Level 3 (grand-centred mean)	Safety Climate (aggregated group score)				

For the analysis of the 'Risky' outcome variable a Poisson regression was used since the raw data was both skewed and consisted of counts, for example the number of times in the past hour where an assumptions has had to be added to account for a piece of missing data (Snijders & Bosker, 1999). Under these conditions the outcome would be a non-negative integar, that is, a count rather than a dichotomy. Thus the Poisson regression model was a reasonable choice to apply in this case.

9.10 HLM6 Results

The HLM6 results are presented in a tabular format in the following manner:

Final Estimation of level 1 and level 2 variance components					
Random Effect	Standard Deviation	Variance Component	df	Chi-square	p-value robust
Intercpt1 (R0)					
Final Estimation of level 3 variance components					
Random Effect	Standard Deviation	Variance Component	df	Chi-square	p-value robust
Intercpt1 / Intrcpt2(U00)					

Fixed Effect	Co-efficient	Standard Error	T-ratio	Approx df	p-value* Robust statistic
For intrcpt1, P0					
Intrcpt2,					
Dependent variable					
Intrcpt3					
Compliance					
Dependent variables					
Temporal variables					

9.11 Summary

This chapter has described the basic instruments that have been developed to interpret the data in the Pilot and Main Study. In the next chapter, Chapter Ten reflects upon the specific stages of the field research in the Pilot and Main studies

Section 3: Field Study Work

Chapter Ten

Main Study Results

10.1 Overview

Chapter Ten investigates the structure of the data gathered using the two methods described in Chapter Nine. The questionnaire and PDA records were gathered between the 11th September 2006 and 2nd March 2007. The ethical considerations attached to this study into human behaviour ensured that the participant's data remained both confidential and anonymous.

This chapter has been divided into three parts. Part One deals with the factor structure that emerged from the Main Study questionnaire and feeds Part Two which describes the relationship between the outcome variable 'Error' and 'Risky' in an exploratory PCA using the PDA data. Part Three investigates the nature of the nested daily diary data. The sample size involved in the completion of this study is n = 167. The data from the sample was collected from a relatively high number of design teams (n = 55) that were all involved in the design of hazardous installations. The participants were drawn from three organisations working on eight hazardous design projects. The number of raw PDA observations gathered from the daily diaries is n = 6087.

The sample population gender was predominantly male at 93.4% and the age profile was just over 43 years. The vast majority of the 169 designers were full-time employees (n = 167). Full-time working varied between the standard contract hours of 40 hours per week up to in excess of 50 hours per week. 20% of the designers worked 50 hours or more. The average hours worked per week was 43.4 hours. Nearly 60% of the designer's had completed at least 6 years work in the offshore design sector (mean

= 7.41 years). The sample of designers reported their average level of overall industrial experience to be 18.5 years, suggesting a high degree of general industrial experience.

The first five sections are devoted to the principal component analysis (PCA) attached to the exploratory investigation of the questionnaire structure. Each section describes the factor structure of the construct under investigation, an assessment of the emerging structure's reliability and some commentary on the results. Following the factor analysis the average scale scores have been calculated and entered into the SPSS data model. The next section presents a correlations matrix constructed from all variables scaled in the principal components analysis and reports on the significant relationships. Finally, the first part concludes with a two-level hierarchical linear model addressing the relationships between the 'Error' outcome variable and the other emergent factors.

10.2 Exploratory Factor Analysis structure

Chapter Nine notes that a factor analysis requires a large sample size (Stevens, 1992). There are three advantages conferred by the large sample contained within this study. Firstly, any aspects of the questionnaire where problems exist should be revealed. This helps the researcher to make better informed decisions about the robustness of the questionnaire that has been used and the associated results. The principal issue relating to robustness revolves around whether the participants are able to make sense of the issues being presented to them in the questions. In other words, do the participants understand the questions that are being asked? This understanding is clearly a personal evaluation of each question based on the participants own perceptions. By way of example, the designers may have a 'better' understanding of the fatalistic questions contained in Section Four 'Your Attitudes to Work' of the questionnaire because they can relate to them more readily.

The second aspect concerns the normative measure of the values. These values may be inherently flawed because of the socially desirable responses that some of the questionnaire items may attract. Meglino and Ravlin (1998) were concerned with the rating scales being unable to adequately distinguish between the participant's scores. Meglino and Ravlin (1998) concluded that if a bias exists in the data set it was because the participant's responses maybe skewed towards the extreme ends of the scale. Whilst the exploratory factor analysis commences with an initial frequency check, where any cases of skewness and kurtosis are noted, the principal components factor analysis has opted to use all data (Ferguson & Cox, 1993; Muthen & Kaplan, 1985).

Thirdly, a number of measures relating to job characteristics, safety climate and individual personality differences have already been used in other research. Therefore the intent of this large scale survey is to provide an indication that the context in which these questions are now being applied, indicate that the selected instrument is doing exactly what it is meant to. Mitchell (1985) states that the validity of the scales used should be reported if at all possible. One way of achieving this is to subject the pre-existing scales contained within the Likert method to a principal component analysis. The intent of the principal component analysis then becomes a method to establish if the emergent items produce the same factor structures that the scales are supposed to possess. The computer package SPSS makes the application of the chosen procedures very straightforward.

The first PCA addresses the analysis of job characteristics from the section of the questionnaire titled 'Your Work' (Barnett & Brennan, 1995; Breaugh, 1985; Caplan, et al, 1975; Daniels 1996; Daniels & Guppy, 1995; Hackman & Oldham, 1975; Kahn, et al, 1964). The PCA was conducted using the Direct Oblimin rotation method. The eight Risk Perception questions were also embedded in Section one (after Slovic, Fischoff & Liechtenstein, 1982) with four in each of the categories of dread and unfamiliarity and these are analysed using the Varimax rotation method.
Section Two of the questionnaire addresses 'Your Team Work' (after Cox & Cheyne, 2000; Zohar & Luria, 2005) contains 24 questions which have been analysed using the Direct Oblimin rotation method.

The principal components factor analysis has also been conducted on the data sets where there are no priori expectations. The Social Culture questions in Section Three appear under the heading 'Your Attitudes to Work' (see HSE, 2002) and contain 33 questions. The analysis of Section Three has been completed using the Varimax rotation method. The psychological personality questions in Section Four (Goldberg, 1999) are all reflective of work that has been previously validated. The IPIP 50 question set has been directly imported into the Main Study questionnaire. Interspersed within this section are adaptations of Wallace and Chen's (2005) questions that deal with the scales of attention and memory in relationship to cognitive failure. Both sets of items were analysed using the Direct Oblimin rotation method.

Part One

10.3 The 'Your Work' Principal Components Analysis (PCA)

10.3.1 Overview

A PCA has been carried out on a number of aspects addressing the specific perceptions of a designers' work. The aim of this examination is to establish the underlying reaction of the designers to the dimensions associated with their work.

10.3.2 Job characteristics

All items were subjected to a frequency distribution check to identify if the participant's responses to any of the questions within Section 1 were skewed but all items were entered into the analysis in accordance with the procedure set out in Chapter Nine. Following a series of iterations a four factor extraction was confirmed when all variables were entered into the analysis. The KMO and Bartlett's test of sphericity, anti-image correlations, eigenvalue cut-off of 1.00 are reported using the Direct Oblimin method. The co-efficient are displayed by size and values suppressed below 0.3 as previously described (Ferguson and Cox, 1993).

10.3.3 Rotation Method: Oblimin with Kaiser Normalization.

The Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) is 0.742 and Bartlett's Test of sphericity was 953.0. Four eigenvalues were above 1.000 with component one reporting 4.46 (20% of variance) component two 2.86 (13% of variance), component three 2.17 (10% of variance) and component four 1.4 (6.4% of variance).

Table 10.1: Job characteristics structure matrix

	Description	Component			
		1	2	3	4
Support	Can you talk to other people at work to decide what to do about work problems?	821			
	Can you rely on other people at work when things get tough?	.763			
	Is it easy to talk to other people at work about work problems?	.732			
	Can you seek advice from other people about work problems?	.724			
	Do other people at work make your work life easier for you?	676			
	Do other people at work listen to your work problems?	667			
	Can you confide in other people at work?	.630			
	Do people at work help you get the things or information you need to do your job?	483			
Skills/demands	Do you work on complex designs?		829		
	Does your job require detailed technical knowledge?		801		
	Does your job require complex or high level skills?		.703		
	Do you work long hours?		.544		
Job Autonomy	Are you allowed to decide how to get your job done?			.778	
	Can you choose how you do your job?			.742	
	Can you control the sequencing of your work activities?			639	
	Do you have some control over what you are supposed to accomplish?			628	
	Are you able to modify your job objectives?			582	
Role Clarity	Are your work objectives clearly defined?				337
	Are you clear about your job responsibilities?				378
	Are your work tasks well defined?				412
	Are you clear about what others expect of you at work?				418

10.3.4 Reliability

Factor 1, team support has a Cronbach's alpha of 0.837, factor 2, skills/demands has an alpha of 0.79, factor 3, job autonomy has an alpha of 0.75 and factor 4, role clarity has an alpha of 0.78.

10.3.5 Discussion

Section One of the questionnaire, entitled 'Your Work', contained 35 co-mingled job characteristic items addressing Job Autonomy, Team Support, Role Clarity, Job Demands and Skills. The emergent structure produced a four factor solution which appears consistent with theory (Barnett & Brennan, 1995; Breaugh, 1985; Caplan, Cobb, French, Van Harrison & Pinneau Jnr., 1975; Daniels 1996; Daniels & Guppy, 1995; Hackman & Oldham, 1975; Kahn, Wolfe, Quinn, Snoek, & Rosendahl, 1964). Factor 2 emerged as a combination of two constructs by coupling together Demands and Skills. From the original 35 questionnaire items 21 items remain after applying factor saturation criteria (Velicer, Peacock & Jackson, 1982) and deleting cross-loaded items where the difference was ≤ 0.200. The scale reliabilities of the four factors are very good.

Factor 1 corresponds to Team Support, Factor 2 matches skills and demands, Factor 3 relates to Job Autonomyand finally, Factor 4 addresses Role Clarity.

10.4 Risk Perception

A PCA has been carried out on the Risk Perception scales in order to establish the underlying reaction of the designers to certain risk perception dimensions. The two aspects of risk perception that were assessed include dread and unfamiliarity. The total variance explained indicates that just a single factor with an eigenvalue of 2.923 accounting for 36.5% of the variance emerged from the analysis.

Table 10.2: Risk Perception structure matrix

Description	Item
Do you work on projects where the hazards pose a significant and widespread risk to the environment or the public?	.487
Do you work on projects where the consequences of any accident might not easily be controlled?	.726
Do you work on projects where the long-term outcomes of the risks are uncertain?	555
Do you work on projects where others might be exposed to risks they cannot control?	.728
Do you work on projects where the health and safety risks can be unpredictable?	.752
Do you work on projects where the hazards pose a significant risk to future generations of the general population?	443
Do you work on projects where the risks cannot easily be observed by those exposed?	.711

10.4.1 Reliability Analysis

The reliability analysis of these extracted seven items shows a Cronbachs alpha-value of 0.747.

11.4.2 Discussion

The original eight items decomposed into seven items in a single factor – the eighth item was deleted in accordance with the procedure detailed in Section 9.8.3. This single factor shows good scale reliability. This test demonstrates that risk perception in this sample forms a single construct comprising of the two components initially put forward, dread and unfamiliarity.

10.5 Safety Climate Principal Components Analysis (PCA)

A principal components analysis has been carried out on a number of aspects of the participants' work team. The aim of this exploratory assessment is to establish the underlying reaction of the designers to the dimensions associated with organisational safety climate. This analysis was based upon already established scales (after Cox & Cheyne, 2000; Zohar & Luria, 2005).

10.5.1 Rotation Method: Direct Oblimin with Kaiser Normalization.

All items were loaded into the rotation method and a single factor extracted. This final extraction has a KMO measure of sampling adequacy is 0.859 and the Bartlett test of sphericity is 1523.4. Component 1 has an eigenvalue of 8.0 that accounts for 33.23% of the variance.

Table 10.3: Safety Climate structure matrix

Component	Item
There is good communication about safety issues.	332
We often give tips to each other to maximise the safety of our designs.	.595
Our team leader talks about the importance of safety.	688
Safety issues are assigned a high priority.	527
Our team leader makes sure we receive appropriate recognition for achieving safety targets on the job.	.326
Our team leader would listen to my concerns about a design's safety.	538
Our team leader suggests new ways of making our designs safer.	457
We encourage each other to raise safety concerns.	.721
Our team leader spends time advising me on how to make designs safer.	.400
Our team leader encourages us to give safety a priority	745
Our team leader shows determination to ensure our designs are safe.	.795
There are always enough people to get the design completed so it is safe.	615
Our team leader behaves in a way that displays commitment to safe designs	300
Our team leader encourages me to voice my ideas about safety in our designs	621

Table 10.3: Safety Climate structure matrix (Continued)

Component	Item
Sometimes, the team finds it necessary to assign safety as a lower priority to meet project deadlines.	.765
Our team leader waits for things to go wrong before taking action.	276
Some health and safety procedures and systems are not really practical for this design team.	.300
We are strongly encouraged to report unsafe design features	.794

10.5.2 Reliability

The reliability analysis of these extracted components shows a Cronbachs alpha-value of 0.895.

11.5.3 Discussion

The original 24 questionnaire items contained in Section Two entitled 'Your Team Work' decomposed into an 18 item single factor. The reliability of the scale is very good.

10.6 The Social Culture Principal Components Analysis (PCA)

An exploratory PCA was carried out on a number of aspects addressing the designers' Social Culture. The aim of this exploratory assessment is to establish if there is any underlying reaction from the designers to the dimensions associated with an *Individualistic, Egalitarian and Hierarchical* or *Fatalistic* attitude to risk

The selection of rotation method was based upon the theoretical reasoning behind the constructs being examined. Therefore the decision was taken to run and report the Varimax procedure.

10.6.1: Rotation Method Varimax with Kaiser Normalization.

This PCA was concluded over three iterations that included the deletion of items with low value measurements of sampling adequacy < 0.600, and items that cross loaded and where the difference was ≤ 0.200. The final extraction has a KMO measure of sampling adequacy is 0.712 and the Bartlett test of sphericity is 845.672. Component 1 has an eigenvalue of 3.94 that accounts for 14.6% of the variance and component 2 eigenvalué of 3.4 and 12.6% of variance.

Table 10.4 Social Culture structure matrix

	Description	H, E, F or I	Component Item 1	Component Item 2
Group Culture	Thorough planning and well-executed procedures limit mistakes in fabrication and use.	H	.643	
	Rules and procedures are effective in preventing accidents	H	633	
	Fabricators and users should never be exposed to risk	E	622	
	The best way to reduce risk is thorough and well-executed rules and procedures.	H	569	
	Rules and procedures reduce risk to acceptable levels.	H	564	
	Comprehensive planning and systems reduce risk	H	.557	
	No level of risk is acceptable in a design.	E	.528	
	All designs should be examined from every possible angle before being signed-off.	E	497	
	Design organisations should strive to eliminate risk	E	462	
	Checking and approval procedures always capture significant design mistakes	H	458	
	Safety in a design should never be compromised for profit	E	.428	
	Safer designs rely upon sound engineering judgment	I	386	
	Members of a design team should all agree that the design is safe before it is signed off.	E	.376	
Chance	Risks are too uncertain, in order to make detailed plans	F		.633
	Designers are not responsible for the behaviour of fabricators and users.	I		585
	Whatever designers do have little bearing on eventual risk in a design	F		.578
	Designs do not always need thorough checking to be considered safe	I		523
	Designs don't need to account for all risks	I		.518
	Risks are too uncertain in order to be able to assign responsibility	F		.477
	Fabricators and users should be responsible for their own safety	I		463
	Rules can get in the way of efficient design	I		.451
	Fabricators and users should determine the level of risk they are willing to bear.	I		.435
	All designers know that the benefits of technology compromise safety	I		411
	No design can ever be free of risk	F		.360
	Fabricators can always modify designs if they want to make them safer	I		.319

Note: E = Egalitarian; F = Fatalistic; H = Hierarchical, I = Individualistic

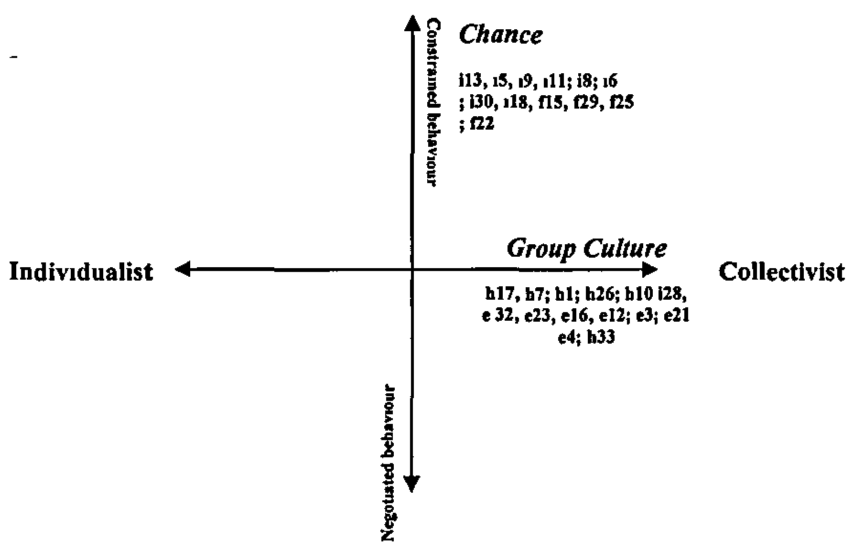
10.6.2 Reliability

The reliability of Factor 1, *Group Culture* is 0.795 and Factor 2, *Chance* is 0.704. The two factor solution appears to occupy a position where *Group Culture* is towards the collectivist end of the individualist-collectivist continuum and *Chance* is positioned towards the constrained end of the constrained-negotiated axis.

10.6.3: Discussion

The Main Study questionnaire increased the number of Social Culture items in the section entitled 'Your Attitudes to Work' from 24 in the Pilot Study to 33 in the Main Study. The 33 items were subjected to a Varimax rotation and two factors emerged. These two factors contained 25 items that remained after applying factor saturation criteria (Velicer et al, 1982) and deleting cross-loaded items where the difference was ≤ 0.200. Table 10.4 shows the content of the two emergent factors and Figure 10.1 positions these items within Douglas' (1982) grid-group matrix.

Figure 10.1: Social culture grid-group matrix showing factored item positions



10.7 The Individual Personality and Cognitive Error Principal Components Analysis (PCA)

An exploratory PCA was carried out on a number of aspects addressing the designers' individual personality and predisposition to cognitive error. The aims of this exploratory assessment are two fold. Firstly, to establish the reaction to cognitive error predicted from a separate scale measuring *Memory, Attention* and *Action* This was achieved by applying an adaptation of Wallace and Chen (2005) item development for Cognitive Failure. Secondly, to establish if there are any underlying reactions from the designers to the dimensions associated with *Extraversion, Emotional Stability, Agreeableness, Openness to Experience* and *Conscientiousness.* This was achieved by applying the IPIP 50 related publication (Goldberg, 1999). The factor analysis has been conducted on the data sets where there were priori expectations hence only the Direct Oblimin rotation method is applied and reported.

10.7.1 Cognitive Error Analysis

An exploratory factor analysis has been conducted using the Direct Oblimin rotation.

10.7.2 Rotation Method: Direct Oblimin with Kaiser Normalization (all items)

The PCA was concluded in two iterations with the calculation deleting items with low value measurements of sampling adequacy < 0.600 and items that cross loaded and where the difference was ≤ 0.200. The final extraction has a KMO measure of sampling adequacy is 0.801 and the Bartlett test of sphericity is 244.632. Component 1 has an eigenvalue of 3.156 that accounts for 35.065% of the variance.

Table 10.5 Cognitive error structure matrix

	Item
I often forget whether I have turned off work equipment, such as computers before I leave work	790
I often have difficulty remembering the things required to complete a particular task	.701
I often fail to notice postings or notices on the work email system	.579
I often forget where I have put something I use in my job	558
I often find it difficult to remember work-related phone numbers	509
I often fail to recall work procedures	443

10.7.3 Reliability Analysis

The 'all item' reliability statistic is 0.755

10.7.4 Discussion

The focus of this test was on memory, attention and action. The nine Cognitive Error items were co-mingled within the section entitled 'Behaviours in general'. A single factor emerged comprising of six of the nine original items.

10.8 Direct Oblimin rotation of all 50 IPIP items selecting a five factor extraction

The PCA was concluded in two iterations with all items initially included. The five factor extraction has a KMO measure of sampling adequacy is 0.679 and the Bartlett test of sphericity is 2957.83. Component 1 has an eigenvalue of 6.5 that accounts for 13.0% of the variance; component 2 eigenvalue of 5.16 and 10.3% of variance; component 3 eigenvalue 3.72 and 7.5% of the variance; component 4 eigenvalue 3.06 and 6.12% of the variance and component 5 eigenvalue 2.11 and 4.2% of the variance.

Table 10.6 Individual differences structure matrix

		Component				
		1	2	3	4	5
Emotional in-Stability	I get upset easily	.791				
	I get stressed out easily	.755				
	I have frequent mood swings	722				
	I change my mood a lot	669				
	I get irritated easily	654				
	I often feel blue	644				
	I am relaxed most of the time	- 631				
	I am easily disturbed	.497				
	I worry about things	496				
	I seldom feel sad	- 328				
Extraversion	I have little to say		676			
	I don't like to draw attention to myself		653			
	I keep in the background		621			
	I don't talk a lot		615			
	I start conversations		- 611			
	I talk to a lot of different people at parties		- 580			
	I am quiet around strangers		.538			
	I am the life of the party		- 519			
	I don't mind being the centre of attention.		- 512			
	I feel comfortable around people		- 445			

Table 10.6 Individual differences structure matrix (Continued)

Agreeableness	I sympathize with others' feelings			.719		
	I take time out for others			643		
	I make people feel at ease			609		
	I feel others' emotions			601		
	I am not interested in other people's problems			- 601		
	I am interested in people			.582		
	I have a soft heart			553		
	I am not really interested in others			- 498		
	I feel little concern for others			- 477		
	I insult people			- 299		
Conscientiousness	I like order				.699	
	I make a mess of things				- 672	
	I follow a schedule				567	
	I am exacting in my work				.562	
	I often forget to put things back in their proper				- 531	
	I pay attention to details				.512	
	I place I leave my belongings around				- 503	
	I am always prepared				.486	
	I shirk my duties				- 429	
	I get chores done right away				.427	
Openness-to-Experience	I have excellent ideas					629
	I am full of ideas					604
	I have a vivid imagination					568
	I have a rich vocabulary					.551
	I do not have a good imagination					- 531
	I use difficult words					458
	I do not have a good imagination					- 437
	I have difficulty understanding abstract ideas					- 393
	I am not interested in abstract ideas					.- 334

10.8.1 Reliability Analysis

The reliability of factor 1 is 0.834, factor 2 is 0.827, factor 3 is 0.791, factor 4 is 0.705 and factor 5 is 0.683.

10.8.2: Discussion

The series of test focussed on the IPIP 50 (See Goldberg et al 2006 for a detailed discussion on this issue) with items that factored in two iterations and produced a clean solution that contained no cross loaded items. This solution conforms to the five factor theory of personality (Goldberg, 1992; McCrae and Costa, 1987) where Factor one corresponds to Emotional Stability, Factor two is Extraversion, Factor three is Agreeableness and Factor four relates to Conscientiousness and Factor five is Openness-to-Experience. The original 50 items decomposed into the five factors leaving a total of 48 items. Each factor contains its original ten items except 'Openness-to-Experience' where two of the items cross-loaded onto factor's one and four and were deleted as rogue items

10.9 The Main Study questionnaire factor structure summary

The exploratory principal components factor analysis into the five constructs embodied within the 159 item Main Study questionnaire decomposed into 14 variables. These variables are presented in Table 10.7.

Table 10.7 Risk and the Designer questionnaire item factor structure

Section reference	Construct	No.	Factor Variable	Mean	SD	α
10.3	Job Characteristics	1	Role Clarity	3.952	0.578	0.780
		2	Skills/demands	4.071	0.666	0.790
		3	Job Autonomy	3.479	0.585	0.750
		4	Team Support	3.791	0.636	0.837
10.4	Risk Perception		Unfamiliarity			
			Dread			
		5	Single factor solution termed 'Risk Perception'	3.198	0.678	0.747
10.5	Safety Climate	6	Single factor solution termed 'Safety Climate'	3.810	0.520	0.895
10.6	Social Culture	7	*Group Culture*	6.282	0.846	0.795
		8	*Chance*	3.484	0.976	0.704
10.7	Cognitive Error		Memory			
			Attention			
		9	Single factor solution termed 'Cognitive Error'	2.202	0.581	0.755
10.8	Individual differences	10	Emotional Stability	3.623	0.641	0.834
		11	Extraversion	3.172	0.610	0.827
		12	Conscientiousness	3.453	0.360	0.705
		13	Agreeableness	3.779	0.522	0.791
		14	Openness-to-Experience	3.486	0.448	0.683

The relationships between these 14 variables will be explored in a correlations analysis to establish the strength of any underlying relationships between the factors (see Section 10.10). A two-level hierarchical linear regression has been undertaken to investigate the structure of the modelled questionnaire data and error as the defined outcome variable.

10.10 Correlation Analysis of the PCA outcomes

Correlations are concerned with measuring the linear relationship between two variables. It is important to appreciate that this method suffers from a number of weaknesses. Firstly, there is no hard and fast rule as to what constitutes a good or disappointing correlation, although Cohen (1977) indicates correlations in the range 0.10 - 0.30 can be considered to be small, whereas those in the range 0.30 - 0.50 can be considered medium and those > 0.50 are large.

Correlations only measure the strength of a relationship between two variables. A Pearson product correlation was calculated for each of the 14 scales derived from the principal components factor analysis and yielded some interesting results which are presented in Table 10.8. The Pearson correlation was calculated in order to investigate how closely aligned a measure-of-fit was based upon the 14 scales derived from the exploratory factor analysis. However, the assessment of these 14 scales has concentrated upon cognitive error as the outcome of interest from this correlation. Therefore some significant correlations are excluded from the discussion as they are less relevant to the topic of the thesis.

The 14 scales in the correlations matrix are arranged in the same order as they have been presented in the two-level and three-level hierarchical linear models for the sake of consistency.

Table 10.8: Pearson Correlation matrix based upon the 14 factor item structure

* Pearson correlation is significant at 0 05 (2-tailed) ** Pearson correlation is significant at 0 01 (2-tailed)

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Cognitive Error													
2	Risk Perception	0 014												
3	Emotion Stability	-0.398**	-0.123											
4	Extraversion	-0.112	0.071	0.111										
5	Conscientiousness	-0 254**	-0 017	0.122	-0 061									
6	Group Culture	0 076	-0 116	0.004	-0 009	0.265**								
7	Chance	0 171*	-0 034	-0.076	-0 063	-0.070	0 073							
8	Safety Climate	-0.145	-0 040	0.191*	0 128	0 179*	0 147	-0.398**						
9	Openness	-0.161	0.015	0 210*	0 340**	0.193*	0 040	-0.091	0 037					
10	Agreeableness	-0 070	-0 015	0 094	0.322**	- 0 064	0.103	-0.001	0.215*	-0 065				
11	Team Support	0.112	-0 163	0 106	-0.009	0 074	0 230**	-0 093	0.394**	-0 008	0.179*			
12	Skills/Demands	- 099	0 213*	0 115	0 032	0.212*	0 179*	-0 025	0 197*	0 058	-0 083	0.187*		
13	Job Autonomy	-0 062	0 120	0 080	0 075	0.156	0.115	-0 138	0.148	0 132	-0.009	0 107	0 087	
14	Role Clarity	-0 135	-0 078	0.108	-0.129	0.405**	0.357**	-0 073	0 284**	-0.006	0 030	0 454**	0 324**	0 249**

Firstly, there is no apparent relationship between cognitive error and risk perception. In other words, where a designer's risk perceptions are low then there is no greater likelihood of the designer committing cognitive errors compared to designers whose risk perception is high. Cognitive error on the other hand appears to be negatively related to two personality traits at $p < 0.01$, conscientiousness (-0.25) and emotional stability (-0.40), and at $p < 0.05$ cognitive error is positively related to the social culture *Chance* (0.17).

The next section investigates through the application of a two-level hierarchical model, the linear regression of cognitive error through the structure of the questionnaire data set that emerged following re-scaling and the exploratory PCA.

10.11 Linear Regression of Cognitive Error

Regression is about modelling the structure in a data set. The composition of this two-level hierarchical linear model is described in Section 9.9.3 and it has been developed with 'Error' (Cognitive error) being defined as the outcome variable. The composition of model reflects the strong theory driving the relationship between cognitive error and certain of the personality traits described in Sections 3.4, and in particular sub-sections 3.4.1 and 3.4.4 covering conscientiousness and emotional stability. These personality traits have already considered in Wallace and Chen's (2005) investigation into cognitive failures and in the Clarke and Robertson (2005) meta-analytical review of the Big Five and accident involvement.

Table 10.9: Two-level Hierarchical Linear Regression – Cognitive error model (with robust standard errors)

Fixed Effect	Co-efficient	Standard error	T-ratio	Approx df	p-value* Robust statistic
For intrcpt1, B0					
Intrcpt2,	2 207230	0.040920	53 940	50	<0 001
Team safety Climate	-0 073632	0.150469	-0 489	50	0.313
Group Culture	0.104530	0 048980	2 134	126	**<0.035**
Chance	-0.026213	0.042244	-0.621	126	<0.536
Risk Perception	-0 058795	0.081530	-0 721	126	0.472
Perceived Safety Climate	-0.045150	0 119742	-0 377	126	0 706
Emotional Stability	-0.358475	0 058819	-6 095	126	**<0.001**
Extraversion	-0 1318441	0 095322	-1 243	51	0 220
Openness	-0.018674	0 106211	0.176	126	0 861
Conscientiousness	-0 385103	0 117889	-3 267	126	**0.002**
Agreeableness	-0 070011	0 088630	-0 790	51	0 433
Role Clarity	-0 011764	0 091732	-0 128	51	0 899
Skills/Demands	-0 049397	0 055423	-0 891	51	0 377
Job Autonomy	-0 022507	0 067722	-0 332	126	0.740
Team Support	0 126958	0.088630	-0 790	51	0.433

*The robust statistic p value < 0.05

Table 10.10: Two-level Hierarchical Linear Regression – Variance components

Final estimation of variance components					
Random Effect	Standard Deviation	Variance Component	df	Chi-square	P-value
Intercpt1	0 15962	0.02548	6	14 81578	0 022
Extraversion	0 42036	0.17670	7	36.37594	<0 001
Agreeableness	0.35659	0.12716	7	20.73925	0 004
Role Clarity	0 31345	0.09825	7	14.29268	0 046
Skills/Demands	0 21926	0 04807	7	10.95250	0 140

10.11.1 Discussion of the two-level hierarchical linear regression results

The results of the two-level linear regression (see Table 10.9) indicates that certain independent variables are significant and that other independent variables, that have been suggested by theory as being significant, are not reported as such based upon this analysis. In this exploratory study it is important to report both the expected and the unexpected outcomes and relate them to theory. In this analysis one social culture dimension appears important to predicting cognitive error. In addition, two personality traits predict cognitive error and these cover the theoretically significant personality traits of conscientiousness and emotional stability.

Group culture predicts that more errors will occur ($t = 2.134$ at $p < 0.05$). The personality traits that have been reported to be theoretically significant indicate that those designers reporting high levels of emotional stability will report fewer errors ($t = -6.095$ at $p < 0.05$) and this trend is also reflected in designers who possess high levels of conscientiousness ($t = -3.267$ at $p < 0.05$).

Table 10.10 shows that there remains significant variation between groups, as indexed by the significant variance component for the intercept (variance component = 0 02548 at $p < 0.05$), that cannot be accounted for by the independent variables. Significant variance components for some slopes also indicates that there is significant variability between the teams in the relationships between cognitive error and extraversion (variance component = 0.17670 at $p < 0.05$), agreeableness (variance component = 0.12716 at $p < 0.05$) and role clarity (variance component = 0.09825 at $p < 0.05$). Variability in intercepts indicates that additional, unmeasured predictor variables account for all the variance in the dependent measures. Whereas, the reported variability between the slopes indicates that the relationship between the predictor and the outcome appears to be dependent on some other variable or set of variables. These other variables or sets of variables, whatever they may be, have not been measured and therefore remain unexplained in this study.

10.11.2 Summary

This section has presented the results from a two-level hierarchical linear regression of questionnaire data with respect to the outcome variable 'Error'. The findings suggest that the everyday social cultures, the psychological characteristics attached to 'Conscientiousness' and 'Emotional Stability' and the absence of any ambiguity in a designer's role, which is afforded by 'Role Clarity', are significant predictors of cognitive errors. The next section draws upon the ESM and the PDA data. An exploratory PCA has been conducted on data extracted from the PDA's where the selected outcome variables are Cognitive Error ('Error') and the Use of Risky Design Protocols ('Risky').

Part Two

10.12 The analysis of the outcome variables, Cognitive Error ('Error') and the Use of Risky Design Protocols ('Risky'), in an exploratory principal components analysis (PCA) extracted from PDA data

10.12.1 Overview

The exploratory PCA was carried out on a number of aspects addressing the designers' cognitive error and use of risky design protocols. The aims of this exploratory assessment are two fold. Firstly, to establish the reaction to cognitive error ('Error') predicted from a separate scale measuring *Memory, Attention* and *Action.* The factor analysis has been conducted on the data sets where there were prior expectations hence a Direct Oblimin rotation method was applied and is reported.

Secondly, to establish if there are any underlying reactions from the designers to the dimensions associated with the use of risky design protocols ('Risky'). The factor analysis has been conducted on the data sets where there were no prior expectations hence the Varimax methods was applied.

10.12.2 Use of Risky Design Protocols PCA on PDA data

The exploratory factor analysis has been conducted after three data preparatory stages of checking, and adjustments made accordingly, thus:

1. The PDA files were cleaned;

2. A data frequency check for any biases;
3. PCA by applying Varimax rotation.

The frequency descriptors show no missing data and that the risky protocol 3 "In the past hour have you applied solutions that have worked well in the past?" was the most frequently recorded entry.

Table 10.11: Statistical data for the use of risky design protocols

Data set	Use of risky design protocol 1	Use of risky design protocol 2	Use of risky design protocol 3	Use of risky design protocol 4
Description	In the past hour have you made assumptions about missing pieces of data	In the past hour have you reused a previous design that has not been updated	In the past hour have you applied solutions that have worked well in the past	In the past hour have you added a design feature fit-for-purpose but others need to decide if it's correct
Valid Missing	5816 0	5816 0	5816 0	5816 0
No Yes	4929 887	5197 619	3222 2594	4876 940
Mean Std error of Mean Skewness Std error of skew Kurtosis Std error of kurtosis	0.1525 0 00471 1.934 0 032 1.739 0 064	0.1064 0 00404 2.553 0 032 4 520 0 064	0.4460 0 00652 0 217 0 032 -1.953 0.064	0 1616 0.00483 1.839 0 032 1.382 0 064

The PCA was concluded in a single calculation with all four items included and a single extraction applied. The factor extraction has a KMO measure of sampling adequacy of 0.706 and the Bartlett test of sphericity is 2283.92. Component 1 has an eigenvalue of 1.854 that accounts for 46.34% of the variance. The reliability of the risky scale was low at 0.597.

10.12.3 Cognitive Error PCA on PDA data

The exploratory factor analysis has been conducted following the preparatory stages of checking and Table 10.12 reports the statistical data associated with Cognitive error:

1. A data frequency check for any biases;
2. A check that the data is appropriate for an exploratory factor analysis involving skewed and non-skewed data with correction for these conditions as appropriate;
3. PCA by applying Direct Oblimin rotation.

Table 10.12: Statistical data for Cognitive Error

Data set	Cognitive error 1	Cognitive error 2	Cognitive error 3
Description	In the past hour has it been difficult to remember how to perform specific design tasks;	In the past hour have you been easily distracted from your work;	In the past hour has it needed effort to type, write or read
Valid Missing	5816 0	5816 0	5816 0
Recall problems No	4792	3292	4772
2 3 4 Very	768 202 24 30	1589 650 186 99	783 179 41 41
Mean Std error of Mean Skewness Std error of skew Kurtosis Std error of kurtosis	1.23 0 579 3 099 0.032 11.778 0 064	1.66 0.919 1.496 0 032 1.981 0.064	1.25 0 611 3.206 0.032 12 370 0 064

The PCA was concluded in a single iteration with all items included. The single factor extraction has a KMO measure of sampling adequacy is 0.666 and the Bartlett test of sphericity is 4319.03. Component 1 has an eigenvalue of 2.0 that accounts for 66.7% of the variance. The reliability of factor 1 is acceptable at 0.713.

Part Three

10.13 The analysis of interactional effects between diary data, designers and design teams using hierarchical linear modelling.

10.13.1 Overview

This data was collected from a relatively high number of design teams (n = 55) that were all involved in the design of hazardous installations. The participants were drawn from three organisations working on eight hazardous design projects. The number of raw PDA observations gathered from the daily diaries is n = 6087. There were two phases of data reduction to 'clean' the data. The 'not in work' entries were deleted from the PDA register to provide a report containing a maximum of 6030 entries. Participants with a compliance rate of < 25% were then deleted from the same data file. This elimination left a pure data set from 141 participants with n = 5816 observations,

Whilst reporting violations were always possible, the relatively high overall compliance rate of > 63% implies a general willingness of the participants to be involved in the study. The number of designers totalled 167 which included a sample representation from all design teams. The maximum sample size of design teams is 11 design teams per design project. Whilst the collective number of design teams that participated in this study totalled 55 not all hazardous projects contained all discipline teams. In addition to the design teams, there were four client representatives that agreed to be sampled.

10.13.2 Structure of the analysis model

Multilevel regression analysis was used to examine hypotheses 1a through to 1e and test the research question RQ1. The regression model was progressively tested until all the data blocks had been added and the final model run. In each set of analyses, an incremental, stepwise approach was taken to building equations (Snijders & Bosker, 1999). At each step, regression slopes that evinced no significant variation were fixed to be invariant across participants. The significance of variance was judged to be non-significant at $p > 0.20$ or if the reliability of the slope is low < 0.05 (again see Raudenbush & Bryk, 2002). The results for 'Error' are contained in Tables 10.13, and 10.14 and Risky' (The Use of Risky Design protocols) are reported in Tables 10.15, and 10.16.

Level 1:

$y = \pi_0 + \pi_{1\,(Mon)} + \pi_{2\,(Tues)} + \pi_{3\,(Wed)} + \pi_{4\,(Thur)} + \pi_{5\,(Mor)} + \pi_{6\,(Lunch)} + \pi_{7\,(Aft)} + \pi_{8\,(Wav\ 1)} + \pi_{9\,(Wav\ 2)} + \pi_{10\,(Wav\ 3)} + e$ (where e is the level 1 error term)................................ (10.13.2.1.)

Level 2:

$\pi_0 = \beta_{00} + \beta_{1\,(Compl)} + \beta_{2\,(Group\ Culture)} + \beta_{3\,(Individualism)} + \beta_{4\,(Safety\ Climate)} + \beta_{5\,(Risk\ Perception)} + \beta_{6\,(Emotional\ Stability)} + \beta_{7\,(Extraversion)} + \beta_{8\,(Openness)} + \beta_{9\,(Conscientiousness)} + \beta_{10\,(Agreeableness)} + \beta_{11\,(Role\ Clarity)} + \beta_{12\,(Skills)} + \beta_{13\,(Autonomy)} + \beta_{14\,(Support)} + r$ (where r is the level 2 error term).. (10.13.2.2)

$\pi_{1\,(Mon)} = \beta_{10} + r_1,$
$\pi_{5\,(Mor)} = \beta_{50} + r_5,$
$\pi_{9\,(Wav\ 2)} = \beta_{90} + r_9,$

Where r_n is the error term

Level 3

$\beta_{00} = \gamma_{000} + \gamma_{001\ (\text{Safety Climate})} + u_{00}$ (where u_{00} is the level 3 error term)............(10.13.2.3)

$\beta_{90} = \gamma_{900} + u_{090},$
$\beta_{100} = \gamma_{1000} + u_{100},$

Where u_{090} and u_{100} are the level 3 error terms

All other slopes had to be fixed by the researcher to be invariant

10.13.3 Results

Table 10.13: 'Error' final estimation of fixed effects (with robust standard errors)

Fixed Effect	Co-efficient	Standard Deviation	T-ratio	Approx df	p-value* Robust statistic
For intrcpt1, P0					
Intrcpt2,	1 379974	0 061476	22 447	50	0 000
Safety climate	0 018880	0 084752	0 223	50	0 825
Intrcpt3					
Compliance	-0 091552	0 159810	-0 573	126	0.567
Group Culture	0 009703	0 036873	0 263	126	0 793
Chance	-0 007944	0 024783	-0 321	126	0 749
Safety Climate	-0 007509	0 051511	-0 146	126	0 885
Risk Perception	-0 004035	0 031784	-0 127	126	0 900
Emotional Stability	-0 121841	0 039858	-3 057	126	**0.003**
Extraversion	0 013132	0 046908	0.280	126	0.780
Openness	-0 045445	0 066071	-0 688	126	0 493
Conscientiousness	-0 072618	0 084479	-0 860	126	0 392
Agreeableness	0 013516	0 050235	0 269	51	0 789
Role Clarity	-0 065675	0 052305	-1.256	126	0 212
Skills	-0 068011	0 042054	-1 617	126	0 108
Job Autonomy	0 002974	0 029440	0.101	126	0 920
Support	-0 032682	0 029578	-1 105	126	0 272
Monday	0 028861	0 02158	1.103	140	0 272
Tuesday	-0 018735	0 021032	-0 891	5453	0 373
Wednesday	-0 030939	0 020641	-1.499	5453	0 134
Thursday	-0 032266	0 022673	-1.423	5453	0 155
Morning	-0 095711	0 020767	-4.609	140	0 000
Lunchtime	-0 096097	0 022838	-4.208	5453	0 000
Afternoon	-0 037441	0 021943	-1.706	5453	0 088
Wave 1	0.122561	0 056638	2 164	5453	0 030
Wave 2	-0 014266	0 043731	-0 326	51	0 745
Wave 3	0.030447	0 034965	0 871	51	0 388

*p < 0 05

Table 10.14: The HLM6 analysis results for 'Error'

Final Estimation of level 1 and level 2 variance components					
Random Effect	**Standard Deviation**	**Variance Component**	**df**	**Chi-square**	**p-value robust**
Interceptl (R0)	0.29663	0 08799	5	718.72919	0 000
Monday slope, (R1)	0.12565	0 01579	105	157.30645	0 001
Morning slope (R5)	0 09575	0.00917	105	139 18617	0 014
Wave 2, (R9)	0.11574	0 01340	62	170 18947	0 000
Final Estimation of level 3 variance components					
Random Effect	**Standard Deviation**	**Variance Component**	**df**	**Chi-square**	**p-value robust**
Intercptl /Intercept2, (U00)	0 09398	0.00883	25	38 89076	0 038
Interceptl/Agreeableness, (U014)	0.11385	0.01296	26	31 16453	0.222
Wave 2/ Intercept 2. (U90)	0 10052	0 01010	26	48.12249	0 005
Wave 3/ Intercept 2. (U100)	0 15103	0 02281	26	116 61546	0 000

The two-level Cognitive Error ('Error') model has one set of variance components indicating variability between teams (Table 10.12). The three-level 'Error' model has two sets of variance components (Table 10.14), reporting variability between individuals over time and between teams. There is component variance and several other statistics contained within these tables including a probability for the intercepts (at level 2 and level 3) and the slopes that have been left to vary between individuals or teams shown in Table 10.14. There is significant variability left to account for ($p < 0.05$) between individuals over time and between teams (e.g. the intercepts at level-2 and at level-3). There is also significant variability between individuals on the extent of the impact of Mondays, mornings, lunchtime and wave 2 on error, and variability between teams on the impact of agreeableness, wave 2 and wave 3 on error.

Variability in intercepts as shown in Table 10.14 indicates that additional, unmeasured predictor variables account for all the variance in the dependent measures. Whereas, the reported variability between the slopes indicates that the relationship between the predictor and the outcome ('Error') appears to be dependent on some other variable or set of variables. These other variables or sets of variables, whatever they may be, have not been measured and therefore remain unexplained in this study. The reason for this lack of measurement is due to the absence of any strong theoretical reasoning for suspecting that slope variability can be predicted from other variables.

Table 10.13 indicates that 'Error' results indicate that only the personality trait Emotional Stability is significant at $p < 0.05$ ($t = -3.057$). This result supports the two-level hierarchical linear regression examination of questionnaire data. The result is also supported by theory (see Wallace & Chen, 2005). Any effects associated with the prevailing safety climate have not been revealed. Chapter Twelve discusses the implications of these results.

<u>Level 1:</u>

$y = \pi_o + \pi_{1\,(Mon)} + \pi_{2\,(Tues)} + \pi_{3\,(Wed)} + \pi_{4\,(Thur)} + \pi_{5\,(Mor)} + \pi_{6\,(Lunch)} + \pi_{7\,(Aft)} + \pi_{8\,(Wav\ 1)} + \pi_{9\,(Wav\ 2)} + \pi_{10\,(Wav\ 3)} + e$ (where e is the level 1 error term)................................ (10.13.2.4)

<u>Level 2:</u>

$\pi_o = \beta_{00} + \beta_{1\,(Compl)} + \beta_{2\,(Group\ Culture)} + \beta_{3\,(Individualism)} + \beta_{4\,(Safety\ Climate)} + \beta_{5\,(Risk\ Perception)} + \beta_{6\,(Emotional\ Stability)} + \beta_{7\,(Extraversion)} + \beta_{8\,(Openness)} + \beta_{9\,(Conscientiousness)} + \beta_{10\,(Agreeableness)} + \beta_{11}$ (Role

$_{\text{Clarity})} + \beta_{12\,(\text{Skills})} + \beta_{13\,(\text{Autonomy})} + \beta_{14\,(\text{Support})} + r$ (where r is the level 2 error term).. (10.13.2.5)

Level 3

$\beta_{00} = \gamma_{000} + \gamma_{001\,(\text{Safety Climate})} + u_{00}$ where u_{00} is the level 3 error term)......... ...(10.13.2 6)

$\beta_{011} = \gamma_{110} + u_{011}$, Where u_{011} is the level 3 error term.

Table 10.15: 'Risky' final estimation of fixed effects (with robust standard errors)

Fixed Effect	Co-efficient	Standard Deviation	T-ratio	Approx df	p-value* Robust statistic
For intrcpt1, P0					
Intrcpt2,	-0 317546	0 09692	-3.426	50	0 002
Team Safety Climate	-0 571757	0 255465	-2 238	50	**0.030**
Intrcpt3					
Compliance	0.483533	0 386671	1 251	126	0 214
Group Culture	0 099807	0 077514	1 288	126	0 200
Chance	0 081380	0 061713	1 319	126	0 190
Perceived Safety Climate	0 386020	0.172095	2 243	126	**0.027**
Risk Perception	0 221816	0 086842	2 554	126	**0.012**
Emotional Stability	-0 029668	0 099752	-0 297	126	0 767
Extraversion	-0 180821	0 096518	-1 873	126	**0.032**
Openness	0 224288	0 110474	2 030	126	**0.044**
Conscientiousness	0.142175	0 179907	0.790	126	0.431
Agreeableness	0.178891	0 106505	1 680	126	**0.095**
Role Clarity	-0 133326	0.148455	-0 898	126	0 371
Skills/Demands	0 084651	0 122614	0 690	51	0 493
Job Autonomy	-0.375700	0.120034	-3 130	126	**0.003**
Support	0 091011	0 135799	0 670	126	0 504
Monday	0 09107	0 052221	2 089	5453	0 036
Tuesday	0 126783	0 048629	2 607	5453	0 010
Wednesday	0 088950	0 048347	1 840	5453	0 065
Thursday	0.100439	0 032227	3 117	5453	0 023
Morning	0 083577	0 036851	2 268	5453	0 023
Lunchtime	0.104491	0 027793	3 760	5453	<0 001
Afternoon	0 004157	0 037635	0 110	5453	0.913
Wave 1	-0 032115	0 076695	-0 419	5453	0 675
Wave 2	-0 050357	0 078984	-0 638	5453	0 524
Wave 3	-0 134584	0 060397	-2 228	5453	0 026

Multi-level Poisson Regressions; variance components are derived for unit specific models, since variances are not produced for population average models,*p < 0 05

Table 10.16: The HLM6 analysis results for 'Risky' (Poisson regression)

Final Estimation of level 1 and level 2 variance components					
Random Effect	**Standard Deviation**	**Variance Component**	**df**	**Chi-square**	**p-value**
Intercpt1	0 83550	0 69806	24	1057 03222	<0.001
Final Estimation of level 3 variance components					
Random Effect	**Standard Deviation**	**Variance Component**	**df**	**Chi-square**	**p-value robust**
Intercept2	0.18562	0 03446	27	39 68497	0 055
Skills/Demands	0.40262	0.16210	28	48.30667	0 010

In this analysis shown in Table 10.15, Safety Climate appears to be an important factor to predicting the use of risky design protocols. The safety climate affect appears significant at level 3 and significant at level 2 ($p < 0.05$) of the nested organisational structure. This important safety climate phenomenon appears to exist at the team level and at the individual level and aggregated at a team level. Risk perception also predicts the use of risky design protocols. In addition, two personality traits appear to predict 'Risky' and these cover the theoretically significant personality trait of Extraversion (marginally at $p < 0.07$) and Openness-to-Experience. Finally, the job characteristics of job autonomy appears significant to predicting the 'Risky' outcome.

The measure of the significance is determined by the magnitude of the t-statistic and whether it possesses a positive or negative value. The safety climate at team level predicts that fewer risky protocols will be applied ($t = -2.238$ at $p < 0.07$) whereas at an individual level safety climate predicts that more risky protocols will be used ($t = 2.243$ at $p < 0.05$). The personality trait that has been reported to be theoretically significant with safety performance indicates that those designers reporting high levels of extraversion will report fewer the use of fewer risky protocols ($t = -1.873$ at $p < 0.05$). It is worth recording that this relationship is in the direction opposite to that predicted earlier. The personality trait Openness-to-Experience reports the use of more risky protocols ($t = 2.030$ at $p < 0.05$). Designers who perceive greater risk in their work tasks report using more risky design protocols ($t = 2.554$ at $p < 0.05$). The results suggest that designers who are provided with high levels of Job Autonomy ($t = -3.130$ at $p < 0.05$) will use fewer risky design protocols.

The significance of the safety climate effects at the individual and team levels shows a subtle relationship between the individual and the team. A positive safety climate is demonstrated at the aggregated team level whereas a reverse relationship is reported at an individual level. These beliefs could relate to the personal benefits of the prevailing safety climate discussed by Alexander et al (1994) and may relate to the scepticism surrounding the leadership qualities of the team leaders at a design team level (see Brown & Holmes, 1986; Zohar, 1980; Zohar & Luria, 2005). This effect may also apply to senior managers of the design organisations that have been reported by Turner and Parker (2004).

The liability that extraverts have to using fewer risky protocols is a little unclear. However, Clarke and Robertson (2005) have reported that the extravert maybe less accident involved. Considering this relationship and what might be expected from a designer under similar circumstances may mean less risk-taking or the use of fewer risk protocols. This is discussed further in Chapter Twelve. The characteristics of the personality trait Openness-to-Experience imply a positive disposition to learning and experimentation. Clarke and Robertson (2005) report that experimentation may involve a degree of improvisation which would be consistent with designers who score high in openness applying more risky design protocols. Two of the four risky protocols that were selected imply improvisation because they include an element of manoeuvring around procedural requirements (e.g. In the past hour have you reused a previous design that has not been up-dated; in the past hour have you added a design feature fit-for-purpose but others need to decide if it's correct).

Hazardous designs involving designers with high scores in Openness-to-Experience create the opportunity for procedural violations through their desire to experiment and hence the use of more risky intentions in order to complete the design tasks. The composition of the risky protocols will be revisited in Chapter Twelve in order to place in context the personality traits that have emerged as significant and the use of risky protocols.

Finally, designers with high levels of Job Autonomy appear less likely to use risky design protocols. This maybe reflective of designers being able to set their own work schedule and by being more self determining over how the design protocols are applied and when they are applied (after Hackman & Oldham, 1975). There are also significant practical implications attached to increasing a designer's levels of job autonomy that need to be considered. These carry a socio-technical component as well as a socio-cultural perspective discussed by Turner (1991). These are discussed at length in Chapter Twelve

Table 10.16 shows that there is significant variability left to be explained between individuals over time (variance component = 0.69806 at $p < 0$ 05) and, marginally, between teams (variance component = 0.03446 at $p < 0.10$). There is also variability in the impact of skills/demands on 'Risky' between teams (variance component = 0.16210 at $p < 0.05$).

The temporal exponents indicate that:

- More risky protocols are applied on all days of the week compared to Friday;
- More risky protocols are applied in the morning and lunchtime compared to afternoons;
- Fewer risky protocols were applied in wave 3 compared to waves 1 and 2.

10.14 Summary

This chapter has presented the results from the exploratory factor analysis work conducted on the Main Study questionnaire and described the emergent factors from a set of PCA. The outcome variable Cognitive Error was then analysed using a two-level hierarchical linear model that revealed the significance of the Social Cultures, the personality traits Emotional Stability and Conscientiousness, and the job characteristic, Role Clarity at this level of analysis. An analysis of the factor structure using PCA associated with Cognitive Error and the Use of Risky Protocols was then conducted on the PDA data. The factor structure and the statistical data for both Cognitive Error and Risky have been reported.

The analysis of the interactional and effects between dairy data, individual designers and design teams has been completed using a three-level hierarchical linear model. The results indicate that with 'Error' defined as the outcome variable the personality trait Emotional Stability is significant. When 'Risky' is described as the outcome variable the Poisson regression indicates that Safety Climate is significant at an individual and team level, the personality traits Extraversion and Openness-to-Experience are significant, higher levels of Risk Perception increase the use of risky protocols and finally that higher levels of Job Autonomy are predicted to reduce the use of risky protocols. The next section, Section Four, begins the process of discussing these results and their implications in far more detail. Relating the findings to how the designer of a hazardous installation addresses cognitive error and the use of risky design protocols when conducting their design tasks and what the theoretical and practical justifications may be.

Section 4

Discussion and Conclusions

Chapter Eleven

Discussion of Results

11.1 Introduction

Chapter Eleven reflects on the results of the thesis. Part One of this chapter commences by discussing the emergent factors that were disclosed through the principal components factor analysis. A Pearson product correlation was conducted on the emergent scales from the PCA and the results are described. Part One concludes by discussing the results from the two-level hierarchical linear regression, where Cognitive Error ('Error') was the defined outcome variable. Part Two of this chapter describes the outcomes from the longitudinal study using the three-level hierarchical linear model. Finally, Part Three addresses the level of support for the research questions. The level of support gained for the research question is determined by the test of the hypotheses and in addition, the longitudinal study revealed some significant effects that were not hypothesised and Part Three presents a discussion on these findings.

Part One

11.2 Job Characteristics

The emergent structure produced a four factor solution which appears consistent with theory (Barnett & Brennan, 1995; Breaugh, 1985; Caplan, et al, 1975; Daniels 1996; Daniels & Guppy, 1995; Hackman & Oldham, 1975; Kahn, et al, 1964). Factor 1 relates to Support, Factor 2 emerged as a combination of two constructs that coupling together Demands and Skills reported by Caplan, et al (1975). Factor 3 related to Job Autonomy and Factor 4 Role Clarity.

11.3 Risk Perception

This analysis indicates that risk perception forms a single construct comprising of the two components initially put forward. Theory indicates that dread and unfamiliarity (Slovic et al, 1982) are significant aspects of risk which the designers appear to consider together.

11.4 Safety Climate

All items were loaded into the Direct Oblimin rotation method and a single factor extracted. The 18 items remaining from the original 24 questionnaire items were summed and divided by 18 to produce a new scale value. Therefore the results indicate safety climate may be characterised by a single dimension in the offshore design organisations that participated in this study (Griffin & Neal, 2000).

11.5 Social Culture

A reliable two factor solution emerged from the Varimax rotation method.The new scales comprised of 13 items in the *Group Culture* construct and 12 items in the *Chance* construct. The eight remaining items were deleted according to the factor saturation criteria (Velicer et al, 1982). The two scales broadly reflect individualism through *Chance* and collectivist views through *Group Culture* which suggest that designers may have more intuitive views when it comes to taking certain risk related decisions.

11.6 Cognitive Error

A single factor emerged from the analysis of cognitive error and the six items were summed and divided by six to produce the new cognitive error scale. These findings appear consistent with those derived by Wallace and Chen (2005).

11.7 IPIP 50 Individual Personality Differences

All 50 IPIP items were loaded into the analysis and only two rogue items were found to cross-load. The analysis produced five emergent factors that were consistent with theory and the application of IPIP 50 (See Goldberg et al, 2006).

11.8 Pearson Correlations Matrix

A Pearson product correlation was calculated for each of the 14 scales derived from the principal components factor analysis. The results indicate that designers with emotionally stable (- 0.4 at $p < 0.01$) and conscientiousness (- 0.25 at $p < 0.01$) personalities are less likely to report higher levels of cognitive error perhaps because of their demeanour that is orientated towards task completion and compliance related issues.

11.9 Linear Regression of Cognitive Error

There are certain effects reported in the two-level hierarchical linear model that are consistent with theory.

11.9.1 Social Culture

Designers conforming to a high *Group* culture ($t = 2.134$ at $p = < 0.05$) may commit more errors through a phenomenon known as '*social loafing*' (Jackson & Harkings, 1985; Jackson & Williams, 1985; Karau & Williams, 1993). Designers embedded in a *Group* culture appear to knowingly rely upon others to correct their individual mistakes and errors and remain confident that this will always be the case. The main explanation for social loafing is that individuals tend to feel unmotivated when working within a team because it is their belief that their contribution is neither evaluated nor valued. According to the meta-analysis conducted by Karau and Williams (1993) social loafing appears to be a pervasive phenomenon. However, Karau and Williams (1993) do report that this effect tends to be absent; in cases where team members believe that their contribution is likely to be both significant and important.

11.9.2 Personality

Wallace and Chen (2005) demonstrated that higher accident involvement could be anticipated where levels of conscientiousness and emotional stability were reported to be low. Evidence of this relationship has also been reported in a meta-analysis conducted on Goldberg's (1992) Big Five using past accident involvement as the measurement (Clarke & Robertson, 2005). The results from this study indicate that fewer errors are reported for designers who are high in conscientiousness ($t = -3.267$ at $p < 0.05$), and high in emotional stability ($t = -6\ 095$ at $p < 0.05$) which is consistent with earlier research.

11.9.3 Job Characteristics

Chapter Five introduced certain job characteristics that were considered appropriate to describing the role performed by the designer. None of the five job characteristics considered as a control measure reported any significant relationship with cognitive error.

11.9.4 Safety Climate

There is no significant effect attached to the mediation of error by the prevailing safety climate.

11.9.5 Summary

There appears to be a number of competing effects determining whether higher or lower levels of cognitive errors are reported in the two-level hierarchical linear regression. More errors are reported by designers subscribing to a *Group* culture and fewer errors are reported for designers with the personality traits of Conscientiousness and Emotional

Stability. Part Two addresses the three – level hierarchical linear regression that was used to model the two outcome variables 'Error' and 'Risky' and discusses the significant findings surrounding this longitudinal study and whether the two-level outcomes are replicated over time.

Part Two

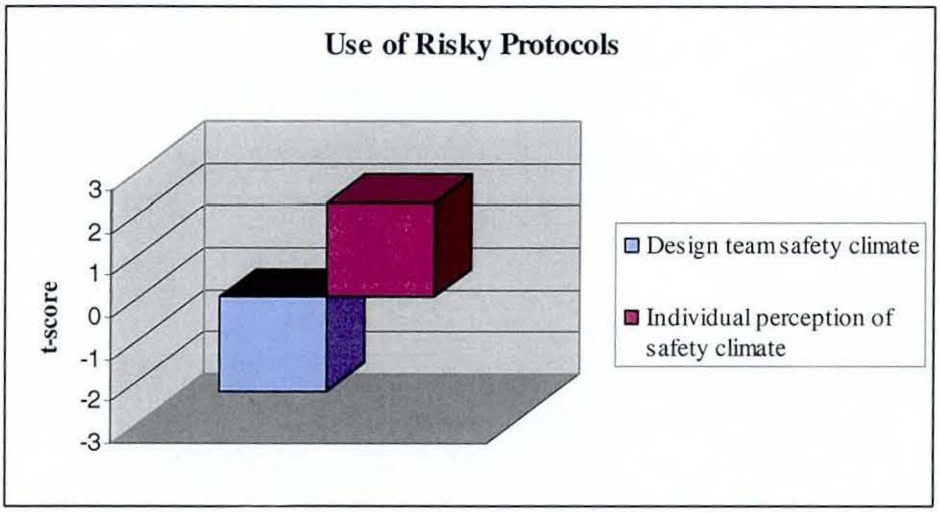
11.10 Commentary on the HLM6 results for 'Risky' and 'Error'

11.10.1 'Risky'

The Poisson regression produced a mixed pattern of significant relationships with the use of risky design protocols. For the 'Risky' outcome variable, safety climate appears significant at the individual and aggregated team level. For the individual perception of safety climate, the designers report increased use of risky protocols ($t = 2.243$ at $p < 0.05$) indicating they may rely upon others within the team to rectify the consequences of their design selections. This conclusion is countered by the aggregated team perception of safety climate which reports a decreased use of risky design protocols ($t = -2.238$ at $p < 0.05$).

This team perception reflects a collectivist view, where the team decides whether the outcome from a risk-benefit trade-off is acceptable to the project (see Vrijling, van Hengel & Houben, 1998; Jonkman, van Gelder & Vrijling, 2003). Parker, Axtell and Turner (2001) have found that safety behaviour, such as taking fewer risks has relationships established in measures of team support, such as in a positive organisational safety climate. Figure 11.1 illustrates the opposing positions adopted by the individual and team level results.

Figure 11.1: Safety Climate and the Use of Risky Design Protocols



These results do not suggest that the prevailing level of design safety climate is poor. However, the findings do indicate that at an individual level, the designer should strive to minimise the risk that is being introduced into a design. The designer needs to understand, 'what are the acceptable levels of risk?' when taking the types of design decision that appear to be routinely undertaken. The designers understanding of the framework within which risk and the design decisions are undertaken appears equally important. This understanding of the framework allows the appropriate design measures to be adopted if and only if, they do not increase the overall levels of risk. Establishing the correct level of risk comes to determine which technologies can be used to address a particular design problem.

Risk communication on this issue is highly significant because, as this study shows, the designer appears to place great reliance on designs that have worked well in the past (see Table 10.14). So updating designs, to make them contextually appropriate, demonstrates an intrinsic organisational quality, whereby the updated designs limit the ability of the designer to take unsafe decisions (Busby & Strutt, 2001). Kahnemann, Slovic and Tversky (1982) indicate the importance of heuristic theory in this way, by explaining why the use of past designs retains such a significant position in the mind of the designer. The process heuristic explains how these past rules have an accumulative effect, as they progressively build-up a designer's knowledge. What the theory fails to explain is why designers would assume that past designs would always provide them with beneficial solutions. One explanation is that this knowledge reappears to create the designer's own set of rules, being applied as *aide memoires*, that in turn directly impact features of a design. Tversky and Kahnemann (1974) indicate that easily recalled data maybe more commonplace and the more frequently applied *aide memoire* because it allows the designers to enact quick choices and saves time. The important finding from this research is that design team safety climate compensates for individual design choices that appear to increase risk.

The designer's risk perception ($t = 2.554$ at $p < 0.05$) indicates that increased levels of risk perception invoke greater use of risky design protocols. Daniels (1996) indicates that risk communication on these types of issues is an important, participatory and a two-way process that allows designers to make better informed decisions. For hazardous designs, this is a very important decision if successful choices allow the designer to break the cycle of leaving it to others to rectify mistakes. The designer's knowledge of risk and their perceptions of risk, described by Slovic et al (1982), probably reside towards the expert-end of an expert-layman knowledge continuum on risk. This status implies that the designer should have a greater appreciation of the threat posed by most, if not all, of the inherent aspects of the designs they are executing. Slovic et al, (1982) has illustrated that the risk construct appears to generate many different attitudes towards risk. For example, the designers may be demonstrating unwarranted confidence in the merits of a design, by assuming that the outcomes are always going be successfully completed. It is important that these views are placed in context. According to Kates (1971) experience of past events seems to exert the most influence in persuading the designer to adopt a particular feature. In order to conduct a risk-benefit trade-off of these design features it is necessary to remove any vagueness from the design decision. This form of analysis requires the adoption of the classical positivist view of risk. Aven and Kristensen (2005) present different risk categories that may assist the designer in this process, by helping bring the assessment to a rapid conclusion.

Kristensen, Aven and Ford (2006), also point towards using a risk management approach to help resolve such issues, as it conforms to:

> 'More than just an expert analysis of risk and uncertainty' (at pg 422).

The Health and Safety Executive (HSE, 1992) expect in cases where there is significant uncertainty, that the risk treatment will be addressed within a framework that looks at the cost-benefit or cost-effectiveness of the design measures. This is in order to demonstrate that risks have been reduced to meet the 'as low as reasonably practicable' (ALARP) standard applicable to offshore designs. These results indicate that the designer needs to be thorough in the treatment of risk before any design feature is crafted as the permanent solution.

The HSE principle (HSE, 1992a) is based upon a scientific test, which is a comparison between theory and observation, in which theory is rejected if the predictions are inconsistent with observation. Schofield (1998) advocates caution, when attempting to use the results of this analysis to influence decisions taken regarding safety measures. Generally, such scrutiny tends to identify the strengths and weaknesses in the analysis method and in particular, those features over whose validity is doubtful. Therefore the designer needs to be heedful when considering the use of risky design protocols. In the light of this discussion, the selected protocol should avoid being used and thus representing a weakness in the risk assessment system.

The Kahneman and Tversky (1979) model of decision-making under risk conditions concluded that individuals tend to underestimate the outcomes that are merely probable compared to outcomes that are obtained with certainty. This tendency is called the 'Certainty Effect'. The Kahneman and Tversky's (1979) model should be the one that the designer applies to assess the adoption of a risk cautious position. The designers endeavour to achieve these sure gains may be swayed by their perception that the past design protocol represents a low risk option.

On the evidence of this study, the highly transitional nature of the offshore design sector may not appear to lend itself to the creation of an 'effective' or sustainable safety climate.

This lack of effectiveness suggests that designers may not have the relevant time and resources to help develop the 'complete' safety solution. If sufficient time were made available, within the 'typical' project schedule, to allow designers to mentally rehearse some of the design solutions and their checking routines, and then implement the necessary amendments, it may serve to improve the overall quality of the design. Good organisational safety climates tend to ensure compliance (Cox and Cheyne, 2000), whereas overlooking rules and procedures clearly creates the opportunity for risk to remain embedded in the design.

The leadership and the motivational process should tend to encourage less use of risky protocols, by expressing the consequences of risk in emotive terms, such as those contained within the traditional lagging safety indicators (Chmiel, 2005). However, sustaining a positive safety climate appears to be threatened by the short-lived nature of the designer's project contracts. This transient effect may encourage social loafing because the designers perceive that others on the project may rectify their choice of risky decision later in the design process.

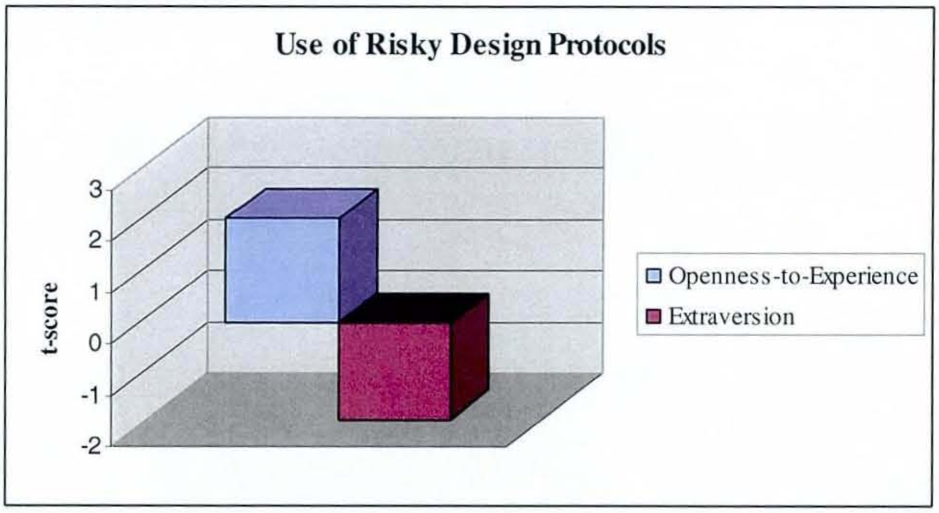
Formal checking and approval procedures are a recognised organisational standard (ISO 9001) that underpins the design process. In addition, independent technical audits are routinely conducted and the HAZOP is a prime example of a formal correction process (Lees, 1980) that is conducted on all hazardous projects.

Fewer demands, including time pressures and problem-solving demands may also reduce the overall use of risky protocols. Fewer problem-solving demands need to be applied when designers are working to the just-in-time project schedules, where the focus is more on the production of deliverables. In cases where the designer perceives the demands to be contradictory to the design logic, Busby (2001) indicates that seeking problem-solving maybe detrimental to work performance because the designer struggles to find a suitable solution. Moreover, the results indicate that the use of risky design protocols could be offset by higher levels of job autonomy ($t = -3.130$ at $p < 0.05$).

Allowing designers a greater measure of self determination and discretion in the way that they schedule their work and approach task completion may allow new and fresh solutions to be applied to difficult problems. This approach is certainly consistent with theory. Turner and Lawrence (1965), Hackman and Oldham (1975), Sims et al, (1976) have all discussed job autonomy in these terms. Since job autonomy appears to reflect the ability to independently set the work schedule and the work procedures, therefore it is important to consider providing all designers with a degree of latitude. The availability of higher levels of job autonomy will allow the designer to spend more time on devising a reasonable work schedule, that uses the full range of available procedures, and hence spend more time on addressing safety related problems.

In summary, to remove risk from the design, the designer needs to confirm that the component parts of design have been updated to minimise risk. The updating of a previous design needs to meet the designer's own expectations of what design outcome should aim to achieve. The designer needs to be sure that any fit-for-purpose design does not undermine the ALARP principle.

Figure 11.2: Personality and the Use of Risky Design Protocols



To expand on the previous line of reasoning, Figure 11.2 presents the significant relationships between personality traits and risks. For designers with personalities that are high in Openness-to-Experience ($t = 2.030$ at $p < 0.05$), the likelihood is that they would tend to adopt a risky protocol, perhaps as part of a trial and error experiment, to see if the experiment solved the particular problem. Costa and McCrae (1980) describe the openness trait as a dimension of personality that distinguishes imaginative and creative people from conventionalists.

The results also indicate that extraverted designers apply fewer risky design protocols ($t = -1.873$ at $p < 0.05$). The literature appears quite ambiguous over how the extraverted designer's may come to apply fewer risky design protocols however, Lajunen (2001) suggests that extraversion is not necessarily always to be associated with on-task mistakes because it is significantly moderated by context. Iverson and Erwin (1997) found that positive affectivity in the extravert had a significant negative correlation with such on-task incidents. Iverson and Erwin (1997) suggest that the more socially adjusted aspects of extraversion, as reported by Clarke and Robertson (2005), will tend to mitigate such involvement, which in turn is reflected in an extravert's higher desire for task engagement. Requesting information and recognising situational contingencies and using gathered data (Staw & Barsade, 1993) engages the extraverted designer in a more thoughtful and careful appraisal of the design and hence may come to limit their use of risky design methods. Dorner (2003) generally differentiates between good and bad designers, by stating that bad designers tend to avoid this form of engagement and reflective thought, as a result of being threatened by standardised rules and procedures. Arthur and Doverspike (2001) recorded that individuals low in conscientiousness exhibit the same behaviours, where failure to follow the prescribed rules was the outcome.

11.10.2 'Error'

For 'Error' the outcome appears less complex with only one significant relationship being attached to the final estimation of parameters. Kletz (2001) suggests that design errors can be reduced by selecting designers who are less error-prone (at pg 12). Notwithstanding the absence of such a hypothesised outcome, selecting designers who demonstrate high levels of conscientiousness do report fewer cognitive errors (Wallace & Chen, 2005), and therefore the outcome of this study represents an encouraging finding, where the relationship is consistent with both cognitive theory presented through cognitive failures (Wallace & Chen, 2005) and personality theory (Costa & McCrae, 1980).

Emotionally stable designers appear to commit fewer errors ($t = -3.057$ at $p < 0.05$). Emotionally stable individuals are less prone to distractions and less reactive to changes in routine situations (McCrae & Costa, 1991). The conditions giving rise to change is not exclusive to the design team and may include the relationship between the designer and the design end-user (Busby, 1998). The HSE report (2003) identified that whilst there are a number of misconceptions between designer and end user assumptions, the resulting conflict attributable to errors in design appears related to two specific on-task issues:

1. The designer's knowledge is provisional and therefore subject to doubt;
2. The failure to correct an error through the non-alignment of logic;

Another important aspect argued by Wallace and Chen (2005) that it is not uncommon for individuals in the workplace is to experience off-task behaviours that are not intended. Off-task effort has been described by Kanfer and Heggestad (1997) to consist of engaging in irrelevant thoughts that inhibit successful task performance. As a consequence designers may forget to apply important rules and procedures. One of the first steps to understanding why designers maybe prone to errors arising from off-task distractions is to assess the complex interactions that happen between the designer and various parts of the organisation (Buckle et al, 2006). Regulating the on-task demands may result in the minimisation of off-task distractions.

One of the most important predictors of safety behaviour associated with on-task demands is role overload (Hoffman et al, 1995) where the designer simply has too many tasks to complete in the time available. The evidence found in this study is that designer's with high emotional stability report fewer errors ($t = -3.057$ at $p < 0.05$). This situation can also occur when task priorities are switched by the skilful designer, so that the design logic avoids priority conflict issues. These issues are all aspects initially attached to unrealistic design schedules, which go beyond a just-in-time framework, and create the action slip that is described within Reason's (1977) notions of error. The emotionally stable designer maybe distracted into spending more time considering suitable control strategies that address role overload, rather than on actual task completion. Reason (1990) suggested that error training, whereby designers are encouraged to develop their own mental models of the system, are seen as an important instruction to help remedy some errors in design.

Wallace and Chen (2005) argue that individuals prone to experiencing cognitive failure might possess poor self-regulatory skills which allows for the occurrence of interference in dealing with intervening and concurrent stimuli. Meyer and Kieras (1997b) report considerable success in developing a production rule-based model in the psychological refractory period (PRP) procedure. The PRP paradigm reflects the basic form of information processing, where two stimuli are presented either concurrently or in very quick succession. The application of Meyer and Kieras (1997b) PRP procedure indicates that if the designer's response to the first stimuli is generally unimpaired, then cognitive failure within the second stimuli is generally assumed to be subject to error.

The implications for the design process are that designers multi-tasking within safety critical tasks may lead to errors in the safety critical tasks. The execution of safety critical tasks that are interrupted by other activities, such as reference to email motivated by the auto-preview function or a telephone conversation, may also result in errors in the safety critical tasks. Wallace and Chen (2005) conclude that cognitive error is most likely to mediate the influence of more distal motivational tendencies (c.f. Kanfer & Heggestad 1997) especially in the designer's selection of safety measures.

The next part of this chapter investigates whether the findings from the analysis of 'Risky and 'Error' have been successful in testing and explaining the hypotheses attached to this research.

Part Three

11.11 Hypothesis testing

This is one of the few empirical studies to test whether personal, organisational and cultural factors can account for certain types of behaviour in designers. In addition, there are a limited number of published studies that have directly tested the interaction between certain of the 14 emergent factors revealed in this study and aspects of a designer's risk-taking and error forming propositions. These events have been measured whilst they have been serving employees on high hazard design projects.

The analysis of interactional effects between diary data, individual designers and design teams has been completed using a three-level hierarchical linear model. This study has been able to confirm that an ESM applying a daily diary methodology and using the PDA as a recording medium, has enabled time-based data to be made interpretable. Hektner et al (2007) put forward that studies of this type should aim to use the best available tools. The methodology applied to this study has certainly achieved that particular goal through the evidence gathered from the participant's observations, the overall sample compliance rate and some of the key conclusions drawn from the analysis of this study.

In addition to discussing the longitudinal study, the examination by hypothesis also draws upon the findings from the Pearson product correlation analysis of the PCA outcomes in Section 10.11 and the two-level hierarchical linear analysis that shows the data structure of the important Cognitive Error outcome variable in Section 10.12.

The research question invited investigation into whether individual differences and other constructs account for cognitive errors and risk-taking in the design of hazardous installations. Chapter Eight set out the five principal hypotheses attached to the main research question. The factor structure of the questionnaire demonstrated a good model of fit with theory and provided high scale validity. The fourteen emergent scales were the subject of a correlational analysis and a hierarchical linear regression with 'Error' as the outcome variable. This test was in order to record the strength of the internal relationships and the structure of the data sets. Each of these scales formed part of the building blocks applied to the two hierarchical linear models. These analyses predict outcomes that have been applied in the interpretation of the hypothesis tests.

In addition, the relationships between constructs, other than those attached to the hypotheses, are also reported at the end of this section. These results illustrate some significant findings associated with the designer's job characteristics, as particularly significant predictors of risk and error.

The hierarchical linear modelling of the longitudinal data shows no support for hypotheses 1a, 1c, and 1e. However, the use of risky protocols and error has been shown to be associated with certain personality traits. Emotional stability predicts fewer errors, supporting hypothesis 1b. Openness-to-Experience predicts the increased use of risky protocols, supporting hypothesis 1d. The results indicate that extraversion appears significant in predicting fewer risky protocols. This relationship was not hypothesised.

Table 11.1 summarises the hypothesis tests and Sections 11.11.1 to 11.11.6 describes the hypothesised test in detail and Section 11.11.7 the non-hypothesised outcomes

Table 11.1: Summary of Hypothesis testing outcomes

Hypothesis Testing		HLM Test method		Outcome
	Narrative	2-level results	3-level results	
1a	Designers with high levels of extraversion should report higher levels of risky protocols		See Table 10.13 to 10.16	The relationship described by hypothesis 1a was not supported.
1b	Designers reporting low levels of emotional stability are more likely to report cognitive errors.	See Table 10.09 to 10.10	See Table 10 13 to 10 16	Hypothesis 1b is supported
1c	Designers reporting low levels of agreeableness are more likely to report cognitive errors.	See Table 10 09 to 10 10	See Table 10.13 to 10.16	The relationship described by hypothesis 1c was not supported.

Table 11.1: Summary of Hypothesis testing outcomes (Continued)

Hypothesis Testing		HLM Test method		Outcome
	Narrative	2-level results	3-level results	
1d	Designers reporting high levels of openness are more likely to use risky protocols		See Table 10.13 to 10 16	The relationship described by hypothesis 1d was not supported.
1e	Designers who possess high levels of conscientiousness are less likely to commit cognitive errors and use less risky protocols	See Table 10.09 to 10.10	See Table 10.13 to 10.16	The relationship described by hypothesis 1e was not supported.

11.11.1 Hypothesis 1a) states: Designers with high levels of extraversion should report higher levels of risky protocols.

There was no support for this hypothesis. In fact, the results of fixed effects from HLM6 indicate that extraverted designers should be applying fewer risky design protocols rather than adopting more risky protocols. In a safety critical environment, such as the offshore oil and gas sector, an important goal should be to avoid risk. The avoidance of risk goal maybe linked to what Higgins (1997) described as a regulatory focus which discusses the critical characteristic of self-regulation and its attempt to reduce discrepancies between the current states and the desired end state. For designers, the current state can be interpreted to mean a state achieved through the application of their 'design logic', whereas the desired end-state reflects upon the end user's expectations of an error free or *clean* design.

There is no support within the two-level hierarchical linear analysis or the correlations matrix for hypothesis 1a.

11.11.2 Hypothesis 1b) states: Designers reporting low levels of emotional stability are more likely to report cognitive errors.

The HLM6 results for 'Error' indicate a significant relationship between the personality trait, Emotional Stability and errors which supports hypothesis 1b. Emotionally stable individuals appear less prone to distractibility and less reactive to changes in routine situations (McCrae & Costa, 1991). In other cases, Kanfer and Heggestad (1997) describe individuals low in emotional stability may lack of on-task effort as being swayed by off-task distractions. Designers who engage in irrelevant thoughts tend to find that it inhibits successful on-task performance. As a consequence designers may forget to apply important rules and procedures.

Emotionally stable designers do not appear to be prone to errors arising from off-task distractions to the same degree, as they appear more accomplished at regulating the complex interactions that occur between tasks, whether they are on-task or off-task, other designers and different teams (Buckle et al, 2006). Also regulating the on-task demands may result in the minimisation of off-task distractions, thereby allowing the emotionally stable designer to retain a higher level of task focus. Hofmann, Jacobs and Landy (1995) suggest that role overload, where the designer simply has too many tasks to complete in the time available, may be a factor in achieving safer designs and that the emotionally stable designer benefits from being able to retain the on-task focus.

The two-level hierarchical linear analysis also supports hypothesis 1b where emotional stability predicts fewer errors. The Correlations matrix shows a significant relationship between Emotional Stability and Cognitive Error, supporting hypothesis 1b.

11.11.3 Hypothesis 1c) states: Designers reporting low levels of agreeableness are more likely to report cognitive errors.

There was no support for this hypothesis. Whilst Barrick and Mount (1991) postulated that a positive relationship should occur between this personality trait and error, because of the agreeable designer's greater distractibility (c.f. Arthur & Graziano, 1996), this was not demonstrated in the results of the designer sample.

The two-level hierarchical linear analysis and the correlations matrix similarly show no significant effect between agreeableness and cognitive error.

11.11.4 Hypothesis 1d) states: Designers reporting high levels of openness are more likely to use risky protocols.

The HLM6 results for 'Risky' indicate a significant relationship between the personality trait Openness-to-Experience and errors which support hypothesis 1d. The results indicate that as levels of openness increases then so does the designer use of risky design protocols. The literature (Costa & McCrae, 1980; 1991) indicates that designers with this personality trait may retain a wider interest view of the project, which gives these designers the ability to see the *'bigger project picture'*. It may also make these designers' more prone to being poor risk decision-makers. Bandura (1997) suggests that whilst a cause of increased openness maybe through further education, which directly increases the skill and knowledge of the designer, but it may not necessarily increase their safety focus. A curious aspect of this finding is that the designer who has naturally high levels of openness maybe more liable to rule violations, experimentation and improvisation (Costa and McCrae, 1980).

11.11.5 Hypothesis 1e) states: Designers who possess high levels of conscientiousness are less likely to commit cognitive errors and use less risky protocols.

There was no support for this hypothesis in the longitudinal study. The HLM6 results indicate that there is no relationship between the personality trait, conscientiousness in error and the use of risky design protocols. However, the findings from other studies do support the hypothetical relationship stated in this thesis (see Arthur & Graziano, 1996; Cellar, Nelson, York & Bauer, 2001; Wallace & Chen, 2005).

Higgins (1997) suggests that individuals in a vigilant state and with a prevention focus would want to avoid errors and reduce the likelihood of mistakes being made. This contrasts with those individuals in a promotional state, where alternative criteria could be selected to complete tasks. The lack of a relationship in the longitudinal study does not imply that the measure of conscientiousness is absent from the designer population sampled in this study, just that it not significant over repeated events and over time.

The two-level hierarchical linear analysis indicates that conscientiousness has significant effects and the correlation matrix indicates a significant relationship with cognitive error supporting hypothesis 1e.

11.12 Non-hypothesised findings

Table 11.2: Summary of non-hypothesised outcomes

Non-Hypothesised outcomes	3-level HLM Test method
1. Higher levels of risk perception are related to the greater use of risky protocols	See Table 10.13 to 10 16
2. Individual safety climate scores suggest designers are inclined to take risks	See Table 10 13 to 10.16
3. Aggregated safety climate scores suggest design teams take less risks	See Table 10.13 to 10.16
4. Designers with increased levels of job autonomy are likely to use less risky protocols	See Table 10.13 to 10 16

In examining the variable of Risk Perception there appears to be no specific relationships attached to cognitive error in either the two-level or three-level models. However, higher levels of risk perception were related to more use of risky design protocols in the longitudinal three-level model. These actual differences in risk perception over time suggests that the designers' who have heightened levels of openness may be developing and applying mental models of risk to adjust the designs as they progress them through to detailing (suggested by Starr, 1969). The actual degree of adjustment in the designers risk perception is difficult to assess however, it maybe that they are exhibiting certain risk preferences in the selection of risky protocols which they propose to use. Designers in this mode might be confident that either other members of the team or the independent HAZOP chair will identify and correct any aspect of their design which does not conform to the applicable design standards or the risk model applied to satisfy legislation.

This thesis has discussed how individual perceptions of risk may adjust the technological measures that are applied to designs by the offshore designers. This process eventually comes to decide whether the risk-benefit trade-off (Vrijling, van Hengel & Houben, 1998) is acceptable to society, to the end-user and of course, the designer's themselves by applying the ALARP principle to their designs (HSE, 1992; Schofield, 1998). The safety climate findings suggest that at an individual level designers take risks. The 1997 Step Change program treated design in a similar vein to the end-users' environment where accidents happen on the front-line. Technology selection was seen as an effective way of making the designers and the design teams more responsible for certain aspects of safety in design. The leadership and the motivational process, that support the design teams should be one that tends to encourage less risky designs, expressing the consequences of the risk choices that the designer's make in fairly emotive terms (Chmiel, 2005).

The safety climate findings at the aggregated team level imply that design teams take fewer risks. These findings carry significant policy implications because of the contradiction that may exist, not only between the individual and the team, but also within the organisations, where less risk-taking is advocated, but where significant time pressure issues are also exerted. These aspects are discussed in the next chapter in Section 12.3. The designer's job characteristics carry practical implications in how risk and errors maybe reduced. The findings of the longitudinal study are reported in Part Two and the majority of the results indicate that safe working would benefit from greater freedoms. Improving the designer's job autonomy implies less subsequent error and fewer risky decisions. This safety awareness could be promoted at an individual level by the safety climate (Cox & Cheyne, 2000).

For designers, the regulatory focus should be a state of vigilance that avoids mismatches between the design and end user's logic and should be viewed as one that also aims to avoid risk. Such a prevention focus is of particular interest to the oil and gas sector with the Step Change (1997) programs emphasis on protection, safety and individual responsibility. Crowe and Higgins (1997) found that those in a promotion-focus condition, in other words those individuals seeking achievement in their work tasks, had a tendency to adopt a risky bias. For designers this could be interpreted to represent an agreement to meet the just-in-time deadlines, whilst they are persisting with difficult tasks, which to the external observer may appear overly optimistic. Whereas, those designers with a prevention-focus would be expected to adopt a more conservative position before agreeing to any project schedule that was considered to be unrealistic. Higgins (1997) suggests that individuals in a vigilant state and with prevention focus would also want to avoid errors. However, Higgins suggests that designers in this state maybe more likely to retain or repeat past successes such as the protocol "In the past hour have you applied solutions that have worked well in the past" in order to achieve this goal. However, the adoption of past designs should be treated with caution.

In contrast, those designers in a promotional state, where alternative strategies maybe applied in order to complete tasks, maybe more prone to more error. These differences in strategic tendencies reflect the regulatory differences in the approach adopted by individual designers. It also creates the opportunity for the hazardous projects to adopt less risky designs if a prevention focus is adopted because it removes the potentially contradictory requirements placed between the design and end-user logic. The difference between the promotion focus and the prevention focus, in strategic terms, has direct implications for the reasons why certain decisions are taken by designers. The promotional state should invoke a desire to make fewer errors of omission but in so doing creates a potentially risky bias.

The HLM6 results indicate that there is no significant relationship between the social cultures of *Group Culture* and *Chance* and error and the use of risky design protocols. The longitudinal examination of the designer's socio-cultural influences does not appear to affect their attitude to risk. This result supports the conclusions of other work in this area, in particular Sjoberg (1997). The absence of any relationship between the social cultures and error and risk in this longitudinal study does not reflect upon any theoretical reasoning that would suggest such beliefs may be grounded in social reality (HSE, 2002). However, it is hard to argue against Sjoberg's (1997) assertion, on the basis of this evidence that:

> "Cultural biases are not a major factor in risk perception but just a very minor contribution" (at pg 126).

The correlations matrix (see Table 10.8) does show that cognitive error is positively related to the social culture *Chance* indicating that fatalistic views, carry increased significance in some designers (see Smallman, 1998). However, in the two-level hierarchical linear regression, this relationship was not significant and *Group Culture* became a significant predictor of cognitive error. While these results may emerge because of shared correlations with other variables in the regression analysis, the lack of a clear picture indicates, that, on balance Sjoberg's (1997) assertion appears to be correct.

11.13 Summary

This chapter has discussed the partial support for the tests by way of hypothesis. The next chapter, Chapter Twelve, brings the thesis to a close and in so doing elaborates on some of the important methodological implications of this work

Chapter Twelve

Conclusions

12.1 Overview

The final chapter draws the thesis to a conclusion. This chapter is presented in three parts. The first part, following its introduction, addresses the significant contributions made by this study to the understanding of risk and errors in the design of offshore installations. The second part considers the practical implications attached to this work. The third part addresses the limitations of this study.

12.2 Introduction

The industrial sector that participated in this organisational study involved the energy sector and in particular, the high hazard nuclear and the offshore oil and gas industry. In the Main Study three organisations granted access to 55 design teams and 167 designers. The aim of the research has been to assess whether the designer can influence the end users' safety performance. The inference drawn from the work by Kinnersley and Roelen (2007) is that 15 years after Reason (1990) published his error model that accidents are still having some of their root causes embedded in the design process.

Part One

12.3 The contribution made by this work

The contribution made by this exploratory work has been its ability to disclose the predictive from the non-predictive affects associated with a designer's perception of risk and cognitive error. The Health and Safety Executive place great importance on reducing accidents and in particular, the human error element that this phenomenon makes to accident statistics and safety performance (HSG 48). The contribution made by this study is therefore important.

This study presents opportunities to change the relationship between design and accidents by providing an exploratory account into some of the possible conditions which are conducive to design error and risk. These findings permit further theory development because of the specific antecedents that have been revealed in this study.

This research has been conducted using an electronic means of sampling designer's experiences in order to capture data as close as possible to the design events. This data included the designer's self-reporting of cognitive error and their use of risky design protocols. As with other experience sampling methodologies, it was important that this extension of the ESM into a new environment retained internal, construct and external validity and these aspects are presented in Part Three of this chapter. The chapter closes by emphasising the importance of this work, discusses the limitations of the study and opens up areas for future work.

The thesis proposed two forms of error that satisfied the criteria of a design contribution affecting safety performance. Chapter One described these error types as errors of omission (Reason, 1990) and errors of commission (Sanders & McCormick, 1993; Higgins, 1997) and related them to risky protocols. Chapter One also examined the design process in detail (Simon et al, 1997), and in particular, the approach taken by Drogoul et al, (2007), the European Transport Safety Council (in report 2003), The Health and Safety Executive and Kinnersley and Roelen (2007) in addressing risk management techniques in design. The thesis suggested certain heuristics (Kahneman et al, 1982; Busby & Payne, 1998) which might be contributory to errors and mistakes reported in the design process.

Exploring the attributions of individual differences and the reported levels of cognitive errors associated with certain personality types (e.g. Wallace & Chen, 2005) emerged as attractive candidates for explaining why human design error, may exist in high hazard designs. Understanding the relationship between individual differences and personality measures such as cognitive error appears, in this case, to influence a designer's inability to accurately deal with design tasks. Mecklebach, Muris, Nijan and De Jong (1996) identified that individual differences in cognitive error were often associated with memory dysfunction. It appears that designers who are perhaps dealing with too much information may actually be more predictive of cognitive errors. This in turn appears to lead to more design mistakes and a resultant embedded risk. Given that the three cognitive error dimensions introduced on page 23 included off-task processes (memory, attention and perception) designers with certain personalities maybe more likely to predict certain outcomes such as the design errors that are fully described in Chapter Two. The thesis investigated the interplay between key design heuristics outlined by Busby and Payne (1988), Kahnemann et al (1982) and Tversky and Kahnemann (1973) such as recalling past designs and the design processes achievement of ALARP and their use was measured.

Part Two

12.4 Overview

There is a degree of overlap between the policy and practical implications associated with this study. In order to try and divorce the practical from the policy, this section of the chapter has endeavoured to address the practical issues in the following manner. Firstly, by recognising that the outcome variables of 'Risky' and 'Error' within the study sample population are sustained by different relationships and therefore need different approaches for improvement.

12.5 Practical implications

This study has made a contribution to understanding the intrinsic relationships between the designer, risk and design errors. To satisfy Reason's (1990) model this process relied upon design methods that recognised the presence of these error types in the design of offshore installations. This trial is traditionally conferred in a HAZID and/or HAZOP (Kletz, 1988) or by using some other similar investigative technique. In Chapter One, Tversky and Kahnemann (1974) suggest the availability heuristic may be more frequently used, but the researcher found that the use of the process heuristic to be the one more frequently applied.

This study experienced a high turnover of designers that has arisen due to the high demand for skilled and experienced designers and the transient nature of the design work. The limited pool of resources appears to have forced design organisations to look towards other industrial sectors to satisfy their resource needs. The oil and gas sector is particularly guilty of recruiting engineers from other industrial sectors without addressing some of the attritional effects associated with the offshore design schedules and its knock-on effect onto the climate for a safe design. Drafting-in engineers and designers from other sectors has, to a degree maintained a good level of safety through the organisational safety climate measure, but at an individual level this study has shown that this competency is not being matched. There is evidence of negative personal attitudes towards safety having been recorded in this study. To achieve a safe design, especially where the matching of skills and demands (Caplan et al, 1964) have been demonstrated in this study to result in fewer errors, indicates the importance of on-going training, even the error training proposed by Reason (1990).

In practical terms, addressing what the solutions need to be reflects heavily upon the content of the first chapter, where several aspects of design were considered. Chapter Two on error and Chapter Four where risk and risk perception was addressed have also revealed potential solutions. The following passages consider the solutions based upon the results of this study and how they might be introduced.

Table 12.1: The Design solutions to using risky protocols

Risk	Narrative	Design solution
Use of risky design protocol 1	In the past hour have you made assumptions about missing pieces of data	The results indicate that designers with high levels of openness-to-experience may be more prone to the use of risky design protocols Bandura (1997) suggests that increases in the skill and knowledge levels of the designer it may not necessarily increase their safety focus Higgins (1997) indicates that designers in a vigilant state and with prevention focus should avoid errors However, Higgins suggests that designers in this state maybe more likely to retain or repeat past successes in order to achieve their particular design goal The adoption of past designs should be treated with caution Designers in a promotional state, where alternative strategies maybe applied in order this design goal maybe more prone to more error These differences in strategic tendencies reflect regulatory differences in the approach adopted by individual designers. These circumstances create the opportunity for the hazardous projects to adopt less risky designs, if a prevention focus is adopted because it removes the contradictory requirements between the design and end-user logic
Use of risky design protocol 2	In the past hour have you reused a previous design that has not been updated	
Use of risky design protocol 3	In the past hour have you applied solutions that have worked well in the past	
Use of risky design protocol 4	In the past hour have you added a design feature fit-for-purpose but others need to decide if it's correct	

Table 12.2: The Design solutions to the different error types

Error types	Narrative	Design solution
Errors of Omission Reason (1979,1990)	This error represents the omission of a design feature that would normally be expected to be incorporated. The design requirements are embodied in industry codes and standards This form of error can occur when an assumption is incorporated in a design and the designer fails to attach an essential facet of the assumption The initial missing piece of data requiring the assumption is necessary for the design to be considered 'complete'.	The traditional correction strategy for the error of omission is through the checking and approvals process In addition, the HAZOP can make recommendations regarding the suitability of the assumptions that have been made The findings from this study indicate that the conscientious and emotionally stable designer is less prone to errors. Therefore in the absence of further recommendations the psychometric properties of the checker and approver of designs should possess these characteristics Also management having a greater appreciation that the designer's knowledge is provisional and therefore subject to doubt (HSE, 2002) and that this should be used to make design schedules more realistic
Errors of Commission Sanders & McCormick, (1993), Higgins (1997)	The incorporation of a design feature that is deemed to be fit-for-purpose but unproven in the new envisaged application The designer reuses the previous design that has not been updated to the new application with a strategy of achievement This usage requires others to check for industry code and standards compliance	The strict adoption of past designs and that should be treated with caution Key to this process is providing the designers with "Feedback" on those designs so that designs can be updated and the designers can then judge their suitability in anew application

Table 12.2: The Design solutions to the different error types (Continued)

<table>
<tr><td rowspan="2">Sub groups of Errors of Commission category</td><td colspan="3">Sub groupings</td></tr>
<tr><td>Errors of Repetition
Busby & Payne (1998)</td><td>A previously successful design feature transposed inaccurately. This error form can occur due to the poor exploitation of a designer's skills during periods of under employment and more probably in time-pressure situations</td><td>This situation occurs when the design logic avoids internal conflicts. These issues are all aspects attached to unrealistic design schedules, which go beyond a just-in-time framework, and create the action slip that is described within Reason's (1977) notions of error. Reason (1990) suggested that error training maybe an important instruction to help remedy some errors in design However, a more realistic solution is tackling the reality of the just-in-time schedule to avoid repetitious errors.</td></tr>
</table>

Table 12.2: The Design solutions to the different error types (Continued)

Sub groups of Errors of Commission category	**Errors of Transmission** Kirwan, (1994)	A design feature added by the designer where the end user needs to be heedful of the risk contained in the design. The risk maybe attached to an assumption made by the designer. This form of assumption refers to how equipment will be fabricated and operated The risk involves incorrect or incomplete interpretation of a design feature. It may include an added design feature that represents a fit-for-purpose solution but where the interpretation is made others who need to decide whether it is correct in the particular application.	Daniels (1996) indicates that risk communication is an important process that allows designers to make better informed decisions. Key to this process is "Feedback" to designers
	Errors of Substitution Hollnagel, (1993)	A design feature that is proven but in this case is used in a new way. Applying solutions that are inappropriate but which have worked well in the past also fall within the substitution category	Designers understanding when it is appropriate to use past design solutions is a key deliverable of "Feedback" Rarely are repeat designs an exact replica of the prototype and whilst the prototype may serve as a test bed for a design, the designer needs to be conscious of the limitations associated with directly substituting a past design into a current design

Knowledge and in particular feedback to enhance a designers knowledge, appears fundamental to the removal of any ambiguity in how the designer approaches task execution in the future. This approach has the benefit of avoiding the use of risky protocols, when only elemental data is available. This process relates to the way that designer's can minimise the need for 'holds' to be placed on designs. It is acknowledged that there is less significance on project performance in the early stages of a design, compared to product performance in the latter stages (Simon et al, 1997). This aspect increases in significance as the design progresses through the different stages of the design process and should never be overlooked. These circumstances arise because of the fixed design timetables attached to product delivery. This is compounded by the time pressure issue associated with the just-in-time-schedule.

Many of these same types of issue, in particular those surrounding design ambiguities, emerge at the end of field life when the final decommissioning and disposal stages are being undertaken. This concern relates to risks that have not been considered in the design of the de-construction work (Simon et al, 1997). These risks occur because the designer is forced to make assumptions about how to dismantle the installation, which is not necessarily the reverse of the installation method (Decommissioning Technology Forum, 2005).

12.5.1: Feedback to designers

Campion and Lord (1982) commented that error correction should be the only purpose of feedback. The lack of feedback almost guarantees the reappearance of the same design mistakes. From a practical point of view, these conclusions depend upon improving the methods of design feedback. There is little or no benefit to be gained by attempting to change the designer's attitude towards task execution (Staw & Boettger, 1990) without improving certain tools of the trade. Features such as job specifications, greater role clarity, job autonomy and matching skills and demands are all important. Developing new rules and design procedures to address improving design safety compliance are highly relevant.

Busby (1999) outlined why feedback, as an error-correcting function was so critical to engineering designers. The responsibility for delivering this feedback rests with the design organisations and is critical for several reasons. High reliability and normal accident views presented Sagan (1993) with a number of theoretical contradictions that are discussed in Chapter One. Sagan (1993) proposed that explicit in the normal accident accounts was a process that undermined the rationality of the so called safer institutional designs, such as those found in the oil and gas and nuclear designs. However, according to Sagan (1993) these safer designs were being undermined through procedures that were poorly structured and unduly complex. Sagan (1993) challenged whether feedback and organisational learning was ever likely to be a feasible design goal in practice and one that allowed designers to correct and learn from their mistakes.

Feedback will come to prevent a future outbreak of designs repeating known mistakes. Feedback must therefore restrict the use of these designs because they have been shown to be faulty. Furthermore, feedback provides engineers and designers with a good learning opportunity that helps the design organisations promote better design practices. The development of new rules and design procedures to address improving design safety should also come from such a process. Feedback is especially important, provided the diagnostics are correct, when the outcome of the product is seen as unpredictable. The design of an offshore installation is not unpredictable *per se* however, there are aspects associated with the design, such as the ALARP demonstration process, which creates an aura for the unexpected.

These unexpected cases are classes of uncertainty that need to be considered in any evaluation of risk. Generally, the unexpected does not relate to risk where the direct effects are predicted with a known probability of occurrence. However, where the effects are imaginable or partially describable, or where both probability and consequences are unknown, it is understandable why the ALARP process is treated in such a way.

The potential impact of these circumstances is that design mistakes create the latent hazards referred to by Reason (1990) that turn out to be detrimental to safety performance (HSE, 2006). Therefore, one of the major practical applications of this research relates to this aspect of the risk management process. This process was described at the very beginning of this thesis in work presented by Simon et al, (1997) and Drogoul et al, (2007). In particular, the risk management methods need to address hazard identification in order to capture the error forms described by Reason (1990) and Sanders and McCormick (1993), risk analysis (Lees, 1980) and HSE (1992), and risk transfer and risk communication illustrated in Bostrum et al, (1994) and discussed by Daniels (1996).

One of the practical implications attached to this research is in personnel selection to safety critical roles as Kletz (2001) has suggested by advocating the selection of designers who were less error prone. Invariably, the satisfaction of checking and compliance with regulatory standards rests with one or two key individuals on a hazardous project. The application of personality profiling is not an unknown practice (Harvey, Murry and Markham, 1995). An extension of this practice to a design environment would serve to widen its benefit to the energy sector. By using such methods, not only can the interventions attached to checking and compliance be better focussed, by employing the right individual but a more sophisticated approach can be developed for other key project roles. This technique even has an application in the role performed by independent HAZOP chairmen.

Part Three

12.6 Limitations

Part Three addresses the limitations associated with this study.

12.6.1 Limitations of the Interview Content analysis

The interview content analysis method that informed on error types presupposed that the participants understood the questions and the context in which they were being asked. The findings from the Content Analysis were then used to develop aspects of the Pilot Study and Main Study questionnaire and verify the error types[18] and risky protocols used in the diary study. This process was able to confirm that there are no unexpected or uncovered issues arising from the design process detailed in Table 1.2.

12.6.2 Experience Sampling Methodological implications

Reis and Gable (2000) considered that a significant time burden would arise from using such an experience sampling methodology, purely as a result of administering the PDA. This expectation had also been affirmed by Ferguson (2005). The enrolment procedure was relatively straightforward and the amount of researcher's time needed in supporting the participants was very low. In so far as this study is concerned, the experiences gained suggest that Reis and Gable (2000) and Ferguson (2005) adopted unduly pessimistic positions. However, this study did rely upon certain practical safeguards being followed in order to avoid excessive time involvement.

[18] These error types relate to those discussed in Table 2.1 'Error Types and Error Forms'.

Ensuring that this study overcame the twin hurdles of reliability and compliance was crucial to this form of methodology in order to obtain robust results. The key to using the PDA, as the recording medium in this form of ESM, was that the selected hardware needed to be durable and the software non-corruptible. From a participants' perspective reliability meant that a PDA time-interval request for a response occurred when it was supposed to occur. The PDAs were programmed to alarm four times a day and five days a week. It was recognised, at an early stage (Loughborough University in-house testing) how important it was that the handsets were not going to create the circumstances that resulted in the participants losing confidence in the outcome of the study because the PDAs were faulty. The researcher had to affect less than ten remote resets during the 24 week field study period. These resets were as a result of participants PDA's not performing as intended and from some of the ergonomic issues alluded to in the following passages, such as designers 'fiddling' with the PDA.

The researcher shares the view about retaining confident expectations in the results, since the aim of the study was to gather the designers' experiences in situ. The in-situ observations were obtained as close as possible to the events being measured, and as unobtrusively as possible. The high reliability attached to this study was achieved, in part, by adopting a methodology, albeit at a much larger scale than had been attempted before this study, using extensive internal testing by a team of researchers at Loughborough University (Daniels, Hartley & Travers 2006; Glover, Boocock, Daniels & Holland 2006).

The researcher attended the host organisation on three of the five days during the Pilot Study trial period in order to enhance the compliance rate. This approach absorbed some of the time burden described by Reis and Gable (2000) and Ferguson (2005). A lesson learnt from the Pilot Study, that ultimately benefited the Main Study, was the adjustment of the volume on the PDA trigger alarm. The design office environments, at both the Pilot Study and Main Study locations, were open-plan. The setting of the PDA alarm took a sympathetic account of the proximity of non-participants to the study.

However, the study also revealed a number of other shortcomings that need to be acknowledged. These carry methodological, as well as practical implications for the adoption of a daily diary based methodology, using the PDA in any future ESM. These concerns relate to certain internal and external validity issues and are discussed in Section 12.6.6 and 12.6.7.

12.6.3 Limitations in the Questionnaire item development

The primary goal of the questionnaire was to create a valid measure of the underlying constructs under investigation. For two constructs, where this measure of validity did not already exist, this required new item development. Nevertheless the new item development was underpinned by strong theoretical reasoning. Theory indicates that dread and unfamiliarity (Slovic et al, 1982) are significant aspects of risk. However, the designers that were sampled appear to consider both of these constructs as highly similar. This aspect could be considered to be a limitation for the study because the seven emergent items were summed and divided by seven to produce a single new scale value rather than two scales. However, as in the case of the social culture construct any reasoning in the conclusions needed to be supported by some pragmatic decisions about how to deal with any new scaling situations. It was essential to start this process with a clear conceptualisation of what was expected from the constructs. Moreover the item wording needed careful attention (see Clark & Watson, 1995) in order to develop a way of measuring the hypothetical constructs of risk perception and social culture e.g. individualism, egalitarianism, hierarchism and fatalism suggested by theory (Douglas, 1990). It is therefore appropriate to issue a cautionary note regarding some of these question items. Some items appear a little ambiguous especially the social cultures items, and are sufficiently broad so as to usable in more than one category, e.g. Q13: "Designers don't need to account for all risks." This ambiguity is potentially a shortcoming of this scale.

The social culture questions were set on an 8-point Likert scaling and asymmetric around point three. Loevinger (1957) argued that the assumption of equal-interval scaling is often not justified. The adopted scale for the social cultures does not oblige the participants to fall on one side of the fence or the other. However, increasing the number of alternatives from the chosen mid-point towards the 'completely true' end of the scale may actually have reduced the scale validity. This would be so if the participants were unable to make sense of the subtle distinctions that were intended by the researcher.

Any understanding of the items is clearly a personal evaluation of each question based on the participant's own terms and values. By way of example, the designers may have a better understanding of the fatalistic questions contained in Section Four of the questionnaire 'Your Attitudes to Work' because they could relate to them more readily. In addition, some questions were reversed in order to obtain a better balance of positively and negatively phrased items. The phrasing of the questions may have caused some confusion amongst some of the participants. A pre-test of these questions was conducted in the Pilot Study to assess the quality of the items and changes were subsequently made. No hypothesis was attached to the social cultures.

12.6.4 Limitations of the Pilot Study

It is important to recognise the potential shortcomings from an assessment restricted by the number of participants over a single week of data gathering. However, an important aspect for the Pilot Study was to assess the organisational context in which this study was conducted and under which the Main Study might be conducted. For the Pilot Study the design teams were distributed between two design centres, n = 12 and n = 21. Thirty-one participants provided data for the whole study period. The design teams were involved in a new build design for de-commissioning part of an existing UK nuclear facility. This context provided a strong anchoring position for the Main Study. The questionnaires and PDAs were tested on a heterogeneous sample representing the entire range of the Main Study target population.

12.6.5 Limitations of the exploratory factor analysis in the Main Study

The decision heuristics proposed for the exploratory factor analysis was designed to retain the maximum breadth of sampled variables, whilst recognising the possibility for creating spurious results.

12.6.6 Internal Validity

The internal validity of the ESM has been determined by the selected analysis method, which for this study was HLM. There were also some assumptions applied during the HLM analysis. Firstly, the aim of the HLM analysis has been not to waste any of the information gathered in the ESM and then secondly, not to distort any of the subsequent interpretations. The exploratory nature of this research provided a momentary insight into the decisions that were taken by designers. This data was recorded at fixed points in time. Momentary recording has in the past raised some concerns over the stability of such data. However, the selected daily diary method provided high internal validity because it required significantly less reliance on retrospective recall, thereby accurately capturing these variations in the variables over time (Reis & Gable, 2000). For this reason the exploratory research created the opportunity to examine the important outcomes concerning error and risk-taking. This has greatly assisted the interpretation of some of the causal reasoning attached to the outcomes.

The slopes of the scatter-plot 'best-fit' lines and the statistical error terms (see 9.9.2.1) were assumed to be represented by a series of straight lines. However the real data that was gathered does not lie exactly on a straight line. Therefore the error term r_i expressed in the generic equation $y = \beta_0 + r_i$ needs careful consideration. It was reasonable to assume that the clustering of points on any of the scatter plots for participants that were in the same design disciplines, may 'vanish' into the error term because their choices were not being observed and recorded. In addition, some design disciplines maybe more homogeneous than other disciplines. This assumption means that the degrees of variance between individuals may not be as different if they share the same values when taking similar design decisions.

There have also been a number of assumptions made about the composition of the design teams (groups) in this study. However, apart from the safety climate dimension no group effects have been measured. Therefore there could have been other group effects that could be important e.g. cohesion. This utility could be significant if the outcomes were to be re-applied more generally. However, these results are specific to the oil and gas offshore design sector and different issues might need to be addressed in studying other high hazard sectors.

There have been a number of conventional problems that this ESM study has had to address. These carried positive as well as negative implications for this study. Firstly, the methodology investigated the hypothetical use of some very specific design protocols. These protocols were phrased in unambiguous terms so as to be immediately recognisable to the designers. However, it is conceivable that junior members of the design teams may not have been familiar with these terminologies, their source terms and their use.

The study of these everyday methods was tracked using the selected interval-contingent trigger method. Firstly, this method safeguarded the study from significant retrospective bias because the designers were assumed to be applying the very specific design protocols, on whatever design they were engaged in producing, during every working day of the trial. The PDA frequency statistics presented Table 10.11 for the four Risky design protocols support this presumption. In fact, the Use of Risky Protocol 3 was positively reported in nearly 45% of all interval-contingent requests. Conversely this may suggest either a degree of reflexivity (Kubrey, Larson & Csikszentimihalyi, 1996) otherwise known as the act of self-reference induced by the involvement in the study, or in brief the circular relationship between cause and effect, reactivity (Vuchinich, Tucker & Harlee, 1988) and memorability or the response to the PDA described by Reis and Gable (2000).

The other dependent variable, 'Risky', that was examined in this study related to Cognitive Error ('Error'). The PDA frequency statistics in Table 10.12 show that from the three Cognitive Error questions, off-task distraction was the most frequently recorded form of error. Off-task distraction was reported at almost twice the rate of the action and memory lapses. This outcome could have been induced by the PDAs.

Secondly, the daily diary study was completed in four waves. In the analysis section of Chapter Ten (10.13.3) a temporal effect was noted. The analysis indicated more errors in the first wave than in the remaining three waves. Affleck et al (1999) suggest that this affect may correspond to the novelty attached to involvement in an ESM such as this study. It also engages in the criticality associated with temporal order data collection described by Ferguson (2005).

No such temporal phenomenon occurred in measuring 'Risky' protocols in the first wave of trials however, a bias is reported in the use of risky protocols in waves two and three. These effects in waves two and three maybe systematic biases introduced by repeatedly assessing the use of same variables. These circumstances could have artificially created a similar time pressure situation to the one that was causing the designers to adopt the risky protocols in the first place.

Thirdly, over the completion of the four waves the number of participants progressively dropped off through absence, refusal to participate and the projects closing down before the ESM could complete all four trials. In Section 9.7.4 some of the attritional issues attached to an ESM have already been described (Hektner et al, 2007). The loss of data through the refusal of designers to participate undoubtedly affected the overall compliance rate of 63%. The numbers of participants, where data was deleted, involved 26 designers out of the original study population of 167.

However, the overall number of observations that were affected by the removal of this data from these 26 designers was comparatively small. The number of raw observations reduced from 6080 from the 167 participants, to an adjusted data set of 5816 observations from the remaining141 participants. The 5816 observations helped preserve the statistical validity of the HLM analysis. The results are considered robust due to the extent that the fraction of missing data was comparatively small at < 10% and the data was efficiently used in the HLM model.

According to Reis and Gable (2000) an ESM that adopts an interval-contingent recording methodology should use regularly defined intervals. The intervals prescribed for this study were two hourly intervals, adopted between 10.00 am, 12.00 am, and 2.00 pm and just before the end of the working day at 4.00 pm. Generally, after distributing the PDA's on day one of the weekly trial, the researcher stayed on the premises where the hazardous project was being engineered. The researcher attended at least the first two requests for data, and usually for all four on day one. This was done to make sure all the PDA's were performing as intended at the start of the trial.

The researcher was on site early on day five to collect the PDAs, and to receive feedback from the participants. The absence of the researcher during the middle period of the week created the opportunity for the participants to be perhaps, less vigilant, than they might have otherwise have been had the researcher been permanently present on-site. The opportunity for the participants to falsify or fake their responses cannot be ruled out. Even with the researcher present on-site, the disposition of the participants across a project that occupied more than one floor in a project office, made ensuring any better level of compliance than the rate achieved was going to be difficult.

The PDAs turned out to be very reliable, both in terms of hardware (battery life and handset robustness) and software (question sets and operator interface). The procedure for uploading the stored data on the PDAs was very simple.

The attritional effects need to be recorded for any future research using this form of diary methodology. The selected method needs to consider how best to retain participant numbers. Retaining participants could be achieved through some form of incentive scheme, by making fewer interventions within one organisation, at the expense of enrolling more organisations, or by increasing the number of researchers present at the host organisation. This final aspect, of increasing the number of researchers, would make the adoption of an unobtrusive intervention study very difficult to achieve under the terms that were initially set out.

12.6.7 External Validity

This ESM measured the use of certain design methods (risky protocols) and cognitive error ('Error') in context. Measurement in context provided the ecological validity for this study. The selected diary methodology also provided a realistic external test of the research question, through the data being collected from the eight different sample groups. The geographic proximity of Organisation A, with three projects in Aberdeen and three in London and Organisation's B and C at different locations in the Netherlands was considered sufficiently distant from one another to discount any lasting effect. Whilst Organisation A, based in London, did provide access to three full-scale projects they were all located within the same office and drawing resources from potentially the same pool. These six project groups from Organisation A had high institutional proximity and this should be considered to be significant. However, the overall sample size is relatively small compared to the total population of designers employed within Organisation A, and more generally, in the field of engineering design.

An interval-contingent strategy developed on the basis of only a single study group may lack the required external validity. The implication for this study, under the circumstances if only a single project participated, would be that the findings may not be generalisable to individuals across the oil and gas sector (Kikcaldy, Athanasou, Trimpop, 2000). However, the number of projects, the total number of participants at n = 167 and the number of raw observations > 6000 were significantly greater than in comparative ESM studies where generalisable conclusions have been drawn from much smaller populations (see Daniels & Harris, 2005; Butler, Grzywacz, Bass & Linney, 2005; Miner, Glomb & Hulin, 2005; Tschan, Rochat & Zapf, 2005).

12.7 Future Research

As a result of this study there are a number of areas where further research should be conducted. These include:

1. Assessing this methodology in different design contexts;

2. Investigating the practical implications attached to this study;

3. Investigating the emergent findings attached to the safety climate paradox;

4. Remove the social cultures from any further analysis

12.8 Closing remarks

This study has been able to confirm that a large scale ESM applying a daily diary methodology and using the PDA as a recording medium, has enabled time-based data to be made interpretable. The contribution made by this exploratory piece of work resides in its disclosure of the predictive affects associated with a designer's use of risky protocols ('Risky') and cognitive error ('Error'). The implication of this organisational study on risk and cognitive error rests in its potential for theory development in the role of the offshore designer and the end user's safety performance.

The ESM and analysis method provided robust statistics to the research questions. This test has been conferred whilst the designers have been serving on high hazard design projects. The study has also developed an instrument that captures designers' risk-taking ('Risky') and Cognitive errors ('Error') in real time and in context. Such intensive large-scale event-sampling studies are very rare across all areas of research and even rarer in studies of work organisations. Typically these types of study have sampled between 30 and 60 participants over a one or two week period (see Daniels & Harris, 2005; Butler, Grzywacz, Bass & Linney, 2005; Miner, Glomb & Hulin, 2005; Tschan, Rochat & Zapf, 2005) compared to 167 participants in up to four weeks. In conducting this research on design engineers, the study has demonstrated the feasibility of large scale studies using this intensive methodology.

In conclusion, this study has been able to make a number of significant contributions to the field of social science and engineering design, which carry implications for the designer in the offshore oil and gas design sector. These implications include:

1. Recognising that designers with certain personality traits are less prone to 'Errors' and risk-taking ('Risky');
2. Recognising that certain organisational factors make designers less prone to using certain risky design protocols ('Risky');
3. Feedback provides the opportunity to debate the appropriateness of using any of the four risky design protocols used in this study;

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A summary report on FPSO lessons learnt gathered from four Norwegian FPSO's dated May 2002 OLF FPSO project, the Offshore Management Centre, Robert Gordon University, Aberdeen.

Appendix 1: Questionnaires

Pilot Study

Loughborough University

Serial number

CONFIDENTIAL

Section 1: Your work.

First, we would like to ask you some questions about your work. Please answer the questions by circling the response that best applies to you, on a 5-point scale, where 1= *Never* and 5 = ***Very often.***

	Never				Very often
1. Can you choose how you do your job?	1	2	3	4	5
2. Are your work objectives clearly defined?	1	2	3	4	5
3. Do you work to tight deadlines?	1	2	3	4	5
4. Can you talk to other people at work to decide what to do about work problems?	1	2	3	4	5
5. Do you work on projects with little scientific knowledge of the risks?	1	2	3	4	5
6. Do you receive feedback on your job performance?	1	2	3	4	5
7. Do you work on projects where the hazards pose a significant and widespread risk to the environment or the public?	1	2	3	4	5
8 Can you decide when to do particular work activities?	1	2	3	4	5
9. Are you clear about your job responsibilities?	1	2	3	4	5
10 Does your job require complex or high level skills?	1	2	3	4	5
11. Can you rely on other people at work when things get tough?	1	2	3	4	5
12. Do you work on projects where the consequences of any accident might not easily be controlled?	1	2	3	4	5
13. Do you work long hours?	1	2	3	4	5
14. Do you work on projects where the long-term outcomes of the risks are uncertain?	1	2	3	4	5
15. Are you given new tasks with little regard for work already in progress?	1	2	3	4	5
16. Are you able to modify your job objectives?	1	2	3	4	5
17. Are you clear about what others expect of you at work?	1	2	3	4	5
18. Can you seek advice from other people about work problems?	1	2	3	4	5
19. Do you work on projects where people might be exposed to risks they cannot control	1	2	3	4	5
20. Can you control the sequencing of your work activities?	1	2	3	4	5
21. Do you ever work for periods where you feel you have too little to do?	1	2	3	4	5
22. Are you allowed to decide how to get your job done?	1	2	3	4	5
23. Do you have a variety of tasks to perform?	1	2	3	4	5
24. Do you work on projects where the health and safety risks can be unpredictable?	1	2	3	4	5
25. Can you confide in other people at work?	1	2	3	4	5
26. Do you have too much work to do?	1	2	3	4	5

27. Do you work on difficult designs?	1	2	3	4	5
28. Do you work on projects where the hazards pose a significant risk to future generations?	1	2	3	4	5
29. Do you have to do a lot at work?	1	2	3	4	5
30. Do you have some control over what you are supposed to accomplish?	1	2	3	4	5
31. Do you work on projects where the risks cannot easily be observed by those exposed?	1	2	3	4	5
32. Does your job require detailed technical knowledge?	1	2	3	4	5

Section 2: Your work team.

Now we would like to ask you about your design team. Please rate the extent to which each statement is a true description of your team on the 5-point scale next to each item, where 1 indicate you disagree strongly and 5 indicates you agree strongly.

	Strongly disagree				Strongly agree
1. There is good communication about safety issues.	1	2	3	4	5
2. Safety rules and procedures are carefully followed.	1	2	3	4	5
3 Our team leader expresses satisfaction when I perform my job with safety as a priority.	1	2	3	4	5
4. Sometimes, the team finds it necessary to assign safety as a lower priority to meet project deadlines.	1	2	3	4	5
5. Our team leader waits for things to go wrong before taking action.	1	2	3	4	5
6 We often give to tips to each other to maximise the safety of our designs.	1	2	3	4	5
7. Our team leader talks about the importance of safety	1	2	3	4	5
8. Safety issues are assigned a high priority.	1	2	3	4	5
9. Our team leader makes sure we receive appropriate recognition for achieving safety targets on the job.	1	2	3	4	5
10. Some health and safety procedures and systems are not really practical for this design team.	1	2	3	4	5
11. Our team leader would listen to my concerns about a design's safety.	1	2	3	4	5
12. Our team leader suggests new ways of making our designs safer.	1	2	3	4	5
13. We encourage each other to raise safety concerns.	1	2	3	4	5
14. Our team leader does not intervene until safety problems become serious.	1	2	3	4	5
15. Our team leader spends time advising me on how to make designs safer.	1	2	3	4	5
16. We find that some health and safety procedures do not need to be followed to get the job done.	1	2	3	4	5
17. Our team leader encourages us to give safety a priority.	1	2	3	4	5
18. We are strongly encouraged to report unsafe design features.	1	2	3	4	5
19. Our team leader shows determination to ensure our designs are safe.	1	2	3	4	5
20. There are always enough people to get the design completed so it is safe	1	2	3	4	5
21. Our team leader behaves in a way that displays commitment to safe designs.	1	2	3	4	5
22. Our team leader avoids making decisions that affect safety.	1	2	3	4	5
23. Operational concerns often conflict with design safety procedures.	1	2	3	4	5
24. Our team leader encourages me to express my ideas about safety in our designs.	1	2	3	4	5

Section 3: Your attitudes to work:

We would now like to ask you about your views on risk at work. Please rate the extent to which you agree with each statement on an 8-point scale, where:

1 indicates the statement is **not at all true**
2 indicates the statement is **mostly untrue**
3 indicates the statement is **neither true nor untrue**
4 indicates the statement is **has some truth to it**
5 indicates the statement is **somewhat true**
6 indicates the statement is **mostly true**
7 indicates the statement is **very true**
8 indicates the statement is **completely true**

	Not at all true							Completely true
1. Designers should be responsible for the safety of fabricators and users.	1	2	3	4	5	6	7	8
2. Individual designers can bend some rules in order to get the job done	1	2	3	4	5	6	7	8
3. No level of risk is acceptable in a design	1	2	3	4	5	6	7	8
4. All designs should be examined from every possible angle before being signed-off.	1	2	3	4	5	6	7	8
5. Designs do not always need thorough checking to be considered safe.	1	2	3	4	5	6	7	8
6. Responsible designers reduce risk.	1	2	3	4	5	6	7	8
7. Fabricators and users should be responsible for their own safety.	1	2	3	4	5	6	7	8
8. Risk in a design is inevitable	1	2	3	4	5	6	7	8
9. Members of a design project should work together to ensure the safety of their designs	1	2	3	4	5	6	7	8
10. Design team members should strive to reduce risk below the level set.	1	2	3	4	5	6	7	8
11. Risks are too uncertain to make detailed plans.	1	2	3	4	5	6	7	8
12. Members of a design team should all be happy the design is safe before it is signed off.	1	2	3	4	5	6	7	8
13. Senior managers in this organisation should be responsible for the safety of fabricators and users.	1	2	3	4	5	6	7	8
14. Rules and procedures are effective in preventing accidents	1	2	3	4	5	6	7	8
15. It is important to apply design safety procedures properly.	1	2	3	4	5	6	7	8
16. Fabricators and users should determine the level of risk they are willing to bear	1	2	3	4	5	6	7	8
17 The individual designer is the best person to know if a design is as safe as it can be.	1	2	3	4	5	6	7	8
18. Responsible behaviour by fabricators and users reduces risk.	1	2	3	4	5	6	7	8
19. Risks are too uncertain to be able to assign responsibility	1	2	3	4	5	6	7	8
20. Rules and procedures cannot prevent accidents.	1	2	3	4	5	6	7	8
21. Procedures ensure that risks are as low as possible.	1	2	3	4	5	6	7	8
22. Inevitably, some designs have to be modified during fabrication or use.	1	2	3	4	5	6	7	8
23. Whatever designers do has little bearing on eventual risk in a design.	1	2	3	4	5	6	7	8
24. Comprehensive planning and systems reduce risk.	1	2	3	4	5	6	7	8

Section 4: Behaviour in general:

On the following pages, there are phrases describing people's behaviours. Please use the rating scale below to describe how accurately each statement describes *you*. Describe yourself as you generally are now, not as you wish to be in the future. Describe yourself as you honestly see yourself, in relation to other people you know of the same sex as you are, and roughly your same age. Please read each statement carefully, and then indicate how well the statement describes you on a five point scale, where:

1: Very Inaccurate
2: Moderately Inaccurate
3: Neither Inaccurate nor Accurate
4. Moderately Accurate
5. Very Accurate

	Very inaccurate				Very accurate
1. I am the life of the party.	1	2	3	4	5
2. I feel little concern for others.	1	2	3	4	5
3. I am always prepared	1	2	3	4	5
4. I get stressed out easily.	1	2	3	4	5
5. I have a rich vocabulary.	1	2	3	4	5
6. I don't talk a lot	1	2	3	4	5
7. I am interested in people.	1	2	3	4	5
8. I leave my belongings around.	1	2	3	4	5
9. I am relaxed most of the time.	1	2	3	4	5
10. I have difficulty understanding abstract ideas	1	2	3	4	5
11. I feel comfortable around people.	1	2	3	4	5
12. I insult people.	1	2	3	4	5
13. I pay attention to details.	1	2	3	4	5
14. I worry about things	1	2	3	4	5
15. I have a vivid imagination.	1	2	3	4	5
16. I keep in the background	1	2	3	4	5
17. I sympathize with others' feelings.	1	2	3	4	5
18. I make a mess of things.	1	2	3	4	5
19. I seldom feel sad.	1	2	3	4	5
20 I am not interested in abstract ideas.	1	2	3	4	5

Section 4: Continued

	Very inaccurate				Very accurate
21. I start conversations	1	2	3	4	5
22 I am not interested in other people's problems.	1	2	3	4	5
23. I get chores done right away.	1	2	3	4	5
24. I am easily disturbed	1	2	3	4	5
25. I often forget whether I have turned off work equipment, such as computers before I leave work	1	2	3	4	5
26. I have excellent ideas.	1	2	3	4	5
27. I have little to say.	1	2	3	4	5
28. I have a soft heart.	1	2	3	4	5
29. I often fail to notice postings or notices on the work email system	1	2	3	4	5
30. I often forget to put things back in their proper place.	1	2	3	4	5
31. I get upset easily.	1	2	3	4	5
32. I do not have a good imagination.	1	2	3	4	5
33. I talk to a lot of different people at parties.	1	2	3	4	5
34 I often fail to recall work procedures	1	2	3	4	5
35. I am not really interested in others.	1	2	3	4	5
36. I like order.	1	2	3	4	5
37. I often find it difficult to remember work-related phone numbers	1	2	3	4	5
38. I change my mood a lot	1	2	3	4	5
39. I am quick to understand things.	1	2	3	4	5
40. I don't like to draw attention to myself.	1	2	3	4	5
41. I often daydream when I should be listening to somebody	1	2	3	4	5
42 I take time out for others.	1	2	3	4	5
43. I shirk my duties.	1	2	3	4	5

Section 4: Continued

	Very inaccurate				Very accurate
44. I often have difficulty remembering the things required to complete a particular task	1	2	3	4	5
45. I have frequent mood swings.	1	2	3	4	5
46. I use difficult words.	1	2	3	4	5
47. I don't mind being the centre of attention.	1	2	3	4	5
48 I often find it difficult to focus my full attention on work activities	1	2	3	4	5
49. I feel others' emotions.	1	2	3	4	5
50 I follow a schedule.	1	2	3	4	5
51. I get irritated easily.	1	2	3	4	5
52. I spend time reflecting on things.	1	2	3	4	5
53. I often forget where I have put something I use in my job	1	2	3	4	5
54. I am quiet around strangers.	1	2	3	4	5
55. I make people feel at ease.	1	2	3	4	5
56. I am exacting in my work.	1	2	3	4	5
57. I am often distracted by my co-workers	1	2	3	4	5
58. I often feel blue.	1	2	3	4	5
59. I am full of ideas.	1	2	3	4	5

Section 5: About yourself:

Finally, we would like to ask for some background information

1. Gender

Female ( ) Male ( )

2. What is your age?

.... yrs

3. What is your job title? ....

4. How long have you been in your present job? ... .

yrs

5. How long have you worked for this firm?

.. . ... yrs

6. How long have you worked in this industry?

.... yrs

7. How long have you worked in other hazardous industries? .... yrs

8. What is your highest qualification? ....

9. How many major projects have you worked on in this industry? ....

10. Do you work full-time or part-time? Full-time ( ) Part-time ( )

11. About how many hours per week do you work? ....

12. How would you describe your ethnic group? .. ..

<u>Appendix 2: Main Study</u>

Serial number

☐☐☐☐

Loughborough University

CONFIDENTIAL

Section 1: Your work: First, we would like to ask you some questions about your work. Please answer the questions by circling the response that best applies to you, on a 5-point scale, where 1= *Never* and 5 = *Very often*.

	Never				Very often
1. Can you choose how you do your job?	1	2	3	4	5
2. Are your work objectives clearly defined?	1	2	3	4	5
3. Do you work to tight deadlines?	1	2	3	4	5
4. Do people at work help you get the things or information you need to do your job?	1	2	3	4	5
5. Do you work on projects where there is little scientific knowledge of the risks?	1	2	3	4	5
6. Do you receive adequate feedback on your job performance?	1	2	3	4	5
7. Do you work on projects where the hazards pose a significant and widespread risk to the environment or the public?	1	2	3	4	5
8. Can you decide when to do particular work activities?	1	2	3	4	5
9. Are you clear about your job responsibilities?	1	2	3	4	5
10. Does your job require complex or high level skills?	1	2	3	4	5
11. Do other people at work listen to your work problems?	1	2	3	4	5
12. Do you work on projects where the consequences of any accident might not easily be controlled?	1	2	3	4	5
13. Do you work long hours?	1	2	3	4	5
14. Do you work on projects where the long-term outcomes of the risks are uncertain?	1	2	3	4	5
15. Do people at work tell you that they value your contributions?	1	2	3	4	5
16. Do you ever work for periods below your level of ability?	1	2	3	4	5
17. Are you given new tasks with little regard for work already in progress?	1	2	3	4	5
18. Are you able to modify your job objectives?	1	2	3	4	5
19. Is it easy to talk to other people at work about work problems?	1	2	3	4	5
20. Are you clear about what others expect of you at work?	1	2	3	4	5

PLEASE TURN OVER

Section 1: continued

	Never				Very often
21. Do other people at work make your work life easier for you?	1	2	3	4	5
22. Are your performance criteria clear?	1	2	3	4	5
23. Do you work on projects where others might be exposed to risks they cannot control?	1	2	3	4	5
24. Do people at work tell you that they have confidence in you?	1	2	3	4	5
25. Can you control the sequencing of your work activities?	1	2	3	4	5
26. Do you ever work for periods where you have too little to do?	1	2	3	4	5
27. Are you allowed to decide how to get your job done?	1	2	3	4	5
28. Do you have a variety of tasks to perform?	1	2	3	4	5
29. Can you seek advice from other people about work problems?	1	2	3	4	5
30. Are you clear about how to do your job?	1	2	3	4	5
31. Do you work on projects where the health and safety risks can be unpredictable?	1	2	3	4	5
32. Can you confide in other people at work?	1	2	3	4	5
33. Do you have too much work to do?	1	2	3	4	5
34. Do you work on complex designs?	1	2	3	4	5
35. Are your work tasks well defined?	1	2	3	4	5
36. Can you talk to other people at work to decide what to do about work problems?	1	2	3	4	5
37. Do you work on projects where the hazards pose a significant risk to future generations of the general population?	1	2	3	4	5
38. Do you work on many tasks in quick succession?	1	2	3	4	5
39. Does your job require detailed technical knowledge?	1	2	3	4	5
40. Can you rely on other people at work when things get tough?	1	2	3	4	5
41. Do you have some control over what you are supposed to accomplish?	1	2	3	4	5
42. Do you work on projects where the risks cannot easily be observed by those exposed?	1	2	3	4	5
43. Is your job ever simple or repetitive?	1	2	3	4	5

PLEASE TURN OVER

Section 2: Your work team. Now we would like to ask you about your design team. Please rate the extent to which each statement is a true description of your team on the 5-point scale next to each item, where 1 indicates you disagree strongly and 5 indicates you agree strongly.

	Strongly disagree			Strongly agree	
1. There is good communication about safety issues.	1	2	3	4	5
2. Safety rules and procedures are carefully followed	1	2	3	4	5
3. Our team leader expresses satisfaction when I perform my job with safety as a priority.	1	2	3	4	5
4. Sometimes, the team finds it necessary to assign safety as a lower priority to meet project deadlines.	1	2	3	4	5
5. Our team leader waits for things to go wrong before taking action.	1	2	3	4	5
6. We often give tips to each other to maximise the safety of our designs.	1	2	3	4	5
7 Our team leader talks about the importance of safety	1	2	3	4	5
8. Safety issues are assigned a high priority.	1	2	3	4	5
9. Our team leader makes sure we receive appropriate recognition for achieving safety targets on the job.	1	2	3	4	5
10. Some health and safety procedures and systems are not really practical for this design team.	1	2	3	4	5
11. Our team leader would listen to my concerns about a design's safety.	1	2	3	4	5
12. Our team leader suggests new ways of making our designs safer.	1	2	3	4	5
13. We encourage each other to raise safety concerns.	1	2	3	4	5
14. Our team leader does not intervene until safety problems become serious.	1	2	3	4	5
15. Our team leader spends time advising me on how to make designs safer.	1	2	3	4	5
16. We find that some health and safety procedures do not need to be followed to get the job done.	1	2	3	4	5
17. Our team leader encourages us to give safety a priority.	1	2	3	4	5
18. We are strongly encouraged to report unsafe design features.	1	2	3	4	5
19 Our team leader shows determination to ensure our designs are safe.	1	2	3	4	5
20 There are always enough people to get the design completed so it is safe.	1	2	3	4	5
21. Our team leader behaves in a way that displays commitment to safe designs.	1	2	3	4	5
22. Our team leader avoids making decisions that affect safety.	1	2	3	4	5
23 Operational concerns often conflict with design safety procedures.	1	2	3	4	5
24 Our team leader encourages me to voice my ideas about safety in our designs.	1	2	3	4	5

PLEASE TURN OVER

Section 3: Your attitudes to work. We would now like to ask you about your views on risk at work. Please rate the extent to which you agree with each statement on an 8-point scale, where:

1 indicates the statement is **not at all true**
2 indicates the statement is **mostly untrue**
3 indicates the statement is **neither true nor untrue**
4 indicates the statement is **has some truth to it**
5 indicates the statement is **somewhat true**
6 indicates the statement is **mostly true**
7 indicates the statement is **very true**
8 indicates the statement is **completely true**

	Not at all true							Completely true
1. The best way to reduce risk is thorough and well-executed rules and procedures.	1	2	3	4	5	6	7	8
2. The individual designer is the best person to know if a design is as safe as it can be.	1	2	3	4	5	6	7	8
3. No level of risk is acceptable in a design.	1	2	3	4	5	6	7	8
4. All designs should be examined from every possible angle before being signed-off.	1	2	3	4	5	6	7	8
5. Designs do not always need thorough checking to be considered safe.	1	2	3	4	5	6	7	8
6. Fabricators and users should be responsible for their own safety.	1	2	3	4	5	6	7	8
7. Thorough planning and well-executed procedures limit mistakes in fabrication and use.	1	2	3	4	5	6	7	8
8. Designers are not responsible for the behaviour of fabricators and users.	1	2	3	4	5	6	7	8
9. Fabricators and users should determine the level of risk they are willing to bear.	1	2	3	4	5	6	7	8
10. Rules and procedures reduce risk to acceptable levels.	1	2	3	4	5	6	7	8
11. Rules can get in the way of efficient design.	1	2	3	4	5	6	7	8
12. Members of a design team should all agree that the design is safe before it is signed off.	1	2	3	4	5	6	7	8
13. Designs don't need to account for all risks	1	2	3	4	5	6	7	8
14. Operator preferences help improve design safety.	1	2	3	4	5	6	7	8

PLEASE TURN OVER

Section 3: Continued

	Not at all true							Completely true
15. Risks are too uncertain, in order to make detailed plans.	1	2	3	4	5	6	7	8
16. Fabricators and users should never be exposed to risk.	1	2	3	4	5	6	7	8
17. Rules and procedures are effective in preventing accidents.	1	2	3	4	5	6	7	8
18. Fabricators can always modify designs if they want to make them safer.	1	2	3	4	5	6	7	8
19. Designers should always see the job through to handover.	1	2	3	4	5	6	7	8
20. Rules and procedures cannot prevent accidents.	1	2	3	4	5	6	7	8
21. Responsible behaviour by fabricators and users reduces risk.	1	2	3	4	5	6	7	8
22. No design can ever be free of risk.	1	2	3	4	5	6	7	8
23. Design organisations should strive to eliminate risk.	1	2	3	4	5	6	7	8
24. Inevitably, some designs have to be modified during fabrication or use.	1	2	3	4	5	6	7	8
25. Whatever designers do have little bearing on eventual risk in a design.	1	2	3	4	5	6	7	8
26. Comprehensive planning and systems reduce risk.	1	2	3	4	5	6	7	8
27. Sharing design problems improves safety.	1	2	3	4	5	6	7	8
28 Safer designs rely upon sound engineering judgement.	1	2	3	4	5	6	7	8
29. Risks are too uncertain in order to be able to assign responsibility.	1	2	3	4	5	6	7	8
30. All designers know that the benefits of technology compromise safety.	1	2	3	4	5	6	7	8
31. Operators improvise to solve design problems.	1	2	3	4	5	6	7	8
32. Safety in a design should never be compromised for profit.	1	2	3	4	5	6	7	8
33. Checking and approval procedures always capture significant design mistakes.	1	2	3	4	5	6	7	8

Section 4: Behaviour in general:

On the following pages, there are phrases describing people's behaviours. Please use the rating scale below to describe how accurately each statement describes *you.* Describe yourself as you generally are now, not as you wish to be in the future. Describe yourself as you honestly see yourself, in relation to other people you know of the same sex as you are, and roughly your same age. Please read each statement carefully, and then indicate how well the statement describes you on a five point scale, where:

1: Very Inaccurate
2: Moderately Inaccurate
3: Neither Inaccurate nor Accurate
4: Moderately Accurate
5: Very Accurate

	Very inaccurate				Very accurate
1. I am the life of the party.	1	2	3	4	5
2. I feel little concern for others.	1	2	3	4	5
3. I am always prepared.	1	2	3	4	5
4. I get stressed out easily.	1	2	3	4	5
5. I have a rich vocabulary.	1	2	3	4	5
6. I don't talk a lot.	1	2	3	4	5
7. I am interested in people.	1	2	3	4	5
8. I leave my belongings around.	1	2	3	4	5
9. I am relaxed most of the time.	1	2	3	4	5
10. I have difficulty understanding abstract ideas.	1	2	3	4	5
11. I feel comfortable around people.	1	2	3	4	5
12. I insult people.	1	2	3	4	5
13. I pay attention to details.	1	2	3	4	5
14. I worry about things.	1	2	3	4	5
15. I have a vivid imagination.	1	2	3	4	5
16. I keep in the background.	1	2	3	4	5
17. I sympathise with others' feelings.	1	2	3	4	5
18. I make a mess of things.	1	2	3	4	5
19. I seldom feel sad.	1	2	3	4	5
20. I am not interested in abstract ideas.	1	2	3	4	5

PLEASE TURN OVER

Section 4: Continued

	Very inaccurate				Very accurate
21. I start conversations.	1	2	3	4	5
22. I am not interested in other people's problems.	1	2	3	4	5
23. I get chores done right away.	1	2	3	4	5
24. I am easily disturbed.	1	2	3	4	5
25. I often forget whether I have turned off work equipment, such as computers before I leave work.	1	2	3	4	5
26. I have excellent ideas.	1	2	3	4	5
27. I have little to say.	1	2	3	4	5
28. I have a soft heart.	1	2	3	4	5
29. I often fail to notice postings or notices on the work email system	1	2	3	4	5
30. I often forget to put things back in their proper place.	1	2	3	4	5
31. I get upset easily.	1	2	3	4	5
32. I do not have a good imagination.	1	2	3	4	5
33. I talk to a lot of different people at parties.	1	2	3	4	5
34. I often fail to recall work procedures	1	2	3	4	5
35. I am not really interested in others.	1	2	3	4	5
36. I like order.	1	2	3	4	5
37. I often find it difficult to remember work-related phone numbers	1	2	3	4	5
38. I change my mood a lot.	1	2	3	4	5
39. I am quick to understand things.	1	2	3	4	5
40. I don't like to draw attention to myself.	1	2	3	4	5
41. I often daydream when I should be listening to somebody	1	2	3	4	5
42. I take time out for others.	1	2	3	4	5
43. I shirk my duties.	1	2	3	4	5

PLEASE TURN OVER

Section 4: Continued

	Very inaccurate				Very accurate
44. I often have difficulty remembering the things required to complete a particular task	1	2	3	4	5
45. I have frequent mood swings.	1	2	3	4	5
46. I use difficult words.	1	2	3	4	5
47. I don't mind being the centre of attention.	1	2	3	4	5
48. I often find it difficult to focus my full attention on work activities	1	2	3	4	5
49. I feel others' emotions.	1	2	3	4	5
50. I follow a schedule.	1	2	3	4	5
51. I get irritated easily.	1	2	3	4	5
52. I spend time reflecting on things.	1	2	3	4	5
53. I often forget where I have put something I use in my job	1	2	3	4	5
54. I am quiet around strangers.	1	2	3	4	5
55. I make people feel at ease.	1	2	3	4	5
56. I am exacting in my work.	1	2	3	4	5
57. I am often distracted by my co-workers	1	2	3	4	5
58. I often feel blue.	1	2	3	4	5
59. I am full of ideas.	1	2	3	4	5

PLEASE TURN OVER

Section 5: About yourself:

Finally, we would like to ask for some background information.

1. Gender (please circle)

Female Male

2. What is your age? .... yrs

3. What is your job title?

CAD Designer	Design Co-ordinator	Engineer	Senior Engineer
Principal Engineer	Lead Engineer	Project Engineer	Engineering Manager
Project Manager	Other (please state)		

4. Will your designs be subject to HAZOP? Yes......... No.........Don't know ...

5. How long have you been in your present job? .... yrs

6. How long have you worked for this firm? .... yrs

7. How long have you worked in this industry? .... yrs

8. How long have you worked in other hazardous industries? .... yrs

9. What is your highest qualification? ....

10. How many major projects have you worked on in this industry? ....

11. Do you work full-time or part-time? Full-time

Part-time

12. About how many hours per week do you work? ....

13. How would you describe your ethnic group?...

Thank you, very much for your co-operation

Please now place it in the envelope provided and give it to the member of the research team

The palmtop computers will be distributed first thing next Monday morning

Appendix 3: PDA question sets

PDA questions waves 1, 2 and 3.

Where are you now?

In office
On site
Work at home
Not in work

Are you currently working to a strict deadline?

In the past hour, how many issues without an obvious solution have you had to deal with?

In the past hour, did you change the order in which you normally do your work tasks to solve the issues?

In the past hour, did you discuss the issues to help you solve them?

In the past hour, did you change your work objectives for the hour to get your emotions off your chest?

In the past hour, did you talk to people at work about the issues to get your emotions off your chest?

In the past hour, did you change your work objectives for the hour to solve the issues?

In the past hour, did you ask for other people's views to help solve the issues?

In the past hour, did you change the order in which you normally do work tasks to get your emotions off your chest?

In the past hour, did you confide in other people about the issues to get your emotions off your chest?

How anxious do you feel right now?

How enthusiastic do you feel right now?

How fatigued do you feel right now?

How motivated do you feel right now?

How worried do you feel right now?

How tired do you feel right now?

In the past hour, has it been difficult to remember how to perform specific design tasks?

In the past hour, have you been easily distracted from your work?

In the past hour, has it been difficult to remember design guides?

Do you regularly have to make assumptions about missing pieces of data?

Do you ever reuse previous designs that have not been updated?

Do you apply solutions that have worked well in the past?

I added a design feature fit-for-purpose but others need to decide if it's correct.

Wave 4

Where are you now? TYPE |In office; On-site; Work at home; not in work;

Are you currently working to a strict deadline? |No|Yes - but not imminent|Yes - imminent

In the past hour, how many issues without an obvious answer or solution have you had to deal with? |0|1|2|3|4|5 or more

How does dealing with this many issues affect your work performance? |Improves it a lot|Improves it a little|No effect|Makes it a little worse|Makes it a lot worse

How does dealing with this many issues affect your ability to work to your full potential? |Improves it a lot|Improves it a little|No effect|Makes it a little worse|Makes it a lot worse

How anxious do you feel right now? |Not at all=1|2|3|4|Very=5

How enthusiastic do you feel right now? |Not at all=1|2|3|4|Very=5

How fatigued do you feel right now? |Not at all=1|2|3|4|Very=5

How motivated do you feel right now? |Not at all=1|2|3|4|Very=5

How worried do you feel right now? |Not at all=1|2|3|4|Very=5

How tired do you feel right now? |Not at all=1|2|3|4|Very=5

In the past hour, has it been difficult to remember how to perform specific design tasks? |Not at all=1|2|3|4|Very=5|

In the past hour, have you been easily distracted from your work? |Not at all=1|2|3|4|Very=5

In the past hour, has it been difficult to type, write or read accurately? |Not at all=1|2|3|4|Very=5

In the past hour, have you made assumptions about missing pieces of data? |Yes|No

In the past hour, have you reused a previous design that has not been updated? |Yes|No

In the past hour, have you applied solutions that have worked well in the past? |Yes|No

In the past hour, have you added a design feature fit-for-purpose, but others need to decide if it's correct? |Yes|No

Appendix 4: Pilot Study

Overview

The Pilot Study was conducted as an organisational sampling study to test the experience sampling methodology that was proposed in Section Two. Participants came from within the safety critical nuclear engineering industry and totalled 33 design engineers in two teams.

Pilot Study

Data was collected in two ways. Firstly the background questionnaire was administered that aimed to capture, not only some of the stable factors related to work, team and job characteristics but also to collect key demographic data. On the Friday preceding the period of the ESM, participants were given a presentation that outlined the background and importance of the research work in which they were involved and a demonstration on how to use a PDA. At the conclusion of this session, the participants were given information including the presentation slides and some information covering some of the most frequently asked questions about the PDA, and their use. The participants completed a questionnaire to assess some of the stable factors. The PDAs were distributed to participants on the first day of the ESM period (a Monday). The PDAs administered brief questionnaires four times daily over the course of one working week (Monday-Friday at 10.00, 12.00, 14.00 and 16.00). An alarm on the PDAs signalled when the questionnaire was to be completed.

Cognitive functioning was assessed by three items reflecting the major domains of cognitive error: errors of memory, attention and action (Wallace & Chen, 2005). This assessment was adapted items from Wallace and Chen's work-specific measure, and asked participants to rate their cognitive error over the previous hour (e.g. 'In the past hour, have you been easily distracted from your work?'). A five-point scale was used for affect and cognitive error items (1 = 'Not at all', 5 = 'Very'), and scores calculated by summing item ratings and dividing by the number of items in the scale.

Risky decisions were assessed by four items tapping into the use of risky protocols in design work. Risky design protocols, whilst not necessarily unsafe in themselves however, they do carry potential risk during fabrication and use (Sharit, 1998). These protocols were chosen from the analysis of interviews with other hazardous industry designers (n = 11) and representatives from end-user fabricators or end-user operators of hazardous installations (n = 4). These individuals did not participate in the Pilot Study or Main Study. Designers were asked to state whether they had used any of these protocols during the previous hour ('Yes' = 1, 'No' = 0). The use of risky design protocols were assessed through the following questions:

1. In the past hour have you made assumptions about missing pieces of data?
2. In the past hour have you reused a previous design that has not been updated?
3. In the past hour have you applied solutions that have worked well in the past?
4. In the past hour have you added a design feature fit-for-purpose but others need to decide if it's correct?

At the end of the working week the PDA's were collected from the participants and the data entries downloaded. The researcher attended the host's office on the Monday, Wednesday and Friday of the study week to provide support to the participants, answers any queries regarding the research work, resolve any problems associated with the PDA handsets, and discuss how their work processes were conducted.

Analytical Framework

The analysis undertaken in the Pilot Study only examined the scale reliabilities for the factors that emerged from the exploratory PCA.

Results

The sample provided complete PDA data on 456 occasions out of a possible 599 (after taking into account known instances of absence etc). The overall compliance rate was 76% (individual ranges 26% -100%). To examine reliability over the range of scales the internal statistic known as the Cronbach's α for each scale was calculated. This statistic refers to the homogeneity of the scale. The acceptable level for internal reliability is around 0.7 and above. A very low alpha indicates that the scale does match the items as intended.

The results indicate that the scale values for Job Autonomy at 0.710, Support at 0.620, and Role Clarity and Demands were < 0.600. Risk Perception was 0.830 and all Safety Climate scale values were > 0.700 with the exception of Rules. The social culture scores for Individualism were 0.586, Egalitarianism 0.712, Hierarchism 0.742 and Fatalism 0.703. The IPIP 50 scores demonstrated strong theoretical support with extraversion at 0.884 Agreeableness at 0.794, Conscietiousness at 0.776, Emotional Stability at 0.910 and Openness-to-Experience at 0.709.

Overall the Pilot study methodology proved successful. In cases where the internal scale reliability was below 0.7 the questionnaire sets were re-evaulated and where necessary the questions adjusted to add clarity and remove ambigiuity or more questions added to improve the structure of the question set. The full details are given in Chapter Nine.

Summary

The Pilot Study has been completed within an aligned hazardous industry and with sufficient numbers of participants to make it a meaningful staging post for the Main Study. The feedback from the Pilot Study was that the designers understood the process and what was being presented on the PDAs requests. Scale reliabilities were generally satisfactory. However, the content of the job characteristics and social culture constructs need to be revisited prior to the main study in order to make them more robust. Finally, over the one week trial period the PDA handsets proved to be reliable and the Pilot Study recorded a 76% compliance rate.