Safety Hazard and Risk Identification and Management

In Infrastructure Management

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Declaration

This thesis has been completed by Jennifer Mary Campbell under the supervision of Dr Simon D. Smith and Professor Michael C. Forde and has not been submitted for any other degree or professional qualification. I declare that the work presented in this thesis is entirely my own except where indicated by full references.

SIGNATURE

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- Carillion staff who allowed the collection of data
- Students David Moriarty and Phil Beausang
- Online survey participants
- Brainstorming workshop participants

Abstract

Infrastructure such as transportation networks improves the condition of everyday lives by facilitating public services and systems necessary for economic activity and growth. However, constructing and maintaining transportation infrastructure poses safety hazards and risks to those working *at the sharp end*, leading to serious injuries and fatalities. Therefore, the identification of hazards and managing the risks they create is integral towards continually improving safety levels in Infrastructure Management.

This work seeks to fully understand this problem and highlight past, present and future issues concerning safety in a comprehensive literature review.

A *decision support tool* is proposed to improve the safety of transportation workers by facilitating hazard identification and management of associated control measures.

This *Tool* facilitates the extraction of safety knowledge from real paper-based safety documents, capturing existing worker's knowledge and experiences from industrial 'corporate memory'. The *Tool* suggests the most appropriate control measures for new scenarios based on existing knowledge from previous work tasks. This is achieved by classifying work tasks using a new method based on unilateral UK legislation (*Reporting of Injuries, Diseases and Dangerous Occurrences (1995) Regulations*) and the innovative use of *Artificial Intelligence* method *Case Based Reasoning*. *Case Based Reasoning* (CBR) allows transparency in the *Tool* processes and has many benefits over other safety tools which may suffer from 'black box' stigmatism.

The *Tool* is populated with knowledge extracted from a real transportation project and is hosted via the internet (www.Total-Safety.com).

The end product of the *Tool* is the generation of bespoke method statements detailing appropriate control measures. These generated paper documents are shown to have financial and quality control benefits over traditional method statements. The *Tool* has undergone testing and analysis and is shown to be robust.

Finally, the overall conclusions and opportunities for further research are presented and progress of the work against each of the five research objectives is assessed.

Contents

Declaration i

Acknowledgements ii

Abstract iii

Contents v

List of Tables x

List of Figures xiii

List of Appendices xvii

CHAPTER 1: THESIS OUTLINE AND RESEARCH CONTRIBUTION 1

1.1 Background 3

1.1.1 Sponsors 4

1.2 The Problem: Keeping Bob Safe! 6

1.3 Research Objectives 8

1.4 Thesis Contribution & Publications 11

CHAPTER 2: THE UK CONSTRUCTION INDUSTRY 13

2.1 The UK Construction Industry - An introduction 15

2.2 Infrastructure: The Cornerstone of UK Society 17

2.3 Infrastructure Management 19

2.3.1 Transportation 19
2.3.2 Roads 19
2.3.3 Rail 22
2.3.4 Reporting Safety 26

2.4 Accidents 30

2.4.1 Rail Workers Injuries 30
2.4.2 Road Worker Injuries 32
2.4.3 Injuries in General 34

2.5 Revitalising Health and Safety 39

2.5.1 CDM 2007 41

2.6 Skill Shortage, Company Culture & Future Growth 43

2.7 Discussion and Research Direction 46

2.8 Conclusions 48

CHAPTER 3: RISK & HAZARD MANAGEMENT 49

3.1 Introduction 51

3.2 Clarifying Hazards & Risks 53

3.3 Safety Management 59

3.3.1 Safety Hazards & Risks 60

3.4 Past Research 63

3.5 Infrastructure Workers 'At Risk' 66

3.5.1 Workers Risk Assessments 67

3.6 Discussion and Research Direction 73

3.7 Conclusions 74

CHAPTER 4: MANAGING SAFETY KNOWLEDGE 75

4.1 Introduction 77

4.2 Knowledge Management 79

4.3 Identifying and Transferring 'Safety Knowledge' 80

4.4 Reviewing Safety Knowledge Literature 84

4.4.1 Method 84

4.4.2 Medium 86

4.5 Research Discussion and Direction 92

4.6 Conclusions 96

CHAPTER 5: ARTIFICAL INTELLEIGENCE METHODS 97

5.1 Introducing Artificial Intelligence 99

5.2 Reviewing AI Methods 101

5.2.1 Expert Systems 101

5.2.2 Artificial Neural Networks 102

5.2.3 Case Base Reasoning 104

5.2.4 Hybrid & Fuzzy Systems 106

5.2.5 Discussing AI Methods 109

5.3 CBR in the Construction Industry 112

5.3.1 The Management Life-cycle of Construction Projects 112

5.3.2 Thinking and Planning Phases 113

5.3.3 'Doing' Construction, Operation and Maintenance Phases 115

5.4 Research Discussion and Direction 117

5.5 Conclusions 118

CHAPTER 6: DEVELOPING A SAFETY TOOL 119

6.1 Maintaining Research Focus - Keeping Bob Safe! 121

6.2 Development Strategy 123

6.2.1 Target Users 123
6.2.2 Methodology & Hosting Platform 127
6.2.3 Data 129
6.2.4 User Interface & Reporting 139
6.2.5 Tool Features 147

6.3 Summary and FAQs 152

CHAPTER 7: TOOL DESIGN & DEVELOPMENT TESTING 157

7.1 Introduction 159

7.2 Case Base Design 160

7.2.1 Tables 160
7.2.2 Queries 166
7.2.3 Forms 168
7.2.4 Reports 169

7.3 Retrieval Algorithm 170

7.3.1 Calculating a CBR Number 170
7.3.2 Assessing Similarity 172

7.4 Development Testing 177

7.4.1 Test 1 - User Classifications. 177
7.4.2 Test 2 - Tool Weightings 185

7.5 Conclusions 196

CHAPTER 8: PROOF OF CONCEPT TESTING 197

8.1 Introduction 199

8.2 TEST 1 – Prototype Tool 201

8.2.1 Test 1 Conclusions 207

8.3 TEST 2 – The Online Tool 208

8.3.1 Invitation Strategy & Online Survey 208
8.3.2 Test 2 Conclusions 219

8.4 TEST 3 – Comparing Method Statements 221

8.4.1 Conclusions 228

8.5 TEST 4 – Brainstorming Exercise 229

8.5.1 Ice-breaker 230
8.5.2 Win-win & Brainstorming Formats 232
8.5.3 The Group Work Task 237
8.5.4 Brainstorming vs. Tool 245
8.5.5 Conclusion 246

8.6 Test Series Conclusions 247

CHAPTER 9: CONCLUSIONS & FURTHER RESEARCH 249

9.1 Introduction 251

9.2 Conclusions 252

9.3 Proposal for Further Work 255

9.4 Lessons Learned 258

REFERENCES 259

List of Tables

Table 1.1 Measuring Chapters 1-4 against Research Objectives 9

Table 1.2 Measuring Chapters 5-8 against Research Objectives 10

Table 1.3 Table of Publications 12

Table 2.1 Most common fatal injuries in UK Industries 34

Table 2.2 Revitalising Health & Safety Targets (Health and Safety Executive 2007a) 39

Table 3.1 Examples of Industrial Disciplines, Hazard Groups & Risk Categories, adapted from BS4884-3:1996 54

Table 3.2 Risk Evaluation Methods (quantitative & qualitative) adapted from BS4884-3:1996 56

Table 3.3 Risk Assessment ‘Excavating Trial Pits’, PH/MS0013 68

Table 3.4 Risk Assessment on ‘car park’, MS/Larkhall/111 Rev B 69

Table 3.5 Risk Matrix Example 70

Table 3.6 Likelihood Example 70

Table 3.7 Severity Example 71

Table 3.8 Management Action based on Risk Matrix Example 71

Table 5.1 Comparing AI Methods 111

Table 6.1 Mitigation Table 133

Table 6.2 Summary of Designer Matrix 134

Table 6.3 Common Control Measures 135

Table 6.4 Engineering Volunteers Adding a further 21 Method Statements........... 137

Table 6.5 Number & type of method statements used in each extraction phase 139

Table 6.6 Tool Harm Classification 141

Table 6.7 Harm Categories – Online version 141

Table 6.8 Tool Hazard Classification.. 142

Table 7.1 Example of a Database Table.. 160

Table 7.2 Determining Database Tables 161

Table 7.3 Reference Tables.. 162

Table 7.4 User Tables 162

Table 7.5 Database Input Tables... 163

Table 7.6 Database Output Tables 164

Table 7.7 Mitigation Range (B) based on a Simplified Case Base......................... 174

Table 7.8 Comparing *CBR Numbers* from Engineering Students............................ 179

Table 7.9 Designer *CBR Numbers* 180

Table 7.10 Subjectivity 184

Table 7.11 Harm Categories– Prototype 186

Table 7.12 RIDDOR Reportable Diseases.. 186

Table 7.13 Harm Categories – Online version 187

Table 7.14 Comparing the Prototype and On-line versions of the *Tool* 187

Table 7.15 Likelihood Combinations & Weightings 188

Table 7.16 Harm Combinations& Weightings.. 188

Table 7.17 Hazard Combinations & Weightings 189

Table 7.18 Variations 189

Table 7.19 Exploring Likelihood Weightings... 190

Table 7.20 Exploring Harm Weightings 191

Table 7.21 Exploring Hazard Weightings.. 192

Table 7.22 Work Task Series (x-axis)... 193

Table 7.23 Arbitrary CBR Numbers 193

Table 7.24 Comparing mitigations returned by *Tool* using variations 1,2&3.......... 194

Table 8.1 Results using initial Case Base – CBR learning ‘switched off’ 205

Table 8.2 Summary of Results 205

Table 8.3 Comparing Results: *CBR Learning* ‘on’ or ‘off’ 206

Table 8.4 Demographic of User Work Experience 214

Table 8.5 User Qualifications & Combined Number of Years Work Experience (average)... 215

Table 8.6 Online Survey Results.. 216

Table 8.7 Comparison of Traditional & Tool-generated Method Statements.......... 227

Table 8.8 Win-Win Goals 232

Table 8.9 Brain-storming Results... 237

Table 8.10 Demographic of Brain-storming Groups 238

Table 8.11 Summary of Results 243

List of Figures

Figure 1.1 Keeping Bob Safe 7

Figure 2.1 Civilisation Scale 17

Figure 2.2 Rate of fatal injuries (2003) of EU member states (Health and Safety Executive 2006) 29

Figure 2.3 Standardised Incidence Rate of over 3 day accidents at work in Europe, 2003 (Health and Safety Executive 2006) 29

Figure 2.4 Fatal Injuries to rail Workers 1975 to 2005. 31

Figure 2.5 Fatal Injuries to workers (all industries) by accident 1996/97 to 2005/2006 *(Health and Safety Executive 2006)* 35

Figure 2.6 Number of major injuries by kind of accident 1996/97 to 2005/06 *(Health and Safety Executive 2006)* 35

Figure 2.7 Safety During Project Cycle, adapted from Humphrey et al. (2000) 37

Figure 2.8 Construction as percentage of Gross Domestic Product (Construction Products Association 2006)... 45

Figure 3.1 Established Risk Management Cycle adapted from Baker *et al* (1999)... 54

Figure 3.2 Safety Management Flow Chart 58

Figure 3.3 Research Focus 59

Figure 3.4 Continual Improvement Risk Management Spiral 62

Figure 4.1 Visual Puzzle (Covey 2004). 81

Figure 4.2 Advantages of Internet Medium 88

Figure 5.1 Artificial Neural Network Diagram 103

Figure 5.2 CBR Cycle (Campbell et al. 2007b) – adapted from Watson (1995) 105

Figure 5.3 Life-cycle of a Construction Project 113

Figure 5.4 Research Focus using *‘Think, Plan Do’* Model 118

Figure 6.1 System diagram of *Tool* (Campbell and Smith 2007b) 126

Figure 6.2 Tool Development 127

Figure 6.3 Designer’s Visual Matrix 134

Figure 6.4 Work Task Classification Entry Template – Version 1, prototype 144

Figure 6.5 Work Task Classification Entry Template – Version 2, internet 145

Figure 6.6 Tool Features Represented as Process Flow Chart (Campbell and Smith 2007b) 147

Figure 6.7 User Selection Screen, Prototype 148

Figure 6.8User Selection Screen, internet-ready version (Campbell and Smith 2007a) 149

Figure 6.9 Example of a Method Statement 150

Figure 7.1 Case Base Relationships - 1 of 2 165

Figure 7.2 Case Base Relationships - 2 of 2 165

Figure 7.3 Example of Microsoft Access Query (interface & SQL statement) 167

Figure 7.4 Form Example 168

Figure 7.5 Example of a Report 169

Figure 7.6 Similarity using Range Intersection Method (Campbell et al. 2007b) ... 172

Figure 7.7 Range Intersection Method ... 175

Figure 7.8 Nearest Neighbour Method ... 175

Figure 7.9 Examples of mitigation or user distributions ... 176

Figure 7.10 Prototype Classification Screen ... 178

Figure 7.11 Exploring Likelihood Weightings ... 190

Figure 7.12 Exploring Harm Weightings ... 191

Figure 7.13 Exploring Hazard Weightings ... 192

Figure 8.1 Prototype Tool Classification Screen ... 203

Figure 8.2 www.Total-Safety.com ... 209

Figure 8.3 Online Survey ... 209

Figure 8.4 Registration Questionnaire ... 210

Figure 8.5 Online Survey Work Task Classification (Campbell and Smith 2007a) 211

Figure 8.6 Online Survey User Selection Screen (Campbell and Smith 2007a) ... 212

Figure 8.7 Feedback Questionnaire ... 213

Figure 8.8 Original Risk Assessment ... 223

Figure 8.9 Original COSHH Assessment ... 224

Figure 8.10 Tool - generated Method Statement (example 1 of 2) ... 225

Figure 8.11 Tool - generated Method Statement (example 2 of 2) ... 226

Figure 8.12 Representations of ice-breaker exercise ... 231

Figure 8.13 Brainstorming - Linear Format 234

Figure 8.14 Brainstorming – Spider Format 235

Figure 8.15 Brainstorming -Output/Input Format 236

Figure 8.16 Group 1 239

Figure 8.17 Group 1 Extraction Method 239

Figure 8.18 Group 2 240

Figure 8.19 Group 2 Extraction Method 240

Figure 8.20 Group 3 241

Figure 8.21 Group 3 241

Figure 8.22 Group 4 242

Figure 8.23 Group 4 Extraction Method 242

Figure 8.24 Graph showing effect of work experience during the brainstorming exercise 244

Figure 8.25 Comparison of Brainstorming & Online Survey Results 245

Figure 8.26 Estimated Cost of Brainstorming Workshop 246

List of Appendices

APPENDIX A .... CONTRACTOR BACKGROUND

APPENDIX B .... PUBLICATIONS

B1. IMPROVING INDUSTRIAL VALUE AND LONGEVITY OF SAFETY MANAGEMENT RESEARCH

B2. CBR RESEARCH USING THE 'THINK', 'PLAN', 'DO' CLASSIFICATION METHOD

B3. SAFETY, HAZARD AND RISK IDENTIFICATION AND MANAGEMENT IN INFRASTRUCTURE MANAGEMENT: A PROJECT OVERVIEW

B4. KNOWLEDGE TRANSFER OF SAFETY CRITICAL INFORMATION BY THE INTERNET

B5. ELICITING SAFETY KNOWLEDGE FROM TRANSPORTATION METHOD STATEMENTS

B6. IDENTIFYING HAZARDS IN TRANSPORTATION CONSTRUCTION AND MAINTENANCE TASKS: A CASE

BASED REASONING APPROACH USING RAILROAD DATA

B7. SAFETY MANAGEMENT IN TRANSPORTATION CONSTRUCTION & MAINTENANCE

APPENDIX C .... UK LEGISLATION TABLES

APPENDIX D. .... LIST OF METHOD STATEMENTS

APPENDIX E ....EXAMPLE CODE

APPENDIX F.. ADDITIONAL TABLES

APPENDIX G .... ORIGINAL METHOD STATEMENTS

APPENDIX H. ....TOOL METHOD STATEMENTS

APPENDIX I..TRAINING

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CHAPTER 1: THESIS OUTLINE AND RESEARCH CONTRIBUTION

Ultimately, the aim of safety hazard and risk management – in infrastructure management as well as in other areas of construction – is the prevention of worker fatalities and injuries. Achieving this, in the context of virtually infinite hazards and ways in which they could lead to harm, is not so straightforward. This chapter defines *the problem* in detail, outlines the proposed methods by which this problem might be solved, and indicates the structure of this thesis which, it is hoped, will ultimately lead to achieving this goal.

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1.1 Background

This research proposes the development of a decision support *Tool* towards aiding hazard identification in the work place. This is achieved by identifying similar characteristics in work tasks, thereby allowing hazard controls used for a past problem to be applied and / or modified for new work tasks. This research gained inspiration from an MSc project by Gregory Carter (University of Edinburgh, 1999 to 2004) who investigated the management of health & safety hazards and associated risks on construction projects (Carter and Smith 2006). The fundamental aspects of Carter's earlier project were recognised as having significant potential towards improving safety in other fields i.e. transportation construction and maintenance projects.

The research presented in this thesis aims to improve worker safety within transportation construction and maintenance tasks by:

- Aiding the identification of hazards.
- Facilitating decision support based on the suitability of control measures.

The ultimate, over-arching aim of the work presented in this thesis is to provide measures to reduce fatalities and injuries to workers in the field of transportation construction and maintenance. More specifically, aims can be further defined as:

- Providing understanding of how identification of hazards may be improved.
- Allowing risks which might lead from these hazards to be further appreciated.
- Facilitating the provision of adequate control measures to mitigate these risks.

The problem leading to these aims is further clarified in section 1.2, and research objectives towards achieving these aims are discussed in section 1.3.

1.1.1 Sponsors

The research project is supported by the Engineering Physical Science Research Centre (EPSRC) under their *Industrial CASE* scheme whereby financial contributions are made by both the EPSRC and an industrial partner. In the case of this project, the ESPRC contributed two thirds of the total research costs whilst *Carillion Transport* (a subsidiary of Carillion plc) the remaining third. The total value of the research project over a period of three years was £74,857.

- **The Engineering and Physical Sciences Research Council (EPSRC)** is one of seven Research Councils funded by the Government through the Department for Innovation, Universities and Skills[1] (DIUS). ESPRC is a non-departmental governmental public body (NDPB) and is the UK's main agency for funding research in the filed of engineering and physical by investing around £740 million a year via research grants, training awards and access to major national and international research facilities (www.epsrc.ac.uk).

- **Carillion Plc** is one of the UK biggest construction companies with an annual turnover of circa £4bn (see ***Appendix A*** for more background on this sponsor). Carillion was created in July 1999 through the de-merger of Tarmac Construction Services and Tarmac Quarry Products. The Tarmac name has been retained with the aggregate products company whilst Carillion has expanded its original remit under the 'Construction Services' banner to include the management of transportation infrastructure. Since 1999 Carillion plc has expanded through the acquisition of smaller UK companies such as building specialist *Mowlem*, consultants *TPS* and, more recently, the civil engineering contractor *Alfred McAlpine*. *Carillion Transport* was formed in 2004 to encompass maintenance and construction projects for both the road and rail industries where previously they operated independently.

[1] http://www.dti.gov.uk/science/index.html

- However, *Carillion Transport* proved to be a short lived venture and was divided back into the constitute parts of road and rail in 2007 after a series of events within the rail sector, namely:
    - Limited availability of maintenance contracts due to a Network Rail introducing 'in-house' policies aimed at improving cost efficiencies and reliability.
    - Carillion banned from tendering for new Network Rail projects in August 2006 following concerns about a deteriorating workforce safety record. The six month ban was lifted after Network Rail conducted a safety audit concerning workforce operations to confirm improvements in workforce safety records.
    - Network Rail reduces the number of track renewal contractors from six to four in 2007. Bypassing Carillion, Network Rail decides to work with Amey SECO (JV), Balfour Beatty (BBRIS), First Engineering Ltd and Jarvis plc.
    - Carillion sells its Rail Plant business along with associated contracts to building rival Colas in early 2008 (The New Civil Engineer Magazine: Briefs 2008)

1.2 The Problem: Keeping Bob Safe!

Consider two different types of hypothetical worker:

- **Bob** is part of a team of workers at the sharp end, concentrating on mainly manual tasks.
- **Andy** is an engineer who is effectively Bob's boss. He is responsible for ensuring a safe system of work for Bob and his team.

In order to keep Bob safe during his working day, Andy scopes the proposed work and determines a method of performing the task safely. Andy foresees safety problems (or hazards) based on his own work experience, or his creative ability to invent plausible unsafe scenarios. This can include any number of details depending on a particular type of work / site location, i.e. the order of subsidiary tasks, types of materials / plant etc. Andy then must find appropriate solutions, using risk assessment methods to compare the impact of these hazards and whether his solutions provide an appropriate *safe system of work*. This process is usually documented as a *method statement* and given to Bob's team in the form of a report.

The important questions to consider in this scenario are:

- Has Andy correctly identified **<u>all</u>** the safety issues?
- Are Andy's solutions the most appropriate?
- Does Bob perform his task as Andy has instructed?
- Can Bob find a better solution?
- How can solutions be identified and communicated between Bob / Andy and their counterparts?

Figure 1.1 Keeping Bob Safe

1.3 Research Objectives

This project seeks to address the research aims previously discussed and further clarified through the issues raised in the *Problem Scenario* in the previous section. The research intends to develop a method of aiding Bob and Andy to identify and manage both the safety issues and their associated solutions, ultimately saving lives. To this end, five research objectives can be defined:

- Investigate and fully understand the extent, nature and impacts of *the problem*.
- Undertake a comprehensive literature review, to further objective 1 and to establish potentially viable research routes.
- Develop the *Decision Support Tool:* its processes, features and management strategy.
- Test, analyse and validate the *Tool*.
- Consider further improvements and future research opportunities.

This thesis is structured into nine chapters. Table 1.1 and Table 1.2 highlight the key elements within each chapter, and demonstrate how these relate to the research objectives above.

Chapter	Objectives				
	1	2	3	4	5
Chapter1: Introduction This chapter highlights: • Research problem, aims and objectives • Contribution to knowledge • Publications list	✓				
Chapter 2: The UK Construction Industry This chapter highlights: • The role of transportation infrastructure within the UK construction Industry. • A brief history of both *roads* and *railway* in the UK and various UK laws and regulations relating to the safety of workers in the management of transportation infrastructure. • Accident statistics inherent to workers in the Road and Rail Industries • The need to facilitate knowledge transfer between old and new working generations.	✓	✓			
Chapter 3: Hazard & Risk Management This chapter highlights: • Concepts of *hazard* and *risk.* • The importance of risk management and hazard identification / analyses in reducing accidents and ultimately saving workers' lives. • The Industry's heavily reliance on *qualitative risk assessments*. • 4 categories of literature aimed to improve safety for infrastructure workers are identified as *knowledge management, artificial intelligence methods, monitoring tools* and *behaviour / cultural issues.* • *Knowledge Management* and *Artificial Intelligence Methods* are chosen for further investigation in Chapters 4 &5	✓	✓			
Chapter 4: Managing Safety Knowledge This chapter highlights: • Different research methods employed to improve knowledge management of safety related issues within the Industry. A literary review of past studies are categorised into six methods and five types of medium,. • 3 types of communicating safety knowledge are identified as written, verbal and tactile.	✓	✓			

Table 1.1 Measuring Chapters 1-4 against Research Objectives

Chapter	Objectives				
	1	2	3	4	5
Chapter 5: Artificial Intelligence Methods This chapter highlights: • 4 forms of AI methods are compared in order to identify a suitable AI technique to improve and facilitate the transfer of Safety Knowledge associated to infrastructure management work tasks. • Case Based Reasoning is identified for an extended literature review • A new method of grouping literature is proposed and introduced as the '*Think, Plan, Do*' Model and is used to identify opportunities for CBR applications in Infrastructure Management.	✓	✓			
Chapter 6: Developing a Safety Tool This chapter highlights various *Tool* processes and features and proposes: • AI method *Case Based Reasoning* to be employed in the form of a *Tool.* • RIDDOR classification method is proposed to improve alignment between UK legislative requirements and hazard management • Bespoke site-specific method statements as the physical outcome of the *Tool*. These can be marketed to potential users as a simple, yet more time-efficient method of achieving current tasks			✓		
Chapter 7: Tool Design & Development Testing This chapter highlights: • *Case Base* Design • The new *Range Intersection Algorithm* to assess similarity. • Two development tests towards improving the *Tool* investigate *User Classification* and *Tool Weightings*			✓		
Chapter 8: Testing Proof of Concept This chapter highlights • *4 tests towards testing proof of concept:* • *The proposed Tool is shown as a viable alternative to current methods via a series of test, including financial and quality benefits.*			✓		
Chapter 9: Conclusions & Further Study This chapter highlights: • The key elements of the research. • Recommendations for continued research. • Progress against *research objectives*					✓

Table 1.2 Measuring Chapters 5-8 against Research Objectives

1.4 Thesis Contribution & Publications

The research presented in this thesis has several contributions to the fields of hazard & risk management, and of artificial intelligence applications. These contributions are briefly summarised as:

- *Tools* to aid hazard identification and management incorporating innovative use of Artificial Intelligence (AI) methods. These create bespoke method statements based on specific site conditions.
- The '*Think, Plan, Do*' Model allows research literature to be mapped directly onto the established project lifecycle and is used to identify research opportunities.
- A new method of assessing similarity between stored and new work tasks – the *Range Intersection Algorithm*.
- A *Classification Method based on RIDDOR*, linking hazard identification directly to the UK's legal requirements.
- A new worker group as the target audience – those who act as *Facilitators and Authors of Method Statements* (FAMS).
- New layout of Method Statements allowing the effectiveness of hazard identification and management processes to be monitored and assessed.

Table 1.3 gives details of the seven publications whereby J. M. Campbell acted as main author. Permission has been given by the publishers to reproduce the five conference papers and two journal papers in full as ***Appendix B***.

Authors	Title	Conference / Journal
Campbell, J M, Smith, S D Forde, M C	Improving Safety Management in Transportation Construction and Maintenance	***Journal – under review*** Proceedings of ICE, Transport, 2008
Campbell, JM, Smith, S D, Forde, M C and Ladd, R D	Identifying Hazards in Transportation Construction and Maintenance Tasks: A Case Based Reasoning Approach using Railroad Data	***Journal*** Presented at the Transportation Research Board 86th Annual Conference, 21-25 January 2007, Washington, DC and published within '*Transportation Research Record'*, Journal of the Transportation Research Board, No. 1995.
Campbell, J M, Smith, S D Forde, M C	Eliciting Safety Knowledge from Transportation Method Statements.	***Conference*** Railway Engineering, 21-22 June 2007, University of Westminster, London, UK.
Campbell, J M Smith, S D	Safety, Hazard and Risk Identification and Management in Infrastructure Management: A Project Overview.	***Conference*** 23rd Annual Conference of the Association of Researchers in Construction Management, 3-5 September 2007, Belfast, UK.
Campbell, J M Smith, S D	Knowledge Transfer of Safety Critical Information by the Internet	***Conference*** 23rd Annual Conference of the Association of Researchers in Construction Management, 3-5 September 2006, Belfast, UK.
Campbell, J M Smith, S D	Improving Industrial Value and Longevity of Safety Management Research	***Conference*** 22nd Annual Conference of the Association of Researchers in Construction Management, 4-6 September 2006, Birmingham, UK.
Campbell, J M Smith, S D	CBR Research using the 'THINK', 'PLAN', 'DO' Classification Method	***Conference*** 22nd Annual Conference of the Association of Researchers in Construction Management, 4-6 September, Birmingham, UK. 2006.

Table 1.3 Table of Publications

CHAPTER 2: THE UK CONSTRUCTION INDUSTRY

Construction is a very large research field for the simple reason that it covers so many different types of trades and work tasks; building new railways, re-conditioning oil rigs, maintaining roads, inspecting homes, decommissioning nuclear power plants and infrastructure management are just a few facets of the construction industry.

Infrastructure management, which could be considered a subset of the Construction Industry, can be viewed as a versatile multi-tool, improving the condition of everyday lives by facilitating public services, systems and facilities necessary for economic activity.

This chapter focuses on transportation infrastructure highlighting the past, present and future issues concerning the safety of those who work in this industry.

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2.1 The UK Construction Industry - An introduction

The construction setting incorporates many engineering sectors including mechanical, electrical and chemical engineering processes. These engineering sectors are facilitated by the presence of suitable infrastructure, as provided mainly by civil engineering. This further establishes infrastructure management as playing an important role within construction, maintenance and operational activities associated with our quality of life.

This chapter will concentrate on infrastructure as a subset of the Construction Industry and shows the importance of the Industry in relation to UK and worldwide economies. Statistics from UK Government bodies – the Health and Safety Commission (HSC), the Health and Safety Executive (HSE), the Office of Rail Regulation (ORR) etc – highlight the level of occupational accidents in the UK. Campaigns to improve practice are discussed along with the implication of the UK skills shortage on company culture and future work loads.

The chapter is structured in seven sections:

- **Section 1 – The UK Construction Industry**

Brief introduction and chapter structure.

- **Section 2 – Infrastructure: The Cornerstone of UK Society**

Modern civilisation requires many basic services and infrastructure for the improvement of society. In this section the research topic of transportation infrastructure and subsidiary topics of road and rail are introduced and compared.

- **Section 3 – Infrastructure Management**

Discussion of the role of transportation infrastructure and a brief history of both the roads and railway networks in the UK is presented. This section also highlights the various UK Acts of Law, Regulations and regulatory authorities (HSE/ORR) relating to the safety of workers in the management of transportation infrastructure.

- **Section 4 – Accidents**

This section highlights published accident statistics inherent to workers in the Road and Rail Industries.

- **Section 5 – Revitalising Health and Safety**

The campaign to improve current practice and reduce accidents and injuries is highlighted and the Construction (Design and Management) Regulations 2007 are discussed.

- **Section 6 – Skill shortage , Company Culture & Future growth**

The industry's loss of skilled workforce is discussed and issues relating to efficient knowledge transfer between old and new working generations are highlighted.

- **Section 7 – Conclusions**

Lack of safety knowledge and expertise has been identified as significantly contributing to fatalities and injuries in the UK Infrastructure workforce.

Despite encouraging trends in worker fatalities over the last few decades, worker safety in the Infrastructure Sector must continually improve. To facilitate ambitious safety targets, companies must manage and act upon safety critical information and knowledge more effectively. This, in turn will improve the low levels of safety as perceived by Media, currently overshadowed by high profile public train crashes. In addition to these knowledge management issues, companies must direct the skills of their staff efficiently to negate the impact of skills shortages and escalating legal culpability.

2.2 Infrastructure: The Cornerstone of UK Society

Modern civilisation requires many basic services for the improvement of society. Throughout the ages these have progressed according to the advancement of industry and technology but can still be simplified into four categories:

- Materials for shelter and provision of food - wood, bricks, bronze, steel etc
- Fuel - wood for fires, coal for steam power, motor vehicle fuel
- Basic Amenities - drainage, fresh water.
- Self Improvement - establishment of education and learning facilities.

The advancement of 'society' from a subsistence existence is not world wide and developing counties lie at a different area of a sliding Civilisation Scale from the UK. Consider the proposed current UK position in Figure 2.1. It is not the aim of the author to judge or make comment on whether certain societies are 'better' than others. However, it is obvious that society in the UK at present is heavily reliant on material needs and services along with an ever increasing logistical demand:

- What do we need and where? When do we need it?
- How can we get it there on time?
- How can we improve?

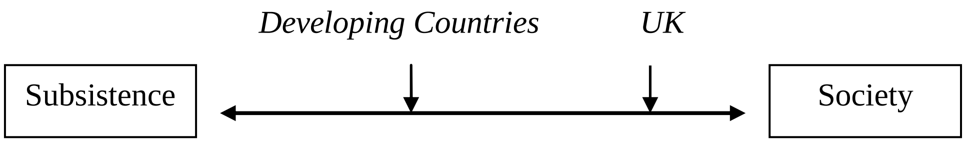

Figure 2.1 Civilisation Scale

In short, UK society is very dependant on 'infrastructure' as the basic underlying asset, framework or system of our organised society. These include our transportation networks such as road and rail, water distribution and waste removal and power generation not to mention subsidiary supplier or retail related processes.

> *"Every year, over two billion tonnes of goods are moved within the UK and nearly half of all trips made by people involve some form of interaction with business. A properly resourced, well managed transport system is essential not only to the efficient running of business but to everyone's quality of life"*. Richard Lambert, Director-General, Confederation of British Industry (CBI), (Construction Products Association 2006)

The management of existing infrastructure and the construction of new and improved infrastructure schemes are clearly integral to the expansion of UK society.

2.3 Infrastructure Management

As touched upon in the previous section, the term 'infrastructure' can relate to many different aspects of our everyday life. In this section the role of transportation infrastructure is introduced and a brief history of both the roads and railway networks in the UK is given.

2.3.1 Transportation

The UK transportation sector facilitates the movement of valuable physical commodities for the individual needs of the nation and the expansion of business. The existence of modern roads and railways are so inherent in our everyday urban lives that the concept of being without these assets can be quite alien and certainly outside living memory. The next two sections serve as a brief reminder of the history of roads and railways in the UK and have been drawn from The Future of Rail White Paper (Department for Transport 2004) and information downloaded from official web pages:

- Highway Agency - www.highways.gov.uk.
- Department for Transport - www.dft.gov.uk/pgr/roads.
- Welsh Assembly - http://new.wales.gov.uk/topics/transport/roads
- Department for Regional Development (NI) - www.drdni.gov.uk
- Transport Scotland - www.dft.gov.uk/pgr/roads

2.3.2 Roads

In the UK primitive tracks were evident from Stone Age times, however Roman engineers are often given credit for building 'modern' roads. Originally intended to give strategic advantages to their conquering armies, these roads were soon adopted for trade and general transport between cities. Via Appia, the first Roman road was started in 312 BC and stretched for over 6,018 kilometres across Western and Southern Europe. Although some Roman roads remained in use for more than 1,000 years after the decline of the Roman Empire, in general roads started to wear away due to no maintenance after the Romans left Britain in the 5th century.

In the Middle Ages, individual parishes were responsible for the road maintenance in their area, with local people forced by law to work unpaid in order to keep the roads in good repair. This system using both paid and unpaid labour continued circa 1555-1835 until turnpike trusts were introduced by the 18th century.

Turnpike trusts were a collection of businessmen who gained permission from Parliament to either maintain and toll a section of existing road, or build and maintain a new one for a given period. This financial arrangement led to new building methods for stronger roads allowing wheeled traffic to travel more easily. By 1830 there were more than 1,000 Turnpike companies in England, maintaining 32,000 kilometres of road. Big cities became connected by stagecoach networks and travel time was reduced from weeks to days when compared with travel in the preceding century. The arrival of the first railway lines resulted in a decrease in road custom (both passengers and freight). Turnpike Trusts gradually became bankrupt with the last company closing in 1895 and town and district councils became responsible for the roads by the end of the 19th century. Spurred on by the national and political issue of increased number of motor vehicles, the ‘Trunk Roads Act’ in 1936 ensured that the UK Government had direct control over 30 of the principal roads of Britain.

This system is still in use today with less important roads left in the control of the local parishes and councils however the responsibility for the trunk roads has been split over the last decade or so to devolved government powers in Scotland, Wales and more recently Northern Ireland:

- The Scottish Executive, established in 1999, is responsible for managing and awarding ‘*Term Maintenance Contracts for Management and Maintenance of the Scottish Trunk Road Network*’. The network comprises almost 3,500km and although representing only 6 per cent of Scottish roads, it carries almost one third of the total traffic volume and 57 per cent of heavy commercial vehicle traffic.

Four main contractors maintain the trunk roads in the southeast, southwest, northeast and northwest of Scotland. Similarly, the Transport Act 2000 provides the Scottish Executive with a role in determining rail services provided by the Scotrail franchise, under Network Rail. Currently, Strathclyde Passenger Transport Executive is a co-signatory to the Scotrail contract and has a role specifying services in the West of Scotland. ‘Transport Scotland’, an executive agency, was established in 2006 to help deliver the Scottish Executive’s investment programme over the next decade and is directly accountable to Scottish Ministers.

- The Welsh Assembly, established in 1999, is responsible for over 1,600 km of trunk road and 120 km of motorways and spends around £210 million per annum (2008 prices).. The Railways Act 2005 coupled with the Transport (Wales) Act 2006 gave the assembly a broader range of powers for the delivery of improved transport infrastructure and services in Wales such as specifying services and fares for local services. .

- The Highways Agency (HA), established in 1994, continues to be responsible for all national roads in England - a total of 10,458 kilometres of trunk roads and motorways valued at over £72bn (2008 prices). The HA is responsible for assessing and prioritising improvement to trunk roads, awarding the work to contractors based on quality, ability and cost. It is envisaged that Network Rail will continue in it’s current role as several of its responsibilities are gradually given to devolved governments.

- The Northern Ireland Road Service are currently responsible is for over 25,000 kilometres of public roads and 5,800 bridges in Northern Ireland. However, Northern Ireland foresees high growth in transportation infrastructure and a Regional Strategic Transport Network (RSTN) is being investigated. The RSTN would consist of the rail system, five key transport corridors, four link corridors, and the Belfast Metropolitan Area transport corridors, (Department for Regional Development 2001).

2.3.3 Rail

The evolution of steam engines enabled public railways to boom in the mid to late 1800s with fluctuating build quality. This varied from the Brunel's Great Western Line designed for speed, to low standards line against a backdrop of soaring land price (Department for Transport 2004).

The UK Government nationalised the railways in the 1940s, reducing the plethora of small privately financed companies grown in the Victorian era into the "Big Four" regional companies. Although significant investment for 'wear and tear' of two world wars was promised, little Government funding was available until the 1950s modernisation plan by which time transport and economic change towards car and lorry had resulted in declining numbers in rail passenger and freight traffic. This modernisation plan and the Beeching railway closures of the 1960s failed to reverse this dwindling trend (Department for Transport 2004).

The rail industry was privatised in the early 1990s on the assumption that private sector innovation, discipline and mentality would reduce the railway's public funding requirement and improve quality of service.

Several countries across Europe can be used as management models for the rail industry with separate ownership of track and train. Examples include Scandinavia's and the Netherlands' separate and publicly owned infrastructure and operating companies, whilst Germany unites train operations and infrastructure management companies under a single holding company.

Rail privatisation in the UK proved less successful with ill defined Government outputs leading to distorted and inefficient incentives between the different parts of the industry. During this move, the network infrastructure 'owner' Railtrack retained few core engineering skills due to a Governments compulsorily outsourcing scheme and instead awarded engineering work to infrastructure maintenance companies (Department for Transport 2004)

These companies were responsible for carrying out maintenance / renewals, defining specification and inspecting their own work. These factors contributed to the inability of Railtrack to know the extent of track condition and effectively monitor the quality of works. The subsequent accidents at Paddington, Hatfield and Potters Bar caused by ill maintained or degraded infrastructure, a progressive collapse in confidence in the condition of the rail network, and location-wide speed restrictions across the network.

In October 2002 Network Rail (limited by guarantee) took over Railtrack's responsibilities for the management and operation of the network. Accountable to the industry via its members, Network Rail is run on a commercial basis with access to private sector finance and management skills but without shareholders. More recently the need to address Railtrack legacy issues has required Network Rail to restructure the company and take maintenance operations back in-house to improve cost efficiencies and reliability.

Examples of high profile crashes Network Rail has 'inherited' over the last decade include:

- **Southall crash, 1997**, killed seven people and injured more than 150 when a driver missed a red light and collided with a goods locomotive crossing its path. The in-cab automatic warning system, as recommended by a previous inquiry into a similar crash at Clapham almost a decade before, had been fitted to the Southall train but was not operating. Manslaughter charges against 52-year-old driver and the train operator were dropped however, and operator Great Western Trains fined £1.5million (BBC News 1999).
- **Paddington Collision, 1999**, killed 31 passengers and injured more than 400 people when a Thames train collided with a Great Western Express after passing a red light near Paddington station. The signal had been the scene of six 'near miss' incidents over prior years (Massey 2006). Network Rail pleaded guilty under the Health and Safety at Work etc Act (1974) by failing to ensure the signal was

clearly visible and admitted that part of the signal was obscured (Fernandez 2007; Massey 2006).

- **Hatfield derailment, 2000**, killed four when the London to Leeds express passenger train derailed whilst travelling at 115mph over a degraded section of track. Five rail managers were charged with breaches in health and safety and the maintenance contractor (Balfour Beatty Rail Maintenance) was charged with corporate manslaughter. Balfour Beatty was fined £10m for negligence, later reduced to £7.5m by an appeal court due to disparity between this fine and the smaller fine of £3.5m on Railtrack for failing to ensure the contractor was performing its duties. All managers were acquitted of the charges (Dyer 2006).

- **Potters Bar derailment, 2002**, was caused by faulty points near Potters Bar station, killing seven. Three rail repair contracts operated by Jarvis, the maintenance contractor at the centre of the inquiry, were taken 'in-house' by Network Rail in 2003. Rail infrastructure company Network Rail and Jarvis accepted liability on behalf of the rail industry for claims brought over the Potters Bar crash "whilst the accident remained under investigation" (Massey 2002).

- **Tebay worker fatalities, 2004**. Four workers died after being hit by a flatbed trailer while working on a section of the West Coast Main Line in February 2004. Two men were jailed for nine and two years after being found guilty of four counts of manslaughter (BBC News 2006).

- **Grayrigg 2007,** resulted in the death of an 84 year old woman passenger and injuries to 22 others when the London to Glasgow Virgin Pendolino train derailed near Kendal in Cumbria. A report into the derailment from the Rail Accident Investigation Branch (RAIB), said faults with the points meant the tilting train could not follow its intended path over the tracks (Rail Accident Investigation Board and Department for Transport 2007). Investigators found one of three stretcher bars keeping them a set distance apart was not in position whilst two were fractured and bolts were missing. Two Network Rail employees, aged 60 and 64, are currently under arrest on suspicion of manslaughter (BBC News 2007; The New Civil Engineer Magazine: Briefs 2007).

The first two train incidents involved 'driver error' and a SPAD (Signal Passed At Danger). These types of incidents are declining with the advent of intelligent braking systems that do not allow such 'driver error' to occur. The Tebay incident was caused by faulty brakes in a subcontracted rail trailer during 'green zone working' whereby normal trains are suspended, allowing only work related plant on site. This incident happened at relevantly low speed. The remaining three incidents in 2000, 2002 & 2007 were caused by degraded and ill maintained track. Of special note is the most recent incident in 2007 at Grayrigg, where the modern design of Pendolino trains was hailed to have saved many lives and injury due to in-built safety features including crumple zones at the front of the trains, safety exits and ladders. The carriages remained intact and none of the windows broke as the train tumbled down an embankment, meaning no passengers were thrown through the windows. Also the driver of the train was 'hailed a hero' after it emerged he stayed at the controls suffering neck and shoulder injuries - the Rail Accident Investigation Branch said there was no evidence to indicate the driving of the train or the condition of the train were contributory factors to the derailment (BBC News 2007).

The way in which these events are reported by the press signify greater public interest to passenger fatalities, even anger over small fines administered towards companies from the Courts. Some have felt so strongly that they have created campaign groups for better safety, for example the 'Safety on Trains Action Group' was founded by a mother after the death of her son in the Southall train crash in 1997.

There is little of this vehemence in national news concerning the death of the Tebay workers who were killed in2004.

2.3.4 Reporting Safety

The construction industry is reported by the Health and Safety Executive as being one of biggest industries in the UK with over two million workers (Health and Safety Executive). Despite economic prowess, the industry is a dangerous place to work and over the last quarter century approximately 3000 people have died in the UK from injuries they received during construction work with many more injured or made ill. Research in 2005 suggested that the fatality rate in construction corresponds to a 1:165 chance of being killed at work (assuming a 40 year work term for the average worker), and theorised that it is almost inevitable that an individual worker will experience several reportable non-fatal injuries over the course of a working lifetime in construction (Vedder and Carey 2005). A few common features that characterized the construction industry, thus leading to unusual risks are:

- Limited scope for preassembly of construction elements due to mobility constraints, requiring structures or elements to be built on-site,
- Unique projects requiring specific planning and component parts,
- Relatively high levels of manual labour,
- Automation for mechanising hard physical work mostly limited to manual handling of materials and logistics (trucks, cranes, etc.).

The UK has many legislative acts and regulations to ensure those working in the infrastructure management are protected from harm (see ***Appendix C***). Of special note are the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (1995) or RIDDOR (Health and Safety Executive 1999). These regulations require employers to notify certain occupational injuries, diseases and dangerous events to the Health and Safety Executive (HSE) or in the case of rail related incidents, the Office of Rail Regulation (ORR). The RIDDOR injury types are broadly categorised as major injuries, diseases, '3-day' injuries whereby the person is incapable of work for three days, or any 'near miss' incidents that did not result in people being harmed but easily could have done. RIDDOR reporting is unilateral across all industries and provides the main statistics for the Health and Safety Commission and the Office of

Rail Regulation to convey the current state of the safety to the UK Government. A brief explanation of the these two UK government bodies is given below:

- The Health and Safety Commission (HSC) consists of a chairman and nine industrial members who are responsible for setting the high level goals and initiatives of health and safety issues in the UK. The Health and Safety Executive (HSE) are a large government body consisting of advisors, inspectors and researchers who facilitate these initiatives and publish government reports. Similar government bodies exist in Australia (National Occupational Health and Safety Commission), Hong Kong (Occupational Safety and Health Council http://www.oshc.org.hk) and the United States of America (Occupational Safety and Health Administration, http://www.osha.gov/). The function of such groups is to promote safety in the work community, regulatory assessment and further development of country-wide strategies.

- The Office of Rail Regulation (ORR), established on 5 July 2004 by the Railways and Transport Safety Act 2003, independently regulates Network Rail's income. All aspects of health and safety regulation were transferred from HSC/HSE to the independent Office of Rail Regulation (ORR) in 2006 as an attempt to simplify the regulatory structure of the rail industry and provide a platform to encourage cultural change across the rail industry. Specific responsibilities of the ORR involve enforcement of health and safety legislation in respect of the operational railway, ensuring that the railway provides value-for-money for fare-payer / taxpayer and acting as a single repository for rail industry data.

Under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 UK employers are required to inform the HSE/ORR (Health and Safety Executive 1999):

- Immediately (e.g. by telephone) to report death(s) or major injuries requiring employees, self employed or general public affected by the works to be taken to hospital.
- If a doctor notifies you that your employee suffers from a reportable work related disease you must send a completed disease report form (F2508A) to the enforcing authority. Examples include: occupational dermatitis, asbestos, leptospirosis (Weil's disease) etc.
- If there is an accident connected with work resulting in a 3-day injury. This is where employees or self employed are absent or are unable to do the full range of normal duties for more than 3 working day. This timescale including days they wouldn't normally be expected to work such as weekends i.e. an accident on a Friday resulting in a worker being absent from work on the day of the accident and the following Monday would be reportable as a 3-day injury.
- If something happens which does not result in a reportable injury, but which clearly could have done, it may be a dangerous occurrence which must be reported immediately (eg by telephone) to the enforcing authority.
- A completed accident report form (F2508) is required within ten days of informing the enforcing authority.

The UK statistics as reported by the HSE/ORR are in keeping with other European countries and suggests the issue of health and safety of the construction worker is of worldwide significance. Figure 2.2 and Figure 2.3 as published by the Health and Safety Executive compare the UK to other EU members (Health and Safety Executive 2006). However, it is theorised that reported statistics of non fatal accidents are likely to be overly optimistic when the effects of poor reporting, failure to collate and undertake effective analysis are considered (Haslam et al. 2005).

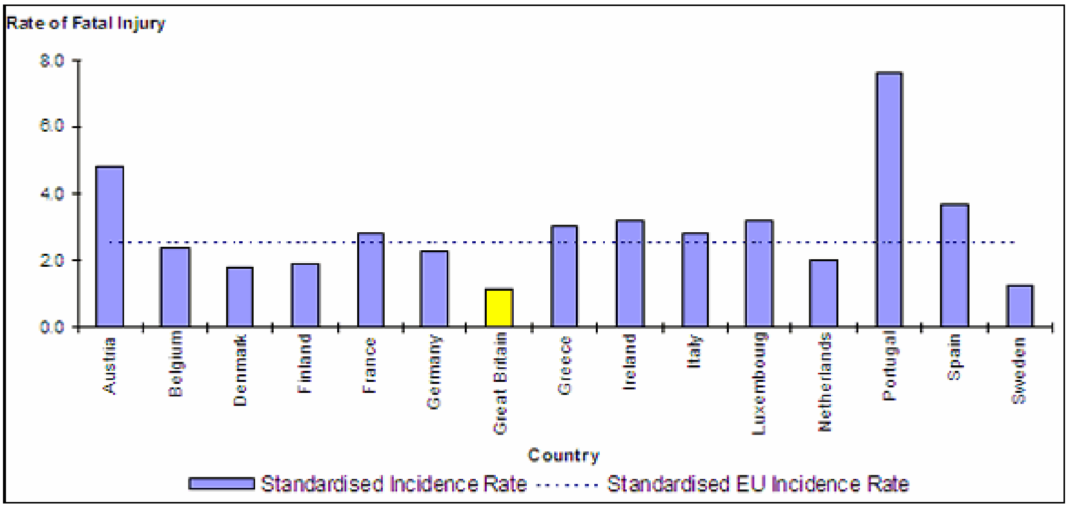

Figure 2.2 Rate of fatal injuries (2003) of EU member states (Health and Safety Executive 2006)

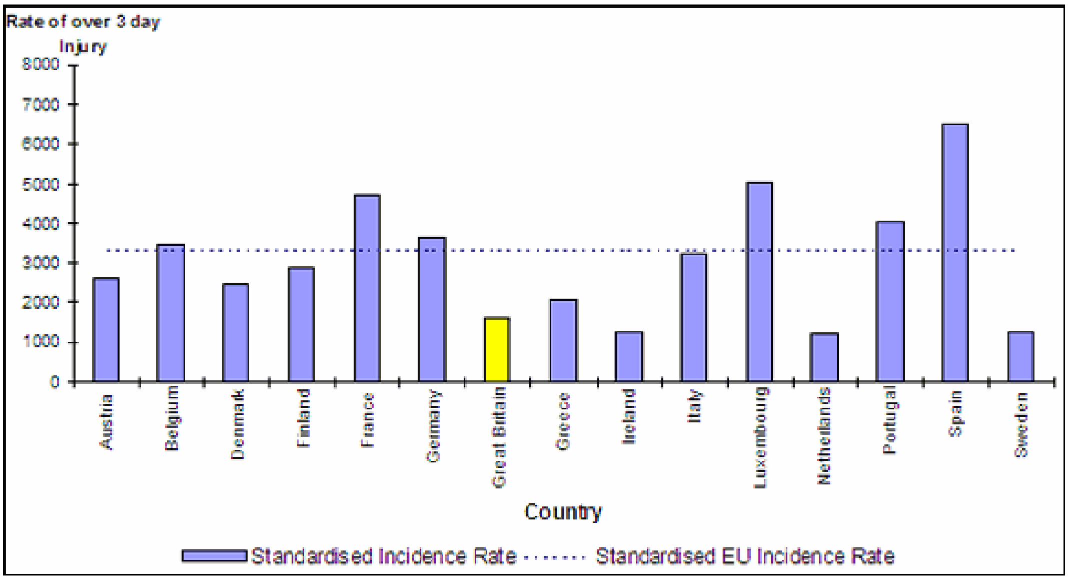

Figure 2.3 Standardised Incidence Rate of over 3 day accidents at work in Europe, 2003 (Health and Safety Executive 2006)

None-the-less the reporting of accidents by construction companies has been viewed as 'generally poor, coupled with a failure to collate and undertake effective analysis of the data collected' (Gyi et al. 1999).

2.4 Accidents

Construction work has been described to be non-repetitive and ergonomically dangerous, requiring heavy lifting and awkward postures, resulting in a high proportion of injuries and fatalities (Byung 1998). The most common kinds of fatal injury to workers in recent years have been falling from a height, being struck by a moving vehicle and being struck by a moving or falling object. In 2005/06, these three kinds of accident combined accounted for 54% of all fatal injuries to workers (Health and Safety Executive 2006).

This section highlights published accident statistics inherent to workers in the Road and Rail Industries.

2.4.1 Rail Workers Injuries

A previously discussed, safety within the rail sector can be dominated by high profile crashes and derailments of passenger trains such as Hatfield, but accidents and injuries sustained by rail workers in the construction and maintenance operations cannot be ignored. Figure 2.4 shows the number of rail workers fatally injured between 1975 and 2005 reproduced from HSE and ORR Records (Health and Safety Executive 2005b; Office of Rail Regulation 2007a). The sources and methods of reporting these statistics may not be directly comparable but the trend clearly shows track worker fatalities have generally reduced over the last 20 years from circa 20 per annum in the late 1970s and early 1980s, reaching lower figures in the 1990s to and increasing again in the new millennium. Historically most fatalities to track workers resulted from being struck by trains or road/rail machine plant but some fatalities have been contact with electricity (5 fatalities in 2003) or during unloading of materials from a wagon. Increasing number of deaths in recent years cannot solely be attributed to lax safety but more likely to be attributed to the increase in relevant work load. No government information is available correlating the number and type of construction or maintenance workload with worker injuries.

Figure 2.4 shows some interesting trends and has been 'zoned' for discussion. At first glance the steady falling trend in Zone A can be compared with a dramatic drop in fatalities in Zone B, corresponding to privatisation and skills outsourcing, whilst Zone C shows an increase in fatalities after Network Rail reclaimed maintenance works. This trend would suggest that worker safety was better managed in Zone B due to privatisation.

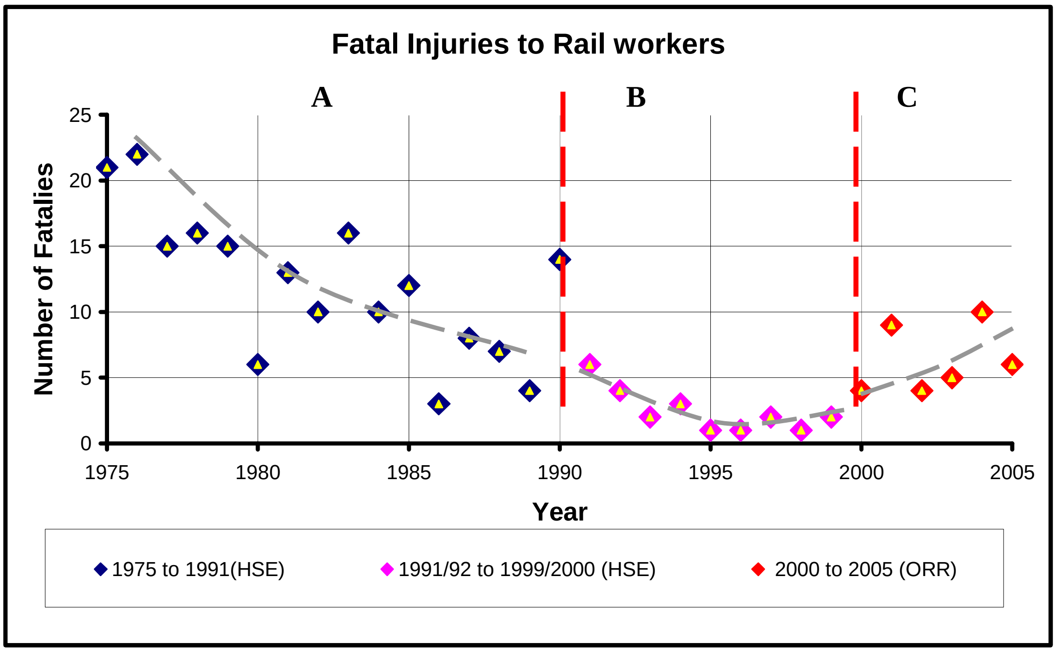

Figure 2.4 Fatal Injuries to rail Workers 1975 to 2005.

However, other factors must be taken into account and a quick praise of the UK's privatisation regime must not be hastily given. These factors suggest a microcosm and include:

- Differences in reporting strategies and associated political pressures justifying privatisation as a 'good decision'.
- Delay or lag time associated with dissemination, understanding, and compliance with regulations such as CDM (introduced in 1994, revised 2007) and new contract types. Increasing trends could signify complacency or re-direction of effort resulting with other internal / external initiatives.

- Increasing trend in Zone C could signify a loss of skilled workers or interaction problems caused by incoming workers from different work experience i.e. learning curve for highway or 'road' experienced workforce.

- Simultaneous degrading of infrastructure reaching a 'critical' time in rail life-span.

This last would suggest the trend in Zone C will continue to rise, irrespective of Network Rail reclaiming maintenance 'in house', unless serious investment for infrastructure replacement is commissioned. Present scales and prioritising methods for investment schemes can be likened to using a sticking plaster to solve an ailing leg joint when a hip replacement is the necessary.

2.4.2 Road Worker Injuries

It is very difficult to extract meaningful statistics relating to road workers as it is unclear if these are reported in either the HSE's Construction or Transport categories. 2005/2006 saw 8 of the 59 Construction Industry deaths (13.5%) occurring in the construction of highways, roads, airfields and sports facilities, whilst 18 of the 63 deaths (28.5%) to transport workers occurred in land transport. There is no indication if there are any deaths or injuries relating to road maintenance tasks. Realising that these statistics are not infallible and are only indicative, the number of deaths to road workers can be estimated at around 26 deaths in 2005/2006. There is little evidence of injury data in previous years for road workers.

However anecdotal evidence suggests injuries to road workers is far higher than rail counterparts (Highways Agency 2006). A campaign by the *Highways Agency* in August 2005 to inform motorist of the impact their driving towards worker safety, states the following:

> *"So far this year (2005), four workers have died and five have been seriously injured in incidents on Highways Agency routes in England. This compares to one death and 17 serious injuries in 2004 and two deaths and 10 serious injuries in 2003."* David Virden of Mouchel Parkman

In addition, a survey of the 400 road workers conducted in 2004 showed the following (Highways Agency 2006):

- Almost 20% said they had suffered some injury caused by passing vehicles in the course of their careers while working on the road network
- 3% sustained major injuries.
- 13% sustained slight injuries.
- 77% said they had suffered verbal abuse from drivers.
- 40% reported having objects thrown at them by motorists.
- 54% had experienced a near miss with a vehicle.

As there is little statistical data, it is reasonable to assume that had data been available the resulting trends would follow those exhibited by general injuries in the Construction Industry due to the similarity of work task.

2.4.3 Injuries in General

Consistently, the most common kinds of fatal injury to workers in recent years have been published by the Health and Safety Executive (HSE) as:

- Falling from a height.
- Being struck by a moving vehicle.
- Being struck by a moving or falling object.

In 2006/07 these three kinds together accounted for 51 % (126 of 241) of all fatal injuries to workers. Table 2.1 shows similar figures for proceeding years.

Year	Falls from Height , Struck by moving vehicles / objects	All UK Fatalities	Percentage
2006/07	126	241	51%
2005/06	114	212	54%
2004/05	134	220	61%
2003/04	140	235	60%

Table 2.1 Most common fatal injuries in UK Industries

(Health and Safety Executive 2004; Health and Safety Executive 2005a; Health and Safety Executive 2006; Health and Safety Executive 2007b).

Figure 2.5 and Figure 2.6 are taken from HSE publications and show the improvement in fatal and major injuries over the last decade (Health and Safety Executive 2006).

The Health and Safety Executive (HSE) estimates 75% of all fatal accidents in the building and civil engineering industries in the UK are generally caused by ineffective management action (Health and Safety Executive 1988)

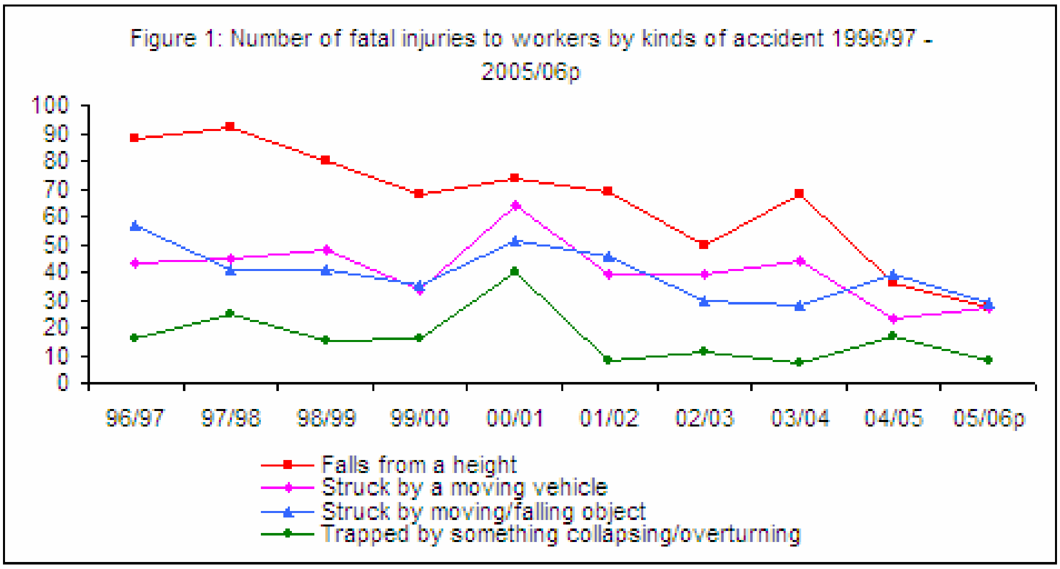

Figure 2.5 Fatal Injuries to workers (all industries) by accident 1996/97 to 2005/2006 *(Health and Safety Executive 2006)*

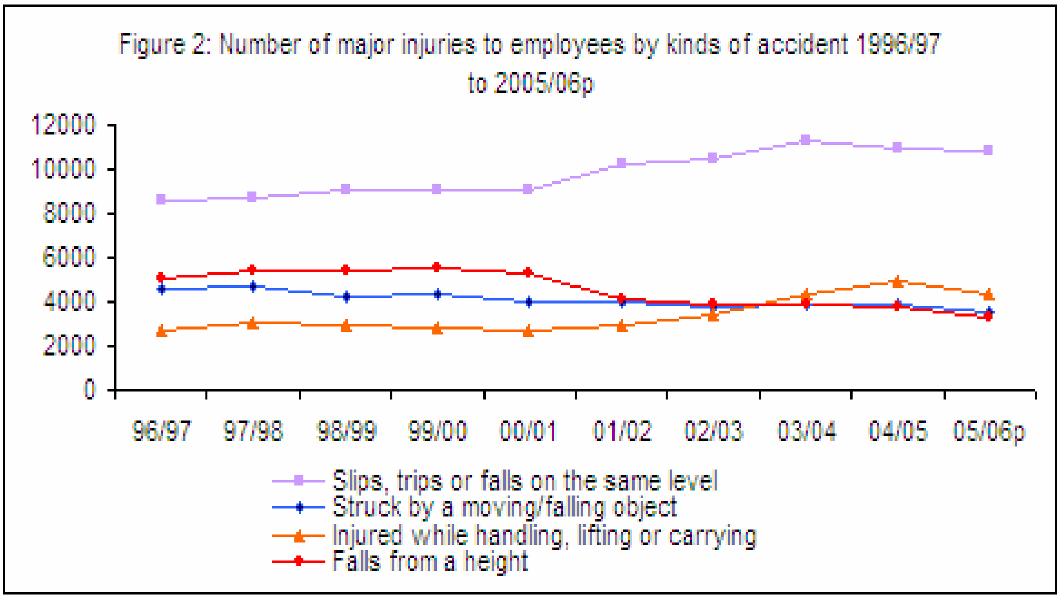

Figure 2.6 Number of major injuries by kind of accident 1996/97 to 2005/06 *(Health and Safety Executive 2006)*

The Labour Force Survey (LFS) is carried out by the Social and Vital Statistics Division of the Office for National Statistics. Its purpose is to provide information on the UK labour market under a European Union Directive using internationally comparable measures that can then be used to develop, manage, evaluate and report on labour market policies. The LFS estimates there is severe under reporting from the self-employed workers who are estimated to report less than 5% of non-fatal injuries; meaning that numbers and rates of injury are more meaningful for employees than the self-employed. Furthermore, links between sub-contractors numbers and increased accidents figures due to communication issues and lack of coordination have been proposed (Rowlinson 1997). This infers an increased frequency of accidents when third/fourth party subcontractors are involved unless greater effort in controlling management and communication processes is instilled in the work ethic.

Considering the effects of poor reporting, and failure to collate and take effective analysis, the reported statistics of non fatal accidents are likely to be overly optimistic and are linked to a lack of understanding and / or communication between parties at a reasonably high 'design level' to workspace users (Haslam et al. 2005)

UK Government statistics (Health and Safety Executive 2003b; Health and Safety Executive 2003c) has also shown the high fatality rate occurring to male construction workers aged over 55 years and those who are less familiar within the Construction Industry. This identifies two groups of workers who suffer greater risk than others; the 'New Worker' with little or no experience of the given site and the 'Retirement Age Worker'. This finding is consistent with other studies, such as Byung's research classifying national construction statistics for South Korea in terms of company size, work experience, accident type etc - over 90% of non fatal injuries and deaths occur during the first year of employment (Byung 1998).

Research into behaviour and decision making during a project has shown that accident numbers can depend on the project time line and reach a peak during the middle of projects (Humphrey et al. 2004). The same study shows that allocation of safety resources, in the case of the study financial expenditure, was relatively constant yet dipped during the middle section of the project. These trends are exaggerated and reproduced in Figure 2.7 and shows an area where these two tends coincide as having higher accidents *in potentia*.

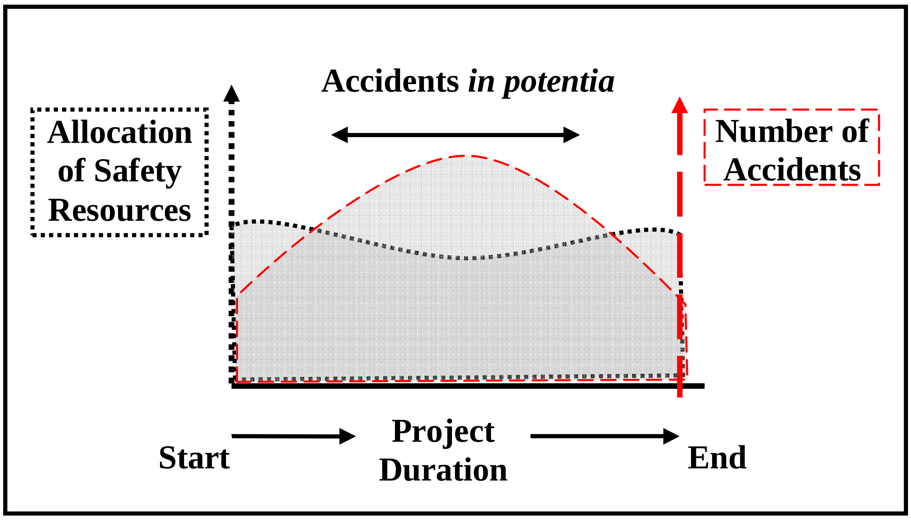

Figure 2.7 Safety During Project Cycle, adapted from Humphrey et al. (2000)

Thus accidents *in potentia* area could be further compromised as the number of new workers increases during the busiest and most labour intensive time of a project. Increased levels of recruitment of 'new hires' has been shown to correlate with higher rates of workplace injury (Health and Safety Executive 2005c).

Better monitoring and effective management of safety expenditure during the project lifetime and 'smoothing' peaks and troughs of labour acquisition / placement could ensure incoming 'new workers' benefit from the same safety allocation as those working from the start of the project. Also, this raises the question of company size and *'relative'* allocation of safety resources, such as small or medium enterprises (SMEs) or the self employed who may have limited resources and training available in comparison to large scale organisations (Harms-Ringdahl 2004).

A further interesting phenomenon is where these accidents happen. Research has found a significant proportion of accidents relate to off-task activities where method statements relating to specific tasks are not applicable, with few of these off-task activities appropriately scoped or assessed for risk (Haslam et al. 2005). This is corroborated by Health and Safety Executive statistics that around 1/5 of accidents are not linked directly to construction activities and occur off-task, such as preparation activities or moving around site (Health and Safety Executive 2003a; Health and Safety Executive 2003b). Nearly half of accidents may relate to work place factors such as poor house keeping and work scheduling, leading to inappropriate site layout and space availability (Haslam et al. 2005).

2.5 Revitalising Health and Safety

Despite improving safety trends, the general opinion is that Industry cannot afford to become complacent. This is shared by the House of Commons Transport Select Committee on the railways and also various authors of public inquiries into rail safety (Cullen 2001a; Cullen 2001b; Uff 2000). Two key publications are the *Revitalising Health and Safety Strategy* and *The Future of Rail White Paper*.

The June 2000 Revitalising Health and Safety Strategy Statement (Department of Environment Transport and the Regions 2000) contained the first ever UK targets for health and safety systems. These ambitious targets to be fulfilled by 2010 for all industries, and their progress are given in Table 2.2.

UK Targets	Reduction	Progress so far
Rate of work related ill health	20%	✗**Not** on track
Rate of fatalities and major injuries	10%	✓**On** Track
Rate of working days lost	30%	✗**Not** on track

Table 2.2 Revitalising Health & Safety Targets (Health and Safety Executive 2007a)

Rising to the challenge, the Construction Industry aims to surpass the national targets and reduce the rate of fatal and major injury to workers by 66% by 2009/10. This can be compared to the UK-wide targets to reduce the rate of fatal and major injury to workers by 10% over the entire economy within the same timescale (Department of Environment Transport and the Regions 2000; Health and Safety Commission 2004).

Although the HSE have not published the progress of the Revitalising Health and Safety campaign specifically to the Construction Industry, the 28% rise in construction fatalities in 2007, accounting for 77 of the total of 241 industry deaths is a great concern.

The Future of Rail White Paper (Department for Transport 2004) is another key document highlighting areas where rail safety could be improved, namely:

- Creating a streamlined process of risk assessment to replace the current regimented, over-emphasised standard-based safety procedure. This would bring Rail in line with other industries where such procedures can negate innovative safety issues and lead to expensive engineering solutions.
- Encouraging a cultural move towards a risk-based safety system where decisions are based upon analysis instead of standards followed unquestioningly, whatever their impact.
- The ORR is responsible for data and information storage to ensure one set of consistent data for use by Government and the industry, thus centralising information to reduce a major bureaucratic burden on the rail industry.

Both the HSE and the ORR regularly run safety campaigns and working groups to facilitate these dramatic changes. Both government groups inform employers of the many UK regulations and legislative acts to ensure the health and safety of the general public and their employees and subcontractors in industry (see ***Appendix C***).

The next section gives more details on one of these regulations: the Construction (Design and Management) Regulations 2007 along with discussion on other issues for improving safety.

2.5.1 CDM 2007

CDM is a common abbreviation for the UK Construction (Design and Management) Regulations, first introduced 1994 and revised in 2007.

Industry-wide consultation in 2002 lead to the decision to revise CDM, in the hope of reducing the bureaucracy that had frustrated many of the CDM 1994 duty holders, including:

- Main Contractor.
- Client.
- CDM Co-ordinator.
- Designer.

The new CDM 2007 Regulations offer a single regulatory package including a revision to the previous CDM 1994 publication and inclusion of the previously separate Construction (Health Safety and Welfare) Regulations 1996. The CDM (2007) Regulations are divided into 5 parts:

- Part 1 deals with the application of the Regulations and definitions.
- Part 2 covers general duties that apply to all construction projects.
- Part 3 contains additional duties that only apply to notifiable construction projects, i.e. those lasting more that 30 days or involving more than 500 person days of construction work.
- Part 4 contains practical requirements that apply to all construction sites.
- Part 5 contains the transitional arrangements and revocations.

An Approved Code of Practice (ACoP) has also been issued to aid those working under CDM 2007 by offering practical examples of good practice and provides guidance to what is *'reasonably practicable'* to comply with this law. Approved Codes of Practice have a special legal status, as disregard of an ACoP may result in prosecution unless compliance with health and safety related law can be proven in another way. Practitioners who demonstrate they have followed ACoP advice comply with the law in respect of those specific matters on which it gives advice.

The ACoP for CDM 2007 explains:

- The legal duties placed on clients, CDM co-ordinators, designers, principal contractors, contractors, self-employed and workers.
- The circumstances in which domestic clients do not have duties under CDM 2007 (but the regulations still apply to those doing work for them).
- Gives information on the new role of CDM co-ordinator – a key project advisor for clients and responsible for coordinating the arrangements for health and safety during the planning phase of larger and more complex projects.
- Which construction projects need to be notified to HSE before work starts and gives information on how this should be done.
- How to improve co-operation and co-ordination between all those involved in the construction project and with the workforce.
- What essential information needs to be recorded in construction health and safety plans and files, as well as what should not be included.
- How to assess the competence of organisations and individuals involved in construction work.

The last point of competency highlights a very topical problem: the UK skill shortage.

2.6 Skill Shortage, Company Culture & Future Growth

A further problem to the industry, impacting upon the direction of the research project, is the dilution of tacit knowledge within construction companies. This is in part due to the UK skill shortages (Egan 1998) and an aging and retiring working population.

The skills shortage has effected other related engineering disciplines with UK universities unable to supply enough graduate engineers (Spinks et al. 2006; The New Civil Engineer Magazine:Spotlight Article 2006). This is not confined to the UK as the American Society of Civil Engineers(ASCE) has reported that three quarters of firms in the USA rank skills shortages as their top worry (Owen 2006a).

In addition, the cultural mix of the available work force demonstrates different needs compared to the older generation workforce. This in turn is contributing to increased staff turnover as companies fail to grasp workers social, cultural and work life balance needs. A case in point is the report by New Civil Engineer Magazine that almost half (46%) of those partaking in a job satisfaction survey cited poor salary as a motivator to leave their present employer with other factors such as being undervalued and / or poor staff benefits. Those who were satisfied with their present job cited their variety of work, good job prospects, feeling valued and working close to home as their most important factors (The New Civil Engineer Magazine 2006a)

The eventual replacement of UK national structural design codes and standards by the European Building Regulations or 'Eurocodes', along with recruitment of foreign manual workers, may ease this pressure but presents different dilemmas; how to dynamically collect, store and transfer safety critical knowledge from one generation to another whilst considering differing technical language, culture, experience and training.

Without efficient use of engineering and managerial staff the Construction Industry may risk delays and high costs in future infrastructure ventures such as CrossRail and the 2012 London Olympic Games (Baker 2008; The New Civil Engineer Magazine: News Article 2006a).

In addition to specific transport needs for the 2012 London Olympics, future major work currently includes:

- Nottingham Express Transit - £578M investment in tram system (The New Civil Engineer Magazine 2006b).
- £2.4bn expansion and upgrade of Thameslink stations (Owen 2006b)
- The northern extension of London's Docklands Light Railway includes 6km of route running from Canning Town to Stratford International. Completion of the £200M project is due in 2010, ahead of the 2012 Olympics.
- London's £10.3bn Crossrail project connecting railway networks east and west of London via tunnels under the capital between Paddington, Liverpool Street and Docklands (Hansford 2006a).
- With an estimated 10% growth in freight traffic over the next few years a £4M project is underway to upgrade 430km of east coast line between Elgin and Mossend near Glasgow (Greenman 2006).
- Phased widening of 100km of M25 to four lanes in each direction (2008-2016) and 30 year maintenance contract worth around £100M a year (Hansford 2006b)
- European Rail traffic Management System (ERTMS), a new £59M signalling system, is due to be trialled in North Wales in 2008 (Young 2006)
- Continuation of the Scottish Maintenance and Management of Trunk Roads Contracts (The New Civil Engineer Magazine: News Article 2006b)

- Replacement Forth Road Bridge (Scotland) and associated transport infrastructure estimated around £3.25 billion expects completion by 2016 (Baker 2008).

Currently construction represents approximately 10% of the UKs Gross Domestic Product. The estimated 27% rise in government spending since 2000 to £37billion along with Private Finance Initiative (PFI), Public Private Partnerships (PPP) and Early Contractor Involvement (ECI) schemes has boosted the Construction Industry, especially road and rail infrastructures (Arnold 2006).

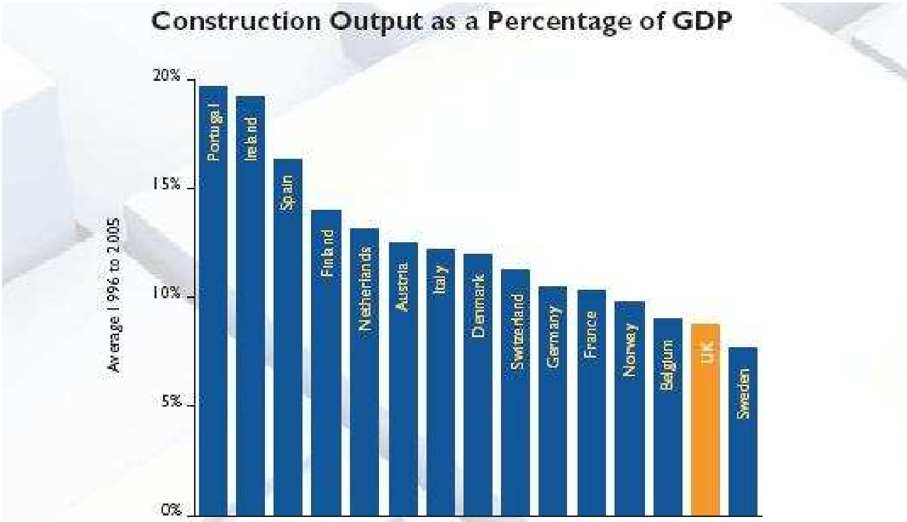

Figure 2.8 Construction as percentage of Gross Domestic Product (Construction Products Association 2006)

None-the less, Figure 2.8 shows the UK at the lower end of the European scale, perhaps atttibuted by the following:

- The UK overall value of GDP could be higher than other countries, thus reducing the percentage rate for construction.
- The UK has an ‘established’ infrastructure, unlike Portugal for example.
- The UK being a physically smaller country therefore may be more comparable to more financial based countries, i.e Singapore.

- The UK may have smaller freight movement due to being an island with the only physically connection to Europe via the Channel Tunnel.

- The economic strength of the UK currency may have biased these results by being unable to compare 'like for like' i.e. economic impact on trading construction materials between Europe and Asia.

2.7 Discussion and Research Direction

This chapter identifies the role of transportation infrastructure within the UK Construction Industry with a specific focus on safety issues.

The UK construction industry is one of the largest employers - it is also one of the UK's biggest *killer* industries for workers. Despite a reduction in worker deaths over the last two decades, the UK cannot be complacent and must continue to strive towards ambitious targets set by the *Revitalising Health and Safety Strategy Statement*. Regulatory authorities report around 5 to 10 workers die every year in the Rail Industry whilst deaths relating to Road Infrastructure can be estimated in the 20s (ambiguity, however, lies in reporting categories).

Statistics from reinforce the issue that lack of safety knowledge and expertise both in specific and general terms contribute to fatalities and injuries to those working in Infrastructure Management. The following trends were noted:

- Safety is slowly improving and accident numbers are generally decreasing.

- Road and Rail worker trends are not strictly comparable but suggest rail workers are safer than road workers (6 rail fatalities vs 26 road fatalities in 2005/2006). This does not take into account of relation of fatalities to 'man hours' on site or the coverage / linear distance involved in the associated infrastructure.

- Two worker types have been identified as high risk:
  - 'New Worker' with little or no experience of the given site
  - 'Retirement Age Worker'

- Around 1/5 of accidents happen 'off task'

- Relationship between project lifecycle, expenditure of safety resources and accident rate has been cited as an area of concern. A link between labour scheduling in conjunction with these factors is also plausible.

The present condition of both Roads and Rail are inherited from past construction and maintenance or legacy issues. Existing rail infrastructure also dictates future design such as the inability to use double-decker trains whilst issues of road maintenance, existing capacity and congestion charging have climbed higher on the political and environmental agenda. The devolvement of Scotland, Wales and Northern Ireland presents an interesting situation for both road and rail industries.

The *perceived* level of safety in infrastructure is overshadowed by high profile public train crashes. Conversely, there appears to be less outcry over the 1000+ driver and passenger accidents happening every year on UK roads - or is this yet to come? Devolution has brought many changes to the way UK roads are managed including outsourcing of maintenance and management schemes to contracting companies. The narrow public mindset and low tolerance towards those failing to communicate safety critical knowledge effectively and efficiently may transfer to the Roads Industry.

High public interest and escalating legal culpability signify a step change in the way companies must manage and act upon safety critical information and knowledge. This is further recognised by regulatory bodies with official comments stating 'Inadequate planning of work has been a feature of fatal and major workforce incidents' (Office of Rail Regulation 2005).

Lastly, current work in the Transport Infrastructure Sector is booming with many more projects planned for the next decade. Worker safety must continually improve to demonstrate the Infrastructure Sector is worthy of such ambitious projects and positive accolades must attempt to combat the UK 'trial by media' society. In addition to these knowledge management issues, companies must direct the skills of their staff efficiently to negate the impact of skills shortages.

2.8 Conclusions

This chapter highlights the importance of infrastructure assets road and rail towards maintaining and improving UK economy.

As a subset of the UK's Construction Industry, the Infrastructure Industry poses risk of injuries and fatalities to its workforce and poor safety knowledge and lack of expertise, have been identified as significant contributions to these statistics.

In addition, the increasing trend of litigation, company reprimands and individuals being charged and imprisoned signify a step change in the way companies must manage and act upon safety critical information and knowledge.

The following three chapters focus on research avenues aimed towards further understanding these problems and developing a solution:

- Chapter 3: Risk & Hazard Management.
- Chapter 4: Managing Safety Knowledge.
- Chapter 5: Artificial Intelligence Methods.

CHAPTER 3: RISK & HAZARD MANAGEMENT

Hazards within transportation based projects may cause serious harm – not only to company employees but also to the general public. These hazards, their associated risks and mitigations must be managed in order to reduce the possibility of accidents and lighten harm severity.

Most legislation delegates the technical control of hazards to those who create them. This chapter provides an insight into current practices used to manage such ‘technical control’ in industry: risk assessment and risk management processes. Possible weaknesses within these current practices are identified and research direction is proposed as an attempt to address such issues.

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3.1 Introduction

Accidents and their impacts have been described and quantified in Chapter 2. These can be seen as unexpected / undesirable events leading from an unmitigated *risk* or an unidentified *hazards*. In brief, hazards are circumstantial events or physical substances that can potentially cause harm to people, property or processes, whilst risks are classed as the combination of the likelihood and severity of these given hazards occurring.

This chapter introduces the concepts of identifying / managing hazards and risks, discussing integral safety management processes towards reducing accidents and ultimately saving workers' lives.

The chapter is structured in seven sections:

- **Section 1 – Introduction**

Introduction and chapter structure is given.

- **Section 2 – Clarifying Hazards and Risks**

This aim of this section is to clarify the different processes attributed to hazard and risk management in order to reduce fatalities and injuries to workers in infrastructure management. Hazard processes are identified as critical towards improving the safety of infrastructure worker.

- **Section 3 – Safety Management**

The *Safety Management Flow Chart* demonstrates the established *Risk Management Cycle (RMC)* depends upon hazard identification and analysis processes. Also, the established *RMC* model does not account for ALARP (*As Low As Reasonably Practical*) tolerance levels and an enhanced to the *RMC* model is proposed to allow continual improvement.

- **Section 4 – Past Research**

Four research categories are identified towards improving safety for infrastructure workers; *Knowledge Management*, *Artificial Intelligence Methods*, *Monitoring Tools & Frameworks* and *Behaviour / Cultural Issues*. *Knowledge Management* and *Artificial Intelligence Methods* are identified for further research in Chapter 4 and Chapter 5 respectively.

- **Section 5 – Infrastructure Workers 'At Risk'**

Anecdotal evidence suggests risk analysis methods used to keep infrastructure workers safe are predominately qualitative and experience based. Two examples of risk assessment bring into sharp focus that the methods of hazard and risk management processes often between companies with little similarity even within the same project.

- **Section 6 –Discussion and Research Direction**

Many hazards associated with preparatory stages are currently not being correctly identified; hazards that are not identified cannot be effectively managed. It is proposed that the development of a *Tool* can aid hazard identification processes and provide improved performance at individual, team and organisational levels.

- **Section 7 – Conclusions**

The main conclusions of this chapter are:

  - Unidentified hazards act as bottle-necks in the risk management process.
  - There is little evidence of the effectiveness of mitigations.
  - There is high reliance on worker competence acting as control measures during risk analysis stages.

3.2 Clarifying Hazards & Risks

The UK Government, like many other countries, delegates the technical control of hazards to those who create them, concentrating their role instead towards policy making and assessment of safety related management systems (Swuste and Arnoldy 2003). Industry's answer is the use of *Risk Management* processes.

The British Standard BS4884-3:1996, identical to European standards IEC 300-3-9:1995, provides guidelines to risk analysis and defines the following (BSI 1996):

- *Harm* – physical injury or damage to health, property or the environment.
- *Hazard* – a source of potential harm or a situation with a potential for harm.
- *Hazard identification* – the process of recognizing that a hazard exists and defining its characteristics.
- *Risk* – combination of the frequency, or probability, of occurrence and the consequence of a specified hazardous event.
- *Risk Assessment* – the overall process of risk analysis (identification and estimation) and risk evaluation (measurement and tolerance).
- *Risk Management* – the systematic application of management policies, procedures and practices to the tasks of analysing, evaluating and controlling risk.

BS4884-3:1996 explains that these concepts are unilateral to many disciplines, hazard groups and risk categories. Examples of these are given in Table 3.1.

Disciplines	Risk Categories	Hazard Group
Systems Analysis	Individual	Technological
Probability & Statistics	Occupational	Social
Engineering	Property Damage & Economic Loss	Lifestyle
Management Science Human factors	Societal	Social Science
Health Science	Environmental	Natural
Social Science		

Table 3.1 Examples of Industrial Disciplines, Hazard Groups & Risk Categories, adapted from BS4884-3:1996

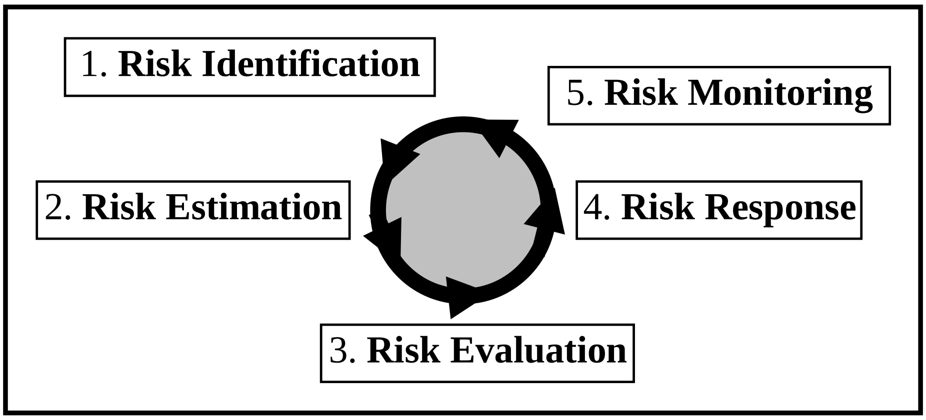

Figure 3.1 Established Risk Management Cycle adapted from Baker *et al* (1999)

The established *Risk Management Cycle* (RMC) is shown in Figure 3.1 (Baker *et al.* 1999). Although BS4884-3:1996 does not explicitly express each of these stages in this form, definitions from this document are paraphrased below:

- *Risk Identification* is formalised after significant hazards have been identified. Hazard Analysis includes hazard identification, classification and assessment of associated mitigation techniques to establish whether hazards can be avoided or that they will not affect the dependability of a working system (Smith and Harrison 2005). Where hazards are eliminated and / or their consequences are deemed insignificant, analysis may be discontinued at this point and assumptions and deciding judgements documented.

- *Risk Estimation*, or the calculation of risk, can be expressed as predicted mortality rates, frequency versus consequence plots and / or expected loss rates. A common method is to determine a risk level by combining the frequency of hazard event with and severity of associated consequences. Assignment of frequency and severity values, in addition to associated weightings, allows the level of risk to be estimated as the product of these two terms e.g.

Severity x Frequency = Risk Level.

Frequency and severity values can be estimated by either qualitative or quantitative methods. Qualitative methods are classified by descriptive arguments, such as a range 'low to high', or enumerated on a predefined scale (Cuny and Lejeune 2003; Smith and Harrison 2005) whilst quantitative examples include:

  - Statistical analysis e.g. regression, least squares, path analysis.
  - Artificial Intelligence Methods such as Expert Systems.
  - Probability Theory.
  - Bayesian Inference.

- *Risk Evaluation* determines whether risk is tolerable or warrants a response. This phase can be conducted using quantitative, qualitative methods or a combination thereof. Table 3.2 gives some examples, however a more comprehensive list can be found in BS4884-3:1996. Risk tolerance is still a developing area of research of its human dynamics. An example of risk tolerance is whether or not companies decide to tender for new projects (Kahneman and Lovallo 1993). Risk tolerance has been linked higher improved decision-making performance and resource efficiency in addition to lower costs and shorter project durations (Kwak and LaPlace 2005). However, there is undoubtedly a juggling act between good and bad outcomes; taking large risks to enable opportunity, balancing the overall result (Kwak and LaPlace 2005).

- *Risk Response* includes:
  - *Avoidance* or elimination of hazard.
  - *Retention*, whereby risk falls below a given level or range, deemed acceptable or tolerable level. No further response is necessary.
  - *Transfer* of the risk to a third party (i.e. employing subcontractor or insurance premiums)
  - *Reduction* of the severity or frequency associated with given hazard. This may produce a residual risk that lies within a tolerable zone.

- *Risk Monitoring* ensures the responses are performing adequately throughout the lifecycle of the system, facility or activity. Thus can be achieved using audits and / or retrospective evaluation analyses.

Quantitative	**Qualitative**
Bayesian Analysis	Individual experience
Sensitivity analysis	Engineering judgement (gut feeling)
Delphi Peer group	Brainstorming / Group Work
Cost benefit analysis	
Decision Matrix & Decision trees	

Table 3.2 Risk Evaluation Methods (quantitative & qualitative) adapted from BS4884-3:1996

The *Safety Management Flow Chart* in Figure 3.2 incorporates the hazard inputs and processes necessary to fulfil the five *RMC* processes (see Figure 3.1). This flowchart recognizes several important issues that are ignored in the established model, namely:

- Complete dependence on hazard processes:
  - *Hazard Identification*, acts as the main 'bottle neck' and barrier to risk identification
  - *Hazard Analysis* must be performed to allow estimation and evaluation of risks based on proposed responses.
- Internal cycle and iteration between risk evaluation and estimation stages based on hazard analysis process and results.
- Continual improvement by searching for 'new risks' as well as evaluating previously identified risks, linking Risk Monitoring and Estimation stages.
- Deviation from the model could result in accidents in 3 specific hazard related locations; *Risk Identification*, *Risk Evaluation* and *Risk Monitoring*.

These findings corroborate research linking confidence in risk management directly to the rigour and accuracy of hazard analysis (Smith and Harrison 2005).

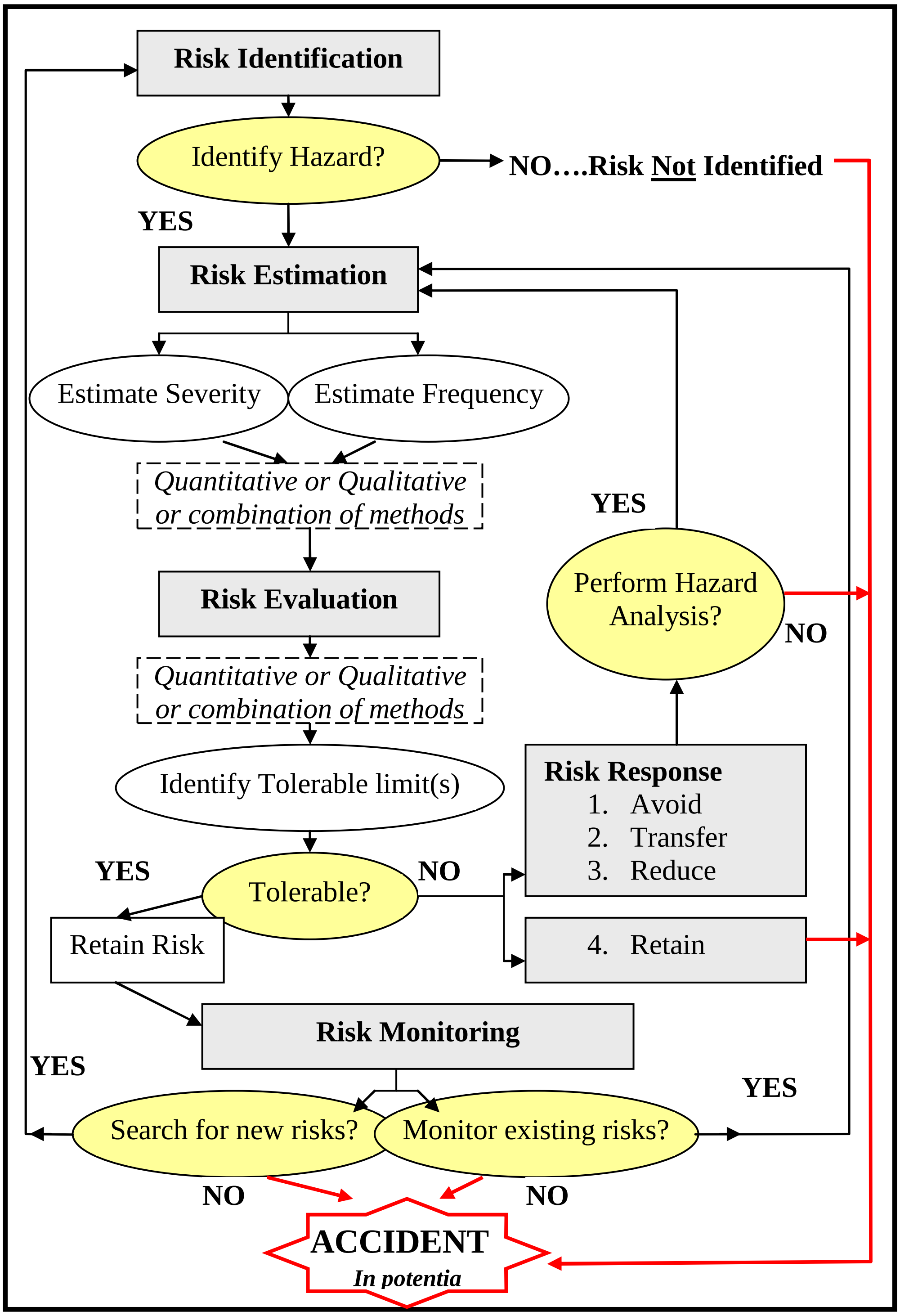

Figure 3.2 Safety Management Flow Chart

3.3 *Safety Management*

Safety Management exhibits the same processes as described in the *RMC* model but within this specific setting and includes the systematic application of management policies, procedures and practices to the tasks of analysing, evaluating and controlling safety risks (Papadakis and Amendola 1997). This also includes safety policy, initiatives, programs, training, campaigns, future research etc.

Occupational accidents are never intentional and can occur through risk being unidentified, incorrectly analysed or the response being ineffective. This section examines hazards and risk within the safety setting, ultimately towards *Keeping Bob Safe* (see Chapter 1)

Figure 3.3 shows various disciplines, risk categories and hazard groups identified in BS4884-3:1996. The fields applicable to the current research focus are highlighted in yellow (see also Table 3.1).

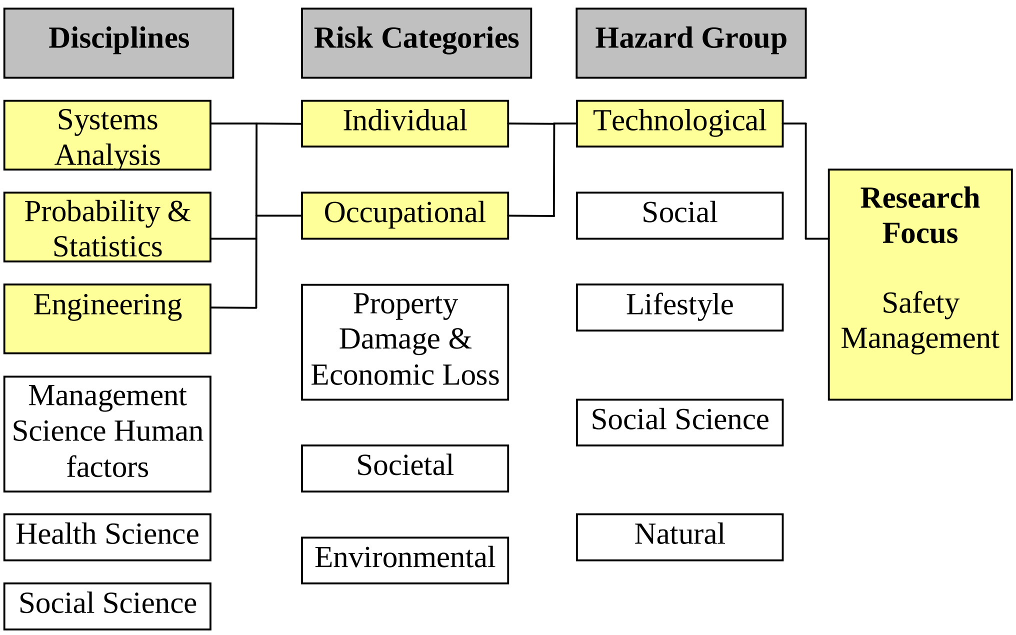

Figure 3.3 Research Focus

3.3.1 Safety Hazards & Risks

Accidents have been attributed to poor identification of hazards at a high level or inconsideration by those responsible for design, supply and purchase of material and equipment (Alistair et al. 1997). Some examples of hazards identified from previous construction-based research are given below (Alistair et al. 1997):

- Unsafe working conditions at heights.
- Stepping on, striking against or tripping over objects.
- Poor lighting conditions.
- Collapse of working platforms i.e. scaffoldings.
- Lifting operations.
- Electrocution.
- Fire hazards.
- Lack of proper access.
- Inadequate education and training.
- Engagement of poor tools and equipment.

Many *safety hazards* are identified in numerous publications by government bodies, researchers and industry. These publications can be classified into three main groups:

- *Retrospective analyses* involve investigating causes and interconnected relationships of specific accidents (causal models).
- *Opinion polls* using questionnaires, surveys and interviews to compare individuals or corporations findings with established hazard analysis methods and / or case studies.
- *Prospective Analysis*. These identify hazards based on 'what if…?' scenarios through systematic reasoning and /or graphical techniques.

The most prominent in the day-to-day safety management is prospective analysis, and of special note is the *HAZOP* method. *HAZOP* stands for Haz ard and op erability studies and originated in process based fields of chemical process engineering *HAZOP* is used to systematically identify every conceivable deviation from the original intention of events or processes, allowing all the possible abnormal causes and the adverse hazardous consequences of the deviation to be determined (Kletz 1992; Vaidhyanathan and Venkatasubramanian 1996a). HAZOP-type methodologies are common in the literature along with industry specific variations and sub headings for consideration (Tixier et al. 2002). However, HAZOP type analysis can be a laborious task, involving teams of experts.

Evaluating *safety risks* and tolerable levels can be complicated with regard to the legal requirements imposed on Industry. The *Health and Safety at Work etc Act (1974)* (Health and Safety Executive 1974) states in the 'General duties of employers to their employees':

> *"It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his employees."*

ALARP is a common term in Industry relating to this statement and is an acronym for '**A**s **L**ow **A**s **R**easonably **P**ractical'.

There is no robust definition of what constitutes '*Reasonably Practical.*'. The ALARP threshold level is set retrospectively by courts to reflect social demand which is constantly changing (Rail Safety and Standards Board 2005).

Smaller companies tend to employ *safety management personnel* who are responsible for managing the safety hazards and risks within the company in the absence of formulated safety policies (Harms-Ringdahl 2004). One of the main debates in these legal proceedings is whether 'poorer' companies should be excused higher tolerance regimes due to financial restraints, whereas this same level in a 'wealthy' company would result in negligence. Such companies often perform a cost-benefit analysis as a decision making aid, simplified as the cost of a mitigation set against the cost of the undesired event.

The UK Rail Industry estimates the costs of accidents to be in the region of £1.36M per fatality although the overall cost is closer to £10M when consideration is given to associated costs such as public enquiries, compensation payments, loss of time/earnings, additional management costs and court fines (Rail Safety and Standards Board 2005). The cost of proposed safety initiatives over time is therefore compared to savings in fatalities and where more than one option is available, like-for-like comparison between initiatives can be made. Other factors are often combined in these types of analysis to produce a more coherent estimation of *'value-for-money'* comparisons.

Monitoring residual risks, along with the effectiveness of existing response measures, are critical steps to ensure identified risks are being suitably managed. Equally important is the continual effort to identify new and previously unidentified risks. However, the established *RMC* model shown in Figure 3.1 does not take tolerance associated with ALARP into account. It is proposed that the *RMC* model can be enhanced to facilitate ALARP by adding a *Reasonably Practical Tolerance Zone*. This is shown in Figure 3.4 as a decreasing tolerance zone in red along with the five *RMC* processes as a tightening 3-D *'spiral'*. This highlights the importance of effective risk management processes in striving to actively reduce ALARP levels in line with continual safety improvements and societal expectations.

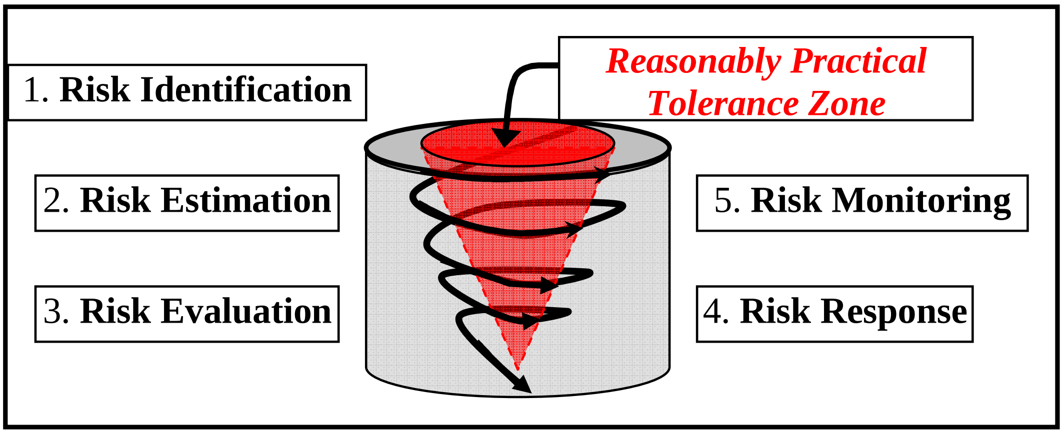

Figure 3.4 Continual Improvement Risk Management Spiral

3.4 Past Research

Research aimed to improve safety for infrastructure workers has taken many forms but can be seen as residing in one of four categories:

- Knowledge management
- Artificial intelligence methods
- Monitoring tool and frameworks
- Behaviour / cultural issues

Knowledge Management and decision support systems tend to rely heavily on manual data collection and interpretation. For example, investigating and drawing inferences from case studies such as paper based accident reports. The advantages of the system mean someone of little knowledge or experience can use the collective knowledge or 'knowledge base' to make a better informed decision. Effective communication and information transfer between management and employees has been shown to yield better safety standards and enhance safety policies (Holt 2001). Examples include:

- Identifying variables contributing to a group of accidents (Haslam et al. 2005)
- Health and safety management systems including the opportunities/benefits provided (Ray and Rinzler 1993) and the barriers encountered (Hinze 1997; Levitt and Samelson 1993) .
- Safety audit checklists to monitor safety performance of construction sites (Duff et al. 1994)

Monitoring Tools can be used to enhance the existing safety management policy by flagging up areas of weak safety. This type of system also reduces human and mathematical errors as data is now directly entered by the user and data collection and calculation is now performed by the computer.

In addition to being highly bureaucratic, another downside of these systems is a tendency to become:

- Orphaned if maintenance is not ongoing to ensure validity.
- Scrapped due to inaction of management to correct identified problems.

Some examples of this type of research include:

- The use of incentives and performance assessment to enhance workplace safety (Cooper et al. 1994; McAfee and Winn 1989).
- measuring the effectiveness of safety campaigns and performance of safety objectives using checklists, inspections, attitude surveys, walk-throughs, and document / record analysis (Haupt 2002).

Artificial Intelligence methods can be viewed as a ‘black box’ where the user’s inputs and factors are processed to give the end solution. These systems can require sophisticated modelling techniques (neural networks etc) and rely on training sets based on:

- Past occurrences transposed from original documents into the programming language. These are reliant on a large knowledge base with ongoing maintenance, monitoring and re-evaluation of the system
- Recording, interpreting, coding and transposing the conversation and methodology of experts the as they solve a given problem

Examples include:

- Applying probability theory to predict undesired events or accidents in situations (Cuny and Lejeune 2003).
- Prediction of safety levels of marine vessels based on marine input variables such as vessel type, location, cargoes etc (Hashemi et al. 1995)
- Development of nuclear safety systems (Lee and Seong 2005; Renders et al. 1995; Ziver et al. 2004) and Light Water Research Reactors (Mazrou and Hamadouche 2004).

- Decision support for aircraft safety inspectors (Luxhoj and Williams 1996; Shyur et al. 1996).
- Accident diagnosis) (Lee and Seong 2005).
- Safety assessment of existing structures (Deng et al. 2005; Lee et al. 2005; Yun and Bahng 2000).

Behaviour / cultural issues, along with managerial attitudes, can be seen as a subset of the overall organization of the company culture. (Holt 2001). Poor attitude and behaviours are difficult to monitor and control although employee perception surveys have been used to test attitudes and effectiveness of promotional safety campaigns (Toole 2002). To this end, Behaviour-Based Safety (BBS) has been widely adopted by the industry as the basis of safety and health workshops, induction talks, charters, and other safety endeavours (DePasquale and Geller 1999). BBS can aid safety culture changes by setting out the goals of the organization and highlighting the safety responsibilities of various parties accordingly.

Studies have also suggested the BBS model can facilitate interpersonal trust, management support, and active employee participation (Bandura 1997; Cheung et al. 2004).

- Workers' behaviours and attitudes (Cox and Cox 1996; Feyer et al. 1997; Lingard and Rowlinson 1997; The Health and Safety Executive 2000; Waring 2005).
- Training and workshops (Glendon and McKenna 1995; Goldenhar et al. 2001; Hammer 1989)
- The value and culture of safety management systems (Krause 1993; Smallwood 2002)
- Development of other theoretical 'root cause' models with attention to site personnel, their behaviour and actions (Haslam et al. 2005). (Duff et al. 1994; Gibb et al. 2001; Suraji et al. 2001)

3.5 Infrastructure Workers 'At Risk'

Hazards encountered by workers in Transportation Infrastructure are not unlike those of other construction work but may have some subtle differences. The issues below are not exclusively 'transportation' yet demonstrate the types of constraints often found in this Industry:

- Work can be influenced by the behaviour of un-controlled third parties such as drivers or the public. There is intense public and political pressure to ensure the given 'infrastructure' remains open and usable with closure only accepted when deemed absolutely necessary.
- Some work tasks are repetitive and / or seasonal by nature, such as grass cutting or winter maintenance.
- With the exception of bridge-type work, infrastructure tasks are more likely to be carried out at (or near) ground level.
- Smaller work teams may be needed due to limited site space and can be more geographically distributed, e.g. several smaller teams (fewer than 10 workers) along a rail line working with no visual contact.
- The work environment can be dynamic and traffic management such as contra flow systems on roads (Department for Transport 2001) whereas 'zoned working' in rail to safeguard workers is more prevalent.
- Providing these safe systems can be constrained by political pressure to achieve time and cost limitations. Many work tasks are scheduled for off-peak, holiday and other unsociable hours; adding inclement weather, low temperatures, long shifts and poor family/work balance factors to the work environment.

Systematic hazard analysis (HAZOP etc) can involve significant personnel effort and time commitment (Pumfrey 2000; Smith and Harrison 2005). Common methods of identifying these hazards in industry involve imaginative anticipation of hazards and operation problems based on individual experience(s) and group discussion and / or brainstorming-type activities. However, there is little evidence whether hazard events identified in this manner are 'exhaustive'.

A few pertinent findings from recent publications include:

- Large-scaled construction companies generally have better safety performance and fewer accidents due to the high level of safety support and commitment shown from the top management (Hinze and Raboud 1988; Mattila et al. 1994).
- Complexities involving communicating and coordination of sequential work between contractors and sub-contractors can result in situations where a smooth work flow is virtually impossible (Vedder and Carey 2005).
- Main contractors may shift all safety responsibilities to subcontractors and neglect to ensure subcontractors are capable of providing a safe working environment (Wilson and Koehn 2000)

3.5.1 Workers Risk Assessments

The Transportation Industry relies heavily on *qualitative risk assessments* to ensure the safety of its work force. This is due to lack of time and resources needed to collect and process quantitative data. The majority of these risk assessments are based on technical factors, however individual organisational and / or cultural issues should also be considered such as financial constraints or political pressures. Examples of these risk factors in a construction setting include:

- Technical and socio-technical systems (Annet and Stanton 2000; Harms-Ringdahl. 2001)
- The influence of 'Risk Factors' such as operator actions, site conditions and construction practices and 'Managerial Processes' towards accidents in construction (Suraji et al. 2001).

Risk analysis for occupational health and safety of workers predominately relies on qualitative yet statistical approach expressing risk levels for specific periods or locations as tables, diagrams, curves, indices etc (Cuny and Lejeune 2003).

Two examples of technical risk assessments excerpts are reproduced and shown in Table 3.3 and Table 3.4. These excepts are taken from the method statements used during the reopening of a railway line in Scotland in 2004/2005 entitled ‘excavating trial pits’ and a ‘station car park’. The first example (Table 3.3) was undertaken by a subcontractor and shows ‘risk rating’ before and after the introduction of control measures or mitigations. The second example, from the Main Contractor, appears to only show the residual risk level after the same risk reduction process. The residual and retained risk highlights the scale of tolerable limits.

Risk	Consequence	Risk Rating	Control Measure	Risk Rating after control
Repair material affecting skin	Skin irritation	18	Wearing suitable PPE, including gloves	8
Manual handling injury	Back Injury	18	Competently trained staff under supervision following approved method of working	8
Contaminants affecting skin	Skin Irritation	18	Wearing suitable PPE, including gloves	8

Table 3.3 Risk Assessment ‘Excavating Trial Pits’, PH/MS0013

In Table 3.3 the risk level of 18 has been deemed as beyond this limit and warrants a control measure to reduce the rating level of 8. In this example there is no indication of how the levels of 18 and 8 were derived. There is also no evidence that the introduction of the given control measurement warrants this reduction of risk from 18 to 8. The derivation of risk level in Table 3.4 can be seen as being the multiplication of the frequency and severity values. However there appears to be little *actual meaning* to these values other than as experience, based upon 'guesstimates' by the originator of the risk analysis.

Item	Risk	Rating			Control Measure
		Severity	**Frequency**	**Total**	
Working with heavy plant	Struck by plant resulting in serious injury, possible fatality	5	1	5	Site Briefing. Banksman with machines, competent plant operatives, certified by approved training organisation. Records kept on file. Only enter area when required.
Drainage / ducting excavations	Trench collapse, falls into excavation, contact with underground services and un authorised access to the public	5	1	5	All work to be supervised by a competent person. A barrier will be erected and maintained around any open excavation, a permit to dig system will be installed a security guard will be on duty during off-site hours

Table 3.4 Risk Assessment on 'car park', MS/Larkhall/111 Rev B

Table 3.5 to Table 3.8 demonstrate how a subcontractor from the same infrastructure project performs risk assessment within their method statement. A reproduction of a risk matrix is given in Table 3.5, definitions of severity and likelihood values are given in Table 3.6 and Table 3.7 and a table of management action is outlined in Table 3.8. These are based on the method statement entitled 'Resistivity Survey and Earth System Testing' from method statement Anniesland/MS/049. Severity issues relating to property damage and commercial / financial concerns have been omitted.

Risk Rating		**Severity**				
		5	**4**	**3**	**2**	**1**
Likelihood	**5**	25	20	15	10	5
	4	20	16	12	8	4
	4	15	12	9	6	3
	2	10	8	6	4	2
	1	5	4	3	3	1

Table 3.5 Risk Matrix Example

Likelihood	Title	Description
1	Remote	Less than once in a five year period
2	Possible	Once within every 1-5 year period
3	Occasional	Once in a period between 2 months & 1year
4	Regular	Once in a period between 1week & 1month
5	Common	Once in a period between 1 day &1week

Table 3.6 Likelihood Example

Severity	Description
1	Trivial, minor or no injury.
2	Injury requiring first aid treatment. Lost time up to 3 days
3	Major injury requiring hospitalisation or reportable under RIDDOR
4	Serious injury that results in the loss of eye, limb or ability to continue work
5	Any fatality / fatalities.

Table 3.7 Severity Example

Risk Rating	Risk Level	Action
20-25	Very High Risk Unacceptable	Stop the activity immediately. Implement control measures to reduce risk to ALARP. Ensure that controls are documented and staff are briefed on their importance.
10-16	High Risk Requires 'action'	A safe system on work must be implemented and briefed prior to the work commencing. Consider stopping the activity if control measures are not suitable. Seek an alternative solution where possible
05-09	Medium Risk	Control measures should be reviewed to ensure they continue to be effective. Acceptable to work with care. Consider additional safety controls to reduce risk further before implement a change.
01-04	Low or minimal risk	No action required. If control measure in place, ensure that they are reviewed in order to remain effective.

Table 3.8 Management Action based on Risk Matrix Example

These examples bring several issues into sharp focus:

- The method of hazard and risk management processes can differ between companies. In addition, variability has been shown within the same project.
- The assignment of severity and frequency values is completely dependent on the opinion of the risk assessor who must 'guesstimate' values and their perception of the risk.
- There is an implied relationship between assignment of control measure and reduction of either severity or frequency values although there is no evidence of the magnitude.
- There is high reliance on worker competence acting as a sole control measure.

The perception of risk, and therefore risk estimation and impact on tolerance is inherently subjective in qualitative risk assessments and relies on the risk assessors' knowledge. Although subjective evaluations correspond closely to objective data obtained from both internal and external sources (Fynes and De Burca 2005), it must be recognised that subjectivity/objectivity can be influenced by several factors, including:

- Selective memory.
- The desire to please.
- The presence of ulterior motives.
- Actively blocking free expression in others.

This problem of *risk perception* in the construction industry has been recognised and has generated a plethora of research topics towards the improvement of Safety Management. One example is the identification of three types of hazards by Delft University of Technology, Netherlands, towards educating future risk managers; Low probability-high consequence, common accident hazards and chronic health hazards (Swuste and Arnoldy 2003).

3.6 Discussion and Research Direction

Despite the identification of hazards via established risk management methods and processes, many accidents relate to generic work place factors such as poor house keeping / work scheduling or occur 'off-task' in preparation for the main work task. Many hazards associated with preparatory stages are currently not being correctly identified; hazards that are not identified cannot be effectively managed. In addition, continual improvement towards lowering risk tolerance levels (see Figure 3.4) and dependence on hazard analysis (see Figure 3.2) have been identified as integral to risk management.

This chapter has highlighted four possible research directions; Knowledge Management, Artificial Intelligence Methods, Monitoring Tools & Frameworks and Behaviour Issues. The next two chapters will further investigate *Knowledge Management* and *Artificial Intelligence Methods* with a view towards the development of a safety model to enhance hazard identification and the management of control measures.

It is envisaged that such a model could improve performance in individual, team and organisational levels, ultimately:

- Saving lives by improving the management of hazard analysis processes.
- Allowing continual improvement during the risk management cycle.
- Facilitate a move to more quantitative-based safety management decisions.

3.7 Conclusions

- *Hazard Identification*, or lack thereof, acts as a bottle-neck to Risk Assessment and Risk Management processes.
- Hazard analysis acts as a major input to the iterative processes of *risk evaluation* and *risk estimation* within the *RMC* model.
- The process of assigning risk is inherently subjective and depends on individual risk assessors' perception and tolerance levels.
- Anecdotal evidence suggest risk levels are assigned based on the experience-based guesstimates with little evidence presented towards the effectiveness of assigned mitigation and how these reduce risk.
- There is high reliance on worker competence acting as control measures.
- *Knowledge Management* and *Artificial Intelligence Methods* are identified for further investigation with a view towards the development of a safety model to enhance hazard identification and the management of control measures.

CHAPTER 4: MANAGING SAFETY KNOWLEDGE

Dangerous decision making can occur through reliance on incomplete or 'corrupted' knowledge. The problem can be exacerbated if the effectiveness of knowledge transfer of between managerial strata and those working at the sharp end is diminished. The collection and use of knowledge, especially in the context of safety knowledge, is therefore of extreme importance.

This chapter will investigate 'knowledge management' and the differences between knowledge and information. It will further consider the various research methods employed in managing safety critical knowledge with the aim of improving worker safety in Infrastructure Management.

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4.1 Introduction

Chapter 2 identifies the link between lack of knowledge and worker injuries whilst the concept of hazard and risk management is discussed in Chapter 3. This chapter marries these two themes by identifying 'safety knowledge' in relation to hazard management and occupational injuries and offers an indication of the different research methods employed to improve knowledge management of safety related issues.

The chapter is structured in six sections:

- **Section 1 – Introduction**

Introduction and chapter structure is given.

- **Section 2 – Knowledge Management**

A brief section defines the differences between *information* and *knowledge*.

- **Section 3 –Identifying and Transferring Safety Knowledge**

Three types of communication are identified as being used on site in infrastructure projects; written, verbal and physical. These practices along with current problem solving ethos are identified as needing review to allow 'trial by success' and continual improvement by identifying and monitoring good safety practice(s)

- **Section 4 –Reviewing Safety Knowledge Literature**

A literary review of past studies presents four *methods* and five types of *medium* is presented.

- **Section 5 – Research Discussion and Direction**

This section discusses three main issues for consideration towards a proposed research direction. These are:

  - Sustainability of research led safety tools in 'real world' situations
  - Resource issues both in the 'development' and 'end user' sense
  - Internet technology is cited as being an attractive facilitating platform and deployment medium along with the possibility of AI collaboration and ways in which the proposed research approach differs from other internet research work is highlighted.

- **Section 6 – Conclusions**

The main conclusions of this chapter are:

  - There is a clear need to showcase and praise 'good' safety practices.
  - Method statements are identified as a source of 'good' safety knowledge and will be collected for possible inclusion in a *Tool*.
  - Target user audience must be identified and their need incorporated into the *Tool* process.
  - *Knowledge based system* model, along with *internet technology* are highlighted as possible methods towards developing a *Tool*.
  - Artificial Intelligence Methods are identified as a possible hybrid partner and are further investigated Chapter 5.

4.2 Knowledge Management

The idea that knowledge is the most valuable source of competitive advantage has been widely considered for years, becoming an economic resource more important than oil, steel, or any of the products of the Industrial Age (Liaw 2005).

The actual definition of 'what knowledge is' can result in a socio-philosophical debate well outside the scope of this thesis. However, in simple terms knowledge is gained through trying to understand the context of information within our society and experiences, in conjunction with the way in which we individually view the world.

Information can be categorised into three strict definitions; structured (drawings or plans), semi-structured (written documents) and non-structured information dialogues and sketches (Gardoni et al. 2005). Many researchers have theorised definitions of 'knowledge' as:

- **The advanced stage of information** and hence requires interpretation, processing and constructs to form knowledge (Liaw 2005).
- **Information in context**, together with an understanding of how to find it and how to use it (Nonaka 1994).
- **The product of a learning activity** in which cognitive experiences such as perception, interpretation, and analysis are used to file information into a cognitive structure based on understanding the local environment and collaborating with other people (Kang and Byun 2001; Liaw 2005).

The two main forms of knowledge *explicit* and *tacit* were recognised in the 1960s (Polanyi 1966). Explicit knowledge can be easily expressed in words, numbers and organized forms communicated via computers, network, and databases (Trentin 2001). Tacit knowledge can be highly personal and hard to define such as bodily skills and mental models that cannot be easily articulated. There is difficulty in communicating and sharing tacit knowledge with others due to individual perception and intuition, therefore users generally tend to focus their efforts on explicit knowledge to create a *knowledge base* (Liaw 2005).

4.3 Identifying and Transferring 'Safety Knowledge'

Knowledge management is a huge research area and can be applied to many, if not all, types of research.

Identifying 'safety knowledge' is a difficult task. Safety knowledge is subjective and deep rooted in experiences (both good and bad) of those who work in the given environment; in other words *tacit* knowledge.

The main problem in identifying 'safety knowledge' is the way in which 'problem solvers' view the problem. This is demonstrated by the 'gestalt-shift' diagram shown in Figure 4.1 where either a young or old woman is visible. Examples of both the young and old women are also given to illustrate the difference in viewpoints.

Safety knowledge can be likened to how people view Figure 4.1 based upon perhaps a million different variants of 'young' or 'old' woman examples or somewhere in between. This brings us back full circle to consider the main problem in identifying *safety knowledge* - the way in which *problem solvers* view the problem.

This issue can be further simplified as not 'what we see' rather 'what we communicated to others'. In other words, student A could describe the 'young woman' to student B who is looking at this visual puzzle for the first time. Student B may or may not see the 'young woman' based on student A's description or may be predisposed to see the 'old woman' irrespective.

There are various different ways of communicating between people working in Infrastructure Management, all of which have caveats:

- Written documentation such as method statements and accident reports.
- Verbal instructions and tool box talks.
- Physically shared experiences.

Using the analogy of the visual puzzle, physically shared experience could be one person of 'greater' knowledge performing one-on-one guidance during tasks, outlining precisely how he/she saw the 'old woman' to one of lesser knowledge.

Unfortunately, due to continual learning the person with ‘greater’ knowledge would require one-on-one guidance from someone with ‘greater +1’ knowledge etc. This would result in excessively large teams of people in a constant stream or ‘pyramid’ of knowledge. Although an aspirational intellectual ideal, this scenario is unfeasible due to skill shortages and also, so many people would be learning that less people would be doing!

Figure 4.1 Visual Puzzle (Covey 2004).

Tool box talks are a well known verbal communication on site. These consist of quick hints and tips on safe procedures to groups on site. This can be likened to flash cards of different possible 'noses' or 'eyes' to the group to help 'old woman' recognition. This does not necessarily mean that the group can identify 'mouths' for example or indeed 'noses' that they have never seen before. Other verbal instructions include safety briefings whereby someone with 'greater' knowledge gives salient issues to those with 'lesser', such as a work ganger or supervisor to his team of manual workers. This produces a limited view of the 'old woman' solely based on the supervisors' description – if he is not a good drawer his team may end up looking at a squiggly blob. This raises several issues:

- Is the supervisor correct in his assumptions of importance?
- Has his communication imparted the knowledge he wanted effectively?
- Who ultimately is responsible for the integrity of knowledge transfer?
- '***Quis custodiet ipsos custodies?***' (who guards the guards)
- Who will go to jail if something 'goes wrong' ?

The last point is somewhat sensationalised, yet tendencies toward social and legal culpability are an ever climbing fear for workers in Infrastructure Management (see Section 2.3.3).

Written methods of communication are more easily auditable for use in court and are generally in great supply within projects. These can include electronic correspondence along with traditional paper reports, plans and drawings. Accident reports and analyses concentrate on 'what went wrong and why'. This biased negativity, when badly managed, can be viewed as a 'witch hunt' and the apportionment of blame. These methods say:

> *"We've identified the failing- you saw the 'young woman'. Here is a method we will use for the next time, so workers see the 'old woman' correctly".*

Unlike accident reports that focus on specifically 'what went wrong' when there is an incident, method statements can be used to effectively capture the 'null' reports and encourage a more optimistic view of 'what was right'. Method statements can be viewed as work task recipes for given site and / or office based tasks. This gives the writers view of the 'old woman' explicitly, thus turning ***tacit*** knowledge into ***explicit*** knowledge. Method statements are prepared by competent workers who are responsible for the planning and completion of individual work tasks, usually at supervisor or engineer level. Method statements and other written recipe-type documents such as Health & Safety Plan / File under CDM regulations (Health and Safety Executive 1994) demonstrate that someone in the organisation has given consideration to safety practice. These documents, and subsequent document under version control, are seen as discrete events or snapshots during various stages of work. Seldom do they actively demonstrate excellence 'in the field' – this is an opportunity missed. Never-the-less, they are a good source of safety knowledge as they can capture how the person preparing the method statement perceived the characteristics or important factors of the work.

Anecdotal evidence suggests safety solutions that do not result in accidents or worker injuries are not recorded, monitored or their 'fit for purpose' level assessed effectively.

A 'trial by success' model is proposed to identify 'good' safety knowledge associated with null events or non-accident work tasks. This is aimed towards identifying, monitoring and improving existing methods and, ultimately, celebrating success of good safety practices within the industry. It is proposed this model can be created by identifying, collecting and transferring site knowledge relating to non-accident (or null) events within a real infrastructure project. The next section explores the various techniques and methods available to facilitate this model.

4.4 Reviewing Safety Knowledge Literature

Capitalising on existing knowledge and efficiently interpreting and / or re-using has proved an important commercial asset, resulting in vast research. However, this research can be categorised into two key aspect: *method* and *medium*. *Methods* are the underlying models or principals, whilst *medium* is the tool or process used to convey the method to the intended destination. This section acts as a literature review of past studies and key research paradigms used in the management of safety knowledge applicable to the UK Construction Industry under these two sub headings.

4.4.1 Method

There are few holistic methodologies that have been shown to be effective in both the 'capture' and 'convey' elements of safety related knowledge management; many concentrate on one aspect to the exclusion of the other.

Four examples are given below:

- **Human-relation models** such as behaviour-based safety can allow the addition of related parameters to highlight the importance of workers' attitudes and relationships among parties (DePasquale and Geller 1999; Feyer et al. 1997). 'Constructivism' is a learning theory that describes how individual minds create knowledge, how it is structured and how it is affected by understanding and feedback (Oliver 2000).
- **Causal models** examine the underlying issues or causes of a particular scenario such as accident investigations / analysis (Cooper 1986; Cox and Ricci 2005; Haslam et al. 2005; Lehto and Salvendy 1991; Williamson et al. 1996). Numerous research has used causal models aimed to identify and improve project performance issues (Duff et al. 1994; Haslam et al. 2005; Jin and Ling 2006; Sousa et al. 2006) (Suraji and Duff 2001; Suraji et al. 2001).

- **Knowledge based systems** whereby tacit knowledge is transferred to explicit. This can be achieved by filtering and increasingly classifying, codifying and documenting individual or group knowledge (Malone 2002) or knowledge mapping (Lin et al. 2006). There are also numerous decision support techniques such as group decision making (Boose et al. 1993) or fault trees (Carpignano and Poucet 1994; Demichela et al. 2004). Good management practice, such as preventing back disorders in the construction sector, can also fall into this category (Gervais 2003). Frameworks are another method of managing the knowledge process and are wide spread in research (Oussalah and Newby 2004; Teo et al. 2005). In a corporate setting, these types of models have been used to identify key safety shareholders such as the supply chain management strata (Hallikas et al. 2004; Nagurney et al. 2005; Young and Kielkiewicz-Young 2001) and can also act as a platform to discuss training and mentoring requirements. Some frameworks are based on other model types, examples include:
    - **Model-based framework** is the basis HAZOPExpert, a tool for automating Hazard and Operability (HAZOP) analysis in the chemical engineering industry (Vaidhyanathan and Venkatasubramanian 1996a). HAZOP is described as a technique of imaginative anticipation of hazards and operation problems by considering events exhaustively within a system or process (Pumfrey 2000; Smith and Harrison 2005).
    - **Machine-based learning** has been used to create a ten stage knowledge acquisition process aimed at the prevention of construction accidents (Arciszewski et al. 1995)
    - **Network Knowledge Maps (NKM)** gives users an overview of available and missing knowledge in core project areas, enabling tacit and explicit knowledge to be managed appropriately (Yu-Cheng et al. 2005).

- **Practical inventions** can improve safety of workers by creating a physical barrier between workers and harm such as an improved design of crash barriers. Within a transportation setting, examples include Automated Train Warning Systems (ATWS) warning rail workers of approaching trains (Evans 2004) and highly-portable positive protection technologies that protect highway workers (Ullman et al. 2007).

The first three models (human relations, causal models and knowledge based systems) rely heavily on their given process of extracting knowledge from the original medium to the new system. There are numerous examples and methods of how to achieve this transition including interviews of key witnesses, surveys and 'data mining'. Unlike survey and interviews, 'data mining' can identify and extract relevant information from historical documents without the need for contacts with individuals (Browne *et al.* 2006; Michalski R.S 1992).

The last model of '*practical invention'* relies not only on the ingenuity of the creator but also on the knowledge and culture of working individuals who may have to actively seek out an innovation for a given circumstance… but how can the person judge the best innovation based on their, perhaps limited, individual knowledge? In addition, innovations are (generally) new to industry, how are such innovations deployed and accepted to becoming the norm?

4.4.2 Medium

In this section the use of different forms of medium used to facilitate methods of knowledge management is highlighted. In short, these are given as:

- Document Control
- Databases
- Locally held computer programs
- Distributed computer programs or systems
- Internet

Document and version control is the underlying principal of all the other medium types. In the most simple form document control can be a filing system whereby information is stored in specific categories depending on their intended use and stage of updating; in other words a quality management system or QMS. One example of QMS is the *ISO 9000 Quality Management Series* from the International Organization for Standardization. The International Organization for Standardization (ISO) is one of the world's largest developers of international standards, established in 1946 "to facilitate the international coordination and unification of industrial standards" (International Organization for Standardization Accessed 23 May 2007).

Although all of the medium types rely on 'quality management' in some form or another on, one step beyond document control is use of a database.

A database is a structured collection of information whereby computer programs may easily query and search the information for specific items or groupings. Database Management Systems can be structured into many different layouts such as a hierarchical or tree-like structure with set parent /child categories and relational networks where all entities are placed according to their individual relationships with one another. An example of key research in this field include interfacing algorithms in large database management systems (Lavington et al. 1999)

The method of structuring and querying databases can be easily achieved via computer programs; either locally or distributed via a network. In addition, common 'querying' language can be used on commercially available software (such as products *Microsoft Excel* or *Microsoft Access*) or bespoke applications. A further example includes software package **INLEN** (inference & learning) developed to acquire knowledge about construction accidents and their prevention. **INLEN** is an automated rule learning and building decision support tool used in conjunction with a 10 stage knowledge acquisition process and STAR methodology-based machine learning. (Arciszewski et al. 1995; Michalski R.S 1992; Michalski R.S 1986).

Internet use in the new millennium has surpassed most expectations; from it's practical invention in the 1960s to aid academics to share research information, it is now used by the masses for both education and entertainment. Within the corporate community, the internet is used to facilitate sharing contractual and project-based information such as drawings along with correspondence (e-mail). Like e-mail, the World Wide Web is a subsidiary group within the internet. The Web uses shared protocol language to enable links between resources, usually with the aid of a 'web browser' such as Internet Explorer from computing and application giant Microsoft. These browsers interpret website or domain names users requests as an IP or Internet Protocol address e.g. if a user wants to visit the search engine website www.google.com, their computer relates this domain name to IP address 209.85.165.147 and requests access to view the associated web pages (see www.myip.co.in for more details). The advantages of internet technologies in comparison to other types of medium is demonstrated in Figure 4.2

	Group Size	**Deploy**	**Maintain**
Document Control	Small	Difficult	Difficult
Databases			
Local Programs			
Distributed Programs			
Internet	Large	Easy	Easy

Figure 4.2 Advantages of Internet Medium

Many academic and research fields have made good use of internet and www technology. Seven examples pertinent to managing information relating to general knowledge management or worker safety include:

- **The Open Research System (ORS)** is a web-based metadata and data repository. ORS was designed and built to assist geographically distributed scientific research teams by promoting open sharing of data within and across organizational lines and geographic distances (Schweik et al. 2005).

- **WAKC** or Web-based Assisted Knowledge Construction tool is based on the theory of Constructivist Knowledge Analysis of Tasks (CKAT) where users can revise their concepts and enhance their understanding with each stage using a knowledge retrieval tool (Liaw 2005). Research by the same author suggests search engines such as Google and user behaviour of browsing web page contents, bookmarks and abstracts can facilitate and also assist knowledge transfer.

- **Construction Safety and Health Monitoring (CSHM)** is a web-based safety and health monitoring system for construction management systems. Both internet and database systems are used with the intent to create a total automated safety and health management tool. CSHM uses PHP Programming Language in conjunction with a MYSQL Database Backend (Cheung et al. 2004). This system allows remote access of management data including automated collection, measurement, assessment, storage, and presentation of data. The output data was selected by the researchers based on literature searches, and later formed a basis for discussion and interviews with experts and professionals in the field, these included:
    - Number of accidents/lost man-days
    - Fire Protection /Electrical safety
    - Safe work practices
    - Housekeeping
    - Personal protective equipment
    - Hygiene & first aid facilities

These performance parameter (above) depend on size and scale of projects, the current law / regulations and the market situations. This research proposed the role of a Data Administrator using templates to input relative health and safety performance data.

- **Virtual construction sites** have been used to create a databases of actual buildings under construction for distribution via the internet or in a CD-ROM form. This is aimed to aid teaching/learning in civil engineering education when 'real time' site visits may not be possible due to scheduling, access difficulties, and / or safety requirements (Wilkins and Barrett 2000). Another 'virtual safety' application is the creation of a 3-D virtual model of a structure to help those involved in the design stages visualise inherent hazards and modify these before the construction phase (Hadikusumo and Rowlinson 2002).

- **The SAFETYNET** webpage and collaborative framework aim is to reduce the time delay between research results and their practical use in industry and stimulate further development and adoption of technologies in process safety (Nivolianitou et al. 2001).

- **The ANnotation tool for Industrial TeAms (ANITA)** is a research activity at the EADS Corporate Research Centre, concentrating on managing academic word documents and visual presentations (Frank 2003.; Frank. C 2003; Gardoni et al. 2005). ANITA differs from other tools by allowing the user to attribute points of view / annotations to documents, add descriptive meta-data indexes/keywords and place the document in specific geographical document zones. A template hosted on PHP and MySQL platforms facilitates data capture whilst a retrieval module searches document zones by content description. Authors suggest these indexes and annotations are 'more up-to-date than the published document', proposing this tool could facilitate 'asynchronous and delocalised exchanges of content description among experts'. They further theorise ANITA as a way of partially tracking tacit knowledge as an expert can expresses doubts, concerns or remarks more easily. An interesting scenario is where 'user No1' can retrieve documents from the research library of 'user No2', and automatically place them in the index classification of 'user No3'. However, this benefit of ongoing updating could potentially be a curse in an industrial setting; there may serious implications regarding intellectual property, the possibility of lax document control and the assignment of legal responsibilities using this system.

- **Safety Risk Model (SRM)** is used in the corporate setting by the Office of Rail Regulation (Office of Rail Regulation 2007b). The model is a structured representation of the causes and consequences of potential accidents arising from railway operations and maintenance on the railway. It comprises a total of 120 individual computer based models, each representing a type of hazardous event. This enables users to identify key areas of risk associated with their operations and to prioritise investment in safety, using a risk-based decision-making approach. It is populated using data from the UK rail industry's safety related incident data as taken from a Safety Management Information System (SMIS) supplemented by other industry data sources. Statistical methods and structured expert judgement from technical specialists are used to enable predictions from low frequency but potentially high consequence accidents for which there is little or no relevant data available. The SRM uses FaultTree+ software by Isograph Ltd and although the SRM allows breakdown of risk profile to fine level of detail, there are some notable weaknesses; not all hazards are analysed to same the level of detail, the tool requires high levels of expertise to use and lastly, the tool is not sensitive to sudden changes in frequency or consequence of hazards due to periodic (rather than continuous) updating. The aim of the model is to inform the UK Railway Group/ Rail Safety & Standards Board (an independent not-for profit organisation producing rail standards and safety guidance) and those in the wider railway industry of the dominant contributors to risk on the mainline railway. The most recent results of the model were published within the 'Profile of Safety Risk on the UK Mainline Railway' in February 2005 and version 5 of the model is currently in development.

4.5 Research Discussion and Direction

In this Chapter the difference between knowledge and information has been discussed and a 'trial by success' model aimed towards celebrating good safety practices within the industry is proposed.

It is proposed 'good' safety knowledge associated with non-accident work tasks within a real infrastructure project can be identified, collected and transferred.

A review of past literature relating knowledge management relating to worker safety includes highlights several possible research directions:

- Four *methods* are highlighted; human-relation models, causal models, knowledge based systems, and practical invention.
- Five different types of *medium* are discussed including document control, databases, computer programs (local and distributed) along with internet and www technologies.

In considering the direction of the current research, it is important to acknowledge that others have attempted to create suitable knowledge management systems and/or frameworks (Arciszewski et al. 1995; DePasquale and Geller 1999; Liaw 2005). Many research scenarios have proved to be unsustainable for 'real world' situations and enjoy short-lived success or were unable to transfer from research to industry by being poor *value-for-money* (Kaneko et al. 2006; Sousa et al. 2006). Similarly, innovative individuals within the corporate setting have taken on this huge challenge, only to realise their achievements are 'orphaned' upon their career progression or retirement. Mining these legacy or 'orphaned' systems for general knowledge and /or integration into a new system can be cumbersome with little validation of whether the transposition is accurate. Also, collecting examples to train models can be difficult or expensive and the process is often underestimated by researchers in terms of collecting accident records, identifying attributes preparing examples etc (Arciszewski et al. 1995).

Secondly, the issue of resources is an important factor in the research direction; both in the 'development' and 'end user' sense. In scoping the research direction, one must establish realistic goals based on the research team size, additional specialist resources and type / quantity / quality of available data when deciding on a particular research method. In addition, the research direction should clearly focus on what level of competence or computer literacy the main user will have and who will ultimately benefit from the research.

The third issue towards clarifying a research direction is acknowledging that internet technology has undoubtedly changed safety research, but one must ask "is the internet is here to stay?"

If so, the use of internet discussion groups (Matzat 2004) and weblogs for knowledge sharing and learning spaces (Ras et al. 2005) may become more readily accepted in a corporate setting and future application could use this technology to sharing knowledge among people with similar interests; one example is 'buddy finding' where collaborative software agents or filtering techniques on emails, mailing lists, chat rooms and social networking are used to match 'buddies' (Li et al. 2006). The use of wiki-based websites are becoming more wide spread e.g. Wikipedia[2], a collaborative authoring encyclopaedia where visitors can add, remove, and edit content. Other examples include 'DICOM Wiki', a web-based collaboration and knowledge database system (Nakata et al. 2005) and proposals to use wiki technology in general classroom settings (Wang and Turner 2004).

If the internet is set to become obsolete with the advent of new technologies, what form will they take? Relevant new technologies such as GRID computing allow geographically distant and unused resources such as Desktop PCs to solve massive computational problems. This technique of distributing processing problems is being used at to simulate 'faster than real time' fires upon structures at the University of Edinburgh to offer varying scenarios and safe practice to fire engineers and firemen

[2] http://en.wikipedia.org/wiki/Main_Page accessed 25 May 2007

(Berry et al. 2005). None-the-less, the extensive effort required to translate between a possible new or different technology and that of the existing internet will not be limited to this particular research thesis, and will amount to a huge overhaul of existing systems and computer networks worldwide. This event was considered unlikely over the three year duration of this research work.

Identifying major pitfalls of current research allowed further development of research direction and distinguishing how the new approach will differ from other such work.

The seven research examples given in previous section are not without certain limitations:

- **ANITA** could create an unmanageable audit trail of legal responsibility.
- **SRMs** end user could be labelled as a group board member or director level, and as such decisions at this level may have less direct impact on those working *at the sharp end*.
- Both **SAFETYNET** and **The Open Research System (ORS)** are basically a web assisted management-level frameworks. These are dependant on expert 'users' to prioritise generic objectives but do not give the much needed guidance to those communicating these requirements to the work force. In other words they draw their own version of the 'old woman' without guidance or suggestions on how this is to be communicated.
- **WAKC** and the concept of **virtual construction sites** are good examples of synchronising education and good safety practice. However, they both appear to be very 'development' intensive. In a practical sense, it is difficult to envisage the cost of creating a 'virtual site' as being good value-for-money compared to the individual responsible for identifying and mitigating hazards conducting a 'walk-over' on a day to day basis.
- **CSHM** is a well rounded management-level system / framework and is a good example of a prototype web-based safety and health monitoring system for

construction projects. However the reliance on additional staff as 'administrators could lead to two scenarios;

- o Highly trained engineers and supervisors being further stretched in their duties by becoming data input clerks,
- o Employing those who have no or little experience in health and safety re-typing information into the system from paper based work documents.

Both scenarios are unattractive and difficult to implement in an industrial setting in the UK due to limited funds and skill shortages.

Lastly, the CHSM research represents much larger resources in terms of researchers and funding that this research project can offer.

Researching different literature has shown that adoption of solely one method or medium may not be the best direction for the current research. This chapter has also highlighted several different methods of knowledge management and on consideration a hybrid is an attractive approach.

There is a clear need to showcase and praise 'good' safety practices in industry. This action will aid in redressing the imbalance of both public and industry in their regard of 'important' events. Using a 'trial by success' mentality negates certain research methods such as a casual approach. As the link between knowledge and injuries has been established, this leads towards using a *knowledge based system* model. However, there are a further two related issues:

- Collecting and storing knowledge is pointless unless it influences future decision making for the betterment of working conditions.
- Quality of this knowledge must be management to insure a 'rubbish in = rubbish out' model does not occur.

Lastly, there is an issue of effective communication of safety knowledge, achieved via shared physical experiences, verbal instructions or written documentation. The process of collecting the first two types would involve the researcher being part of a work team. This may bias results as the act of the researcher simply being present may interfere with the manner those with 'greater knowledge' impart knowledge to others. Those involved in these case studies may feel fear of reprisal or resentment towards their organisations or the researcher. There are additional problems concerning the multi-valued and multi-source nature combining subjective knowledge (Dembicki and Chi 1991)

Written documentation can be collected after the event without these issues and have the advantage that they have already transferred tacit knowledge, from the writer, to explicit knowledge in the form of a report. Unlike the other two types of knowledge transfer, they are easily auditable and are often used in courts of law. Thus method statements have been identified as source of 'good' safety knowledge for 'trial by success' model.

4.6 Conclusions

- There is a clear need to showcase and praise 'good' safety practices in industry and a 'trial by success' model is proposed.
- Method statements associated with non-accident events are identified as source of 'good' safety knowledge.
- Examples of effective communication of safety knowledge must be collected i.e. method statements
- Target user audience must be identified and their need incorporated into the *Tool* process.
- Knowledge based system model, along with internet technology are highlighted as methods towards developing a *Tool*.
- Further investigation of Artificial Intelligence Methods as a possible hybrid partner. This is achieved in the following chapter.

CHAPTER 5: ARTIFICAL INTELLEIGENCE METHODS

Artificial Intelligence (AI) emulates human decision making or reasoning. The aim of this chapter is to identify a suitable AI technique to improve and facilitate the transfer of Safety Knowledge associated with infrastructure management work tasks. Four different forms of AI methods are compared in this chapter; Expert Systems, Case Based Reasoning, Artificial Neural Networks (or ANNs) and Fuzzy& Hybrid Systems.

Case Based Reasoning is identified for an extended literature review focussing on research within the Construction Industry. A new method of grouping literature is proposed as a means to identify opportunities for CBR allocations in Infrastructure Management; the *'Think, Plan, Do'* model. .

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5.1 Introducing Artificial Intelligence

Artificial Intelligence (AI) is a collective term used to describe research associated with emulating human decision making in artificial computer based systems and strives to replicate human thought processes and / or learning methodologies. The digital revolution and advances in computation in the early 1950s led to the birth of Artificial Intelligence (AI) from research parents cybernetics and cognitive science (Mirzai 1990). In 1950 a landmark paper by Professor Alan Turing proposed a means to test the capability of a machine 'to think' based on the concept of *the imitation game* (Turing 1950). Now commonly known as the *Turing Test*, a machine is said to pass when a human judge cannot reliably tell the difference between two un-seen subjects: a real human and a machine imitating a human. Many variations of the test have been suggested such as substituting the roles of the subjects (replacing the judge for a machine etc), but to date no machine has passed a pure *Turing Test*.

Never-the-less, there are many practical applications based on the concept and the research field continues to grow as the philosophical debate on defining 'thinking', 'consciousness' and 'intelligence' continues.

This chapter aims to find a suitable AI method to facilitate the knowledge based system models identified in Chapter 4. The chapter is structured in five sections:

- **Section 1 – Introducing Artificial Intelligence**

A brief introduction to the history of Artificial Intelligences is given along with details of chapter structure.

- **Section 2 – Reviewing Artificial Intelligence**

Four different forms of Artificial Intelligence techniques methods are compared and discussed in this section. Case Based reasoning (CBR) is identified as a potential methodology to stop worker wasting time, effort and resources in 're-inventing the wheel' and is further investigated in the following section.

- **Section 3 – CBR in Construction Industry**

A new method of mapping current research against the generic project life-cycle diagram is proposed. The *'Think, Plan, Do'* model is used to delineate different uses of CBR applicable to the Construction Industry and clearly demonstrates the imbalance of CBR applications throughout the cycle of projects. The model highlights the opportunity to use CBR methods not only in safety management, but also as an educational aid and a method to actively measure safety competence.

- **Section 4 – Discussion & Research Direction**

This section discusses three main issues for consideration towards a proposed research direction. These are:

  - Developing a *Tool* based on AI methods to highlight work site dangers and possible solutions?
  - A method of aiding construction workers' education and demonstrating competence in safety management?

- **Section 5 – Conclusions**

The main conclusions of this chapter are:

  - Combining Case Based Reasoning (CBR) and hazard management is identified as a new research niche.
  - Case Based Reasoning (CBR) is identified as method for facilitating a Tool.

5.2 Reviewing AI Methods

This section examines the key differences between four AI methodologies:

- Expert Systems,
- Artificial Neural Networks (ANNs)
- Case Based Reasoning.
- Fuzzy & Hybrid Systems

This chapter is used to identify a possible method of improving processes of hazard and risk identification / management, followed by an extended literature review of this research method applicable to Industry.

5.2.1 Expert Systems

Expert systems follow a set of rules established by the experiences and judgement of ‘experts’ in the given discipline and are by definition, reliant on the quality and breadth of the knowledge obtained from the human experts used to train the system or model (Lavington et al. 1999; Suokas et al. 1990).

Expert systems are a form of ‘IF/THEN’ rules. This can be summarised as ‘if ‘A’ occurs, then perform action ‘B’. The number, details and interactions of ‘A’ occurrences and ‘B’ actions are collated from human experts.

The process of extracting these expert judgements include complex computer models based on transcribed conversation and reasoning during group work, surveys and one-on-one interviews. This process can be work intensive for all parties; the knowledge facilitator who creates the scenarios, the busy and expensive group of ‘experts’ and the modelling specialist who must correctly interpret this data. The modelling specialist may encounter additional problems due to their lack of understanding in ‘expert’ language or use of qualitative or fuzzy terms. The resulting model may also bias due to low number or quality of experts and their judgements, thus requiring a longer data gathering exercise to train the model than originally intended and perhaps a complete re-design of the model relationships. Thus, solutions, relationships and input criteria in expert systems tend to be 'hard-wired' with little flexibility for future acquisition of expert knowledge or changes in research direction.

5.2.2 Artificial Neural Networks

Artificial Neural Networks (ANNs), is the term associated with the mapping and interconnection between basic attributes called (artificial) neurons or nodes. Research into neural network were inspired by biological processes in the human brain, thus connections between neurons are based upon mathematical formulae and can allow changes in overall network structure based on information flowing through the network (Kurd and Kelly 2007). Increasing amount of neural network research is being conducted for a diverse range of business activities (Wong et al. 1997). Within the construction industry examples include estimation of product costs (Zhang and Fuh 1998), safety predictions based on marine input variables such as vessel type, location, cargoes etc (Hashemi et al. 1995) and also as a method of identifying key financial project performance issues (Chua et al. 1997) and stakeholder perceptions (Baets et al. 1998),

ANN's can allow dynamic structuring of data based on information flowing through the 'network' in terms mapping, interconnection and relationships. Back propagation techniques can also be used to recognise patterns in unfiltered data (Ung et al. 2006; Zhang and Fuh 1998).

Figure 5.1 shows relationships between basic attributes called (artificial) neurons or nodes. The connections between these are based upon research related mathematical formulae (Kurd and Kelly 2007).

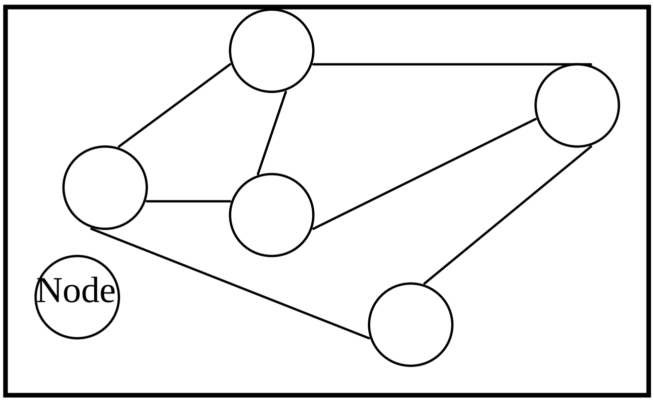

Figure 5.1 Artificial Neural Network Diagram

Examples of industrial applications of ANN's are numerous, some include:

- Estimation product costs (Zhang and Fuh 1998).
- Fault diagnosis in batch chemical plants (Ruiz et al. 2000) .
- Method of identifying key financial project performance issues (Chua et al. 1997).

Within the safety domain, ANN's have been used in a variety of different settings:

- Development of nuclear safety systems (Lee and Seong 2005; Renders et al. 1995; Ziver et al. 2004) and Light Water Research Reactors (Mazrou and Hamadouche 2004).
- Decision support for aircraft safety inspectors (Luxhoj and Williams 1996; Shyur et al. 1996).
- Accident diagnosis advisory system (ADAS) (Lee and Seong 2005).
- Safety assessment of existing structures using back-propagation to estimation parameters in complex structural systems (Deng et al. 2005; Lee et al. 2005; Yun and Bahng 2000).

5.2.3 Case Base Reasoning

Case Based Reasoning (CBR) is a methodology arising from research into cognitive science (Watson 1999). CBR is an analogy based paradigm that uses past examples to learn from past solutions. CBR is not limited to research fields with expert knowledge in artificial intelligence, nor is it linked with any particular technology and as such, researchers are free to use any technology, or combination thereof, that can facilitate CBR (Watson 1999). Thus, researchers have an abundant choice of applications with which to facilitate CBR methodology, from simple databases to web applications; information technology and the internet have been cited as major drivers for changes in all aspects of business processes and activities (Sung-Sik et al. 2004).

In the wake of these, the use of CBR has expanded beyond the realm of Artificial Intelligence to be applicable in many other research field and real-life businesses. The wide scope of CBR has enabled applications ranging from medical diagnosis and management (Chang 2005; Hsu and Ho 2004) to litigation outcomes (Sung-Sik et al. 2004), education (Smith et al. 1992) and marketing (Chiu 2002). Within an engineering backdrop CBR has been used in mechanical (Gao et al. 1998; Xu et al. 2003), electronic (Vong et al. 2002) and chemical engineering processes (Surma and Braunschweig 1996).

CBR research has been attributed to many areas throughout the life-cycle of projects (Campbell and Smith 2006),examples include:

- Cyclical construction processes (Graham and Smith 2004)
- Transportation planning (Khattak and Kanafani 1996)
- Procurement construction tools (Bao et al. 2004)

Irrespective of technology used or intended industry, a CBR system requires at least four processes; Retrieve, Re-use, Revise and Retain.

The CBR cycle in Figure 5.2 shows the established journey of a ‘case’ (or a stored solution to a past problem) from being retrieved from the case base or library, to being re-used or revised depending on the current problem, and finally being stored for use in the next cycle (Campbell et al. 2007b).

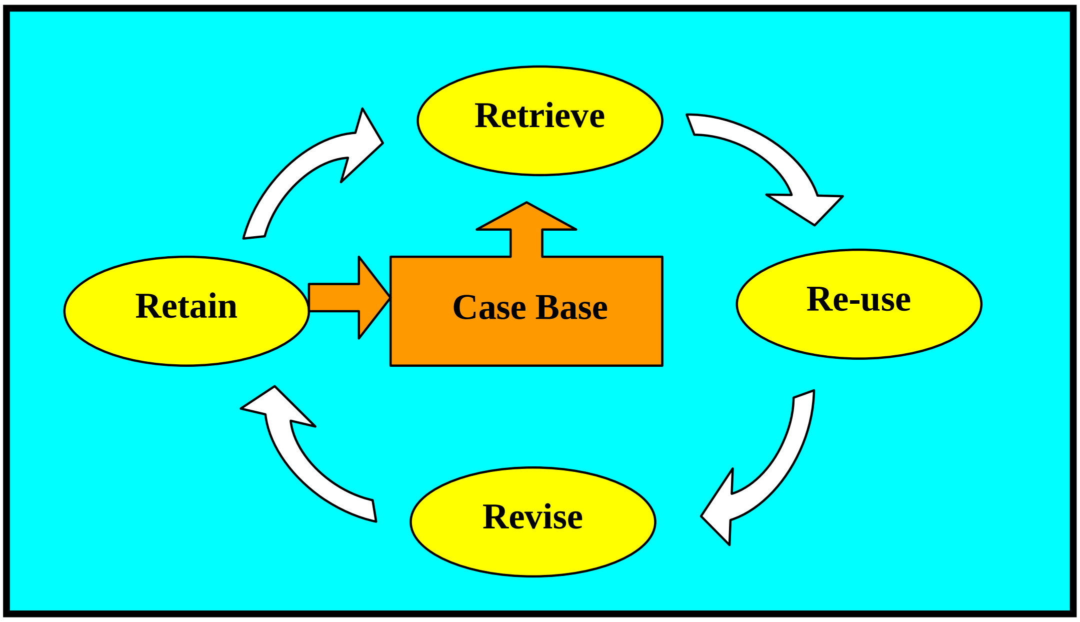

Figure 5.2 CBR Cycle (Campbell et al. 2007b) – adapted from Watson (1995**)**

Although consistency in describing 'cases' and their attributes is needed to make case retrieval meaningful, exact matching of a problem / solution set is not required due to the concept of a similarity threshold value.

This similarity value is based on comparison between attributes inherent to the current problem, and those exhibited in the stored cases.

Attribute values can be user defined arbitrary values, based on experiences or estimated by empirical functions. Alternatively, similarity techniques can be used such as:

- *Nearest neighbour techniques,* where total similarity of a given case to a new case is based on the sums of weighted similarity values for each case attribute.
- *Induction techniques*, where algorithms can be used to build decision trees based on clustering of similar cases together and identifying patterns from case histories.
- *Fuzzy Techniques*, where linguistic terms such as ‘good’, ‘fair’ or ‘poor’ are used instead of quantitative values or scales. The description and limits of these qualitative terms can be more easily altered than quantitative step changes.

Irrespective how the similarity between the current problem and the stored cases is defined or calculated, the method must not obstruct nor bias the process in which a user can accept or decline recommended cases from the library. Consistency in assigning case values during their journey through the CBR cycle is crucial to ensure a consistent definition of attributes. With these caveats, the validity of the retrieval mechanism must be periodically assessed; ensuring CBR applications in everyday use do not spiral into a decaying ‘rubbish in / rubbish out’ model.

5.2.4 Hybrid & Fuzzy Systems

Fuzzy logic is a concept where an entity can be categorised in linguistic terms such as ‘good’, ‘poor’ and ‘slightly’ and fuzzy set theorem allows entities to be grouped out with traditional crisp ‘0 or 1’ logic definitions. Examples of ‘fuzzy’ systems include a supply chain model enabling decision makers to analyse and trade-off customer service levels, product cost etc, depending on their risk attitude (Wang and Shu 2007), decision support tools for contractor bidding queries (Lin and Chen 2004) and geotechnical excavation (Cheng and Ko 2002; Cheng et al. 2002). There are also many application of fuzzy logic being used within risk analysis and safety engineering systems (Chou and Yuan 1992; Karwowski and Mital 1986; Keller and Kara-Zaitri 1989; Lee and Cha 2005; Lee 2006; Wang et al. 1995; Wang et al. 1996).

Fuzzy analysis has even been used to compare and analyse the effectiveness of different industrial safety tools (Tam et al. 2002). Other examples of 'fuzzy' research and applications include:

- Supply chain model enabling decision makers to analyse and trade-off customer service levels, product cost etc, depending on their risk attitude (Wang and Shu 2007)
- Optimising building performance using fuzzy probabilistic functions (Holicky 1999)
- Risk-assessment approach based on fuzzy functions has been used to derive a model based on relative risk assessment (MRRA) in ship navigation (Hu et al. 2007)
- Quality control measures to minimize falsework failures uses fuzzy sets, fuzzy logic concepts and fuzzy probability to determine critical event combinations (Hadipriono 1986)

Hybrids, where two or more AI techniques or methods are combined are quite common in the literature. The most common is the combination of fuzzy logic with ANNs to allow linguistic or qualitative terminologies. Examples of Fuzzy / ANN Hybrids include:

- SCANN - Safety Critical Artificial Neural Network- uses a neuro-fuzzy system called FSOM (fuzzy self-organising map) as a framework to better describe qualitatively and quantitatively behaviour in safety critical systems (Kurd and Kelly 2007) .
- Neural network techniques and fuzzy logic have been used to develop a model to assist ordinary operators during their daily operations to increase safety and improve operating performance of biological wastewater treatment process. (Du et al. 1999)
- 'Risk Prediction Model' uses ANNs and fuzzy set theory to evaluated navigational safety by converting linguistic risk-related parameters from the fuzzy

property to the crisp-valued attribute to assess the overall risk level (Ung et al. 2006)

- 'Integrated fuzzy neural network' has been shown to have superior learning performance and decreased computational time of a using case studies of two engineering analysis and design examples (Hung and Jan 1999).

- Partnering of ANNs and knowledge-based computation architecture to explain the output of neural subsystems (Johnson et al. 1993)

- A computer assisted crack diagnosis tool aids non-experts in diagnosing the cause of cracks in reinforced concrete structures. The tool uses expert knowledge, primarily from technical books about concrete and concrete cracks and users inputs in the form of linguistic variables to evaluate the crack causes under consideration (Kim et al. 2007-in press; Lu and Simmonds 1997).

- Fuzzy-based and knowledge-based intelligent scheduling system for estimating rainfall effect on productivity and duration of highway construction projects (Nang-Fei et al. 2005a; Nang-Fei et al. 2005b).

Similarly, research applications in fuzzy-expert hybrids include:

- Crack diagnosis tool aids non-experts to diagnose the cause of cracks in reinforced concrete structures (Kim et al. 2007-in press; Lu and Simmonds 1997).

- Platform 'start-up' tool for the offshore petroleum industry uses heuristic rules for automated of the start-up procedures (Campos et al. 2001).

- Decision Support System (DSS) for safety monitoring of hillsides applies fuzzy set theory to collected data and identifies slope stability, locating areas of adverse conditions requiring attention and listing their possible causes (Cheng and Ko 2002).

5.2.5 Discussing AI Methods

In this section the main differences between CBR, Expert Systems, ANNs and fuzzy / hybrid combinations have been highlighted.

CBR methodology has many advantages over the Expert Systems and ANNs. In Expert Systems, solutions, relationships and input criteria tend to be 'hard-wired' and inflexible due to onerous knowledge extraction processes. This process is often work intensive for all participants:

- Knowledge facilitator(s) researching and creating suitable scenarios.
- Busy and expensive group(s) of 'experts'.
- Requires conversational statements or 'know how' conveyed during group work / surveys / one-on-one interviews to be transcribed / translated into computer algorithms.
- Modelling specialist(s) who must correctly interpret this data and produce a final product.

Lastly, validating Expert Systems can be difficult due to a low number or quality of experts and their judgements, resulting in perhaps a longer data gathering exercise to train the model than original intended, or even a complete re-design of the model relationships. The time and resource constraints was viewed as an unacceptable risk towards completing the research project and resulted in this methodology being unviable.

ANNs, unlike Expert Systems, allow relationships and interaction to be redesigned in accordance with the information available, making ANNs a good tool to recognise patterns in data. Comparative case studies between ANNs and CBR techniques have been published (Arditi and Tokdemir 1999). Such comparative studies include predicting construction litigation (Arditi and Tokdemir 1999) and estimating construction costs (Kim et al. 2004) favoured CBR by it's ability to cope with missing data and impacts of long term use.

Disadvantages to using ANNs are three fold and given below.:

- ANNs cannot detect when they are working outside their range of competence or using 'bad' quality of data beyond their range of experience (Johnson et al. 1993) .
- ANNs cannot communicate with human decision makers in human terms to explain their output, nor can they easily explain their decision processes (Johnson et al. 1993).
- Ensuring ongoing maintenance and validity of ANNs after initial certification is difficult (Kurd and Kelly -In press, due 2007)

ANNs can be viewed as a 'black box' with little visibility of the why a particular answer is chosen by the system. This can present problems within the industrial setting if users fear that the new tool will replace their job, or even worst, workers may become complacent in the belief that the new system is infallible leading to legal culpability issues for the tool designers and maintenance operators.

Expert Systems and ANNs are generally digital and require hybridisation with fuzzy logic or linguistic terms to convey any real meaning to users. Once the development stages are complete there is little guarantee that these system will be able to cope with situations unanticipated by the initial experts or modellers. The technologies involved may bias the system or behave in a way that hampers natural evolutionary change within the knowledge domain. In any case, there is little doubt that maintenance upgrades and retrofits of these systems can prove costly and will eventually lead to conversion of a legacy system into new and improved future technologies.

Unlike Expert System and ANNs, the case oriented and analogies based techniques of CBR are able to deal with qualitative data, thus negating the need to combine with fuzzy logic systems. Additional benefits include:

- Users can incorporate their own 'expertise' into a stored library
- Solution can adapt & allow change
- Unlimited number of users
- Self learning with minimum calibration

The main advantages of CBR are the transparency it offers, along with the ability to continually learn and calibrate itself with user interactions. Table 5.1 compares the three main AI methods - Expert Systems, ANNs and CBR. CBR is identified as having many advantages and could easily be pitched to workers as a knowledge aid running parallel to their daily task of identify hazards and deciding on control measures, rather than an alien artificial intelligence engine with the aim of replacing high skilled workers. CBR is identified as a potential methodology to stop workers wasting time, effort and resources in 're-inventing the wheel' and requires further investigation.

	Expert Systems	**ANNs**	**CBR**
Solutions	Solutions are 'hard wired' into system	Solutions can be skewed by missing data	Users can incorporate their own 'expertise'
Validation	Is the 'expert' solution correct for every situation?	Post certification validation is difficult to validate	Solution can adapt & allow change
Group Size	Small groups	'Meaningful' output translation by expert	Unlimited number of users
Calibration	Re-design of relationships can be work intensive	Data collection & Modelling can be work intensive	Self learning with minimum calibration
User perception	***'black box'*** Replaces high skilled workers?	***'black box'*** Replaces high skilled workers?	***Analogy*** Stops high skilled workers 'reinventing the wheel'

Table 5.1 Comparing AI Methods

5.3 CBR in the Construction Industry

As established in Chapter 2, the Construction Industry plays an important role by employing around 2 million workers (or 7% of the total working population) and accounts for 10% of the UK Gross Domestic Product (Department of Trade and Industry website, www.dti.gov.uk).

Furthermore, this particular industry plays a major role improving the quality of people's lives by providing infrastructure. None-the-less, an expanding global market coupled with consumer desires to buy cheap and dependable products have lead to streamlining within the industry. As high turnover does not necessarily equate to high profit, companies seek to reduce costs for competitive advantage by improving working efficiencies, reducing wastage and pursuing both internal and external collaborative networks.

This section uses an innovative *'Think, Plan, Do'* model to demonstrate how Case Based Reasoning (CBR) is being used against this industry backdrop to fulfil both consumer and engineering needs.

5.3.1 The Management Life-cycle of Construction Projects

The construction industry has been described as being experience oriented, and that the correct application of this expertise is crucial to solving problems (Yau and Yang 1998b). Hence, there is little surprise that Case Based Reasoning methodology has been used to solve various construction problems.

A new model is proposed to establish research trends within a generic project lifecycle; the '*Think, Plan and Do*' model. This new model maps the current trend of CBR research directly onto the conventional project management phases within a project life-cycle, see Figure 5.3.

The six phases shown as project lifecycle include:

1. Scoping and feasibility assessment of the project.
2. Estimating, scheduling and design phases.
3. Construction, relating to building a completely new asset.
4. Operational maintenance of the asset.
5. Improvements, where the asset undergoes renovation or change of use.
6. Decommission and demolition. This can be seen as the reverse of the construction stage where the original environment is re-instated.

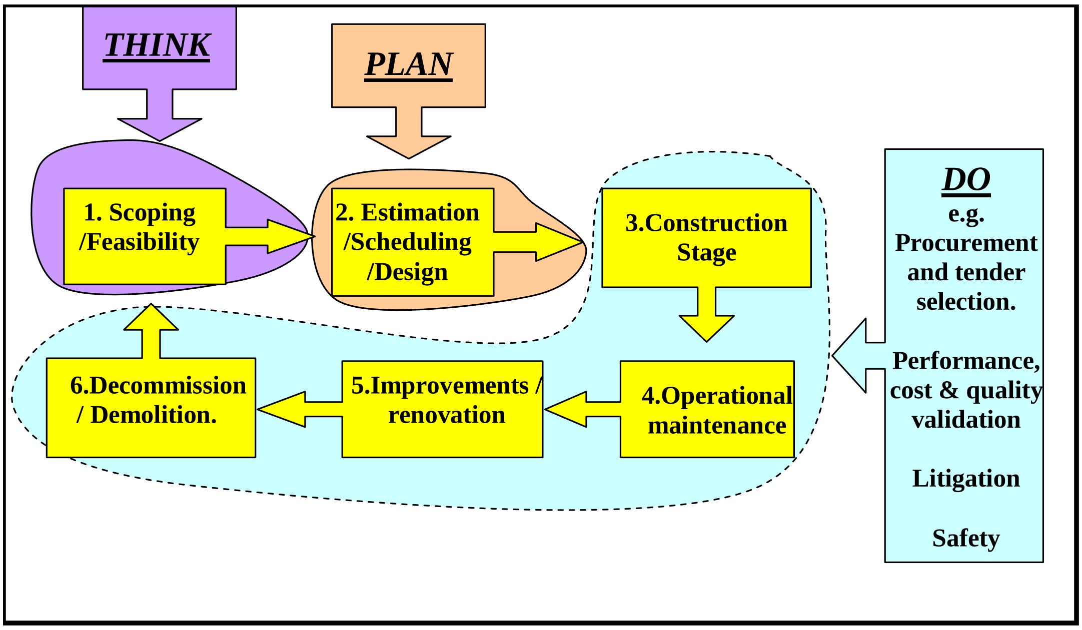

Figure 5.3 Life-cycle of a Construction Project

5.3.2 Thinking and Planning Phases

Starting at the early stages of an infrastructure project, the customer or client will have identified a 'need'. Whether this need is a new housing development, road maintenance or bridge strengthening becomes irrelevant to the process of finding the best type of contract and choosing a competent construction firm; in other words procurement. A decision system for procurement selection is particularly suited to CBR because 'intuition and experiential knowledge feature highly'(Luu et al. 2003). Luu's prototype 'Case-based Procurement Advisory System' (CPAS) uses case attributes of different procurement strategies and contract types to mimic decision processes exhibited by experts. Similar research focusing on the procurement stages of construction include ‘QuickBids’ (Bao et al. 2004), ‘CASEBID’ (Chua and Li 2001), the contractor pre-qualifier tool EQUAL (Ng 2001) and MADM the multiple attribute decision-making for offshore structures (Sii and Wang 2003).

Following on this theme, it is intuitive that well planned, managed and controlled construction projects are more likely to be finished within the agreed time scale, budget and specifications when compared to lackadaisical projects. As such, this area of research is rich in CBR applications to enhance the planning, scheduling and estimating processes such as transportation planning (Bhavsar et al. 2007), and choosing pre-engineered steel buildings (Lotfy and Mohamed 2002). Futher examples using CBR methods include:

- CBR-CURE, a construction planning tool estimates construction duration and cost based on project characteristics (Yau and Yang 1998b),
- CBRefurb, a system used towards the refurbishment of houses (Marir and Watson 1995),
- CBRidge, a bridge construction planning and scheduling tool (Tah et al. 1999).

CBR applications can function in more than one aspect of the project life cycle. By functioning in both a case-based estimating and design role, the NIRMANI tool (Perera and Watson 1998) generates schematic designs for light industrial warehouses based on past designs and client requirements and gives cost estimations for any structural or architectural changes.

‘Design’ is also an important part of the planning process, sometimes requiring inventive solutions to the restrictions imposed by the realities of the working environment; thus ‘design’ is also a prolific area for CBR research. Bridge design using CBR method features highly and includes the system CASETOOL (Kumar and Krishnamoorthy 1995) and various other CBR bridge design research and applications (Andrade et al. 2003; Moore and Lehane 1999; Reich and Fenves 1995).

Other applications include the design of a water supply dispatching system (Zhang and Wang 2004) and the analysis and selection of transport planning schemes (Khattak and Kanafani 1996).

CBR in the 'design' role extends beyond an infrastructure setting to the CASTLES selection system for retaining walls (Yau and Yang 1998a), ship design (Kowalski et al. 2001; Kowalski et al. 2005) off shore well design (Mendes et al. 2003) and a proposed system to help design engineers and material engineers in the submarine cable laying industry (Mejasson et al. 2001).

Following on from design, the advancement of engineering tools and materials has also been a CBR research topic, including CBR as a tool for materials selection (Amen and Vomacka 2001) and integrating design within computer aided drawing or CAD packages as the next evolutionary stage (Pu and Reschberger 1991; Sun and Chen 1996).

5.3.3 'Doing' Construction, Operation and Maintenance Phases

The 'thinking' and 'planning phases' discussed earlier mainly focus on providing a holistic yet limited view of the entire project. The estimations and predictions from these initial stages are constrained by the fact that it is difficult and financially impractical to predict every eventuality in detail. Thus, due to the dynamic nature of construction, operational and maintenance type activities the iteration of planning, estimating and scheduling within the 'doing' aspect of the project life cycle is customary.

Construction phase activities within infrastructure management are diverse and domain specific. CBR applications, systems and tools have been applied to solve specific operational activities, including:

- 'CasePlan' for boiler assembly in power plants, (Dzeng and Tommelein 2004)
- Research in estimating productivity of masonry wall construction (Karshenas and Tse 2002)

- Estimating productivity of cyclic construction operations (Graham and Smith 2004)
- Improving concrete placement simulation with a case-based reasoning input (Graham et al. 2004)
- Construction of PC-based expert system for cold forging process design (Katayama et al. 2004).

In comparison, there are comparatively few examples of CBR applications relating specifically to operational and maintenance activities within infrastructure management. Examples portraying CBR in a maintenance role include research to ensure the safe performance of steel bridges over their remaining lifetime (Waheed and Adeli 2005) and similar research in bridges management and deterioration embrace inspection tasks such as testing, structural re-analysis and re-evaluation of bridges (Morcous et al. 2000; Morcous et al. 2002a; Morcous et al. 2002b). CBR research in a maintenance role can also be seen in fault diagnosis for commercial aircraft (Haiqiao et al. 2004) and jet engines (Xu et al. 2003).

CBR research and applications in 'operational' tasks have been mainly geared towards the domain of process engineering. Examples include resource management application for warehouse operation (Chow *et al.* 2006), process/ control support systems for a bleached chemi-thermo-mechanical pulp (Xia and Rao 1999) and electric furnace for slag de-coppering (Moczulski and Szulim 2004).

Enveloping many of the 'doing' phases are business and performance related CBR applications. Examples include predicting the success of information systems outsourcing (Hsu et al. 2004) and assessment of contractor scheduling (Dzeng and Lee 2004).

Similarly, research into financial and litigation aspects of the construction industry has lead to CBR being used to support construction negotiation (Li 1996), predicting the outcome of construction litigation (Arditi and Tokdemir 1999; Tokdemir 1999) and aiding auditors assessing risk within manufacturing industry accounting processes (Sung-Sik et al. 2004)

Notwithstanding the diversity of CBR research, the application of decision support methods, tools and systems in safety and risk management appears to be one of the fastest growing topics. Some examples of CBR applications within safety and risk management include construction safety planning (Chua and Goh 2002), the HAZOPExpert analysis system (Vaidhyanathan and Venkatasubramanian 1996b), risk management and deployment (Gouriveau and Noyes 2004), and incident reporting in safety-critical systems (Johnson 2002)

5.4 Research Discussion and Direction

The *'Think, Plan and Do'* model has been presented and used to map several CBR research methods, systems and tools directly to the project lifecycle. Using this methodology demonstrates CBR research is strongly focussed on facilitating 'thinking' and 'planning' phases. This can be compared with relatively little research on the 'doing' phase, despite this phase dominating most of the project life-cycle (see Figure 5.3).

Past CBR applications have presented a holistic view of given project (whether this be in a planning, scheduling, estimating, predicting) to inform management either of current or past trends for consideration. It appears that many researchers overlook these 'human' elements of their systems extending only as far as CBR and 'fuzzy' hybrids. In addition, many CBR 'doing' examples can be seen as the application of the previous phases within a specific task-oriented setting with the exception of safety and risk management applications.

Surprisingly, very few examples were found of CBR being used as collaborative educational aids despite the genre of safety and risk management presenting itself as an obvious and ideal partner.

This presents a new and exciting prospect culminating in new and original applications of CBR research towards:

- Developing a *Tool* based on AI methods to highlight work site dangers and possible solutions?
- A method of aiding construction workers' education and demonstrating competence in safety management?

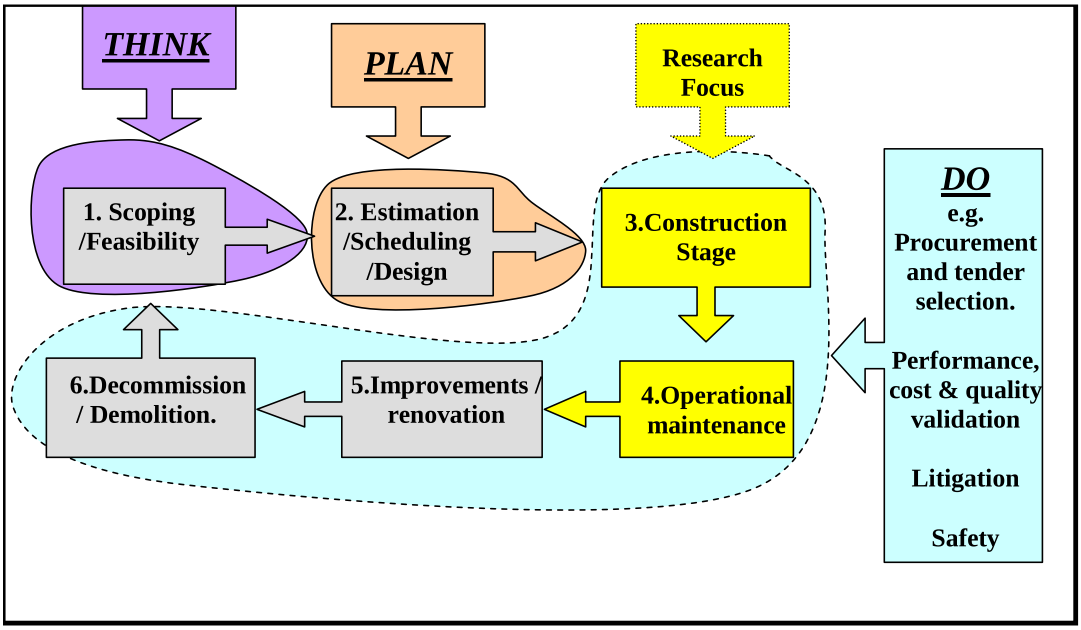

Figure 5.4 Research Focus using '*Think, Plan Do*' Model

5.5 Conclusions

- Case Based Reasoning (CBR) has many advantages over AI methods, namely the transparency, unlike the 'black box' of Expert Systems and ANNs.
- Combining CBR and hazard management is a new research niche.
- CBR is identified as a method to facilitate the proposed *Tool.*

The following two chapters demonstrate the development and testing of the *Tool* using *CBR methodology* identified in this Chapter, in addition to *Knowledge Based System* approach identified in Chapter 4.

CHAPTER 6: DEVELOPING A SAFETY TOOL

The thesis thus far has considered the problem namely *Keeping Bob Safe*.

The thesis proposes improvements to hazard identification and management processes can be achieved by utilising the knowledge and experience of existing workers and disseminating it to others.

To this end, a *Tool* has been developed using CBR methodology whereby mitigation measures are retrieved from a database search. Selection of suitable risk mitigations is based on whether these have been used in similar examples of past work tasks. These suggested mitigations can either be accepted or declined by users and / or new mitigations can be added and uploaded to the database library for use in the next cycle.

This chapter details the development stages of the *Tool.*

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6.1 Maintaining Research Focus - Keeping Bob Safe!

Consider the two different types of hypothetical workers introduced in Chapter 1.

- **Bob** is part of a team of workers *at the sharp end* concentrating mainly on manual tasks.
- **Andy** is an engineer who is effectively Bob's boss. He is responsible for ensuring a ***safe system of work*** for Bob and his team.
- How can Andy keep Bob safe?

As highlighted in previous chapters, method statements produced by Andy describe how the given work task is to be undertaken. These generally include some form of risk management documentation and in theory, communicate these to Bob. Bob may be asked to read and familiarise himself with the procedures in the document, but more usually this information is collated by the work task foreman and verbally explained to the team.

Current practice does not 'close the feedback loop' with little or no way of knowing whether:

- Bob (including his foreman or members of his team) followed Andy's procedures on site.
- Andy's mitigation procedures are effective or whether other methods were employed.

In addition, it must be remembered that Andy is working within the confines of his own work and personal experiences – An 'Andy' with 20 years work experience via a trades background may highlight different issues from one with 2 years site experience and an engineering degree.

Now consider if Andy could quickly call upon the expertise of other 'Andys' when writing his method statement to keep Bob safe. If the knowledge in method statements could be collected, catalogued and re-used, perhaps Andy could be spared the onerous task of effectively 're-inventing the wheel'. Consider also that this process provides a platform for quickly generating bespoke method statements in seconds.

It is proposed that the AI method *Case Based Reasoning* (CBR) can be employed in the form of a *Tool.* This is intended to improve the effectiveness of management action by aiding hazard identification and management processes performed by those responsible for ensuring a safe system of work.

The physical outcome of the *Tool* is the creation of bespoke site-specific method statements for those working on construction and maintenance tasks 'in the field'. This is based on an extension of existing practices and marketed to potential users as a simple, yet more time-efficient method of achieving current tasks.

Chapter 6 focuses on the method employed to make this scenario a reality and is structured in three sections:

- **Section 1 – Maintaining Research Focus: *Keeping Bob Safe!***

Brief introduction and chapter structure is given.

- **Section 2 - Development Strategy**

The development strategy of the *Tool* to accommodate the *Tool* is based on four key elements to enable the *Tool* features to be defined.

  - Target Users.
  - Methodology & Hosting Platform.
  - Data.
  - User Interface.
  - Tool Features.

- **Section 3 - Summary & FAQs**

The chapter summary includes a section in the form FAQs (frequently asked questions) to highlight the limitations of the *Tool*.

6.2 Development Strategy

It is proposed the development of a *Tool* can to improve the effectiveness of management action by aiding those responsible for ensuring *a safe system of work.*

The development strategy of the *Tool* to accommodate the *Tool* is based on four key elements to enable the *Tool* features to be defined. These are:

- Target Users.
- Methodology & Hosting Platform.
- Data.
- User interface.

6.2.1 Target Users

There are many different types of *workers* involved in construction and maintenance tasks ranging from labourer to corporate executives that, in one way or another, could benefit from a *Tool*. Other examples of *Tool* users include those working in the established roles of the *Designer*, *Contractor*, *Client*, *CDM Coordinator* etc.

As the target audience of Andy has been identified, a new group of workers is proposed; those who act as *facilitators and authors of method statements* or FAMS.

FAMS primarily include frontline supervisors and engineers who are responsible for ensuring a safe system of work by creating safety related documents, such as method statements, and distil this knowledge to their team. Research has recognised workers that have important daily influence with staff have the opportunity to control unsafe conditions and prevent accidents (Chew 1988; Haslam et al. 2005; Heinrich et al. 1980; Simard and Marchand 1994). Health & Safety Advisors could also be included in this group as research has identified this role as influential with the ability to stimulate others towards improving safety (Swuste and Arnoldy 2003).

Despite the central role of FAMS, past research (Haslam *et al.* 2005) has portrayed front-line construction supervisors as having:

- Little safety awareness with poor understanding of accident causation and prevention.
- No positive incentive for prioritising safety over project deadlines.

This research found the effectiveness of interactions of those in FAMS-like roles can be enhanced by:

- Positive attitudes and approaches to safety and training
- Improving the nature and extent of interaction with employees
- Thoroughness and willingness to learn from accident investigation

Although these alarming findings have relevance in analysis of specific accidents, their application to generic safety management appears limited. The study itself is predominately focussed on 'trial by error', with variables such as sample size, company size or ratio of accident scenarios to non-accident work tasks being ignored. Never-the-less, Haslam's study reinforces the importance of FAMS competence and their integral part in communicating safety related knowledge to the work team.

Statistics in UK surveys have found around 75% of all fatal accidents in the building and civil engineering industries are caused by ineffective management action (Health and Safety Executive 1988). Thus it is proposed aiding FAMS in their daily job of identifying and managing hazards will reduce the number of accidents.

Having established this new group of workers, an insight into FAMS needs was facilitated by informal staff interviews. This was conducted in a series of site and office based visits to real infrastructure projects, namely two Carillion plc projects:

- The Term Maintenance Contract (TMC), awarded by Wolverhampton City Council in 2005 provides routine maintenance including patching, draining, kerbing and footway works, together with street lighting, sign erection and winter services. The project is worth £3 million a year for five years with an option to extend for a further two years.
- The £35m railway construction project at Larkhall-Milngavie was the first new branch line to open in Scotland for 25 years and was funded by the Scottish Executive with support from South Lanarkshire. The project was completed in 2007 and involved laying three miles of track from a junction near Hamilton Central to the new station at Larkhall, and a one mile extension of the Northern Suburban Line from Maryhill to Anniesland.

These visits and associated interviews were aimed as a brief introduction to the types of projects undertaken by Carillion plc and several different possible aspects for the *Tool* were suggested.

The main consensus was the development of a *Tool* to act as a 'one-stop-shop' for health and safety knowledge and enable streamlining of hazard identification and risk management processes by reducing bureaucracy and improving document control. Other issues are given below:

- Visible routes of communication and updating procedures.
- Streamlining hazard identification and risk management processes.
- Quick information gathering and processing to inform management of important issues.
- Ways of identifying and linking tasks and projects to warn of likely hazards.

- Scope to expand for collaborative and commercial settings i.e. access for prospective or current *Clients* to view strategic safety information or Key Performance Indicators (KPIs). Succinct handover of safety critical information to the *Client* at the end of the project.

These site visits aided in the creation of a system diagram and main interactions of the proposed *Tool* (Figure 6.1).

The main feature is 2-way communication between the database holding information on hazards, risks and best practice data and the web-based user interface, enabling specific hazard and risk data to be downloaded / displayed based on specific user requests. There is also scope to fast-track specific documents or safety alerts to a strategic monitoring team with a visible review and action cycle.

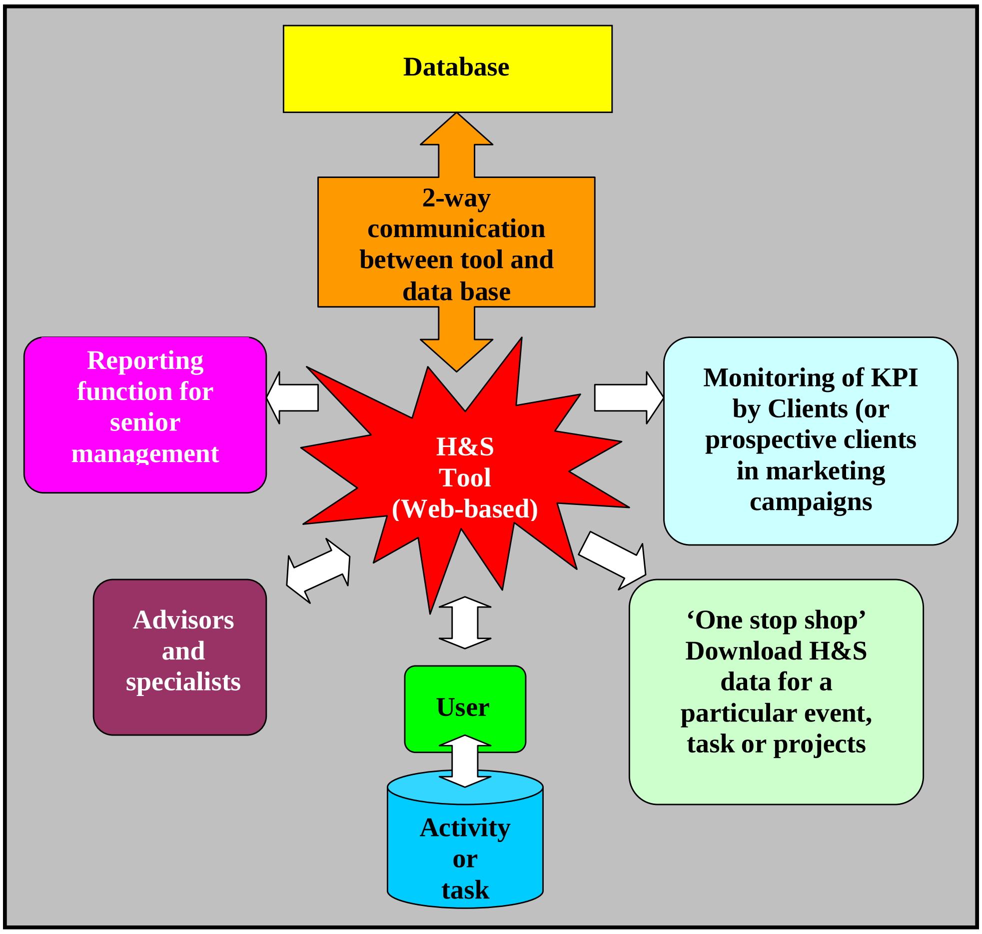


Figure 6.1 System diagram of *Tool* (Campbell and Smith 2007b)

6.2.2 Methodology & Hosting Platform

There are various research methods available in developing a *Tool* and examples of past research are highlighted in Chapters 3-5.

It is proposed a *Tool* employing a hybrid methodology of the *Artificial Intelligence* method (see Chapter 5) in addition to a *Knowledge Management* technique (see Chapter 4) can be utilised to aid the protection of workers performing construction and maintenance tasks from harm. The AI method *Case Based Reasoning* (*CBR*) and *Knowledge Systems,* are identified as a complementary methods of facilitating the *Tool* whilst the internet technologies are identified as a preferred hosting platform. This is shown in Figure 6.2.

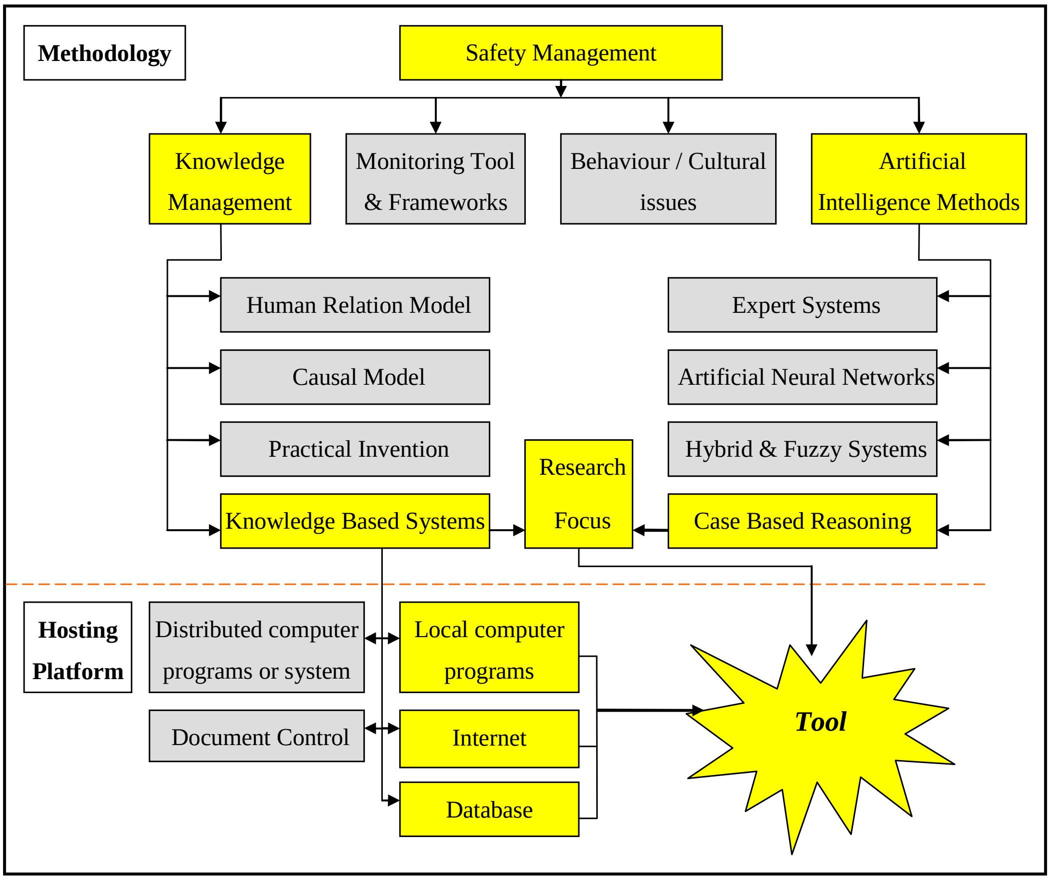


Figure 6.2 Tool Development

Many hosting platforms are available to facilitate the *Tool* including locally held computer programs and databases or distributed computer programs / systems. High costs associated with ongoing maintenance and upgrading of a locally held version of the *Tool* lead to the decision to use now ubiquitous internet technology to host the user interface while employing a database centrally held on a computer network server (Campbell et al. 2008) .

During development of the *Tool*, a locally held prototype of the *Tool* is hosted on a laptop using a *Microsoft Access* application. This interim prototype phase allowed relatively easy changes in visual layout, database design, along with aiding the calibration process and testing (Campbell et al. 2007b). The database used in the prototype is a structured collection of information whereby computer programs may easily query and search the information for specific items or groupings. *Server Query Language* (SQL), a common 'querying' language, is used to allow communication between commercially available or bespoke software. This enabled the database used in the prototype to be transferred to a network server for use with internet technologies.

Hosting the *Tool* on a computer server, as opposed to specific software packages, also gives many advantages including version control and dissemination of upgrades (Campbell and Smith 2007a; Campbell et al. 2007a; Campbell et al. 2007b). A database containing the *Case Base* (library) and other data is held on a computer server and is accessed through a dynamic webpage using server query language (SQL) and browser interface engine *ColdFusion* (an Adobe product). Another Adobe product, *Dreamweaver*, was used to develop a dynamic web site and acts as an editing interface with *ColdFusion*.

Using an analogy of a driving a car instead of a web site:

- The resource of fuel is the *Case Base* of past solutions.
- The drivers controls such as the accelerator act as the web page.
- The *ColdFusion* element can be viewed as the mechanical actions within the car that translate the driver's action into motion.
- The *Dreamweaver* package gives web developer tools to view the engine working.

There are many different types of web architecture commercially available. The decision to use Adobe packages was based on the availability of the software through UoE's procurement and licensing schemes, the availability of *Dreamweaver* training and contact with staff with past experiences using *ColdFusion* (Campbell and Smith 2007b).

6.2.3 Data

Many documents are used on UK construction and maintenance sites relating to safety including the 'Health & Safety Plan / File' and accident reports. Method statements describe how the given work task is to be undertaken and are an excellent source of safety knowledge as they can capture how the person preparing the method statement perceived the characteristics of the work task. These documents are prepared by competent workers who are responsible for the planning / completion of individual work tasks and demonstrate that someone in the organisation has given consideration to safety practice. Unlike accident reports that focus on specifically 'trial by error' when there is an incident, method statements can be used to effectively capture the 'null' reports and encourage an more optimistic view of 'trial by success'.

Method statements rely, in part, on subjective experiences and tacit knowledge of those involved in authoring and approving these documents. However, anecdotal evidence into this process has revealed that method statements (FAMS) can suffer from blind *cut & paste* techniques, whereby the writers of method statements have used control methods from previous documents without demonstrating:

- How the dangers and their control methods from the previous work task relate to a current job.
- The suitability or effectiveness of the methods.
- Quality assurance that these controls are being implemented on site.

Method Statements are often paper-based and generally include some form of hazard identification and/or risk management documentation such as a *Risk Assessment* or *COSHH*[3] related information. Method statements are used by a variety of workers as a recipe for *safe system of work* with copies stored at the work task location and other storage facilities such as main or satellite offices, site offices, remote / sub-contracted storage facilities etc.

Like other paper-based documents, method statements are not stored indefinitely and often destroyed after a given period of time after completion of the work task. This time limit can relate to the duration of warranty periods, or specific clauses in contractual agreements.

A three phase method of extracting safety knowledge from method statements was developed and used to populate the *Tool*:

1. Data Collection
2. Designer
3. Engineering Volunteers (students)

The *Data Collection Phase* is self explanatory whilst the *Designer Phase* emulates the attempts of an innovative individual extracting data from an existing system into a new format, system or tool. The *Engineering Volunteers Phase* demonstrates potential roll-out problems as the designer becomes less involved.

[3] COSHH = Control of Substances Hazardous to Health

Phase 1 - Data Collection

A series of visits over a two month period allowed method statements from a real transportation project to be collection from a satellite site office in Larkhall, Scotland (UK). This £35m railway construction project was the first new branch line to open in Scotland for 25 years was funded by the Scottish Executive.

Examination of the method statements demonstrates the diversity of transportation projects by featuring many traditional civil engineering works such as bridges, earthworks and general concrete works in addition to rail specific work tasks. These method statement formed a basis for ‘null’ report as they were not associated with accidents / accident reports. A total of 57 method statement were collected; 27 related to civil / structural works, 22 related to Rail specific works and 8 related to general construction issues.

Phase 2 - Extraction by Tool Designer

This phase establishes a method of extracting safety knowledge from method statements with a view to populating the Tool’s *Case Base* or library of past solutions. Five method statements were randomly chosen for entry into the *Tool’s Case Base* using this process, relating to the following work tasks:

- Construction of Cabinet, REB & container Compounds (rail specific).
- Junction Mast Erection & wiring modifications (rail specific).
- General Concrete Works (civil / structural).
- Shot blasting / Painting of structures (civil / structural).
- Bridge Demolition (civil / structural).

The *Designer Phase* involved four steps:

1. **Background Knowledge**. The *Designer* reads each work task in order to gain background knowledge.
2. **Mining Statements**. The *Designer* mines each of the method statements for information relating to the safety or wellbeing of workers on site. This is achieved by highlighting and grouping similar worded passages relating to a common feature. This step enabled a list of 62 different mitigations towards improving worker safety to be captured (Table 6.1).
3. **Visual Matrix**. A simple matrix is used to identify and show the relationship between the work task method statements and the listed mitigations and is performed in parallel with the previous step. The visual matrix is shown in Figure 6.3.
4. **Case Base Entry**. The mitigations (in this case all 62) are transferred into the *Case Base*

Table 6.2 gives a summary of the *Designer's Visual Matrix* and shows between 30 and 34 mitigations are extracted from each method statement.

Six mitigations (as detailed in Table 6.3 Common Control Measures) appeared in all five method statements, namely:

- Site Security
- House Keeping
- Manual Handling Training
- Safety Briefing
- Access & Egress Routes
- First Aid Procedure

ID Number	Mitigation Title	ID Number	Mitigation Title
1	Exposing services	32	Waste Material Management
2	Certified Lifting Equipment	33	Fuel Spill Kits
3	Site Security	34	Welfare (Main office)
4	Traffic Management	35	First Aid
5	Storage of COSHH Substances	36	Authorising start of work
6	House Keeping	37	PPE (General Road)
7	Fire Extinguishers	38	PPE (General Rail)
8	Approved Working Platforms	39	PPE(Specific - Road or Rail)
9	Crane / Lifting Operations	40	Completion Criteria (Rail Possessions)
10	Lighting (Temp or Normal)		
11	Noise Protection	41	Certified Plant and Equipment
12	Limiting Shift Hours	42	Lighting- Temporary (RAIL)
13	Access / Egress Routes	43	Fuels on site
14	Handling of materials (Steel)	44	Method Statement Briefing
15	Manual Handling Training	45	Compliance Monitoring Method Statements
16	First Aid Procedures		
17	PTS Training	46	Removal of Existing Waste
18	Safety Briefing	47	Preventing Weil's Disease (Leptospirosis)
19	Isolation & permit system (Overhead Line)	48	Watercourse Protection
20	Correct Fuel Storage	49	Wildlife Protection
21	T3 Possession	50	Hand Arm Vibration (White Finger)
22	Banksman		
23	Supervised Reversing Movements (Rail)	51	COSHH-Concrete
		52	Daylight Working
24	24 Trained Plant Operatives	53	Welfare (site compound or office)
25	Fall Arrest Systems		
26	Use of Ladders	54	Dust Suppression
27	Handling of Radially loaded wires	55	Dewatering Arrangements
		56	Concrete checklist
28	Tensioning Conductors and rigging (Rail)	57	Tools(Hand and powered)
		58	Excavation protection
29	Burning Operations	59	Asbestos Management
30	Works / Equipment "On or near the line" (Rail)	60	COSHH-Lead paint
		61	COSHH-Shot blasting
31	Identifying hidden services	62	Ground Investigation

Table 6.1 Mitigation Table

Designer work tasks
1. Construction of Cabinet
2. Junction Mast Erection
3. General Concrete Works
4. Shot blasting / Painting of structures
5. Bridge Demolition

Mitigation Numbers	1	2	3	4	5
1	•	•	•		•
2	•	•	•	•	
3	•	•	•	•	•
4	•				•
5	•		•	•	
6	•	•	•	•	•
7		•	•	•	•
8				•	
9	•	•		•	
10	•	•		•	
11	•	•	•		•
12	•				•
13	•	•	•	•	•
14	•	•	•		
15	•	•	•	•	•
16	•	•	•	•	•
17		•	•	•	
18	•	•	•	•	•
19		•			
20		•	•		•
21		•			
22	•		•		•
23	•	•			
24		•	•	•	•
25	•	•		•	•
26		•			
27		•			
28		•			
29		•			
30	•	•			
31	•				•
32		•	•	•	•
33	•		•	•	•
34	•			•	
35	•		•	•	•
36	•	•		•	
37			•		•
38	•	•		•	
39	•	•	•	•	•
40		•			
41	•		•	•	•
42	•	•		•	
43		•	•	•	•
44	•	•	•	•	•
45		•	•		
46			•		•
47				•	•
48			•		•
49			•		•
50			•		
51	•		•		
52			•	•	•
53			•	•	•
54				•	•
55			•		
56			•		
57	•				•
58					•
59					
60				•	•
61				•	
62				•	•

Figure 6.3 Designer's Visual Matrix

Work Task	Construction of Cabinet	Junction Mast Erection	General Concrete Works	Shot blasting & painting of structures	Bridge Demolition
Number of Mitigations	31	34	34	33	35

Table 6.2 Summary of Designer Matrix

Mitigation Title	Mitigation Description
Site Security	Appropriate site barriers should be used to ensure unauthorised persons cannot enter the site. Appropriate 'sign-in/ sign-out' procedure should be used during working hours and security present between shifts. Anti-vandal guards and immobilisers should be fitted to plant and any routes used by the public must be maintained (i.e. no trip hazards etc) and segregated from operations. In extreme cases all plant, equipment and materials will be delivered to site at the start of the shift and removed at the end of each shift.
House Keeping	Working areas and welfare facilities should be kept clean and tidy
Access & Egress Routes	Designated access and egress routes to be clearly defined and briefed to all. Routes should be checked for faulty manhole/catchpit cover etc. Highlight trip areas before taking equipment to site. Where these may change, this information must be given prior to work commencing.
Manual Handling Training	Use mechanical means where possible .All personnel trained / competent in team lifting and aware of twisting and repetitive movements. Health screening should be used to monitor progressive cases.
First Aid Procedure	First Aider to be on site and identified in site briefings and listed on site and office notice boards. First Aid boxes to be kept in site office and mobile phone to be made available to contact emergency services. First Aid boxes may also be found in cabs of designated vehicles. The location of nearest hospital / A&E and the journey time should be taken into account
Safety Briefing	Safety briefings must be given before work commences and where the conditions of a given work task have changed.

Table 6.3 Common Control Measures

Phase 3 - Engineering Volunteers (students)

Engineering Volunteers updating the *Case Base* with a larger selection of method statements comprises the third phase. In this case, a further 21 work tasks are uploaded by two undergraduate student volunteers in their final year of Civil Engineering studies at the University of Edinburgh, David Moriarty and Philip Beausang. The two undergraduates had similar backgrounds in education, ability and age. The only notable difference was that one undergraduate (Phil) had worked on a construction site during one summer vacation.

This process was achieved using bespoke templates to enter descriptive information such as title, works manager etc. This phases mirrors the *Designer Phase*, whereby volunteers read and familiarise themselves with the paper method statements in order to gain background knowledge of the work task and encouraged to replicate the matrix technique (see Figure 6.3 Designer's Visual Matrix).

Tutorial style instructions were given to the volunteers and an example method statement processed by the volunteers under the supervision of the *Tool Designer* (the *Designer* has no direct involvement in the volunteer decision making process in order to limit bias). The volunteers processed the remaining work tasks without supervision, identifying 3 new mitigations for inclusion to the *Case Base*; 'working with compacting equipment', 'boring operations' and 'trial pitting'

Table 6.4 shows between 17-40 mitigations are evident in each method statement with only one mitigation (First Aid Procedure), evident in all method statements. Also, thirty-five percent (22 out of 62) of the mitigations identified in the previous phase by the designers occurred 15 or more times.

Work Tasks	**Number of Mitigations**
Bridge Completion Works	40
Collection, removal and disposal of sharps	18
Construction of Stations	38
Demolish Merryton Bridge	37
Demolition of Clyde Avenue Road Bridge	29
Environmental Investigation	26
General site clearance	34
Ground Investigation (Exploratory)	37
Hamilton Rd. Raploch St. Bridge Parapet upgrade	33
Hauchhead Jnct-Mast Erection , wiring modifications	34
Install Concrete foundation signal base MH 419	39
Larkhall line Running of return conductor	33
Long line public address installation	39
Merryton footbridge	26
Removal, disposal & destruction of Japanese Knotweed	17
Repair to Merryton Footbridge	14
Shot blasting / Painting structure	34
Signalling civil works	24
Site Survey	22
Support to Sheet piles	40
Unloading of S+C Materials & building up of panels	40
Average number of Mitigation extracted by Dave(A)	*31.6*
Average number of Mitigation extracted by Phil (B)	*31.5*

Table 6.4 Engineering Volunteers Adding a further 21 Method Statements

In conclusion, the three phase extraction method successfully allows the transfer of safety knowledge between paper-based method statements and the *Tool's Case Base*. In addition there are a number of observations namely:

- **Phase 1-Data Collection**
  - Site visits are crucial in this phase to allow method statements from a real transportation project to be collected.
  - Examination of the method statements from a real transportation project demonstrates work diversity including traditional civil engineering and rail specific work tasks.
- **Phase 2-Designer**
  - Four steps are identified as a valid method of extracting safety knowledge from method statements with a view to populating the *Case Base* (Background Knowledge, Mining Statements, Visual Matrix & Case Base Entry).
  - This step allowed 62 mitigations to be extracted from 5 random method statements.
  - Each method statement was found to have between 30-34 mitigations with six mitigations appearing in all five method statements.
- **Phase 3-Engineering Volunteers *(students)***
  - 21 method statements uploaded to the *Case Base* and a further 3 mitigations were added to the library.
  - Each method statement was found to have between 17-40 mitigations with 'first aid procedure' being the only mitigation found in all 21 method statements. In addition, 22 out of 62 (35%) mitigations identified in the previous *Designer Phase* occurred 15 or more times.

The diversity and the proportion of method statements used in each of the three phases is highlighted in Table 6.5 and given fully in ***Appendix D***

	Total Number	Civil / Structural Engineering	Rail Specific	General
Phase 1	**57**	27	22	8
Phase 2	**5**	3	2	0
Phase 3	**21**	13	4	4

Table 6.5 Number & type of method statements used in each extraction phase

6.2.4 User Interface & Reporting

The interface of the *Tool* was aimed to be straight forward in order to attract practitioners who currently use 'cut & paste' techniques from past method statements. In addition, workers who identify and manage hazards in their everyday work do not relate hazards within RIDDOR (the UK's Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995). Under these regulations companies must register major injuries and / or diseases, '3-day' injuries whereby the person is incapable of work for three working days , or any 'near miss' incidents that did not result in people being harmed but easily could have done (Health and Safety Executive 1999). The method of RIDDOR reporting is unilateral across all industries and provides the main statistics for the Health and Safety Executive to convey the current state of the safety to the UK Government. However, those responsible for identifying and managing hazards in their everyday work (FAMS) do not often relate hazards or harms to RIDDOR classifications, with many viewing this reporting as a regulatory paper chase and increased workload. Thus, it is proposed basing the proposed *Tool* on the robust classification of RIDDOR will further align normal working practice with regulatory hazard management requirements (Campbell et al. 2007b). Furthermore, the use of an established classification technique was conducive to *Case Based Reasoning* methodology whereby cases are retrieved based on similarity of classified attributes.

Consistency in describing case attributes is needed to make case retrieval meaningful but exact matching of a problem / solution set is not required due to the concept of a similarity threshold value. This similarity value is based on comparison between attributes inherent to the current problem, and those exhibited in the stored cases (Campbell and Smith 2006). Attribute values can be user defined arbitrarily values, based on experiences or estimated by empirical functions. Common similarity techniques used include:

- *Nearest neighbour techniques*, where total similarity of a given case to a new case is based on the sums of weighted similarity values for each case attribute.
- *Induction techniques*, where algorithms are used to build decision trees based on clustering of similar cases together and identifying patterns from case histories.
- *Fuzzy Techniques*, where linguistic terms such as ‘good’, ‘fair’ or ‘poor’ are used instead of quantitative values or scales. The description and limits of these qualitative terms can be more easily altered than quantitative step changes.

Whichever way the similarity between the current problem and the stored cases is calculated, the method must not obstruct or bias the process in which a user can accept or decline recommended cases from the library. Consistency in assigning values to new, reused or revised cases on their journey through the CBR cycle is crucial to ensure a consistent definition of attributes.

The proposed *Tool* assesses similarity by prompting the user to assign a classification to the new case or work task broadly based upon categories on RIDDOR.

- 9 Hazard Categories were mapped to 20 RIDDOR ‘*dangerous occurrences’* classifications with ‘failure of any load-bearing fairground equipment’ as this deemed irrelevant (see Table 6.8).
- 5 Harm Categories were similarly taken from RIDDOR but differ between the prototype and internet version of the *Tool*.

***Tool* Harm Categories**	**Weighting**	**RIDDOR Category equivalent**
Main Body Injury	6	(i) fracture other than to fingers, thumbs or toes; (ii) amputation; (iii) dislocation of the shoulder, hip, knee or spine;
Loss of Sight	5	(iv) loss of sight (temporary or permanent); (v) chemical or hot metal burn to the eye or any penetrating injury to the eye;
Electric shock or burn	4	(vi) injury resulting from an electric shock or electrical burn leading to unconsciousness or requiring resuscitation or admittance to hospital for more than 24 hours;
Contact with Harmful Substance	3	(vii) acute illness requiring medical treatment, or loss of consciousness arising from absorption of any substance by inhalation, ingestion or through the skin; (viii) acute illness requiring medical treatment where there is reason to believe that this resulted from exposure to a biological agent or its toxins or infected material; (ix) unconsciousness caused by asphyxia or exposure to a harmful substance or biological agent;
Heat related injuries	2	(x) any other injury: leading to hypothermia, heat-induced illness or unconsciousness; or requiring resuscitation; or requiring admittance to hospital for more than 24 hours;
Other	1	

Table 6.6 Tool Harm Classification

Tool Harms Categories	**Weightings**	**RIDDOR Category equivalent**
Major Injury	6	Major Body Injury (broken limbs, amputation etc), Loss of Sight, Electric Shock / Burn , hypothermia
3-Day Injury	5	Injuries leading to workers being absent or are unable to do the full range of normal duties for more than 3 working day i.e. broken finger(s) or toe(s)
Diseases	4	Poisoning, Skin disease, Lung Disease, Infection and occupational cancers.
Harmful Substance	3	Includes inhalation, asphyxia ingestion or absorption through the skin of: • biological agent • toxins • infected material
Muscular Skeletal Injuries	2	Repetitive strain injuries, hand and arm vibration syndrome (HAV), recurring back pain, sprained ankles etc
Other	1	

Table 6.7 Harm Categories – Online version

***Tool* Hazard Categories**	**Weighting**	**RIDDOR Category equivalent**
Lifting equipment and operations	1	(i) collapse, overturning or failure of load-bearing parts of lifts and lifting equipment;
Electricity	1	(ii) plant or equipment coming into contact with overhead power lines; (iii) electrical short circuit or overload causing fire or explosion;
Unintentional explosion or collapse	1	(iv) unintended collapse of: any building or structure under construction, alteration or demolition where over five tonnes of material falls; a wall or floor in a place of work; any false-work (v) collapse or partial collapse of a scaffold over five meters high, or erected near water where there could be a risk of drowning after a fall (vi) any unintentional explosion, misfire, failure of demolition to cause the intended collapse, projection of material beyond a site boundary, (vii) explosion or fire causing suspension of normal work for over 24 hours
COSHH harmful substance release or contact	1	(viii) accidental release of a biological agent likely to cause severe human illness; (ix) failure of industrial radiography or irradiation equipment to de-energise or return to its safe position after the intended exposure period (x) accidental release of any substance which may damage health (xi) See(xix & (xx)
Collision or derailment	1	(xii) any unintended collision of a train with any vehicle (xiii) derailment or unintended collision of cars or trains
Working at Height and Falling Objects	1	See (v)
Confined Spaces and Diving	1	(xiv) malfunction of breathing apparatus while in use or during testing immediately before use (xv) failure or endangering of diving equipment, the trapping of a diver, an explosion near a diver, or an uncontrolled ascent (xvi) dangerous occurrence at a well (other than a water well)
Pipework, pipeline and closed vessels	1	(xvii) explosion, collapse or bursting of any closed vessel or associated pipework; (xviii)dangerous occurrence at a pipeline
Containers	1	(xix) failure of any freight container in any of its load-bearing parts; (xx) a road tanker carrying a dangerous substance overturns, suffers serious damage, catches fire or the substance is released (xxi) a dangerous substance being conveyed by road is involved in a fire or released

Table 6.8 Tool Hazard Classification

The prototype *Tool*, a locally held version hosted on a laptop computer, used harms based on RIDDOR's *Major Injury* classification (see Table 6.6) whilst these categories were upgraded in the internet-ready *Tool* to include:

- Major Injury.
- 3-Day Injury.
- Disease.
- Harmful Substance.
- Muscular Skeletal Injury.

The first three categories mirror RIDDOR classifications, whilst the category of *Harmful Substance* relates to another of the UK's regulations often considered when identifying hazards - COSHH or the Control of Substances Hazardous to Health (2002). Although muscular skeletal injuries do not warrant isolation within RIDDOR, the addition of this category within the *Tool* reflects the large numbers of workers suffering these injury types in the workplace. Industry-led and UK government campaigns have sought to highlight the hazards associated with these injuries, and the inclusion of the category was also seen as an opportunity to reinforce these 'good practice' campaigns. These are shown in Table 6.7.

In both cases of the prototype or internet-ready *Tool*, the nine hazards and five harms were used as a matrix to form the method of classifying work tasks using an entry template. Figure 6.4 shows the entry template as a *Form* in the locally held 1st version of the *Tool* whilst Figure 6.5 is applicable for the internet ready version.

The *Tool* user must assess the likelihood of each of the given combinations of hazard and harm events as likely, unlikely or not applicable. This process assigns a *CBR Number* to the new work task and is used to compare and assess similarity with past work tasks or stored 'cases'.

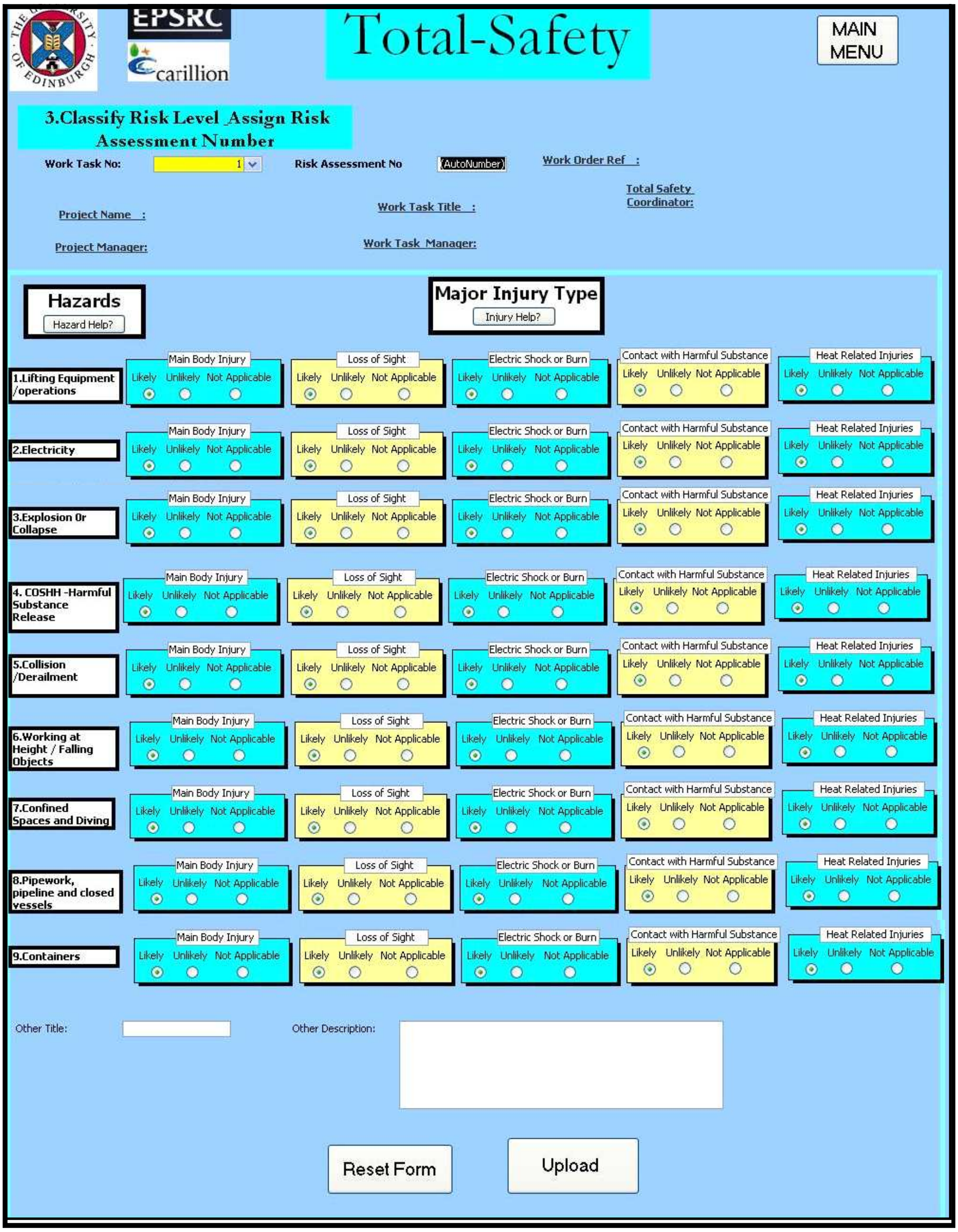
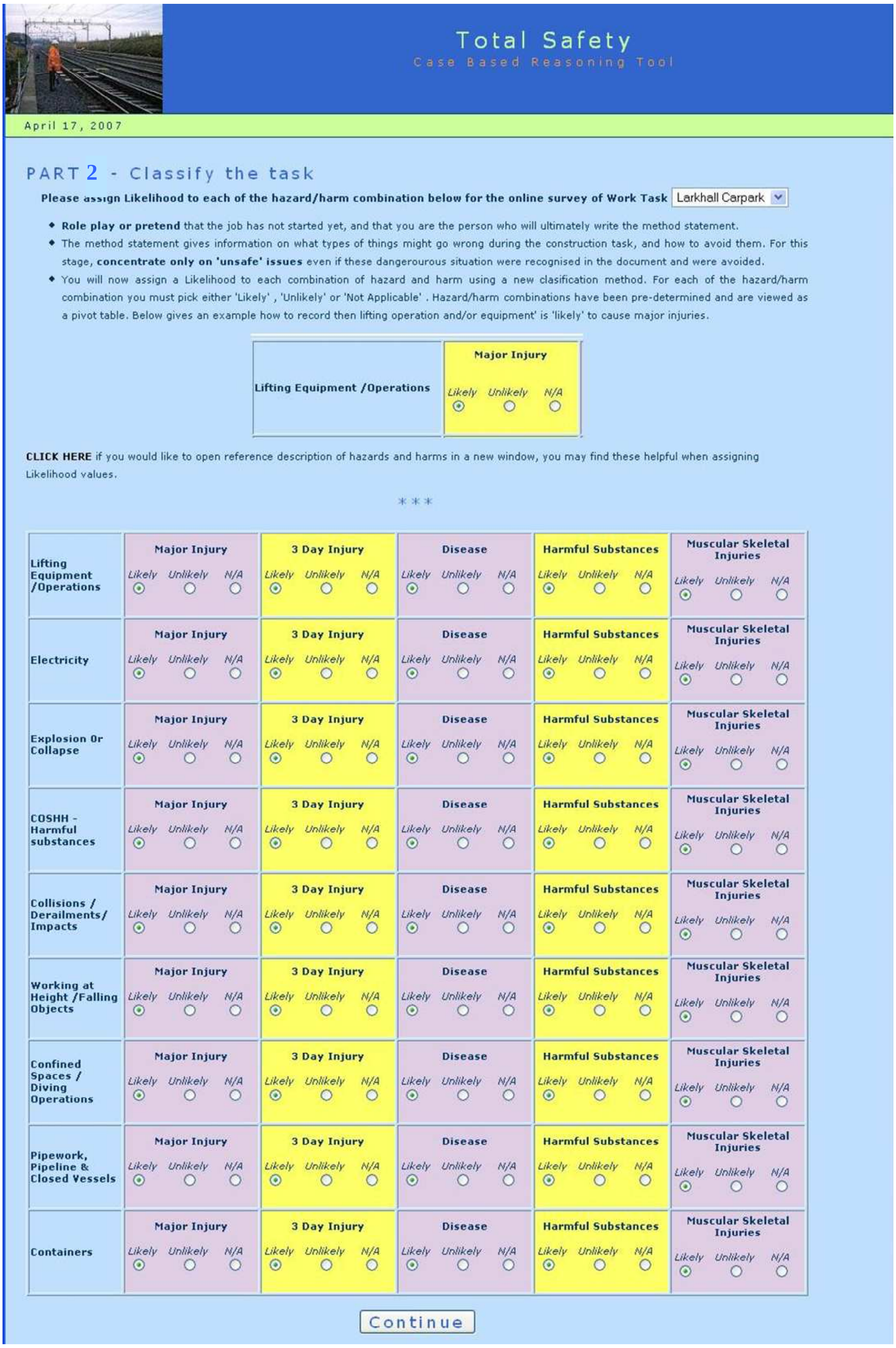


Figure 6.4 Work Task Classification Entry Template – Version 1, prototype



Total Safety

Case Based Reasoning Tool

April 17, 2007

PART 2 - Classify the task

Please assign Likelihood to each of the hazard/harm combination below for the online survey of Work Task Larkhall Carpark

- **Role play or pretend** that the job has not started yet, and that you are the person who will ultimately write the method statement.
- The method statement gives information on what types of things might go wrong during the construction task, and how to avoid them. For this stage, **concentrate only on 'unsafe' issues** even if these dangerourous situation were recognised in the document and were avoided.
- You will now assign a Likelihood to each combination of hazard and harm using a new clasification method. For each of the hazard/harm combination you must pick either 'Likely' , 'Unlikely' or 'Not Applicable' . Hazard/harm combinations have been pre-determined and are viewed as a pivot table. Below gives an example how to record then lifting operation and/or equipment' is 'likely' to cause major injuries.

	Major Injury
Lifting Equipment /Operations	*Likely* *Unlikely* *N/A*

CLICK HERE if you would like to open reference description of hazards and harms in a new window, you may find these helpful when assigning Likelihood values.

* * *

	Major Injury	3 Day Injury	Disease	Harmful Substances	Muscular Skeletal Injuries
Lifting Equipment /Operations	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*
Electricity	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*
Explosion Or Collapse	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*
COSHH - Harmful substances	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*
Collisions / Derailments/ Impacts	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*
Working at Height /Falling Objects	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*
Confined Spaces / Diving Operations	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*
Pipework, Pipeline & Closed Vessels	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*
Containers	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*	*Likely* *Unlikely* *N/A*

Continue

Figure 6.5 Work Task Classification Entry Template – Version 2, internet

Only three choices of *likely*, *unlikely* and *not applicable* are given to the user due to scaling limitations used in assessing similarity. There are 243 or 3^5 ways in which each hazard can be defined under the five harm categories leading to over 2000 different ways in which the work task can be classified across the nine hazard categories; this number was deemed sufficient for the development stage of the *Tool*. The choice of linguistic terms was intended to allow the capture of null reports i.e. that a combination was considered and deemed not applicable. This feature allows evidence, commonly undocumented and discarded as part tacit work task assessment, to be collected. The format of a 9 by 5 matrix as single page display and the use of radio buttons as opposed to drop down menus or linguistic user inputs were designed to streamline the process.

It is proposed that the statistical risks associated with the classification of work tasks and associated hazard management decisions / consequences be collated and analysed by a central specialised risk team. Furthermore it is proposed that this method of splitting risk and hazard management would allow FAMS to concentrate on creating and managing control measures, whilst the statistical risk team can benefit from targeted and centralised risk management training. In short, this method diverges from the established *'jack of all trades and master of none'* persona prevalent in the Industry, with a view to establishing competent workers with diverse skill bases.

6.2.5 Tool Features

The features of the proposed *Tool* are shown in Figure 6.6 as a process flow chart. The items prior to the CBR Function are facilitated by prescribed input templates aimed to accommodate:

- Project and / or work task registration (titles, descriptions, key workers)
- Commercial information (project references, work order numbers) and
- Estimations (projected cost, duration and man hours etc)

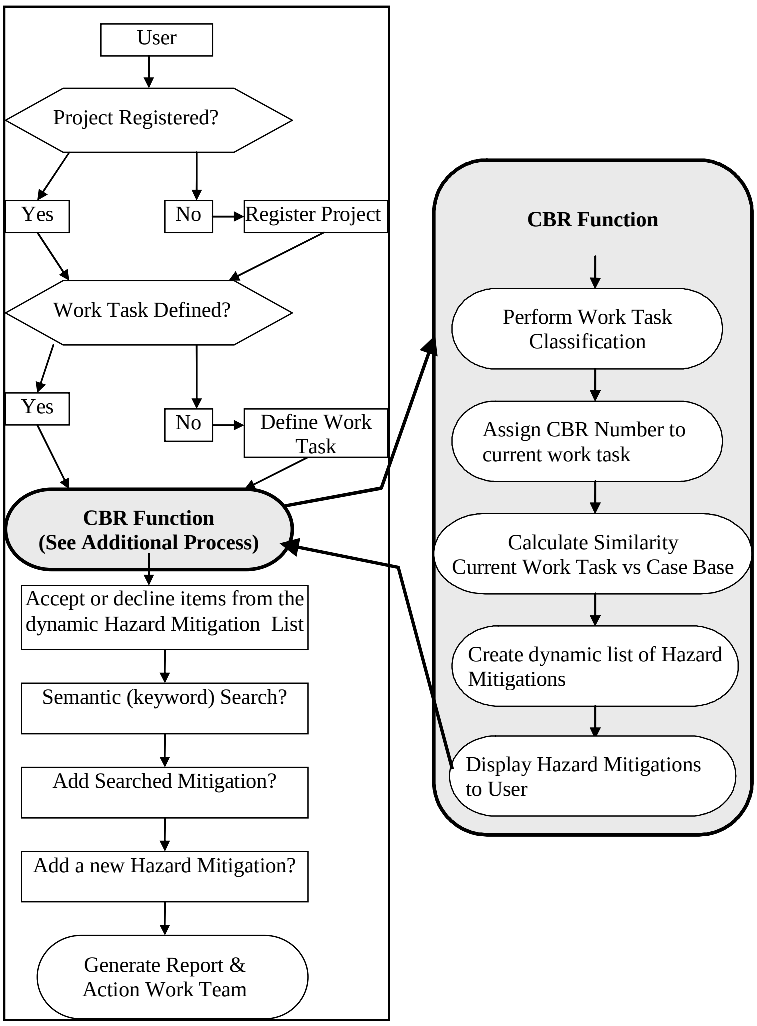


Figure 6.6 Tool Features Represented as Process Flow Chart (Campbell and Smith 2007b)

The CBR Function Process involves the classification of the work task using RIDDOR, the assignment of a CBR Number based on this classification followed by an assessment of this value against previously stored cases. The *Tool* produces a dynamic list of hazards and control measures based on the classification of the work task by the user and the retrieval algorithm. Examples of these hazard / control measure are given in Figure 6.7 and Figure 6.8 for the prototype version of the *Tool* and the internet ready version. The user can accept or decline these suggestions, search all mitigations using a keyword search or add completely new mitigations using prescribed templates This new work task is then uploaded to a library or *Case Base* where the information can be used in the next user cycle.

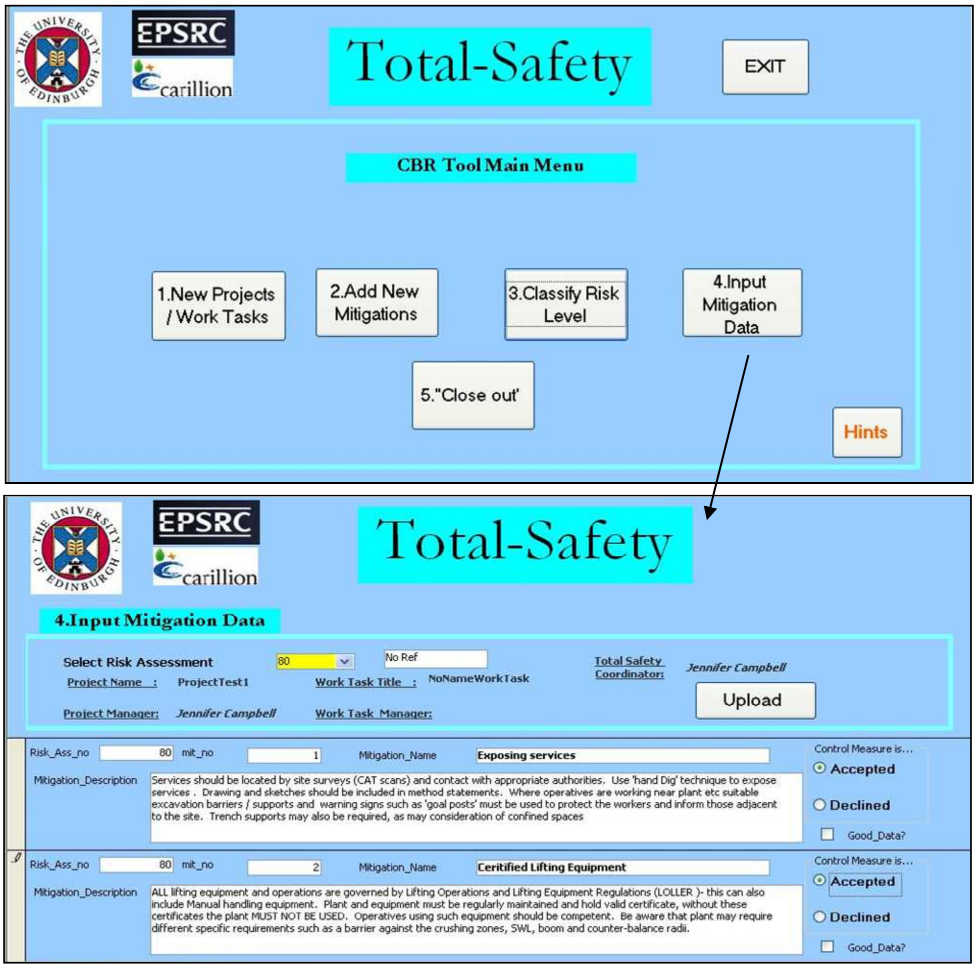
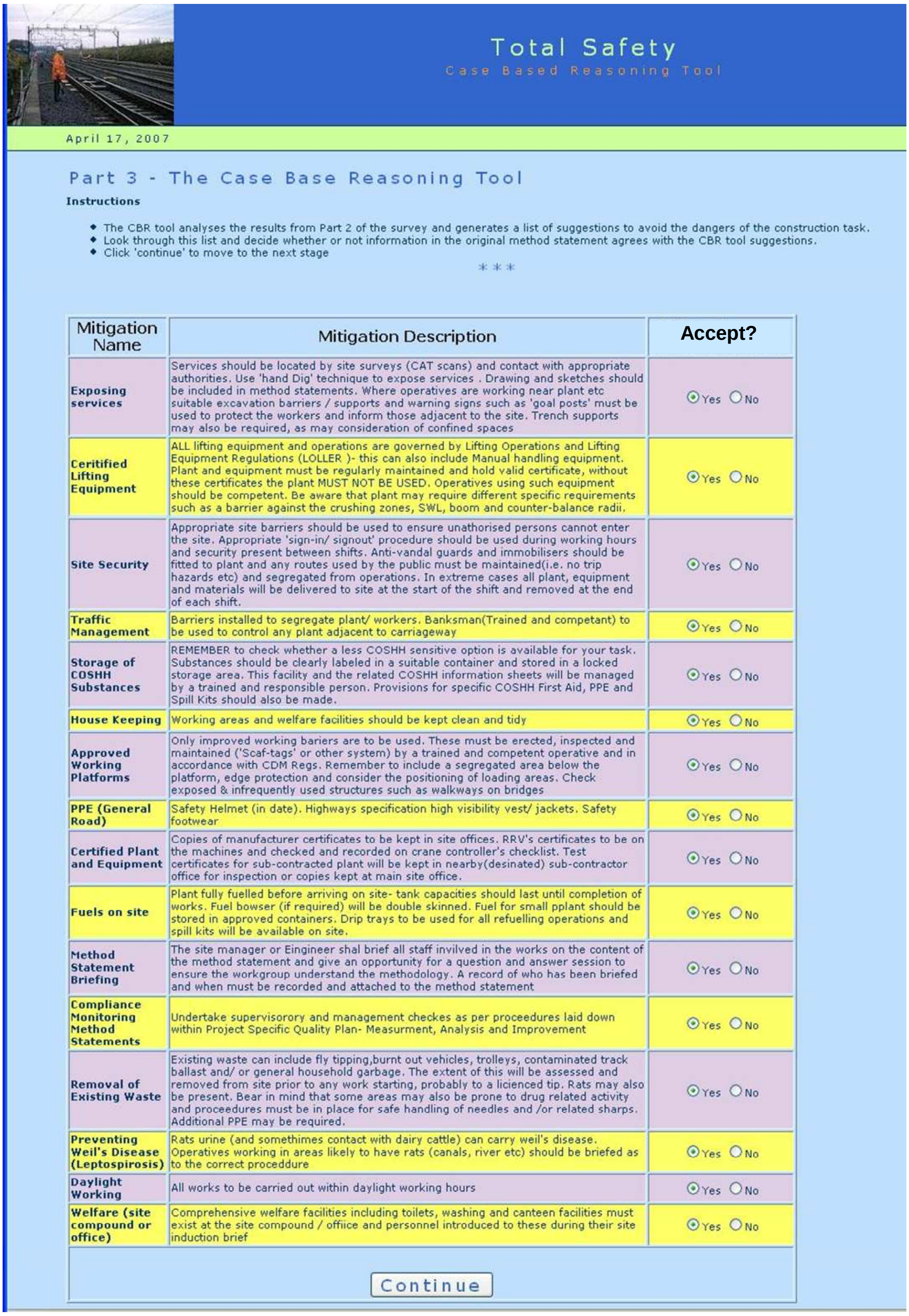


Figure 6.7 User Selection Screen, Prototype



Total Safety

Case Based Reasoning Tool

April 17, 2007

Part 3 - The Case Base Reasoning Tool

Instructions

- The CBR tool analyses the results from Part 2 of the survey and generates a list of suggestions to avoid the dangers of the construction task.
- Look through this list and decide whether or not information in the original method statement agrees with the CBR tool suggestions.
- Click 'continue' to move to the next stage

* * *

Mitigation Name	Mitigation Description	Accept?
Exposing services	Services should be located by site surveys (CAT scans) and contact with appropriate authorities. Use 'hand Dig' technique to expose services . Drawing and sketches should be included in method statements. Where operatives are working near plant etc suitable excavation barriers / supports and warning signs such as 'goal posts' must be used to protect the workers and inform those adjacent to the site. Trench supports may also be required, as may consideration of confined spaces	Yes No
Ceritified Lifting Equipment	ALL lifting equipment and operations are governed by Lifting Operations and Lifting Equipment Regulations (LOLLER)- this can also include Manual handling equipment. Plant and equipment must be regularly maintained and hold valid certificate, without these certificates the plant MUST NOT BE USED. Operatives using such equipment should be competent. Be aware that plant may require different specific requirements such as a barrier against the crushing zones, SWL, boom and counter-balance radii.	Yes No
Site Security	Appropriate site barriers should be used to ensure unathorised persons cannot enter the site. Appropriate 'sign-in/ signout' procedure should be used during working hours and security present between shifts. Anti-vandal guards and immobilisers should be fitted to plant and any routes used by the public must be maintained(i.e. no trip hazards etc) and segregated from operations. In extreme cases all plant, equipment and materials will be delivered to site at the start of the shift and removed at the end of each shift.	Yes No
Traffic Management	Barriers installed to segregate plant/ workers. Banksman(Trained and competant) to be used to control any plant adjacent to carriageway	Yes No
Storage of COSHH Substances	REMEMBER to check whether a less COSHH sensitive option is available for your task. Substances should be clearly labeled in a suitable container and stored in a locked storage area. This facility and the related COSHH information sheets will be managed by a trained and responsible person. Provisions for specific COSHH First Aid, PPE and Spill Kits should also be made.	Yes No
House Keeping	Working areas and welfare facilities should be kept clean and tidy	Yes No
Approved Working Platforms	Only improved working bariers are to be used. These must be erected, inspected and maintained ('Scaf-tags' or other system) by a trained and competent operative and in accordance with CDM Regs. Remember to include a segregated area below the platform, edge protection and consider the positioning of loading areas. Check exposed & infrequently used structures such as walkways on bridges	Yes No
PPE (General Road)	Safety Helmet (in date). Highways specification high visibility vest/ jackets. Safety footwear	Yes No
Certified Plant and Equipment	Copies of manufacturer certificates to be kept in site offices. RRV's certificates to be on the machines and checked and recorded on crane controller's checklist. Test certificates for sub-contracted plant will be kept in nearby(desinated) sub-contractor office for inspection or copies kept at main site office.	Yes No
Fuels on site	Plant fully fuelled before arriving on site- tank capacities should last until completion of works. Fuel bowser (if required) will be double skinned. Fuel for small pplant should be stored in approved containers. Drip trays to be used for all refuelling operations and spill kits will be available on site.	Yes No
Method Statement Briefing	The site manager or Eingineer shal brief all staff invilved in the works on the content of the method statement and give an opportunity for a question and answer session to ensure the workgroup understand the methodology. A record of who has been briefed and when must be recorded and attached to the method statement	Yes No
Compliance Monitoring Method Statements	Undertake supervisorory and management checkes as per proceedures laid down within Project Specific Quality Plan- Measurment, Analysis and Improvement	Yes No
Removal of Existing Waste	Existing waste can include fly tipping,burnt out vehicles, trolleys, contaminated track ballast and/ or general household garbage. The extent of this will be assessed and removed from site prior to any work starting, probably to a licienced tip. Rats may also be present. Bear in mind that some areas may also be prone to drug related activity and proceedures must be in place for safe handling of needles and /or related sharps. Additional PPE may be required.	Yes No
Preventing Weil's Disease (Leptospirosis)	Rats urine (and somethimes contact with dairy cattle) can carry weil's disease. Operatives working in areas likely to have rats (canals, river etc) should be briefed as to the correct proceddure	Yes No
Daylight Working	All works to be carried out within daylight working hours	Yes No
Welfare (site compound or office)	Comprehensive welfare facilities including toilets, washing and canteen facilities must exist at the site compound / offiice and personnel introduced to these during their site induction brief	Yes No

Continue

Figure 6.8User Selection Screen, internet-ready version (Campbell and Smith 2007a)

The *Tool* stores case information such as the work task classification, the list of suggestions given by the *Tool*, and the users selections in the *Case Base*. The next 'case' search will include this information and learn from it to produce a better selection of suggestions. Finally, both work tasks and projects can be 'closed out' after feedback and completion to ensure an auditable trail of safety management ownership.

The physical outcome of the *Tool* is the generation of a paper method statement to be actioned by the work team containing salient factors of the decision making process, listing possible hazards and the methods employed for their control.

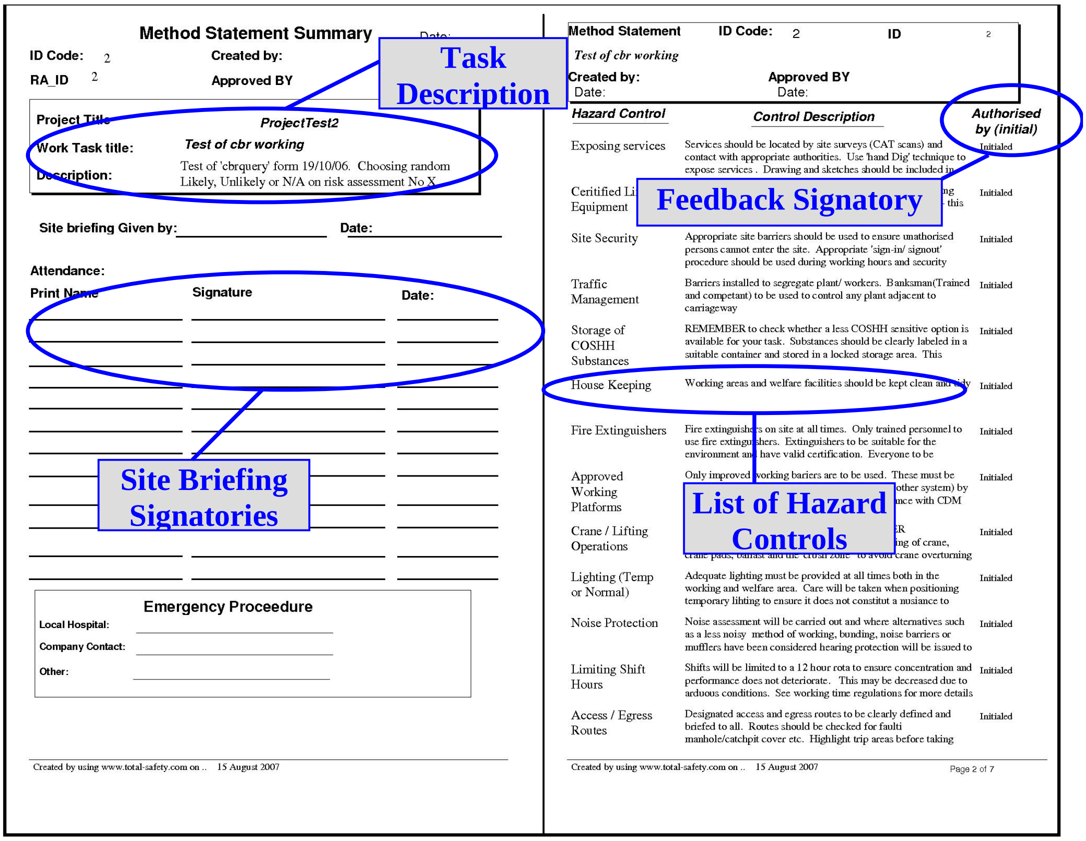


Figure 6.9 Example of a Method Statement

The method statement generated by the *Tool* separates the descriptive work or project related material from the mitigations. The mitigation section mirrors the format of current practice of risk assessment by being tabulated but adds an additional column for quality control and site feedback purposes. This new column requires a signatory to ensure each of the mitigations is used for the work task. The signatory must specify alternative mitigations where those in the method statement are not applicable for the task, the control is ineffective throughout the duration of the task or where a better mitigation is available. This acts as a feedback loop enabling tacit knowledge within site-based individuals to be captured and input back into the *Case Base.*

6.3 Summary and FAQs

Effective communication of safety knowledge throughout a project relies on many different types of worker whether in the traditional Design or Construction roles. Thus a new group of workers is proposed to challenge traditional stereotypes of safety responsibility by including those who *Facilitate and / or act as Authors of Method Statements* or FAMS.

FAMS distil safety knowledge to others through producing written reports such as method statements, verbal interaction and / or understanding such documents with others i.e their work team. Examples of FAMS are Supervisors, Safety Advisors and Engineers (Designer / Construction etc). Unfortunately, research has shown that these groups can have poor concept of risk related processes. This is a serious issue when coupled with Industry's reliance in qualitative risk assessments (see Chapter 3).

The development of the *Tool* was therefore aimed to reduce these qualitative aspects and focus the user towards *hazard* rather than *risk* management. Risks associated with these hazard management decisions and consequences can be collated and analysed by a central specialised risk team using statistical methods. It is proposed that this method of splitting risk and hazard management would allow FAMS to concentrate on creating solutions to safety problems, whilst the statistical risk team can benefit from targeted and centralised risk management training with a view to establishing competent workers with diverse skill bases.

This chapter has highlighted the general process, calculation methods, user inputs and reporting facilities of a new *Tool* developed to aid FAMS in their daily task of identifying and controlling hazards.

However, the design and functions of the *Tool* are by no means perfect or without limitations. This section addresses some pertinent issues using the format of *frequently asked questions* or FAQs. These are given as:

- *"Isn't the RIDDOR classification too generic for all transportation projects?"*

Further study is required to assess this issue. However, a secondary filter layer could be used to delineate between different types of work tasks. Examples could be in the form of Railway / Highway, Construction / Maintenance, Small Projects / Large Projects or combinations thereof. The option of a secondary filter was viewed as customisation to be added by the end user, specific to the company specialisation, rather than rigid structuring in the design of the *Tool*.

- *"RIDDOR classification method does not include categories for psychological damage or mental well being!"*

Although this caveat of RIDDOR has been identified in the Rail Industry (Rail Safety and Standards Board 2005), mental health and psychological damage continues to be unidentified and suffers from social stigma. Challenging this stigma and discrimination is relatively new, such as the Scottish-based "*see me*" campaign launched in October 2002 (www.seemescotland.org.uk).

To counter this, an advanced version of the *Tool* would need to investigate methods of identifying and classifying these types of intangible illnesses. Avenues for this type of research may include psychological assessment of war veterans or mental health patients. Time constraints did not allow further investigation into these issues.

- *"The Tool does not consider risk assessment per se, and the user has no way of knowing the risk level."*

These issues are considered benefits of the *Tool* and the classification and template layouts have been specifically designed to this end:

  - The user is constrained in the number of subjective 'guesstimates', i.e. 45 for all work tasks. Qualitative risk analysis and risk assessment is effectively taken away from the user in preference to statistical quantitative methods
  - Risk can be calculated and analysed with the aid of feedback and accident rates as statistics based on real data.
  - These statistics allow the effectiveness and suitability of mitigations to be monitored for different types of work tasks.

The caveat here is the need for a group of risk-skilled workers to analyse the quantitative statistical results.

In addition to monitoring these statistics, the group could act as quality control for the *Case Base* by researching different control measure or new innovations, deleting obsolete or unsafe mitigations and monitoring significant trends for the benefit of the company.

- *"The User can't <u>revise</u> the Tool's suggestions as per the CBR Cycle"*

The revision aspect is achieved by the *user addendum template* where additional information can be linked to a specific mitigation. This ensures version control of the mitigation by the monitoring group, and re-occurring or similar aspects of addendums deemed as good practice can be added during scheduled updates.

Currently additional templates are available in the internet version in order to:

  - Add addendum comments to accepted mitigations .
  - Perform keyword searches on the *Case Base* for additional mitigations .
  - Add completely new control measures to the *Case Base.*

- *"Can it work with small and large scale tasks?....Surely subjective issues such as user competence, experience and training may skew the case base"*

Economies of scale can be a major issue as initial modelling data sets are often small and the content of the *Case Base* will be subject to scaling effects based on the number, qualifications and experience of the experts (Choi and Eboch 1998; Fynes and De Burca 2005). Firstly, the retrieval algorithm has been designed to take growth of the *Case Base* into account by using the novel *range intersection method.* Where needed, the monitoring group could advise adding appropriate filters if significant trends are found.

Secondly, this scaling phenomena is not a disadvantage but rather an opportunity for corporate benefit; linking *Case Base* trends with data on user experience and training will enable companies to bench mark their overall competence level for continual improvement.

- *"What advantages does the Tool have over 'cut and paste techniques'?"*

Cut and paste techniques are prevalent in a wide range of industries and are informal applications by which information from one document can be reused in other (Bush and Finkelstein 2001) . *Cut & paste* techniques have been advocated in literature for minor review and modification of documentation for two similar projects (Kelly and Lees 1986) and studies have also shown between 20-50% of hazard analysis is reused (Smith and Harrison 2005) .

In general, practitioners who currently use 'cut & paste' techniques from past method statements demonstrate little or no quality control or feedback on suitability. In short, the *Tool* facilitates quality assurance by being able to demonstrate the following:

- How the dangers and their control methods from the previous work task relates to a current job.
- The suitability or effectiveness of the methods.
- Quality assurance that these controls are being implemented on site.

- *"How long will it take a User to go through the process"*

Inputting information on the project and work task is no different from writing a normal report or conveying the information via e-mail. The time taken for the retrieval algorithm to return mitigation suggestions in the internet ready version of the *Tool* is a few seconds and is predominately dependant on the speed of the internet connection. However, due the SQL commands chosen this delay may lengthen if the *Case Base* is very large and careful management is required to keep this run time to a minimum. Alternatively, other SQL commands and methods could be investigated to generate the same results, as could other types of network server and databases. As the total number of records in the *Case Base* was in excess of 3500 with the run time remaining at few seconds, no further investigation on sample size or alternative coding were made.

Similarly, generating a method statement based on the user's selection and additional information takes a few seconds with the majority of user time spent either:

- Inputting information such as work task descriptions
- Work task specific decision processes, i.e. deciding whether to accept / decline the *Tool* suggestions and implement the mitigations accordingly etc.

CHAPTER 7: TOOL DESIGN & DEVELOPMENT TESTING

A CBR based *Tool* is proposed towards *Keeping Bob Safe* and its development strategy is fully detailed in the previous chapter.

This chapter explores the inner workings of the *Tool* in greater detail, highlighting the *Case Base* structure and retrieval mechanisms. Lastly, two tests are used to further aid the develop of the *Tool* and as precursors to proof of concept testing in the next chapter.

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7.1 Introduction

This chapter further investigates the inner workings of the *Tool* including the design of the *Case Base* and the mechanism used to identify, retrieve and display past similar cases to the user. Chapter 7 is presented in four sections, these include:

- **Section 1 – Introduction**

Brief introduction and chapter structure is given.

- **Section 2 - Case Base Design**

This section gives a brief explanation of each of the four *Database Objects* available to the designer along with examples of how these are used in the *Case Base*.

- **Section 2 - Retrieval Algorithm**

This section highlights the way in which the *Tool* retrieves hazards and their control measures. The critical steps in creating a robust retrieval algorithm are described under subheadings:

  - Calculating a classification value (the *CBR Number*)
  - Assessing similarity between classification values

- **Section 3 - Development Testing**

Two tests are performed towards identifying further improvements to the *Tool*:

  - Test 1 - User Classifications
  - Test 2 - Tool Weightings

- **Section 4 - Conclusions**

A summary of the chapter findings is presented.

7.2 Case Base Design

As highlighted in the previous chapter, Microsoft Access was used in the development of the prototype and later transferred to the internet-ready version of the *Tool*. This commercially available application offered four types of *Database Object* for inclusion in the *Case Base*:

- Tables
- Queries
- Forms
- Reports

This section will give a brief explanation of each of these *Database Objects* and highlight examples how they are applied in the Case Base.

7.2.1 Tables

A database consists of one or more *Tables* arranged in rows (records) and columns (fields); *tables* are the basic building blocks of a database. An example of a *database table* is given below.

***Fields** in Columns*

***Records** in Rows*

Hazard_No*	Hazard_ID	Hazard_Name
1	DO_1	Lifting equipment and operations
2	DO_2	Electricity
3	DO_3	Unintentional explosion/collapse

Table 7.1 Example of a Database Table

Tables are a collection of data about specific topics, such as products or suppliers, with each field in the *Table* containing characteristics information, and each record containing detailed information about the topic, such as the name, ID number etc.

Using a separate table for each topic can reduce data-entry errors and make data storage more efficient by eliminating duplicate data. Table 7.2 shows aspects for consideration when determining the structure of a database *Table*.

Consideration	Description
Type of data the table will contain	Field properties are a set of characteristics that provide additional control over how the data in a field is stored, entered, or displayed and depend on a field's data type
Number of fields in the table and their data type	Examples of data types include *Date*, *Currency*, *Number / Autonumber*, and *Text / Memo*
Type of indexes i.e. the primary key and foreign key(s).	A *primary key* uniquely identify each record in a table, cannot allow *Null values* and must always have a unique index. A primary key is used to relate a table to *foreign keys* in other tables.

Table 7.2 Determining Database Tables

In the creation of the *Case Base*, all information was separated into four different types of *Tables*; Reference, User, Input and Output. There are 10 *Tables* in total:

- Table 7.3 details the fields and data type involved in the three 'Reference Tables'relating to *Hazard*, *Harm* and *Likelihood*.
- Table 7.4 details the fields and data type involved in the two 'User Tables'; *User Access Level* and *Users*.
- Table 7.5 details the fields and data type involved in the three Input Tables; Project, Work Task and Mitigations.
- Table 7.6 details the fields and data type involved in the two 'Output Tables'; *Assessment* and *CBR*.

List	Table Title	Fields	
		Title	Type
1	Harm	Number* ID Name Description Severity_No	Auto-number Text *i.e. MA_1* Text *i.eMA_1*=Main Body Injury Text Number *i.e arbitrary Weighting*
2	Hazard	Number* ID Name	Auto-number Text *i.e. DO_2* Text *i.e, DO_2 = Electricity* Number *i.e arbitrary Weighting*
3	Likelihood	ID* Name Value	Auto-number Text *i.e. Likely, Unlikely, N/A* Number *i.e arbitrary Weighting*

Table 7.3 Reference Tables

List	Table Title	Fields	
		Title	Type
4	User Access Levels	ID* Name Access Level	Auto-number Text Number
5	Users	ID* Username Password Access Level	Auto-number Text *i.e generated by registering process* Text *i.e. e-mail address* -Linked to Table 4, User Access Level

Table 7.4 User Tables

List	**Table Title**	**Fields**	
		Title	Type
6	Project	Number* Name Corporate Data	Auto-number Text Text *i.e. Manager Name, job code* Date *i.e. Project Start/End Date* Currency *i.e. Estimated / actual cost*
7	Work Task	Number* Name Project_No	Auto-number Text - Linked to Table 6, Project Number
8	Mitigations	Number* Name Description	Auto-number Text Memo

Table 7.5 Database Input Tables

Data in the *Reference Tables* is predetermined by the *Tool Designer* and can only be amended by users with administrator access privileges. Types of privileges and user access are stored in the *User Tables* whilst project-orientated information is stores in *Input Table: Project* and *Input Table: Work Task.* The *Output Tables* store case specific information such as classification and retrieval information. Dividing the database into a series of smaller related tables allowed the *Case Base* to be effectively condensed into these last two tables; *Assessment* and *CBR.* This resulted in easier management of the overall database and aided data entry.

The relationships between these 10 tables are shown in Figure 7.1and Figure 7.2.

List	Table Title	Fields	
		Title	Type
9	Assessment	Number* WorkTask_No User_Selection CBR Number Mitigation_No	Auto-number Linked to Table 5, WorkTask Number Linked to Table 3, Likelihood Value Number, calculated by CBR Function Linked to Table 8, Mitigation Number
10	CBR	CBR_Key* Assessment_No Accepted	Auto-number Linked to Table 9, Assessment Number Number, user defined as *0 = Decline tool suggestion* *1 = Accept tool suggestion* *2 = Accept with addendum* *3 = Conduct keyword search and add mitigations manually* *4 = Create new mitigation and add data to Table 8*

Table 7.6 Database Output Tables

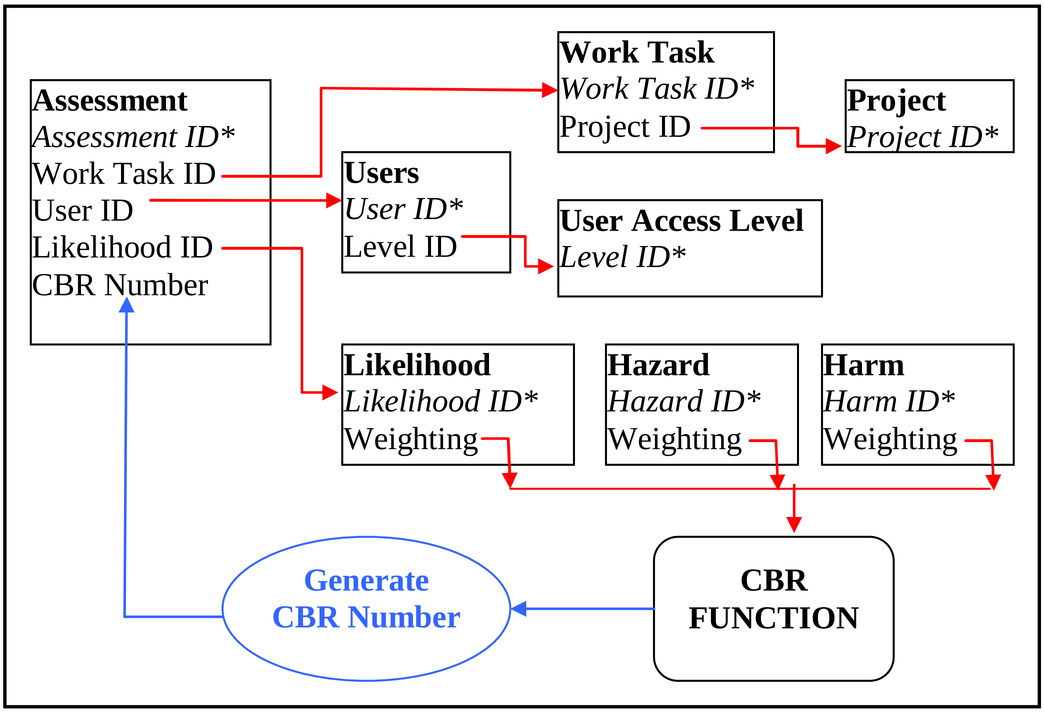


Figure 7.1 Case Base Relationships - 1 of 2

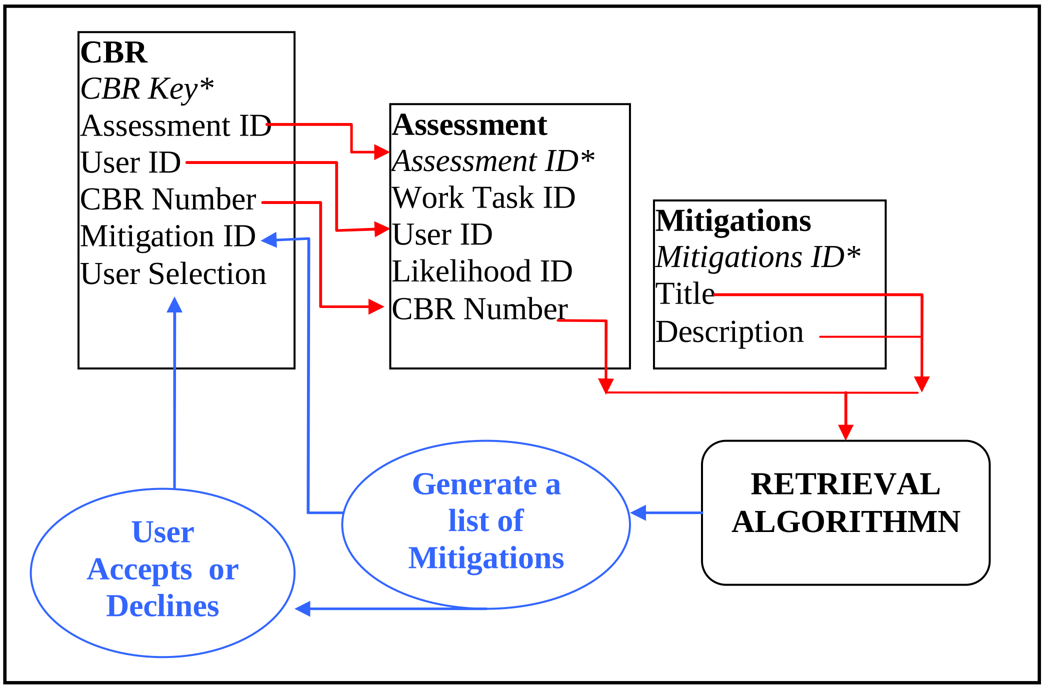


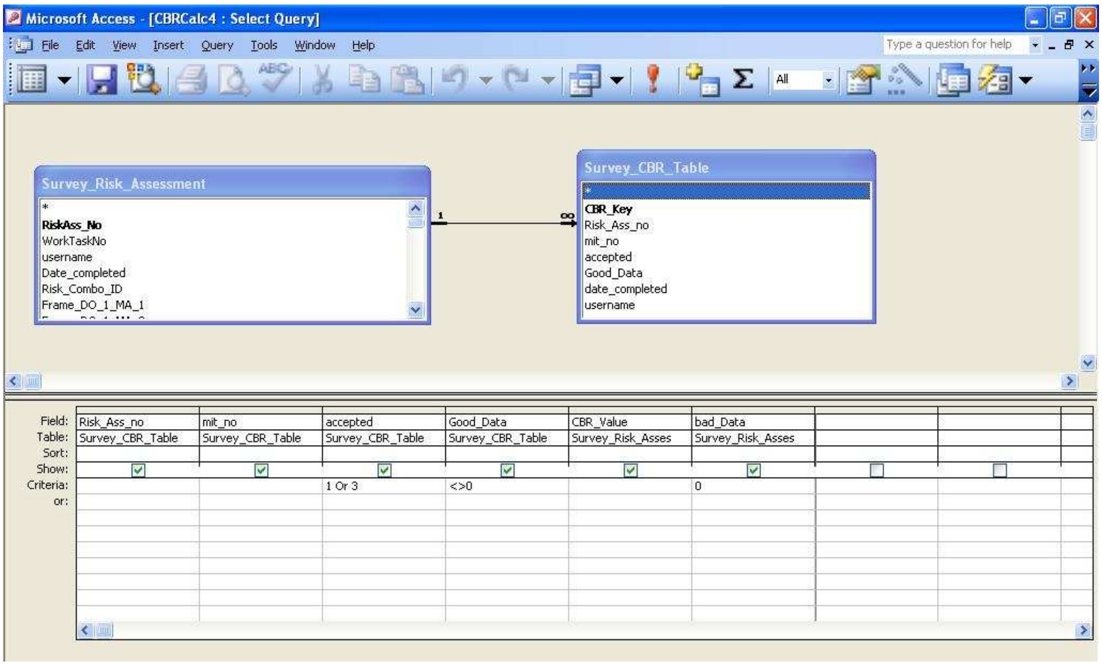
Figure 7.2 Case Base Relationships - 2 of 2

7.2.2 Queries

A *Query* can amalgamate data from multiple tables and perform actions on the data. There are several types of queries in Microsoft Access:

- *Select Queries* retrieves data from one or more tables and displays the results in a datasheet where you can update the records. This can be used to group records in order to perform calculations such assums, counts, averages, etc.
- *Parameter Queries* display dialog boxes prompting users for information, for retrieving or filtering records
- *Crosstab Queries* calculate and restructure data for easier analysis such as calculating sums, averages.
- *Action Queries* can make changes or move many records in just one operation. There are four types:
    - *Delete Queries* deletes a group of records from one or more tables.
    - *Update Queries* make global changes to a group of records in one or more tables
    - *Append Queries* adds a group of records from one or more tables to the end of one or more tables.
    - *Make-Table Queries* creates new tables from all or part of the data in one or more tables.
    - *SQL Queries* uses Structured Query Language (SQL) to query, update, and manage relational databases by using an SQL commands, such as SELECT, UPDATE and WHERE.

During the development of the *Tool*, the designer friendly interface of the Microsoft Access application allowed queries to be easily trialed and updated with limited knowledge of computer coding as SQL statements are generated in the background. SQL-type queries were chosen for easy translation to web technology in later *Tool* versions. Figure 7.3 shows an example of both the *Microsoft Access* interface used during development and the generated SQL code.




```
SELECT
   Survey_CBR_Table.Risk_Ass_no, Survey_CBR_Table.mit_no,
   Survey_CBR_Table.accepted, Survey_CBR_Table.Good_Data,
   Survey_Risk_Assessment.CBR_Value,Survey_Risk_Assessment.bad_Data

FROM
   Survey_Risk_Assessment LEFT JOIN Survey_CBR_Table ON Survey_Risk_Assessment.RiskAss_No
 = Survey_CBR_Table.Risk_Ass_no

WHERE
   (((Survey_CBR_Table.accepted)=1 Or (Survey_CBR_Table.accepted)=3)
AND
    ((Survey_CBR_Table.Good_Data)<>0)
AND
   ((Survey_Risk_Assessment.bad_Data)=0));
```

Figure 7.3 Example of Microsoft Access Query (interface & SQL statement)

7.2.3 Forms

A Microsoft Access *Form* has three uses; *enter* or display data in a database, act as a *switchboard* to open other forms, or facilitate an *action* based on user input, i.e. clicking a 'search' or 'submit' button. Figure 7.4 uses an example of the prototype version of the *Tool* to highlight these three features.

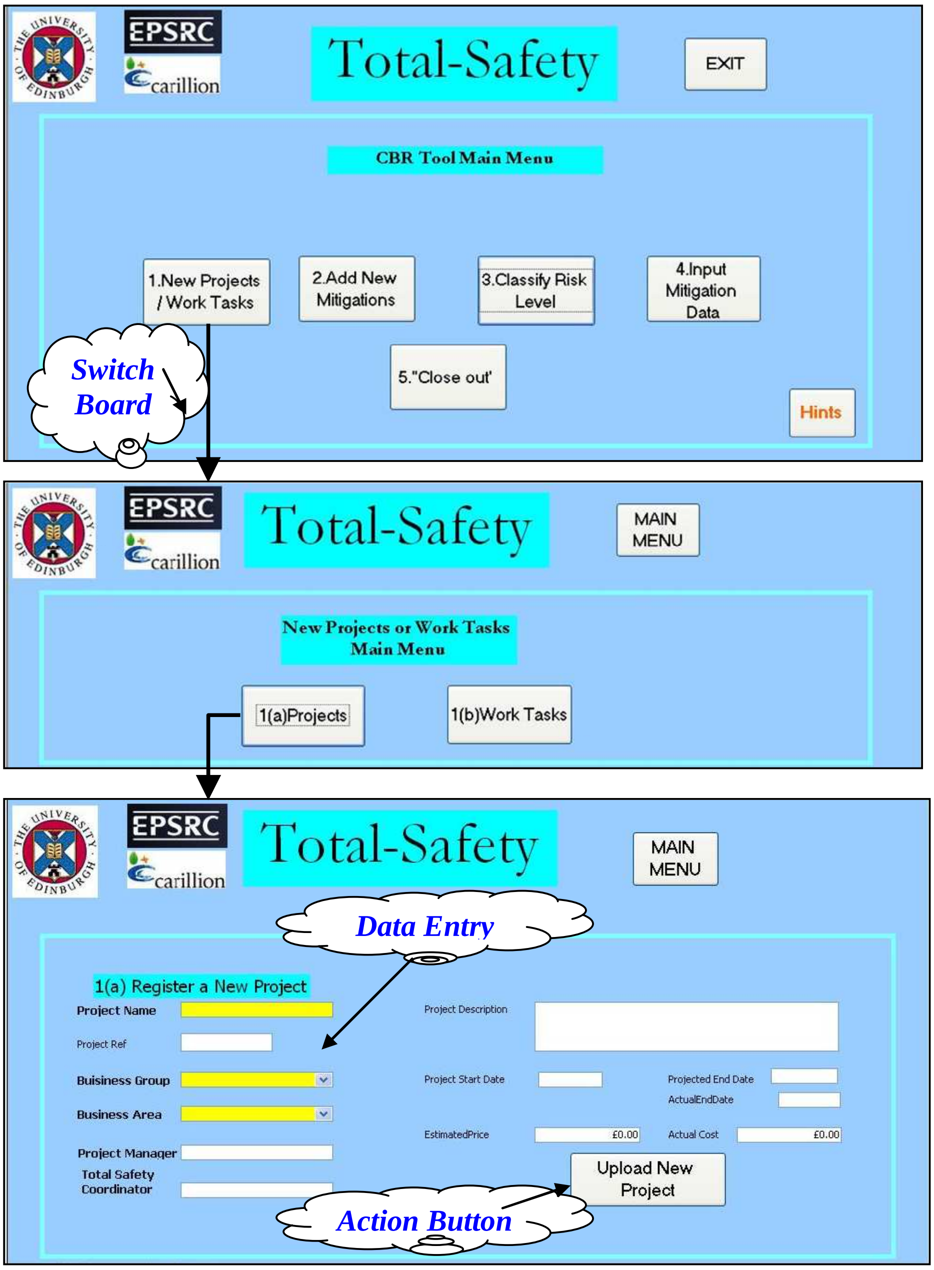
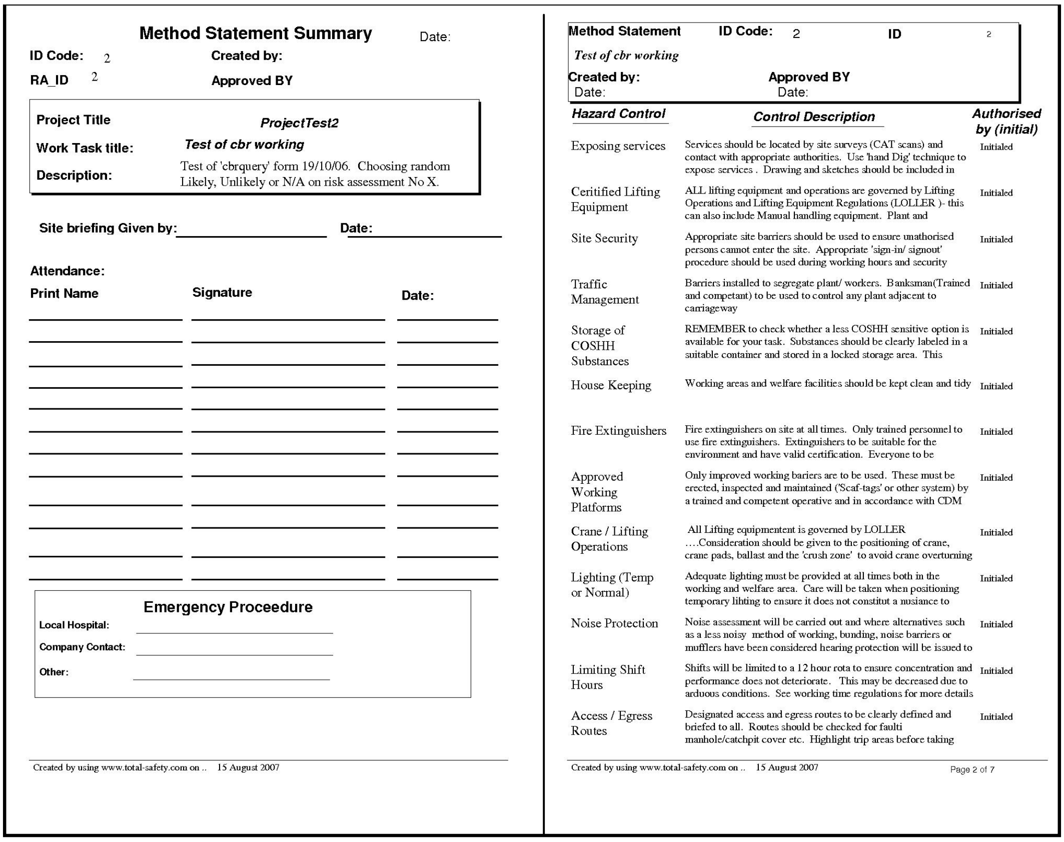


Figure 7.4 Form Example

Most *Forms* are bound to one or more record source, such as fields in the underlying tables, queries or SQL statements. These are linked by using graphical user interface objects called *controls* such as a text box, check box, scroll bar, or command button. These can be used to display data or choices, or perform actions such as calculations and can be stored within the *Form's* design as an expression.

7.2.4 Reports

A *Report* presents information in a printed format based on the layout and presentation options available to the *Tool* user such as totals, charts, record groupings etc. Most *Reports* are bound to one or more *Table* or *Query* in the database with other information (title, page number etc) stored in the *Report's* design.



Method Statement Summary Date:

ID Code: 2 **Created by:**

RA_ID 2 **Approved BY**

Project Title *ProjectTest2*

Work Task title: *Test of cbr working*

Description: Test of 'cbrquery' form 19/10/06. Choosing random Likely, Unlikely or N/A on risk assessment No X.

Site briefing Given by: ____________ **Date:** ____________

Attendance:

Print Name	Signature	Date:

Emergency Proceedure

Local Hospital:

Company Contact:

Other:

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Method Statement **ID Code:** 2 **ID** 2

Test of cbr working

Created by: Date: **Approved BY** Date:

Hazard Control	*Control Description*	*Authorised by (initial)*
Exposing services	Services should be located by site surveys (CAT scans) and contact with appropriate authorities. Use 'hand Dig' technique to expose services . Drawing and sketches should be included in	Initialed
Ceritified Lifting Equipment	ALL lifting equipment and operations are governed by Lifting Operations and Lifting Equipment Regulations (LOLLER)- this can also include Manual handling equipment. Plant and	Initialed
Site Security	Appropriate site barriers should be used to ensure unathorised persons cannot enter the site. Appropriate 'sign-in/ signout' procedure should be used during working hours and security	Initialed
Traffic Management	Barriers installed to segregate plant/ workers. Banksman(Trained and competant) to be used to control any plant adjacent to carriageway	Initialed
Storage of COSHH Substances	REMEMBER to check whether a less COSHH sensitive option is available for your task. Substances should be clearly labeled in a suitable container and stored in a locked storage area. This	Initialed
House Keeping	Working areas and welfare facilities should be kept clean and tidy	Initialed
Fire Extinguishers	Fire extinguishers on site at all times. Only trained personnel to use fire extinguishers. Extinguishers to be suitable for the environment and have valid certification. Everyone to be	Initialed
Approved Working Platforms	Only improved working bariers are to be used. These must be erected, inspected and maintained ('Scaf-tags' or other system) by a trained and competent operative and in accordance with CDM	Initialed
Crane / Lifting Operations	All Lifting equipmentent is governed by LOLLER ….Consideration should be given to the positioning of crane, crane pads, ballast and the 'crush zone' to avoid crane overturning	Initialed
Lighting (Temp or Normal)	Adequate lighting must be provided at all times both in the working and welfare area. Care will be taken when positioning temporary lihting to ensure it does not constitut a nusiance to	Initialed
Noise Protection	Noise assessment will be carried out and where alternatives such as a less noisy method of working, bunding, noise barriers or mufflers have been considered hearing protection will be issued to	Initialed
Limiting Shift Hours	Shifts will be limited to a 12 hour rota to ensure concentration and performance does not deteriorate. This may be decreased due to arduous conditions. See working time regulations for more details	Initialed
Access / Egress Routes	Designated access and egress routes to be clearly defined and briefed to all. Routes should be checked for faulti manhole/catchpit cover etc. Highlight trip areas before taking	Initialed

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Figure 7.5 Example of a Report

7.3 Retrieval Algorithm

Hazards and their control measures are retrieved and presented to the *Tool* user based on how similar the stored work tasks are in comparison to the current problem. Thus establishing taxonomy is a critical step in creating a robust retrieval algorithm. This is achieved in two steps:

- Calculating a classification value (the CBR Number)
- Assessing similarity between classification values

7.3.1 Calculating a CBR Number

The calculation performed in the background during work task classification involves calculating the *CBR Number* in order to compare new and stored cases.

The *CBR Number* is calculated as the standardised sum of the ratio of the classification values as assigned by the user to the worse case scenario (see below).

$$\textbf{CBR Number} = \sum_{i=n}^{i=1} \mathbf{X_i} \; / \; \mathbf{X_{max}} \quad \mathbf{*100}$$

Where:

X_i = Classification Value for each hazard/harm event
= $Z_j * K_j * Y_j$

X_{max} = Worst Case for each pre-determined hazard/harm event (i.e. likely)
= $Z_j * K_j * Y_{max}$

Y_j = Likelihood weighting value associated with hazard /harm event
Y_{max} = Maximum possible likelihood weighting value i.e. 'likely'
Z_j = Harm weighting value
K_j = Hazard Classification weighting
n = Number of hazard/harm events

Equation 7.1 Classification Method

To provide clarity, the entry template in Figure 6.4 will be used as an example of this method. In this figure all 45 predetermined events are set to the worst case (‘Likely’), thus resulting in a standardised maximum of 100%, or a *CBR Number* of 100, let this be called *Example 1*.

Example 1

$\boldsymbol{X_1} = \boldsymbol{X_{max}}$ = (1*6 *3) + (1*5 *3) + (1*4 *3) + (1*3 *3) + (1*2 *3) = 60

$\boldsymbol{X_2} = \boldsymbol{X_3}$ …..etc = $\boldsymbol{X_{max}}$= 60

Where $\boldsymbol{Y_{Likely}}$= 3, $\boldsymbol{Y_{Unlikely}}$= 2, $\boldsymbol{Y_{Not\ Applicable}}$ = 1

$\boldsymbol{Z_j}$ = 1 for all types of hazard classification

CBR Number = (540/540) *100 = 100

Example 2 demonstrates how a *CBR Number* of 97.4 is calculated when four events in *Example 1* are downscaled to ‘Unlikely’ in the following events relating to *‘Lifting equipment and lifting operations’*:

- Loss of sight.
- Electric shock or burn.
- Contact with harmful substances.
- Heat related injury.

Example 2

$\boldsymbol{X_1}$ = (1*6 *3) + (1*5 *2) + (1*4 *2) + (1*3 *2) + (1*2 *2) + (1*1 *2) = 46

$\boldsymbol{X_2} = \boldsymbol{X_3}$ …..etc = $\boldsymbol{X_{max}}$= 60 (see *Example 1*)

Where $\boldsymbol{Y_{Likely}}$= 3, $\boldsymbol{Y_{Not\ likely}}$= 2, $\boldsymbol{Y_{Not\ Applicable}}$ = 1

$\boldsymbol{Z_j}$ = 1 for all types of hazard classification

CBR Number = (526/540) *100 = 97.4

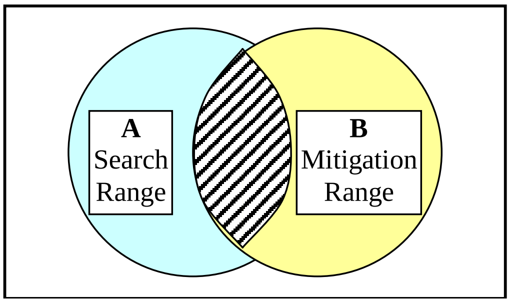
The weightings Table 6.6 Tool Harm Classification and Table 6.8 Tool Hazard Classification used for these examples along with arbitrary values of 3:2:1 for *likely, unlikely* and *not applicable*.

7.3.2 Assessing Similarity

The similarity between the newly classified work task and those stored in the *Case Base* is calculated using one of two methods; *Range Intersection* and *Nearest Neighbour*.

As repetition of mitigations is expected, each will be associated with varying *CBR Numbers* as the Cases Base grows. Thus each mitigation will form a normal or Bell distribution curve that will change as the *Case Base* grows.

The method of intersecting ranges uses these distributions to assess similarity between new and past cases on the intersection of two ranges; the *Search Range(A)* and the *Mitigation Range(B)* as shown in Figure 7.6 (Campbell et al. 2007b).



A = Search Range, corresponding to the new case

Where **CBRLower_Range ≤ A ≤ CBRUpper_Range ,**
and
CBRUpper_Range = CBR Number of new case + 5% ≤ 100%
CBRLower_Range = CBR Number of new case - 5% ≥ 0%

B = Mitigation Range, corresponding to stored mitigations

Where **CBRmit_lower ≤ B ≤ CBRmit_upper,**
and
CBRmit = CBR Number associated with each stored mitigations
CBRmit_lower =Average CBRmit – 1 Standard Deviation
CBRmit_upper =Average CBRmit + 1 Standard Deviation

Figure 7.6 Similarity using Range Intersection Method (Campbell et al. 2007b)

The *Search Range* (A) corresponds to the new case and is calculated as the *CBR Number* ±5%. The value of ±5% assigned is arbitrary for the current *Case Base* however this value can be modified for calibrating other data sets. The *Mitigation Range* (B) is dependant on the standard deviation of the distribution and hence on the number of cases, and will therefore account for growth in the case library.

Where a new case exhibits a *CBR Number* beyond the current limit of the stored cases or outwith the intersected ranges, very few or no mitigations will be returned to the user. This is because the new *CBR Number* falls within the 'outlier' section of the distribution curve. This scenario will be little help to the user and a second level of similarity calculation is required. Nearest neighbour technique is used to retrieve the nearest work task using the root mean squared method.

$$\sqrt{(\text{Stored CBR Numbers}_i - \text{CBR Number}_{current})^2}$$

Equation 7.2 Nearest Neighbour Method

Example 3 shows how the *CBR Number* of 97.4 (see Example 2) would generate a search range of 92.5 to 100.

Example 3

CBR Number **=97.4** (see Example 2)

Search Range$_{_lower}$ = 97.4 – 5% **= 92.5**

Search Range$_{_upper}$ = 97.4 + 5% **= 102 (but no greater than 100)**

= 100

Search range(A) = 92.5 to 100

Table 7.7 represents a simplified version of the case base along with the lower and upper limits of the mitigation search range. Based on the intersection of these ranges, the *Tool* would select mitigations 2, 4 and 5.

Control Measures	CBRmit_lower	CBRmit_upper
1	55.6	68.4
2	77.4	98.2
3	48.5	75.9
4	85.6	100
5	72.6	89.4

Table 7.7 Mitigation Range (B) based on a Simplified Case Base

Where *CBR Number* falls within the 'outlier' section of the mitigation distribution a second layer of similarity calculation using Nearest Neighbour is required. This would be applicable for a *CBR Number* of 50, where the search range would be 47.5 - 52.5 resulting in no mitigations from Table 7.7 being selected. ***Appendix E*** gives examples of SQL code employed to facilitate these retrieval algorithms.

Figure 7.7 and Figure 7.8 highlight another example and shows a distribution for a given mitigation stored within Case Base. The *Range Intersection Method* identifies and displays this mitigation when the *Search Range* lies within ± 1standard deviation, e.g if new work task has a *CBR Number* of approximately 45. The *Nearest Neighbour Method* is employed if the new work task has a value beyond all the mitigation distributions. *Nearest Neighbour Method* is used when the work task has, for example, a *CBR Number* of 15 resulting in the work task with the closest *CBR Number* being selected and all mitigations associated with this stored work task displayed to the user. In the case of Figure 7.8, a *CBR Number* of 15 would result in all the hazard controls used in work task 8 being suggested by the *Tool*.

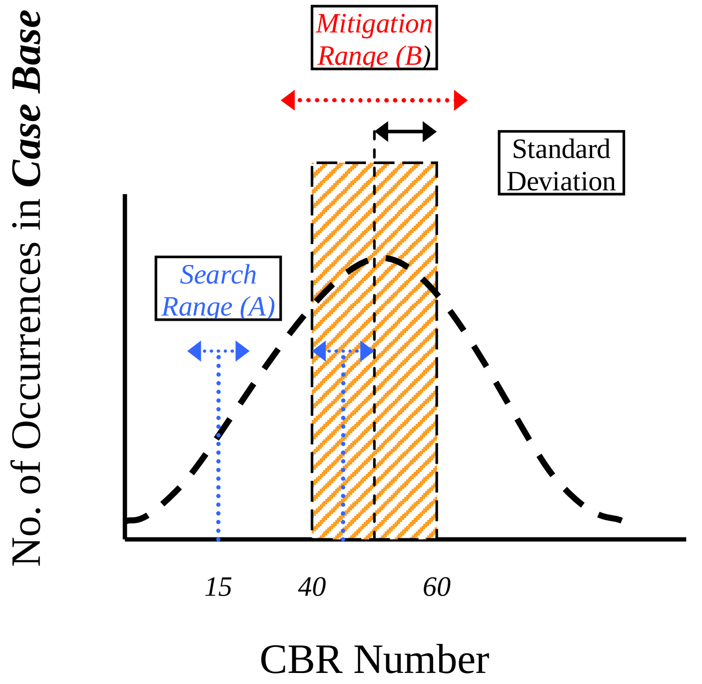


Figure 7.7 Range Intersection Method

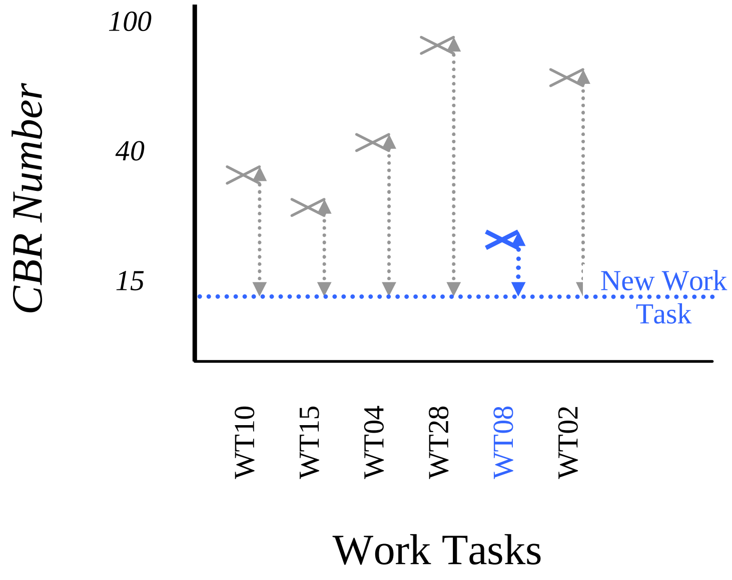


Figure 7.8 Nearest Neighbour Method

It is envisaged that extended use of this method will show some mitigations are predominantly used by work tasks with low or high *CBR Numbers*, resulting in skewed distributions towards the left or right respectively.

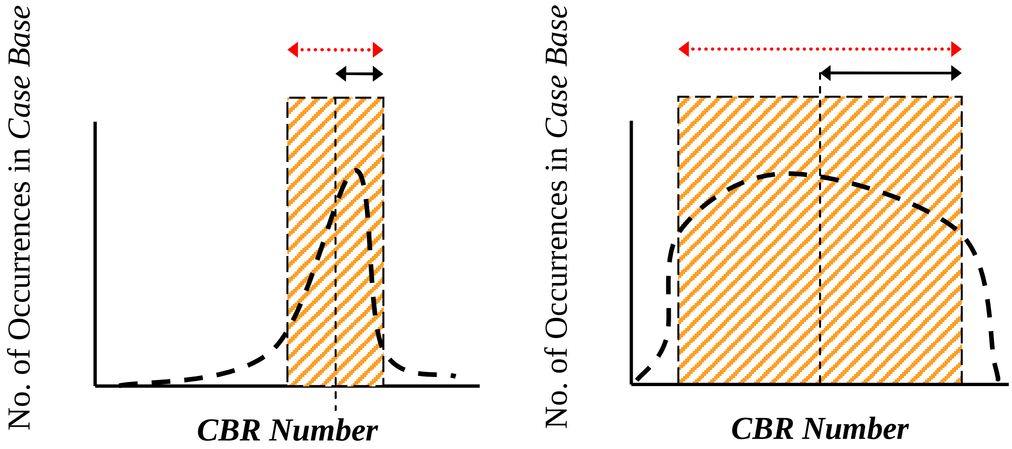


Figure 7.9 Examples of mitigation or user distributions

Inspection of the distributions of the control measures over time could assess '*value-for-money*' for specific control methods or equipment. Similarly user distributions can be inspected to pinpoint specific training needs:

- Flat user distributions with spikes could mean users who usually experience similar hazards, may have encountered a work task that posses extra-ordinary dangers.

- User with a constant *CBR Number* of 100 indicate the user classifying the work task as 'Likely' in all 45 hazard/harm event category and needs further training in using the *Tool*. This is important to ensure 'bad' user input does not skew the *Case Base* data.

7.4 Development Testing

This section explains two tests with the aim towards further developing the *Tool.*

- User Classification
- Tool Weightings

7.4.1 Test 1 - User Classifications.

The aim of this section is to compare how potential users classify work tasks. In addition, this exercise complements the *Three Phase Extraction Method* described in Chapter 6 with the aim of classifying the work tasks populating the *Case Base*. This is achieved in two stages involving the *Tool Designer* and *volunteers* (Dave and Phil).

Both the *Tool Designer* and the *volunteers* classified the work tasks using the *RIDDOR Classification Screen* hosted on the prototype *Tool* with the following role-play considerations:

- Each work task is assumed to be in preliminary stages.
- Classification of the work task and site conditions is happening in *real-time.*
- Personally responsible for ensuring a *safe system of work* (acting as an 'Andy') and who will ultimately write the work task method statement.

A discussed earlier, five random work tasks were processed by the *Tool Designer* for inclusion within the *Case Base* and 21 work tasks by volunteers.

Figure 7.10 shows the prototype classification screen used for the test.

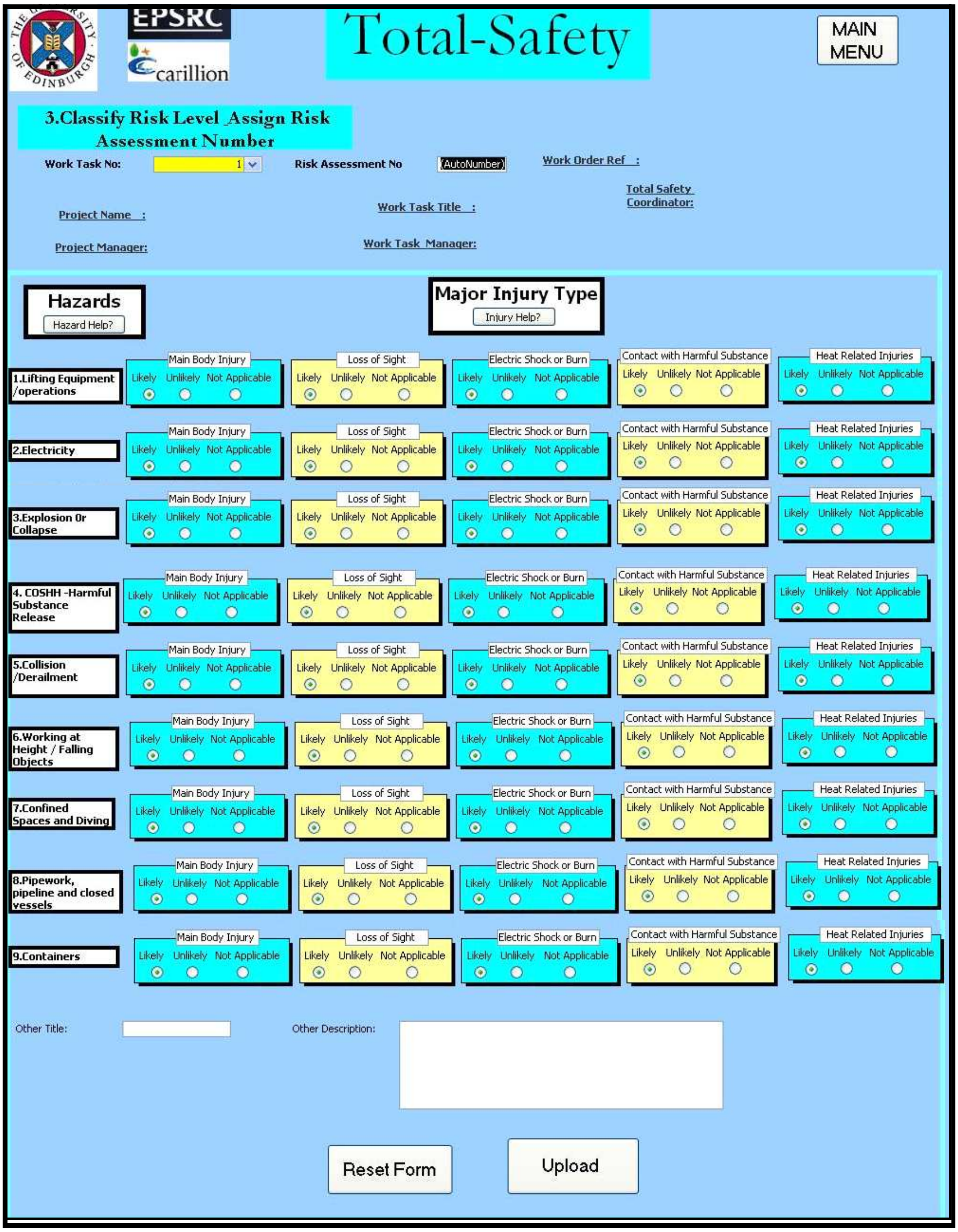


Figure 7.10 Prototype Classification Screen

Method Statement	**A** *Dave*	**B** *Phil*	**CBR Number**
Bridge Completion Works	•		63.7
Collection, removal and disposal of sharps	•		58.3
Construction of Stations		•	80.4
Demolition of Clyde Avenue Road Bridge		•	71.7
Environmental Investigation	•		67.4
General site clearance	•		61.3
Ground Investigation (Exploratory)		•	71.5
Hamilton Rd. Raploch St. Bridge Parapet upgrade		•	84.4
Install Concrete foundation signal base MH 419		•	78.0
Installation of switching equipment	•		71.3
Larkhall line Running of return conductor		•	74.8
Long line public address installation	•		76.5
Merryton footbridge (MS/Lark/064 REV 0)	•		69.5
Removal/disposal/destruction of Japanese Knotweed	•		61.3
Repair to Merryton Footbridge (MS/Lark/086)		•	81.1
Signalling civil works	•		67.0
Site Survey	•		47.6
Sheet piles: Supply & installation of	•		76.86
Sheet Piles(MS/Larkhall/110 Rev.0)		•	84.5
Support of Sheet Piles during driver training (MS/Lark/133)		•	73.5
Unloading of S+C Materials & building up of panels		•	78.1
Total number of Work Tasks	**11**	**10**	
Average CBR number	*65.5*	*77.8*	
Minimum CBR number	*47.6*	*71.5*	
Maximum CBR number	*76.7*	*84.5*	
Standard deviation of CBR number	*8.3*	*4.9*	

Table 7.8 Comparing *CBR Numbers* from Engineering Students

Method Statement Title	CBR Number
Construction of Cabinet, REB & container Compounds	85.9
Junction Mast Erection & wiring modifications	73.3
General Concrete Works	86.7
Shot blasting / Painting of structures	84.6
Bridge Demolition	86.9

Table 7.9 Designer *CBR Numbers*

The *CBR Numbers* for each of the work task are generated by the user assigning 'Likely', 'Unlikely' or 'Not Applicable' for each of the pre-defined hazard/harm events. The *CBR Numbers* generated by the *Tool Designer* are given in Table 7.9 whilst Table 7.8 shows the results from the volunteers

A number of observations can be made from these tables, namely:

- The *CBR Numbers* as classified by the *Tool Designer* range from 73.3 to 86.9 whilst those by the *Engineering Volunteers* ranged from 47.6 to 84.5
- The average *CBR Number* for the *Tool Designer* and the *Engineering Volunteers* (Phil and David) are 83.4, 77.8 & 65.5 respectively. This suggests that the current weighting used in the prototype version of the *Tool* may skew the *CBR Number* towards the top of the distribution curve.
- This difference of approximately 12% in the undergraduate's *CBR Numbers* could be attributed to the differences in:
    - Ambiguity in method statement documentation
    - Complexity of work task
    - Work experience
    - Weighting calibration. This suggests the arbitrary values 3:2:1 attributed to 'likely', 'unlikely' and 'not applicable' require further investigation in order to minimise these discrepancies.

- The undergraduate who had worked on site during a summer vacation appears to show consistently a more pessimistic view of the likelihood of hazards in comparison to his peer.
    - Highest *CBR Number* of 84.5
    - Highest average *CBR Number* of 77.8
    - Smallest standard deviation of *CBR Number* (4.9)

In conclusion, the prototype version of the *Tool* successfully facilitates the classification of work tasks, generating *CBR Numbers* for both the *Tool Designer* and the *Engineering Volunteers*.

These results highlight that users may differ in the way they classify work tasks. To further investigate these issues, the *Volunteers* processed an identical work task for 'Larkhall Station Carpark' using the prototype *Tool* and the same methods as described in previous sections. This can be summarised as two key elements:

- **Role Play** - Classify the work task by role playing as the person responsible for writing method statements.
- **Knowledge Capture** - Detail the mitigations used in the actual method statement,

The results of the *role play* element shows *CBR Numbers* of 66 & 81 and mirrors previous observations that the *Volunteer* with 'site experience' assigns a higher value. This difference of around 14% is attributed to whether the volunteers assigned 'likely', 'unlikely' or 'not applicable' to each of the predetermined hazard/harm events. The volunteer with the site experience (Phil) selected a higher likelihood than his peer 20 times while Dave (with no site experience) selected a higher likelihood only three timed - all 3 occasion where found in the hazard / harm event 'containers'. These finding support the suggestion that *Volunteer* B (Phil) with the greater site experience has a more pessimistic view of the likelihood of safety concerns.

The volunteers classified the work task similarly for 22 out of the 45 pre-determined hazard / harm events (49%). Many of the discrepancies occurred under the hazard/harm events in only 3 hazard categories, namely ‘Explosion and collapse’, ‘Collision and derailment’, ‘Pipe work, pipeline and closed vessels’.

Further examination of the 23 discrepancies showed:

- 15 occasions where Volunteer B (Phil) chose ‘Likely’ whilst Volunteer A (Dave) selected ‘Unlikely’
- 4 occasions where Volunteer B elected ‘likely’ and Volunteer A viewed the event as ‘not applicable’. This occurred in:
  - ‘Collision and derailment’ &‘Electric shock or burn’
  - ‘Collision and derailment’ & ‘Heat related injuries’
  - ‘Pipe work, pipeline and closed vessels’ & ‘Electric shock or burn’
  - ‘Pipe work, pipeline and closed vessels’& ‘Heat related injuries’
- 1 occasion where Volunteer A selected ‘Likely’ and Volunteer B selected ‘Not applicable’ in -‘Containers’ & ‘Contact with harmful substances’
- 1 occasion where Volunteer B selected ‘Unlikely’ and Volunteer A selected ‘Not applicable’ - ‘Lifting equipment & operations’ & ‘Heat related injuries’.
- 2 occasion where Volunteer A selected ‘Unlikely’ and Volunteer B selected ‘Not applicable’:
  - ‘Containers’ & ‘Main body injuries’.
  - ‘Containers’ & ‘Loss of site’.

On closer examination of the *knowledge capture* element, the volunteers agree that 29 of the 64 possible mitigations applied to this work task. This number is in keeping with the ranges found in Chapter 6, section 6.2.3. The undergraduate also agree that a remaining 23 from the same list do not apply, resulting in a total of 52 instances of agreement or 81%.

Agreement was not reached on the remaining 12 mitigations where undergraduate B elected 8 of these 12 to be applicable and the remaining 4 not present in the original method statement document. Conversely, undergraduate A elected 4 of these 12 as applicable and the remaining 8 not present in the document. The 12 mitigations under scrutiny are given in Table 7.10 along with the *Tool Designer's* view.

In short, the *Designer* agreed with four of B's comment and one of A's however it could be argued that the use of a further three mitigations (No 29, 30 & 53 denoted by * in Table 7.10) are implied from the text yet not given explicitly. Similar ambiguity is seen in mitigations 37, 38 and 39 that are related to Personal Protective Equipment in either a 'rail', 'road' or 'general' setting (denoted by ** Table 7.10).

These issues of ambiguity highlight further shortcomings in traditional method statements that they do not record 'nulls' i.e. the document does not say that 'Burning Operations' were considered but decided against, but rather does not mention them at all. The documents lack of information on such subjects forces those involved in the *knowledge capture* process to make reasoned judgements based on their understanding of the text.

This section has combined the processes of *knowledge capture* and *role play* to further examine how the two *Engineering Volunteers* classify and extract safety knowledge from method statements.

The main finding is the poor quality and ambiguity of method statements. This substantiate findings from previous chapter that traditional method statements do not record 'null' reports, unintentionally hide safety knowledge and rely upon the interpretation of the reader.

	BPhil	**ADave**	**Designer**
CBR Number	**80.6**	**66.3**	N/A
Mitigations	Yes/No		
2.Certified Lifting Equipment	Yes	No	Yes
7.Fire Extinguishers	Yes	No	Yes
19. Isolation & permit system (Overhead Line)	Yes	No	No
29.Burning Operations	Yes	No	No*
30.Works/Equipment "On or near the line" (Rail)	Yes	No	No*
37.PPE (General Road)	No	Yes	Yes**
38.PPE (General Rail)	Yes	No	Yes**
39.PPE(Specific - Road or Rail)	No	Yes	Yes**
46.Compliance Monitoring Method Statements	No	Yes	Yes
53.Welfare (site compound or office)	No	Yes	Yes*
58.Excavation protection	Yes	No	Yes
64. Working with compacting equipment	Yes	No	Yes

Table 7.10 Subjectivity

Feedback from the *volunteers* suggests some hazard/harm events are difficult to relate to, especially those with specific types of injury i.e. loss of sight. These comments verified the decision to amend the injury categories during transition to the internet version of the Tool towards more recognisable terminology, including:

- Major Injury
- 3-day injury
- Reportable Disease
- Harmful Substances
- Muscular Skeletal Disorders

7.4.2 Test 2 - Tool Weightings

This section analyses the significance of changing the weightings employed by the *Tool* to generate *CBR Numbers*, namely:

- The effect of upgrading the RIDDOR classification screen during transition between the prototype and on-line versions of the *Tool* is investigated.
- Sensitivity analysis demonstrates the significance of changing the arbitrary weightings used to generate *CBR Numbers*. Thus establishing them variability of *CBR Number* produced by the *Tool* and the validity of mitigation suggested by the *Tool*.

Test 2a) Prototype vs. Online Tool

Both versions of the *Tool* use a pre-determined hazard / harm classification matrix, using nine hazards and five harms.

The prototype version focuses on the major injuries and hazards as defined by RIDDOR[4] . However the *harm categories* used in the prototype version of the *Tool* are unable to consider infectious diseases or issues relating to deteriorating health such as leptospirosis or occupational asthma (see Table 7.11). Further examples of these types of diseases are given in Table 7.12.

Improvements to the harm categories to remedy this problem are given in Table 7.13 and used in the web-enabled version of the *Tool*. (See Chapter 6 for a full explanation of why each category was chosen).

Finally the *volunteers* (Phil and David) who populated the prototype re-assessed each of the work tasks using these new harm categories for the web enabled *Tool.*

The results in Table 7.14 demonstrates the differences in the *CBR Number* generated using the prototype and the web-enabled *Tool* are, on average, very small. In both cases the minimum and maximum *CBR Numbers* are 47 and 84 respectively with the

[4] RIDDOR = Reporting of Injuries, Diseases and Dangerous Occurrence Regulation

average *CBR Number* in both cases around 70-71. Therefore, it can be reasoned that upgrading the RIDDOR classification screen to include dangerous diseases and 3-day alters the *Case Base* very little.

Tool Harm Categories	Weighting	RIDDOR Category equivalent
Main Body Injury	6	(i) fracture other than to fingers, thumbs or toes; (ii) amputation; (iii) dislocation of the shoulder, hip, knee or spine;
Loss of Sight	5	(iv) loss of sight (temporary or permanent); (v) chemical or hot metal burn to the eye or any penetrating injury to the eye;
Electric shock or burn	4	(vi) injury resulting from an electric shock or electrical burn leading to unconsciousness or requiring resuscitation or admittance to hospital for more than 24 hours;
Contact with Harmful Substance	3	(vii) acute illness requiring medical treatment, or loss of consciousness arising from absorption of any substance by inhalation, ingestion or through the skin; (viii) acute illness requiring medical treatment where there is reason to believe that this resulted from exposure to a biological agent or its toxins or infected material; (ix) unconsciousness caused by asphyxia or exposure to a harmful substance or biological agent;
Heat related injuries	2	(x) any other injury: leading to hypothermia, heat-induced illness or unconsciousness; or requiring resuscitation; or requiring admittance to hospital for more than 24 hours;
Other	1	

Table 7.11 Harm Categories– Prototype

Reportable Diseases	Examples
Poisoning	Ingestion of toxic substances etc
Skin disease	Occupational dermatitis, skin cancer, asthma, chrome ulcer, oil folliculitis/ acne
Lung disease	Occupational asthma, pneumoconiosis, asbestosis, mesothelioma
Infection	Leptospirosis, hepatitis, tuberculosis, anthrax, legionellosis tetanus
Other	Examples include occupational cancer, musculoskeletal disorders, decompression illness and hand-arm vibration syndrome

Table 7.12 RIDDOR Reportable Diseases

Tool Harms Categories	Weightings	RIDDOR Category equivalent
Major Injury	6	Major Body Injury (broken limbs, amputation etc), Loss of Sight, Electric Shock / Burn , hypothermia
3-Day Injury	5	Injuries leading to workers being absent or are unable to do the full range of normal duties for more than 3 working day i.e. broken finger(s) or toe(s)
Diseases	4	Poisoning, Skin disease, Lung Disease, Infection and occupational cancers.
Harmful Substance	3	Includes inhalation, asphyxia ingestion or absorption through the skin of: • biological agent • toxins • infected material
Muscular Skeletal Injuries	2	Repetitive strain injuries, hand and arm vibration syndrome (HAV), recurring back pain, sprained ankles etc
Other	1	

Table 7.13 Harm Categories – Online version

	CBR Number	
Work Task	**Internet**	**Prototype**
Repair to Merryton Footbridge	76.3	81.1
Larkhall Station Car Park	79.8	80.6
Demolition of Clyde Avenue Road Bridge	73.0	71.7
Install Concrete foundation signal base MH 419	77.6	78.0
Hamilton Rd. Raploch St. Bridge Parapet upgrade	84.1	84.4
Unloading of S+C Materials, building up of panels	79.8	78.1
Support to Sheet piles	83.0	73.5
Ground Investigation (Exploratory)	74.8	71.5
Construction of Stations	78.3	80.4
Larkhall line Running of return conductor	75.0	74.8
Bridge Completion Works	63.3	63.7
Merryton footbridge	72.0	61.5
Signalling civil works	69.6	67.0
Larkhall Station Car Park	69.8	66.3
Long line public address installation	65.6	76.5
Collection, removal and disposal of sharps	66.9	58.3
Removal/disposal/destruction of Japanese Knotweed	60.6	63.1
Environmental Investigation	66.5	67.4
General site clearance	65.4	61.3
Site Survey	47.2	47.6
Average	**71.43**	**70.34**
Minimum	**47.2**	**47.6**
Maximum	**84.1**	**84.4**
Standard Deviation	**8.77**	**9.36**

Table 7.14 Comparing the Prototype and On-line versions of the *Tool*

Test 2b) Sensitivity Analysis

The sensitivity of the *Tool is* assessed in two ways.

- Variability of *CBR Number* produced by the *Tool*.
- Variability of mitigation suggested by the *Tool*.

The first assessment evaluates the *CBR Numbers* generated by the *Tool* when different weightings are used in each of the likelihood, hazard and harm categories.

Table 7.15, Table 7.16 & Table 7.17 each show three different combinations of values for each of the likelihood, hazard and harm categories used in this test.

	Likelihood Combinations		
	1	**2**	**3**
Likely	3	7	100
Unlikely	2	2	10
Not Applicable	1	1	1

Table 7.15 Likelihood Combinations & Weightings

	Harm Combinations		
	1	**2**	**3**
Major Injury	6	1	2
3-Day Injury	5	1	3
Diseases	4	1	4
Harmful Substance	3	1	5
Other	2	1	6

Table 7.16 Harm Combinations& Weightings

	Hazard Combinations		
	1	2	3
Lifting Equipment/operations	1	9	1
Electricity	1	8	2
Explosion or Collapse	1	7	3
COSHH Harmful substances	1	6	4
Collision, Impact or Derailment	1	5	5
Working at height/ Falling objects	1	4	6
Confined Spaces / Diving operations	1	3	7
Pipework, pipeline & closed vessels	1	2	8
Containers	1	1	9

Table 7.17 Hazard Combinations & Weightings

These 9 individual combinations produce 3^3or 27 variations in which to analyse the problem. As analysing all 27 variations can become cumbersome, five variations are highlighted for further analysis and shown in Table 7.18. (NB, to ease interpretation of graphed results, each work tasks is assigned a number along the x-axis , found in Table 7.22)

	Combinations				Combinations		
Variations	Likelihood	Harm	Hazard	Variations	Likelihood	Harm	Hazard
1	1	1	1	15	2	2	3
2	1	1	2	16	2	3	1
3	1	1	3	17	2	3	2
4	1	2	1	18	2	3	3
5	1	2	2	19	3	1	1
6	1	2	3	20	3	1	2
7	1	3	1	21	3	1	3
8	1	3	2	22	3	2	1
9	1	3	3	23	3	2	2
10	2	1	1	24	3	2	3
11	2	1	2	25	3	3	1
12	2	1	3	26	3	3	2
13	2	2	1	27	3	3	3
14	2	2	2				

Table 7.18 Variations

Table 7.19 show the weightings of *likelihood*, *harm* and *hazard* used to evaluate sensitivity of the *Tool* to changes in *likelihood*. The results are shown in Figure 7.11 where *CBR Numbers* can be seen to follow similar patterns yet are positioned at different ranges:

- The simple 3-2-1 weighting produces *CBR Numbers* between 50-80%
- The 7-2-1 weighting produces *CBR Numbers* between 20-70%
- The logarithmic 100-10-1 weighting produces the largest spread of CBR Numbers between 5-60%

Variation	Weightings		
	Likelihood	Harm	Hazard
1	**3-2-1**	6-5-4-3-2-1	1-1-1-1-1-1-1-1-1
10	**7-2-1**	6-5-4-3-2-1	1-1-1-1-1-1-1-1-1
19	**100-10-1**	6-5-4-3-2-1	1-1-1-1-1-1-1-1-1

Table 7.19 Exploring Likelihood Weightings

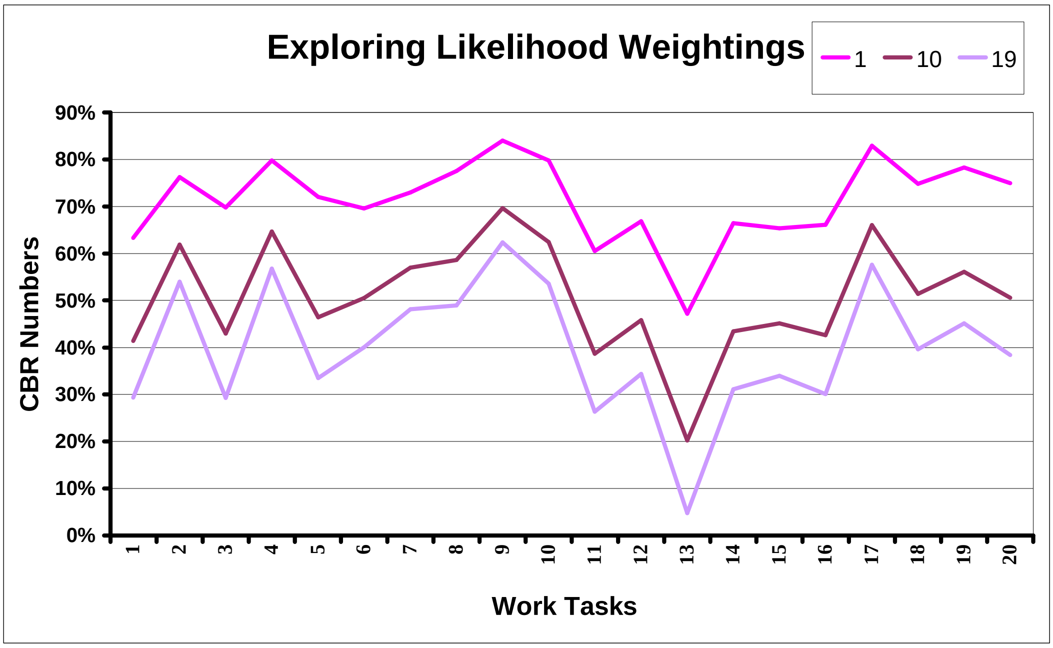


Figure 7.11 Exploring Likelihood Weightings

Table 7.20 shows the weightings of *likelihood*, *harm* and *hazard* used to evaluate sensitivity of the *Tool* to changes in *harm* whilst Figure 7.12 shows the results. This demonstrates that experimenting with the *harm* weightings has very little difference to the *CBR Numbers*. The greatest difference can be seen at work task 'long line public address installation' (see work task 16 in Figure 7.12) as being around 5%.

Variation	Weightings		
	Likelihood	Harm	Hazard
1	3-2-1	**6-5-4-3-2-1**	1-1-1-1-1-1-1-1-1
4	3-2-1	**1-1-1-1-1-1**	1-1-1-1-1-1-1-1-1
7	3-2-1	**1-2-3-4-5-6**	1-1-1-1-1-1-1-1-1

Table 7.20 Exploring Harm Weightings

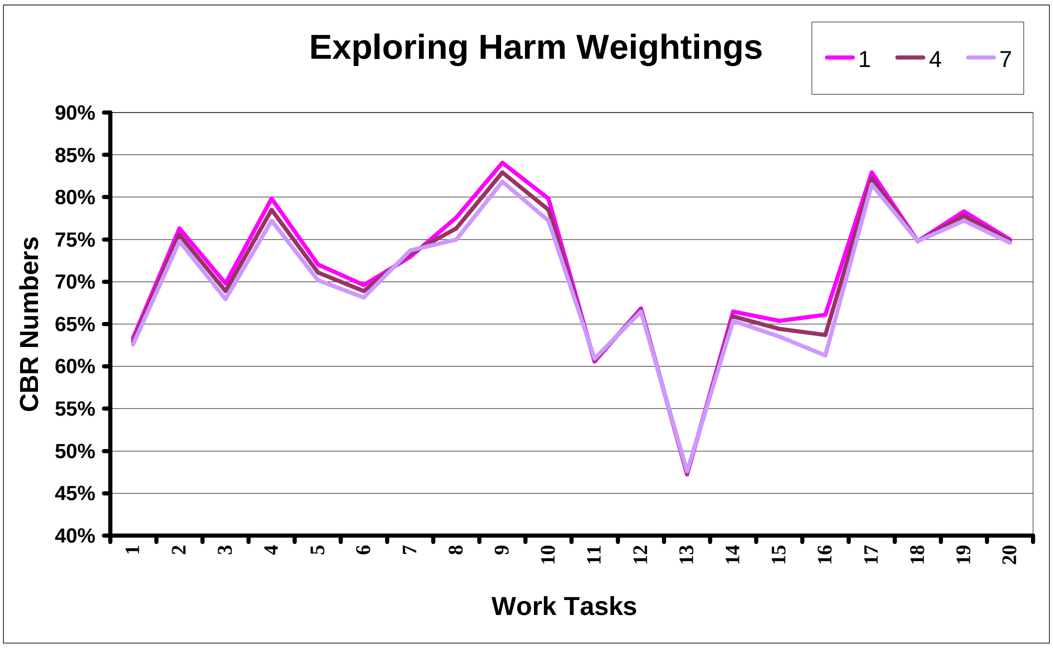


Figure 7.12 Exploring Harm Weightings

Table 7.21 show the weightings of *likelihood*, *harm* and *hazard* used to evaluate sensitivity of the *Tool* to changes in *hazard* whilst Figure 7.13 shows that experimenting with the ranking of hazards can significantly affect the *CBR Numbers*. This implies that the *Tool* is far more sensitive to hazard weightings in comparison to harm and likelihood.

Variation	Weightings		
	Likelihood	Harm	Hazard
1	3-2-1	6-5-4-3-2-1	**1-1-1-1-1-1-1-1-1**
2	3-2-1	6-5-4-3-2-1	**9-8-7-6-5-4-3-2-1**
3	3-2-1	6-5-4-3-2-1	**1-2-3-4-5-6-7-8-9**

Table 7.21 Exploring Hazard Weightings

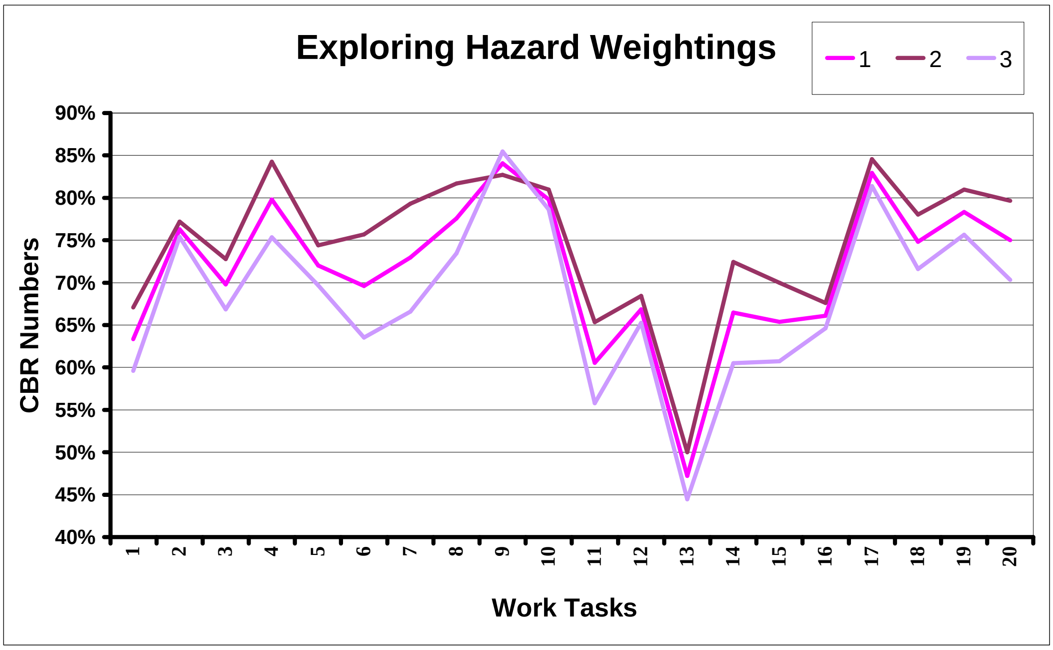


Figure 7.13 Exploring Hazard Weightings

Work Task Series	Work Task Name
1	Bridge Completion Works
2	Repair to Merryton Footbridge
3	Larkhall Station Car ParkA
4	Larkhall Station Car ParkB
5	Merryton footbridge
6	Signalling civil works
7	Demolition of Clyde Avenue Road Bridge
8	Install Concrete foundation signal base MH 419
9	Hamilton Rd. Raploch St. Bridge Parapet upgrade

Work Task Series	Work Task Name
11	Removal/disposal/destruction of Japanese Knotweed
12	Collection, removal and disposal of sharps
13	Site Survey
14	Environmental Investigation
15	General site clearance
16	Long line public address installation
17	Support to Sheet piles
18	Ground Investigation (Exploratory)
19	Construction of Stations
20	Larkhall line Running of return conductor

Table 7.22 Work Task Series (x-axis)

To summarise the findings drawn from Figure 7.11, Figure 7.12 and Figure 7.13 the *Tool* shows little sensitivity to different weightings of *likelihood* and *harms* but significant sensitivity to the ranking of *hazards*.

This leads directly to the second part of the sensitivity analysis – whether the solutions presented by the *Tool* are affected by differences in *CBR Numbers*. This is assessed by comparing the mitigations suggested by the *Tool* when the *Case Base* is calibrated to each of the 3 hazard variation shown in Table 7.21 Exploring Hazard Weightings as a worst case scenario.

Six arbitrary *CBR Numbers*, shown in Table 7.23 represent ‘new’ work tasks with *CBR Numbers* ranging from 40 to 90.

New Work Task	*CBR Number*
A	40
B	50
C	60
D	70
E	80
F	90

Table 7.23 Arbitrary CBR Numbers

These are each submitted to the three different *Case Bases* and the mitigations suggested by the *Tool* compared. A summary of these results is shown below in Table 7.24 (full results are tabulated in ***Appendix F***).

New Work Task	***CBR Number***	**Number of mitigations returned by *Tool***		
		Variation 1	**Variation 2**	**Variation 3**
A	40	22 (A)	22 (A)	22 (A)
B	50	22 (A)	22 (A)	22 (A)
C	60	49	17 (B)	60
D	70	58	61	58
E	80	60	58	55
F	90	4	1	10

Table 7.24 Comparing mitigations returned by *Tool* using variations 1,2&3

The results of this study can be summarised as following:

- Using *hazard variation 1*, where hazards are given equal weightings, the *Tool* produces between 4 and 60 mitigations for work tasks A to F. This variation shows the only increasing trend.
- Using *hazard variation 2*, where hazards are ranked highest to lowest, the *Tool* produces between 1 and 61 mitigations for work tasks A to F.
- Using *hazard variation 3*, where hazards are ranked lowest to highest, the *Tool* produces between 10 and 60 mitigations for work tasks A to F.
- In *Work Task F*, the *Tool* only returns four mitigations using the Range Intersection Algorithm in *variation 1*, four in *variation 2* and ten in *variation 3*. It is recommended that an additional feature be added to allow <u>all</u> mitigations to be presented by the *Tool* where the number of mitigations is below a certain threshold, say a minimum of 15.

- The *CBR Numbers* of some work tasks where found to be beyond the scope of the original *Case Base*, resulting in the secondary level of similarity calculation i.e. using only the range intersection algorithm returned no mitigations and nearest neighbour method is required. This occurred at the following points:
    - **Work Tasks A & B**. The *Tool* produced mitigations based on work tasks nearest neighbour in the *Case Base.* In all variations, the *Tool* returned 22 mitigations from the work task entitled ‘site survey’ in the *Case Base*. The *CBR Number* of the work task ‘Site survey’ calculated using variations 1,2 & 3 are 47.22, 50.00 & 44.44 respectively. This is denoted in Table 7.24 as superscript (A)
    - **Work Tasks C**. The *Tool* returned 17 mitigations from the stored work task entitled ‘Destruction & removal of Japanese Knotweed’ using variation 2. This is denoted in Table 7.24 as superscript (B). The *CBR Number* of this nearest neighbour work task in the case base is calculated using variation 2 as 65.33.

In conclusion, this test has enabled some pertinent findings, namely:

- Upgrading the RIDDOR classification screen to include 3-day injuries, dangerous diseases etc, alters the *Case Base* very little.
- The *Tool* shows little sensitivity to different weightings of *likelihood* and *harms* but significant sensitivity to the *hazard* weightings.
    - *Hazard Variation 1* with equal weighting applied to all hazards produced the only increasing trend of mitigations as *CBR Numbers* increased.
    - This study highlights scope for further study such as calibrating the *Tool* to target specific corporate safety campaigns based on real accident studies.
- Finally, the weighting used in future tests are finalised as:
    - Likelihood: 3-2-1
    - Harm: 6-5-4-3-2-1
    - Hazard: 1-1-1-1-1-1-1-1-1

7.5 Conclusions

This chapter has detailed the following:

- The *Case Base* is hosted using commercially available Microsoft Access application and consists of 10 related database tables.

- *CBR Numbers* are generated based on the classification of work tasks using an innovative RIDDOR-based classification screen. Examples demonstrate how CBR Numbers are calculated.

- Two retrieval algorithms are employed to match stored past work tasks, and their associated hazards and control measures, to new problems.
    - *Range Intersection Method* searches mitigation distributions and displays those which match the criteria of the *Search Range* associated with the new problem.
    - *Nearest Neighbour Method* returns <u>all</u> mitigations associated with the stored work task exhibiting the closest *CBR Number*.

- A development test is employed to further investigate whether the *Tool* is sensitive to changes in arbitrary weightings. Results of the test show:
    - The *Tool* **<u>is not</u>** sensitive to changes in likelihood or harm weightings.
    - The *Tool* **<u>is</u>** sensitive to changes in hazard weightings. This presents an opportunity for further study to investigating the link between hazard weightings and real accident statistics.
    - The Tool weightings are finalised as Likelihood: 3-2-1, Harm: 6-5-4-3-2-1 and Hazard: 1-1-1-1-1-1-1-1-1
    - Work experience appears to have

- A development test employed to further investigate how users classify work tasks shows work experience may have significant links to the perception of risk and therefore the classification of work tasks. This is identified for further investigation in the following chapter, *Proof of Concept Testing*.

CHAPTER 8: PROOF OF CONCEPT TESTING

This chapter details a series of 4 tests with the aim of demonstrating that the *Tool* is fully functioning. On the whole the tests consider real data with real users to demonstrate the *Tool* as fully working. The benefits of the *Tool* in comparison to traditional method statements and brainstorming techniques are also presented.

Overall it is concluded that the *Tool* is not only functioning as intended but also has a number of advantages over more traditional methods of safety management.

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8.1 Introduction

Chapter 8 aims to test whether the two versions of the *Tool*, prototype and internet, are functioning and to what extent. In addition this chapter compares the output of the *Tool*, a generated bespoke method statement, to traditional methods and gives an indication of potential 'value-for-money' in comparison to brainstorming techniques.

Chapter 8 is structured in six sections, namely:

- **Section 1 – Introduction**

Brief introduction and chapter structure is given.

- **Section 2 – TEST 1: Prototype Tool**

The aim of this study is to assess the prototype version of the *Tool* and compare *CBR Numbers* assigned by users with differing work experience. The prototype version of the *Tool* is shown to be fully functioning with both retrieval algorithms operating successfully.

- **Section 3 – TEST 2: The Online Tool**

The aim of this study is to assess the web-enabled version of the *Tool*. A tutorial style online survey demonstrates this version of the *Tool* as functioning and able to make reasonable mitigation suggestions.

- **Section 4 – TEST 3: Comparing Method statements**

The reporting capability of the *Tool* generated method statements is shown to have positive benefits to traditional method statements and provides an auditable alternative to 'cut & paste' techniques.

- **Section 5 – TEST 4: Brainstorming**

This exercise seeks to compare knowledge extracted from paper method statements using brainstorming group techniques with the results of test 2 using the online *Tool*. The *Tool* compares favorably for user with less than 10 years work experience and is shown to be good *'value-for-money'* in comparison to brainstorming techniques.

- **Section 6 – Test Series Conclusions**

The concluding section highlights the main findings of the chapter, namely:

  - Both versions of the *Tool* (prototype & web-enabled version) are functioning and able to make reasonable mitigation suggestions.
  - The *Tool*, along with the generation of method statements, has quality control and financial benefits over traditional methods.

8.2 TEST 1 – Prototype Tool

The aim of this section is to test the prototype version of the *Tool* and compare:

- The validity of the mitigation as suggested by the *Tool*
- Different classification (i.e. *CBR Numbers*) based on user work experience

The study employs two volunteers, representative different types of possible user:

- **'Admin' Volunteer** – representative of a typical data administrator with minimal knowledge and experience in safety of transportation construction or maintenance work.
- **'Civil' Volunteer –** this volunteer represented a pre-chartered engineer with approximately 3 years 'graduate' level experience in civil / structural design and construction work.

Both *Admin* and *Civil* volunteers were asked to read three paper-based method statements and perform the *Role Play* and *Knowledge Capture* elements developed in section 7.4.1 :

- ***Role Play*** **-** Classify the work task by role playing as the person responsible for writing method statements.
- ***Knowledge Capture*** - Detail the mitigations used in the actual method statement,

These three work tasks were described by their associated method statement as:

1. Earthworks
2. Drainage
3. Structure trial holes

The volunteers used the prototype version of the *Tool* to classify each work task, as if this were occurring in 'real-time'.

Below is a description of each of the new cases along with the volunteer who performed the task:

- Case 1: Drainage (Admin)
- Case 2: Earthworks (Admin)
- Case 3: Drainage (Civil)
- Case 4: Earthworks (Civil)
- Case 5: Trial Holes (Admin)
- Case 6: Trial Holes (Civil)

Classification involved the volunteers assigning either *likely*, *unlikely* or *not applicable* in the pre-defined hazard / harm matrix as shown in Figure 8.1. The *Tool Designer* was at hand to answer specific questions from the volunteers but intentionally removed themselves from the decision making process of classifying the work tasks.

The Tool's *CBR Function* is 'switched on', allowing the retrieval algorithms to select and present the user with a dynamic list of hazards and associated control measures based on a small test *Case Base* of five work tasks as defined previously as:

- Construction of Cabinet, REB & Container Compounds
- Junction Mast Erection & Wiring Modifications
- General Concrete Works
- Shot blasting / Painting of structures
- Bridge Demolition

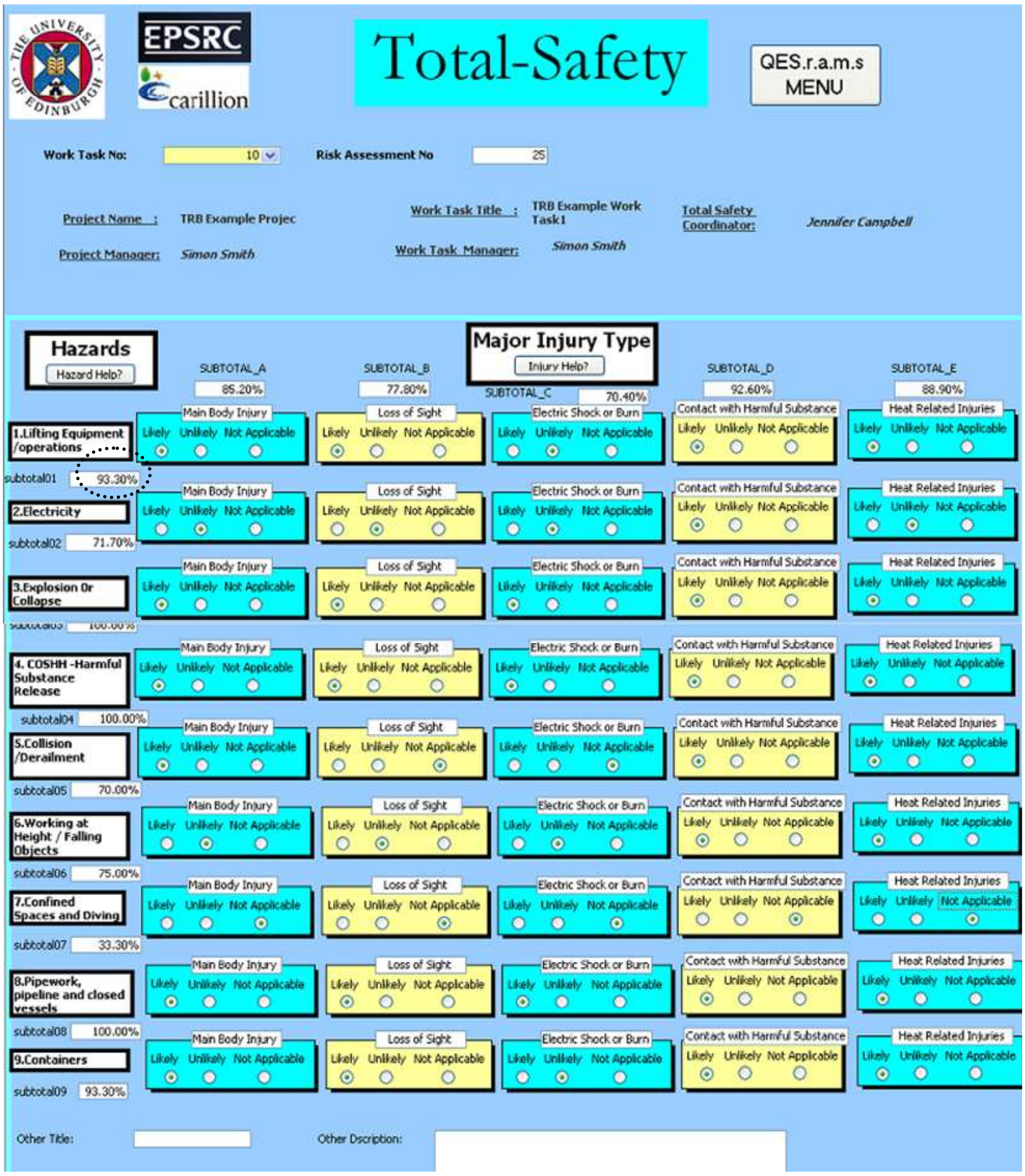


Figure 8.1 Prototype Tool Classification Screen

The volunteers were asked whether the *Tool's* suggestions were relevant, based on their understanding of the work task. The method statements were then mined for comparison by the *Tool Designer* using the steps identified in section 6.2.3:

1. **Background Knowledge**. The *Designer* reads each work task in order to gain background knowledge.
2. **Mining Statements**. The *Designer* mines each of the method statements for information relating to the safety or wellbeing of workers on site. This is achieved by highlighting and grouping similar worded passages relating to a common feature.
3. **Visual Matrix**. A simple matrix is used to identify and show the relationship between the work task method statements and the listed mitigations and is performed in parallel with the previous step.

The results are shown in Table 8.1 and Table 8.2 based upon:

- The original *Case Base* of five work tasks and 62 mitigations.
- The *CBR Function* 'switched on' to produce a dynamic list of mitigations.
- The *CBR Learning Ability* is 'switched off'; meaning new cases are not added to the *Case Base* for use in the next cycle.

The *Range Intersection Method* retrieval algorithm yielded no results for Case 5 and Case 6 due to low classification numbers acting as outliers within mitigation distributions. Therefore the second layer of retrieval, *Nearest Neighbour Method,* displays all mitigations associated with the work task with the closest overall *CBR Number*. Using this method, work task 'junction mast erection & wiring modifications' with a classification number of 73.3% was found to be the closest to both Case 5 (62.6%) and Case 6 (59.46%).

Table 8.2 Summary of Results shows the percentage of mitigations correctly identified by the *Tool*, the average being 76%.

	Admin	Civil	Admin	Civil	Admin	Civil
	Drainage		Earthworks		Trial Holes*	
	Case1	*Case3*	*Case2*	*Case4*	*Case5*	*Case6*
a) CBR Classification Number (%)	**80.74**	**85.74**	**87.60**	**91.84**	**62.60**	**59.46**
b) Number of Actual Mitigations	38	38	35	35	22	22
c) Number of mitigations suggested by tool	32	58	58	37	34	34
d) Number of mitigations correctly identified by tool	23	38	34	31	12	12
e) Number of mitigations wrongly identified by tool	10	20	23	6	18	18
f) Number of mitigations missed	15	0	0	4	9	9
g) % identified correctly *i.e. (d)÷(b)*100%*	60.53	100	100	88.57	54.5	54.5
h) % over suggested but not 'accepted' *i.e. (e)÷(c) *100%*	31.25	34.48	41.38	16.22	52.94	52.94

Table 8.1 Results using initial Case Base – CBR learning 'switched off'

Method Statement	***CBR Number***		**Percentage of Controls correctly identified by Tool**	
	Civil	Admin	Civil	Admin
Drainage	85.74	80.74	100%	60.5%
Earthworks	91.84	87.60	88.57%	100.0%
Trial Holes	59.46	62.60	54.5%	54.5%

Table 8.2 Summary of Results

Table 8.3 demonstrates improved performance when the *Learning Ability* is 'switched on'. This allows new cases and results from previous cases in subsequent searches using *Case Based Reasoning* (CBR) methodology. Although the addition of the first two cases to the *Case Base* do not alter the selection of mitigations presented by the tool for Case 3, the additions of Cases 1, 2 & 3 to the *Case Base* produced improved results of Case 4.

	CBR	
	Off	**On**
	Earthworks Case 4	
a) CBR Classification Number	91.84	91.84
b) Number of Actual Mitigations	35	35
c) Number of mitigations suggested by tool	37	41
d) Number of mitigations correctly identified by tool	31	35
e) Number of mitigations wrongly identified by tool	6	6
f) Number of mitigations missed by tool	4	0
g) Percentage identified correctly	88.57	100
h) Percentage suggested, but not 'accepted' by user	16.22	14.6

Table 8.3 Comparing Results: *CBR Learning* 'on' or 'off'

8.2.1 Test 1 Conclusions

Test 1 shows the *Tool* (prototype) to be fully functioning and also provides a valid method of knowledge transfer between paper documents and the *Tool's Case Base*. Results from this test also signify:

- The classification screen allows user with different types of 'technical experience' to classify work tasks.
- Work experience made little effect as the two volunteers were shown to assign similar *CBR Numbers* (between 3%-5%) to the work tasks.
- Both the *Range Intersection* and the *Nearest Neighbour* retrieval algorithms operated successfully.
- Over half of the control measures (average 76%) can be elicited from paper documents.
- A relatively small case base of five work tasks can be used to find between 54%-100% of mitigation measures in new cases.

8.3 TEST 2 – The Online Tool

The aim of this section is to test the online version of the *Tool* and further explore the issue of subjectivity previously identified, including:

- The validity of the mitigations as suggested by the *Tool*.
- *Tool* validity with regard to scaling effects & data integrity for multiple users.
- The effect of user work experience upon *CBR Numbers*.
- Whether the *Tool* acts in an intuitive way for users.

In addition, an invitation strategy and instruction method is investigated as a possible precursor for 'rolling out' the *Tool* within an industrial setting.

8.3.1 Invitation Strategy & Online Survey

The increased numbers of users needed to assess scaling effects also presents the problem of deploying the *Tool* whilst ensuring the integrity of data for multiple users. This is achieved by using the web based version of the *Tool* rather than the prototype version. The *Case Base* is located on a computer server and accessed through a dynamic webpage using server query language (SQL) and computer interface engine *Coldfusion*. For the purposes of testing, the *Tool* is restricted to those with access to the University of Edinburgh (UoE) computer network as the database holding the *Case Base* of past solution is hosted on a 'development' server (Campbell and Smith 2007a).

A 'blanket' invitation strategy using e-mail was employed to invite all academic / research staff and students within the School of Engineering and Electronics at the University of Edinburgh to participate in an on-line survey. This was followed up by an e-mail from the Head of the School re-enforcing the importance of the research along with face-to-face reminders with colleagues. As a comparison, direct invitation was given to small management consultancy based in Scotland, Glen Clova Ltd.

Potential users were invited to register for a username and password at www.total-safety.com, see Figure 8.2, Figure 8.3 and Figure 8.4. The registration process includes a career summary and is designed to allow comparison between different work experience groups.

Figure 8.2 www.Total-Safety.com

Figure 8.3 Online Survey

Once logged in, users are given written instruction on the research aims of the ‘online survey’. The sections of the online survey and their order are summarised as:

- **Part 1: Background Knowledge**. Users download a PDF version of method statement for background knowledge relating to the construction of Larkhall Station Car Park.

- **Part 2: Role Play & Work Task Classification**. Users role play as the person who will ultimately write the method statement and assess work task as if in ‘real- time’ (see Figure 8.5).

- **Part 3: Case Based Reasoning Function**. A dynamic list of mitigations is presented to the user based on the *CBR Numbers* generated in Part 2. Users decide whether these mitigations are evident in the original method statement and encouraged to add and/or perform a semantic search the *Case Base* if they feel the *Tool* missed something important. This is similar to the *knowledge capture* element discussed in previous tests.

- **Part 4: Feedback Questionnaire**. Aimed to improve the survey methods and establish the time involved in the survey (Figure 8.7).

Figure 8.4 Registration Questionnaire


Total Safety

Case Based Reasoning Tool

April 17, 2007

PART 2 - Classify the task

Please assign Likelihood to each of the hazard/harm combination below for the online survey of Work Task Larkhall Carpark

- **Role play or pretend** that the job has not started yet, and that you are the person who will ultimately write the method statement.
- The method statement gives information on what types of things might go wrong during the construction task, and how to avoid them. For this stage, **concentrate only on 'unsafe' issues** even if these dangerourous situation were recognised in the document and were avoided.
- You will now assign a Likelihood to each combination of hazard and harm using a new clasification method. For each of the hazard/harm combination you must pick either 'Likely' , 'Unlikely' or 'Not Applicable' . Hazard/harm combinations have been pre-determined and are viewed as a pivot table. Below gives an example how to record then lifting operation and/or equipment' is 'likely' to cause major injuries.

	Major Injury
Lifting Equipment /Operations	Likely Unlikely N/A

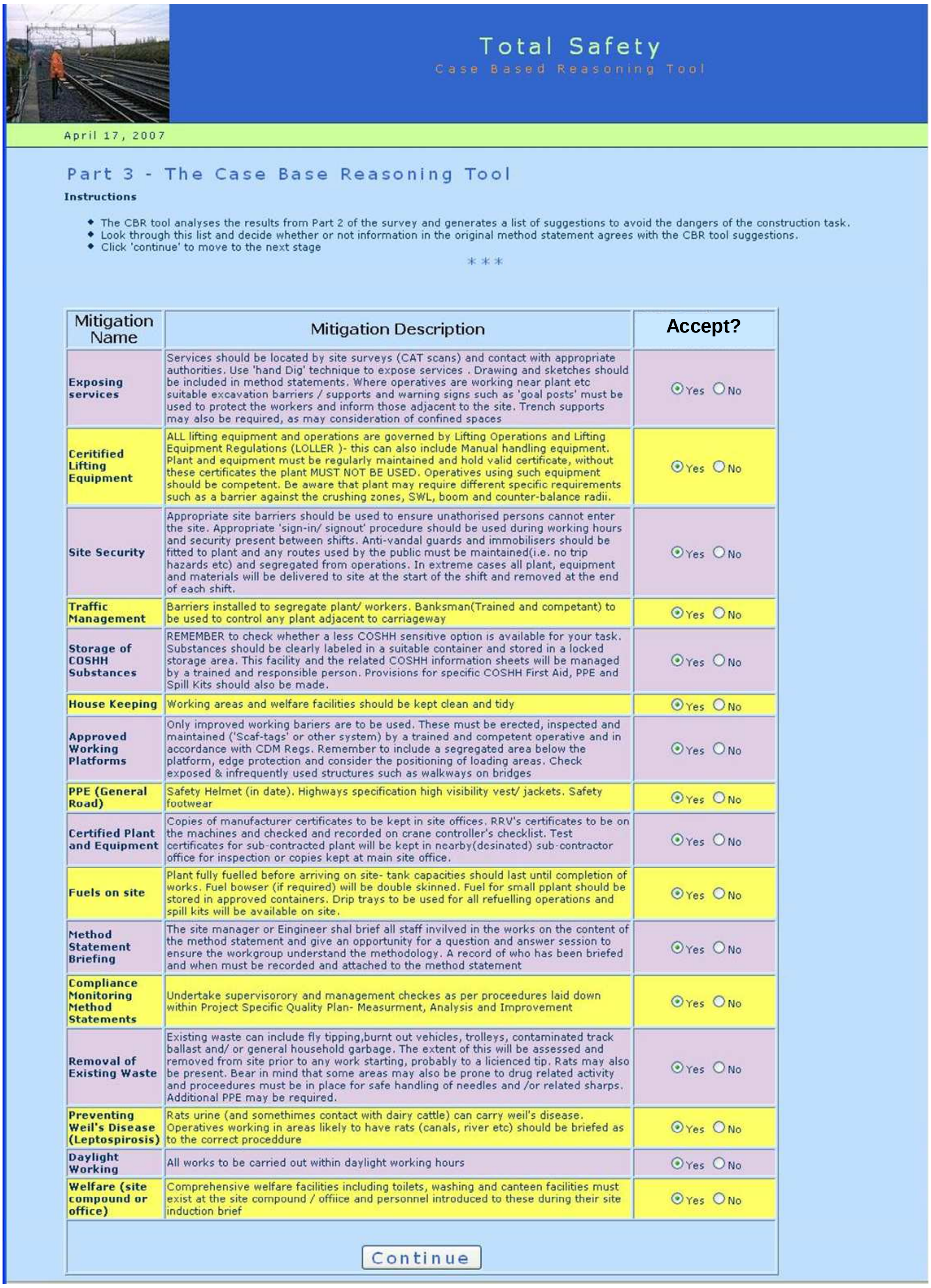
CLICK HERE if you would like to open reference description of hazards and harms in a new window, you may find these helpful when assigning Likelihood values.

* * *

	Major Injury	3 Day Injury	Disease	Harmful Substances	Muscular Skeletal Injuries
Lifting Equipment /Operations	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A
Electricity	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A
Explosion Or Collapse	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A
COSHH - Harmful substances	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A
Collisions / Derailments/ Impacts	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A
Working at Height /Falling Objects	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A
Confined Spaces / Diving Operations	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A
Pipework, Pipeline & Closed Vessels	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A
Containers	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A	Likely Unlikely N/A

Continue

Figure 8.5 Online Survey Work Task Classification (Campbell and Smith 2007a)



Total Safety

Case Based Reasoning Tool

April 17, 2007

Part 3 - The Case Base Reasoning Tool

Instructions

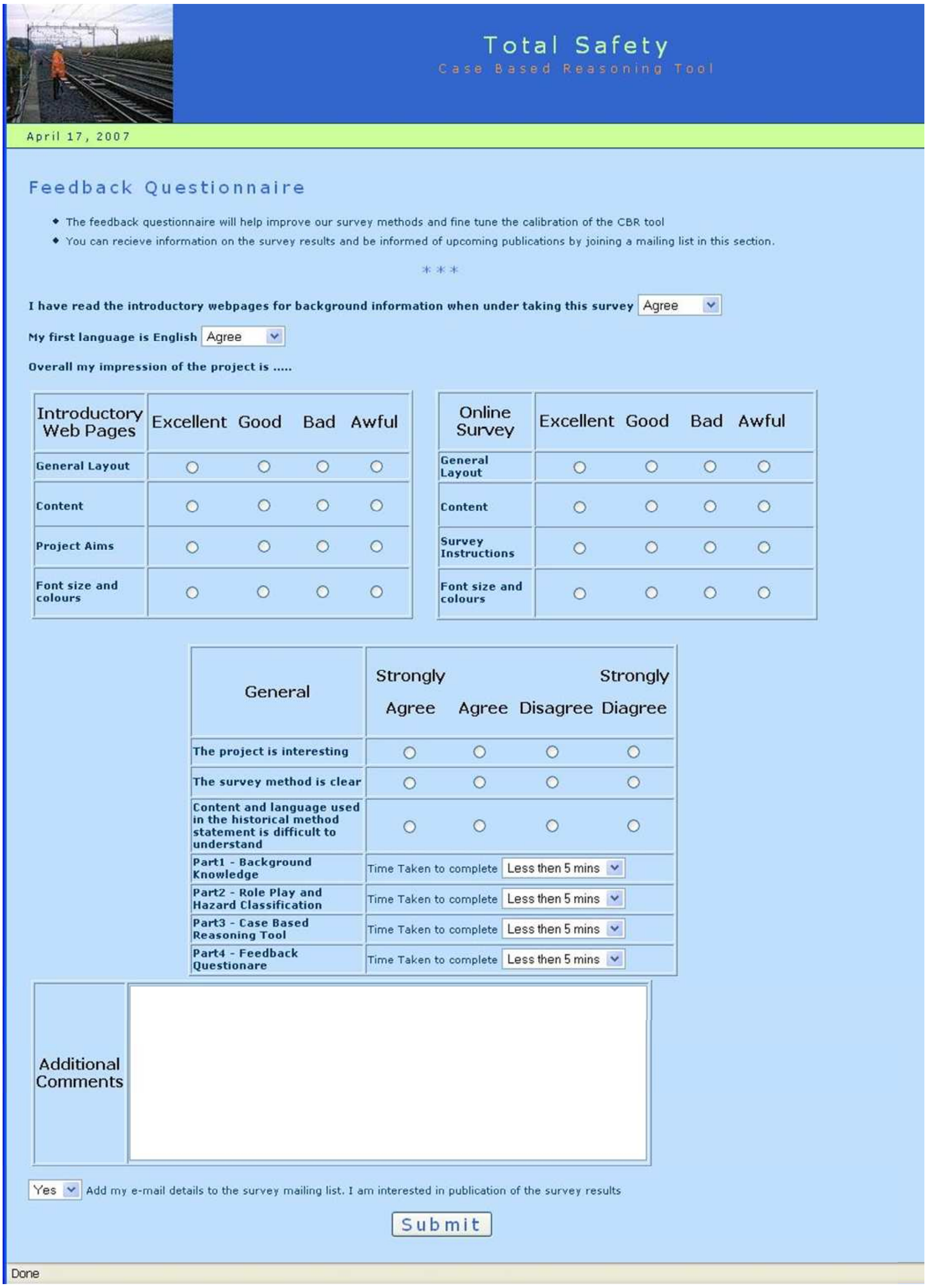
- The CBR tool analyses the results from Part 2 of the survey and generates a list of suggestions to avoid the dangers of the construction task.
- Look through this list and decide whether or not information in the original method statement agrees with the CBR tool suggestions.
- Click 'continue' to move to the next stage

* * *

Mitigation Name	Mitigation Description	Accept?
Exposing services	Services should be located by site surveys (CAT scans) and contact with appropriate authorities. Use 'hand Dig' technique to expose services . Drawing and sketches should be included in method statements. Where operatives are working near plant etc suitable excavation barriers / supports and warning signs such as 'goal posts' must be used to protect the workers and inform those adjacent to the site. Trench supports may also be required, as may consideration of confined spaces	◉ Yes ○ No
Ceritified Lifting Equipment	ALL lifting equipment and operations are governed by Lifting Operations and Lifting Equipment Regulations (LOLLER)- this can also include Manual handling equipment. Plant and equipment must be regularly maintained and hold valid certificate, without these certificates the plant MUST NOT BE USED. Operatives using such equipment should be competent. Be aware that plant may require different specific requirements such as a barrier against the crushing zones, SWL, boom and counter-balance radii.	◉ Yes ○ No
Site Security	Appropriate site barriers should be used to ensure unathorised persons cannot enter the site. Appropriate 'sign-in/ signout' procedure should be used during working hours and security present between shifts. Anti-vandal guards and immobilisers should be fitted to plant and any routes used by the public must be maintained(i.e. no trip hazards etc) and segregated from operations. In extreme cases all plant, equipment and materials will be delivered to site at the start of the shift and removed at the end of each shift.	◉ Yes ○ No
Traffic Management	Barriers installed to segregate plant/ workers. Banksman(Trained and competant) to be used to control any plant adjacent to carriageway	◉ Yes ○ No
Storage of COSHH Substances	REMEMBER to check whether a less COSHH sensitive option is available for your task. Substances should be clearly labeled in a suitable container and stored in a locked storage area. This facility and the related COSHH information sheets will be managed by a trained and responsible person. Provisions for specific COSHH First Aid, PPE and Spill Kits should also be made.	◉ Yes ○ No
House Keeping	Working areas and welfare facilities should be kept clean and tidy	◉ Yes ○ No
Approved Working Platforms	Only improved working bariers are to be used. These must be erected, inspected and maintained ('Scaf-tags' or other system) by a trained and competent operative and in accordance with CDM Regs. Remember to include a segregated area below the platform, edge protection and consider the positioning of loading areas. Check exposed & infrequently used structures such as walkways on bridges	◉ Yes ○ No
PPE (General Road)	Safety Helmet (in date). Highways specification high visibility vest/ jackets. Safety footwear	◉ Yes ○ No
Certified Plant and Equipment	Copies of manufacturer certificates to be kept in site offices. RRV's certificates to be on the machines and checked and recorded on crane controller's checklist. Test certificates for sub-contracted plant will be kept in nearby(desinated) sub-contractor office for inspection or copies kept at main site office.	◉ Yes ○ No
Fuels on site	Plant fully fuelled before arriving on site- tank capacities should last until completion of works. Fuel bowser (if required) will be double skinned. Fuel for small pplant should be stored in approved containers. Drip trays to be used for all refuelling operations and spill kits will be available on site.	◉ Yes ○ No
Method Statement Briefing	The site manager or Eingineer shal brief all staff invilved in the works on the content of the method statement and give an opportunity for a question and answer session to ensure the workgroup understand the methodology. A record of who has been briefed and when must be recorded and attached to the method statement	◉ Yes ○ No
Compliance Monitoring Method Statements	Undertake supervisorory and management checkes as per proceedures laid down within Project Specific Quality Plan- Measurment, Analysis and Improvement	◉ Yes ○ No
Removal of Existing Waste	Existing waste can include fly tipping,burnt out vehicles, trolleys, contaminated track ballast and/ or general household garbage. The extent of this will be assessed and removed from site prior to any work starting, probably to a licienced tip. Rats may also be present. Bear in mind that some areas may also be prone to drug related activity and proceedures must be in place for safe handling of needles and /or related sharps. Additional PPE may be required.	◉ Yes ○ No
Preventing Weil's Disease (Leptospirosis)	Rats urine (and somethimes contact with dairy cattle) can carry weil's disease. Operatives working in areas likely to have rats (canals, river etc) should be briefed as to the correct proceddure	◉ Yes ○ No
Daylight Working	All works to be carried out within daylight working hours	◉ Yes ○ No
Welfare (site compound or office)	Comprehensive welfare facilities including toilets, washing and canteen facilities must exist at the site compound / offiice and personnel introduced to these during their site induction brief	◉ Yes ○ No

Continue

Figure 8.6 Online Survey User Selection Screen (Campbell and Smith 2007a)



Total Safety

Case Based Reasoning Tool

April 17, 2007

Feedback Questionnaire

- The feedback questionnaire will help improve our survey methods and fine tune the calibration of the CBR tool
- You can recieve information on the survey results and be informed of upcoming publications by joining a mailing list in this section.

* * *

I have read the introductory webpages for background information when under taking this survey [Agree]

My first language is English [Agree]

Overall my impression of the project is .....

Introductory Web Pages	Excellent	Good	Bad	Awful
General Layout	○	○	○	○
Content	○	○	○	○
Project Aims	○	○	○	○
Font size and colours	○	○	○	○

Online Survey	Excellent	Good	Bad	Awful
General Layout	○	○	○	○
Content	○	○	○	○
Survey Instructions	○	○	○	○
Font size and colours	○	○	○	○

General	Strongly Agree	Agree	Disagree	Strongly Diagree
The project is interesting	○	○	○	○
The survey method is clear	○	○	○	○
Content and language used in the historical method statement is difficult to understand	○	○	○	○
Part1 - Background Knowledge	Time Taken to complete [Less then 5 mins]			
Part2 - Role Play and Hazard Classification	Time Taken to complete [Less then 5 mins]			
Part3 - Case Based Reasoning Tool	Time Taken to complete [Less then 5 mins]			
Part4 - Feedback Questionare	Time Taken to complete [Less then 5 mins]			

Additional Comments

[Yes] Add my e-mail details to the survey mailing list. I am interested in publication of the survey results

Submit

Done

Figure 8.7 Feedback Questionnaire

Initial results using this strategy were disappointing solely on the few numbers of volunteers willing to undertake the survey. Thirty-three potential volunteers applied for a username and password yet only 8 completed the survey within a two week trial period. This comprised two volunteers from Glen Clova Ltd, a small management consultancy based in Scotland, and six volunteers from the University of Edinburgh.

Details of the volunteers work experience in general disciplines are shown in Table 8.4 whilst Table 8.5 gives details of their highest qualification along with an indication of their average combined work experience within these disciplines.

		Work Experience (Years)			
		Academic / Education	Consulting	Contracting	Health & Safety
University of Edinburgh	Lecturer A (*Simon*)	10-20 years	None	2-5 years	5-10 years
	Lecturer B (*Gareth*)	5-10 years	None	None	None
	PhD Student A (*Julien*)	Less than 2 years	2-5 years	None	None
	PhD Student B (*Ian*)	Less than 2 years	2-5 years	None	None
	Undergraduate -Engineering- (*David*)	2-5 years	None	None	None
	Undergraduate -Non-engineering- (*James*)	None	None	None	None
Glen Clova Ltd	Management Consultant (*Graham*)	None	2-5 yrs	10-20 years	5-10 years
	Senior Administrator (*Carol*)	None	None	5-10 years	None

Table 8.4 Demographic of User Work Experience

The volunteers from Glen Clova Ltd comprised one company administrator (the only female of the test group) and a contractor currently working in the oil industry. The volunteers from the University of Edinburgh included:

- Two engineering lectures
- One non-engineering undergraduate
- Two PhD Students
- One undergraduate student studying an engineering discipline

Due to the use of time ranges in the questionnaire, the precise number of years work experience for individuals could not be calculated. However, the average combined work experience can be estimated based on the minimum and maximum limits of these ranges (see Table 8.5)

		Highest Qualification	**Combined Work Experience (Range in Years)**		
			Minimum	***Maximum***	***Average***
University of Edinburgh	Lecturer A (*Simon*)	Doctorate	17	35	26
University of Edinburgh	Lecturer B (*Gareth*)	Doctorate	5	10	7.5
University of Edinburgh	PhD Student A (*Julien*)	Masters Degree	2	7	4.5
University of Edinburgh	PhD Student B (*Ian*)	Masters Degree	2	7	4.5
University of Edinburgh	Undergraduate -Engineering- (*David*)	Masters Degree	2	5	3.5
University of Edinburgh	Undergraduate -Non-engineering- (*James*)	A Level or Higher Grade	0	0	0
Glen Clova Ltd	Management Consultant (*Graham*)	City and Guilds	17	35	26
Glen Clova Ltd	Senior Administrator (*Carol*)	None	5	10	7.5

Table 8.5 User Qualifications & Combined Number of Years Work Experience (average)

In performing the task, each volunteer is found to classify the work task slightly differently and thus *CBR Numbers* ranged from 45.7 and 90.6 as given in Table 8.6[5]. The order in which the volunteers performed the task is also shown in this table.

		Survey Order	CBR Number	Suggestions by the ***Tool***	Suggestions accepted by Users
University of Edinburgh	Lecturer A (*Simon*)	*1st*	*50.7*	22	5
University of Edinburgh	Lecturer B (*Gareth*)	*8th*	*45.7*	22	6
University of Edinburgh	PhD Student A (*Julien*)	*6th*	*90.6*	30	29
University of Edinburgh	PhD Student B (*Ian*)	*3rd*	*71.0*	26	25
University of Edinburgh	Undergraduate -Engineering- (*David*)	*7th*	*58.5*	65	29
University of Edinburgh	Undergraduate -Non-engineering- (*James*)	*5th*	*71.3*	29	16
Glen Clova Ltd	Management Consultant (*Graham*)	*2nd*	*58.5*	17	17
Glen Clova Ltd	Senior Administrator (*Carol*)	*4th*	*87.2*	33	30
Total				244	157

Table 8.6 Online Survey Results

[5] N.B. *CBR Numbers* from this tables are rounded to the nearest whole number to ease reading and discussion

No appreciable similarities are found within age groups, but examining work experience and gender highlights some interesting factors in how users classify work tasks:

- Both lecturers give the lowest *CBR Number* of 46 and 51 and had the largest experience in academia/ education.
- One of the lecturers (Simon) and the management consultant (Graham) had the same overall average number of years work experience yet the consultant has the higher *CBR Number* and shows a more pessimistic view towards dangers associated with the task.
- Both the management consultant (Graham) and one of the undergraduate students (David) gave a *CBR Number* of 59. The contractor showed the most non-academic experience in the group with between 2-5 years experience in consultancy, over 10 years experience in health & safety and over 20 work experience in general contracting.
- Surprisingly, both the non-engineering undergraduate and one the PhD students from an engineering background assigned a *CBR Number* of approximately 71. The PhD student had an average 4.5 years combined average work experience whilst the other volunteer commented that the area of risk assessment was 'alien' to them.
- The only female assigned the second highest *CBR Number* of 87. This person works as an administrator within the consultancy. Her work experience (7.5yrs average) is predominantly in contracting and business settings.
- The highest *CBR Number* of 91 was gained from an engineering PhD student with average of 4.5 years combined average work.

These *CBR Numbers* are used by the retrieval algorithms to present volunteers with a list of possible mitigations from the *Case Base*. Volunteers then assessed whether these mitigations presented by the *Tool* are evident in the original method statement. The list of mitigations generated in the study ranged from 17 to 65.

A summary of results is given in Table 8.6. This table shows the classification of the work task (*CBR Number*), the number of mitigations suggestions by the *Tool* and the number of users agree as being evident in the original document.

An interesting phenomenon is apparent in the case of David and Graham who both attributed a *CBR Number* of 58.5; however David is presented with a greater number of mitigations by in comparison to Graham (69 versus 17). This increased number indicates the *Tool* is continually learning i.e. the *Tool* improves the selection given to David by incorporating both Graham's input and those volunteers after him (Ian, Carol, James & Julien).

The main findings of the results were as follows:

- The *Tool* suggested a total of 244 mitigations for the eight volunteers, 65% (154 / 244) of these were accepted by volunteers as matching information in the original method statement.
- The number of mitigations declined ranged from 0 to 36.
- Both the lecturers were presented with 22 mitigations but opted that only 6 and 5 of these were evident in the original document (22% & 27%). The four issues the lecturers agreed upon as being evident were entitled 'Exposing services', 'Identifying hidden services', 'Method Statement Briefing' and 'Fuel Spill Kits'. Issues they did not agree on were whether issues of 'House Keeping', 'Safety Briefings' and 'Limited Shift Hours' were in the method statement. It is likely that these individuals compared the *Tool* suggestions with the *Risk Assessment* and *COSHH Sheets* at the rear of the document. This demonstrates how important safety issues, hidden in prose text, can be unintentionally overlooked or ignored.
- Non-lecturing volunteers opted that between 16 and 30 control measures were evident from the method statement document. This corresponds to 44%-100% of the *Tool's* suggestions matching evidence in the original method statement (the average being 80%).
- Only one of the volunteers elected to add new mitigations to the *Case Base*

- No volunteers added mitigations using the available search function.

8.3.2 Test 2 Conclusions

The online survey successfully proved the web-enabled version of the *Tool* as functioning and able to make reasonable mitigation suggestions despite a limited *Case Base* of past events. Other findings include:

- Volunteers were able to use the *Tool* despite differences geographical location and work experience
- The method of using the *Tool* to facilitate knowledge extraction is credible with an average of 80% of the suggested mitigations identified as correct by volunteer users.
- Volunteers with more academic work experiences appear to be more optimistic about in the likelihood of site dangers whilst those with contracting / consultancy experience appear to more pessimistic. There also appears to be differences in how lecturing staff have approached the survey task by relying on the tabulated *Risk & COSSH Assessments* at the rear of the method statement.
- By relying heavily on the content of the *Risk & COSSH Assessments* at the rear of the document, volunteers missed important safety issues hidden in prose text. This highlights the need for clear and concise reporting of hazards and improved pro-forma of method statements.
- Those with less work experience appear to have a range of optimism of site dangers (*CBR Numbers* are between 58&91). This important finding suggests managers should consider work experience when delegating risk-based tasks to engineers with 2- 5 years work experience.
- Many volunteers elected to trust the suggestions of the *Tool* and did not to add further mitigations either by searching the existing *Case Base* or adding new entries. This is an indicative human behaviour and could be called a 'lazy factor'. This is similar to the existing problem of reliance on personal work experience in individuals. However, this problem could be circumvented by increasing the size

of the *Case Base* and hence refining the mitigations distributions. This can be achieved by ‘switching off’ the CBR algorithm and displaying all entries to users for a short period of time. This step is advisable when upgrading the *Tool* from the research development stages to real-time use; this exercise could also be utilised to assess the perception of risk (and tolerance) in corporate bodies.

8.4 TEST 3 – Comparing Method Statements

This test is aimed to compare the method statement generated by the *Tool* and 'traditional' method statements. Anecdotal evidence suggests authors of safety documentation such as method statements, can employ blind 'cut & paste techniques', whereby control methods from previous documents are re-used without demonstrating:

- How hazards, risks and mitigations from the previous work task relate to a current work tasks.
- The suitability or effectiveness of the mitigations.
- Quality assurance that these mitigations are being implemented on site.

This scenario can result in a misplaced assumption that workers are being adequately protected when in reality, inappropriate or ineffective mitigations are in place.

The *Tool* avoids this scenario by suggesting past mitigations used for similar work tasks for which the user must take positive action to consider and accept. The user must determine suitable mitigations separately if no suitable ones are suggested.

The physical outcome of the *Tool* is a generated method statement. This test compares a generated method statement to *real* method statement for the construction of *Larkhall Station Car Park.*

A brief comparison between the original method statement and the *Tool* generated version shows the *Tool* is approximately less than half the length (8 vs. 18 pages). The contents of the original *Risk & COSHH Assessments* are reproduced in Figure 8.8 and Figure 8.9, whilst examples of the content of the *Tool*-generated method statement are shown in Figure 8.10 and Figure 8.11 . Full-sized documents of original and *Tool*-generated method statements are given in ***Appendix G*** and ***Appendix H*** respectively.

The total number of mitigations as suggested by the *Tool* is 33, in comparison to the 17 individual items evident in the *Risk* and *COSHH* sections in the original method statement. This signifies that mitigations are hidden in the main body of the report-style text and the significance of these statements towards worker safety heavily relies on the subjective understanding, judgements and actions of the reader (Campbell *et al.* 2008).

To combat this, the *Tool*-generated method statement separates the descriptive work or project related material from the mitigations. This mirrors the format of the risk assessment in traditional method statements by being tabulated but adds an additional column for quality control and site feedback purposes. This new column requires a signatory to ensure each of the mitigations used for the work task. The signatory must specify alternative mitigations where those in the method statement are not applicable for the task, the control is ineffective throughout the duration of the task or where a superior method is available. Details of these events can be recorded on the final page of the method statement (see Figure 8.11) enabling a feedback loop of tacit knowledge within site-based individuals to be captured and incorporated into the *Case Base* (Campbell *et al.* 2008).

Further differences between the original document and the method statement generated by the *Tool* are shown in Table 8.7.

Larkhall Station Carpark

RISK ASSESSMENTS						
H. A. N O:	ITEM.	RISK.	SEVERITY / CONSEQUENCE RATING.	FREQUENCY RATING.	TOTAL RATING.	CONTROL MEASURE.
	Working with heavy plant	Struck by plant resulting in serious injury, possible fatality	5	1	5	Carillion Site Briefing. Banksman with Machines, Competent plant operators, certificated by approved training organisation. Records kept on file. Only enter working area when required.
	Working with stone haulage wagons/dumpers	Struck by wagons/dumper resulting in serious injury, possible fatality	5	1	5	Carillion Site Briefing. Banksman with Machines, Competent wagon operators, PPE-Hard hats, high-vis vests, Stockpile stone in designated area only. Only enter working area when required
	Drainage /Ducting Excavations	Trench Collapse, falls into excavations, contact with underground services and unauthorized access by public	5	1	5	All work to be supervised by a competent person, A barrier will be erected and maintained around any open excavation, a permit to dig system will be installed, a security guard will be on duty during off site hours.
	Working with compacting equipment	Struck by plant resulting in serious injury, crushed possible fatality	5	1	5	Carillion Site Briefing. Competent roller drivers. PPE-Hard hats, high-vis vest and ear defenders. Only enter working area when required. Time Limits for riding roller- 15mins on/15mins off on imported fill.
	Contact with services	Electrocution, severe burns, Death	5	1	5	Carillion Site Briefing. Competent person to CAT scan area. Protect existing services/cables **Carillion Permit to Dig to be issued** prior to excavation starting. Hand dig only to expose existing services, if required
	General Access to Staff.	Not Working within Agreed Area.	4	2	8	Method Statement/Safety Brief. Clear Demarcation. P.T.S. Certified Staff.
	Pollution of site	Infection from polluted water, e.g. (Weils Disease) Pollution of the watercourse by the works.	4	1	4	Ensure welfare and hygiene facilities are satisfactory. Measures will be taken to stop spills infiltrating the drain run e.g. spill kits available on site.
	Poor lighting	Slips, trips and falls.	1	2	2	Adequate task and site lighting to be provided if required
	Manual Handling	Strains and Sprains	3	2	6	Method Statement. Safety Brief. Trained Staff. Passed out in Manual Handling Skills. Approved handling equipment

Figure 8.8 Original Risk Assessment

COSHH ASSESSMENTS

HAZARD	RISK			CONTROL MEASURES	RESIDUAL		
	F	S	R		F	S	T
Fuel petrol	5	2	10	Store in approved containers, use gloves. First aid, eyes wash with copious amounts of water, skin wash with soap and water, ingestion wash mouth with water do not induce vomiting, inhalation remove person to well ventilated area if unconscious put person in recovery position and assist breathing seek immediate medical back up. If in doubt in any instance seek medical advice.	5	1	5
Fuel Diesel	5	2	10	Store in approved containers, use gloves. First aid, eyes wash with copious amounts of water, skin wash with soap and water, ingestion wash mouth with water do not induce vomiting, inhalation remove person to well ventilated area if unconscious put person in recovery position and assist breathing seek immediate medical back up. If in doubt in any instance seek medical advice.	5	1	5
Hydraulic oil	5	2	10	Store in approved containers, use gloves. First aid, eyes wash with copious amounts of water, skin wash with soap and water, ingestion wash mouth with water do not induce vomiting if more than ½ litre seek medical advice. Inhalation not expected to be a problem .If in doubt in any instance seek medical advice.	5	1	5
Concrete and Mortar	5	2	10	Wear protective overalls, gloves and boots for concreting, mask and goggles for cement dust. If in contact with the eyes flush with clean water for at least 15 mins and seek medical advice without delay. If in contact with skin, wash with soap and water. If skin irritation or pain continues seek medical attention.	5	1	5

Figure 8.9 Original COSHH Assessment

Method Statement ID Code: MS/Larkhall/1 11 rev.0 Unique_ID 103

Larkhall Station Car Park

Created by: glenclova@hotmail.com 10/04/2007

Instructions:

Below is a checklist of control measure for the current work task.

An authorised site signitory MUST check these control measures are in place before starting the job and act as signatory by initialling each measure acordingly.

In the cases below, put a number next to your initial and list addtional information at the end of this document.

A. Control measure is not applicable for the job

B. A safer method is available

C. The control measure was not effective throughout the duration of the task

Hazard Control	*Control Description*	*Authorised by (initial)*
Crane / Lifting Operations	All Lifting equipmentent is governed by LOLLER ….Consideration should be given to the positioning of crane, crane pads, ballast and the 'crush zone' to avoid crane overturning or loss of stability. No-one should be beneath loads(or parts thereof) at any time and barriers should be erected if necessary. Loads outwith the SWL or reach of the jib should not be attempted. All operators (incl. banksman) should be trained and competent. Tielines attached to slung loads at all times and slings checked daily be supervisor / slingers fo visable signs of damage - if found, these must not be used, quarantined and then scrapped	*Initial*
Trained Plant Operatives	Staff trained and certified by approved training organisation. Records kept on file. All staff will carry relevant certification on site and , upon request, present this to COSS or any other recognised safety / audit personnel	*Initial*
Correct Fuel Storage	All fuels to be stored in correct container. Use suitable gloves when handling. Handlers to be trained and aware of first aid reponse. For petrol, deisel and hydraulic oil………..Contact with eyes = wash with copious amounts of water. Contact with skin=wash with soap and water. Ingestion = wash mouth with water BUT DO NOT induce vomiting. (If more than 1/2 litre of hydraulic oil=seek medical advice) Inhalation= remove person to well ventilated area and if unconscious put into recovery position to assit breathing and SEEK IMMEDIATE MEDICAL BACK UP. If in doubt, seek medical advice	*Initial*
Safety Briefing	Safety briefings must be given before work commences, where the conditions of a given worktask have changed.	*Initial*

Created by using www.total-safety.com on .. 29 October 2007 Page 2 of 8

Figure 8.10 Tool - generated Method Statement (example 1 of 2)

Method Statement ID Code: MS/Larkhall/1 11 rev.0 Unique_ID 103

Larkhall Station Car Park

Created by: glenclova@hotmail.com 10/04/2007

Additional Site Information:

A. Control measure is not applicable for the job

B. A safer method is available

C. The control measure was not effective throughout the duration of the task

My Ref	*A/B/C*	*Description / alternative measure*	*Initial*
Example No. 1	A	Trench boxes not required as digging <100mm. ..we used barriers along with plant stop blocks instead	J. Bloggs - 01/01/2001

Created by using www.total-safety.com on .. 29 October 2007 Page 8 of 8

Figure 8.11 Tool - generated Method Statement (example 2 of 2)

Hazard Controls	Method Statement	
	Traditional	Tool - Generated
Crane & lifting Operations	✘	✓
Trained Plant Operatives	✓	✓
Correct Fuel Storage	✓	✓
Safety Briefing	✓	✓
Fist Aid Procedure	✓	✓
First Aid	✓	✓
Manual Handling training	✓	✓
Ground Investigation	✘	✓
Exposing Services	✓	✓
Lighting (Temp & Normal)	✓	✓
Waste Material Management	✘	✓
Approved working platforms	✘	✓
House Keeping	✘	✓
Storage of COSHH substances	✓	✓
Traffic Management	✘	✓
Site Security	✓	✓
Certified Lifting Equipment	✘	✓
Access Egress Routes	✘	✓
Fuels on Site	✓	✓
Fuel Spill Kits	✘	✓
Dust Suppression	✘	✓
COSHH- Lead Paint	✘	✓
Welfare (site, compound or office)	✓	✓
Daylight Working	✘	✓
Preventing Weil's Disease (Leptospirosis)	✓	✓
Removal of Existing Waste	✘	✓
Fall Arrest Systems	✘	✓
Method Statement Briefing	✓	✓
Identifying hidden services	✓	✓
Certified Plant and Equipment	✓	✓
PPE (General Road)	✓	✓
Authorising start of work	✘	✓
Compliance Monitoring Method Statements	✘	✓

Table 8.7 Comparison of Traditional & Tool-generated Method Statements

8.4.1 Conclusions

In short, the reporting capability and ability of the *Tool* to generate meaningful method statements within seconds has positive benefits in comparison to traditional method statements, namely the ability to provide:

- An auditable alternative to 'cut & paste techniques' with improved quality assurances.
- A platform for feedback between those working *at the sharp end* and those who must ensure their safety i.e. a feedback loop allowing the transfer of knowledge between Bob and Andy.
- Shorter and more concise method statements leading to:
  - Proactive management of important hazards.
  - Savings in time, cost and reduced environmental impact.

8.5 TEST 4 – Brainstorming Exercise

This test seeks to emulate the creative process involved in extracting safety knowledge from method statements. The is achieved by facilitating a group brainstorming exercise and comparing group results to each other and individuals who perform the same task using the *Tool* in test 2, section 8.3.

The Institute of Infrastructure and the Environment (IIE) at the University of Edinburgh has an excellent variety of research groups. Weekly seminars facilitate continual learning within the department and are given by academic and industrial guests, as well as members of the faculty, auxiliary staff and PhD students. The seminars are often well attended, offering a prime venue and established time slot to conduct a group exercise.

The test was advertised to possible IIE attendees as a seminar on the topic of 'brainstorming techniques'. Brainstorming is a structured format for group problem solving widely used in Industry.

The three main objectives of the seminar include:

- Promote networking within the working community.
- Learn and use group problem solving techniques used in industry.
- Apply these new skills to obtain a method of extracting safety knowledge from method statements.

8.5.1 Ice-breaker

Seminars at IIE often follow the traditional presentation or lecturing format with the attendees sitting in rows and facing a presentation screen or overhead projector. This is followed by a question / answer or discussion session.

The intention of the icebreaker exercise is to intentionally take attendees out of their *comfort zone* by changing the room layout in order to create a large open space suitable to performing an ice -breaker exercise.

The attendees, who had naturally grouped with friends and colleagues upon entering the room, were asked to re-arrange themselves so the tallest people were at the back of the room and the smallest at the front. Addition constraints of eyes closed and no verbal communication were aimed to be both physically and mentally confusing- a representation of unfamiliar work scenarios. The same exercise was performed at the end of the seminar but without these additional rules, as skills gained during the session were metaphorically *eye-opening* and a *method of communication*.

Observing the group during the ice-breaker exercise provided an insight on how the attendees would address the main exercise, namely:

- High participation rate, with only a few electing not to join in.
- Tall people gravitating to the back of the room and forming a horizontal line.
- Attendees forming a chain of people approximately the same size.
- Attendees continually moving forward, checking their height against random people they met.

Figure 8.12 shows a representation of the ice-breaker group.

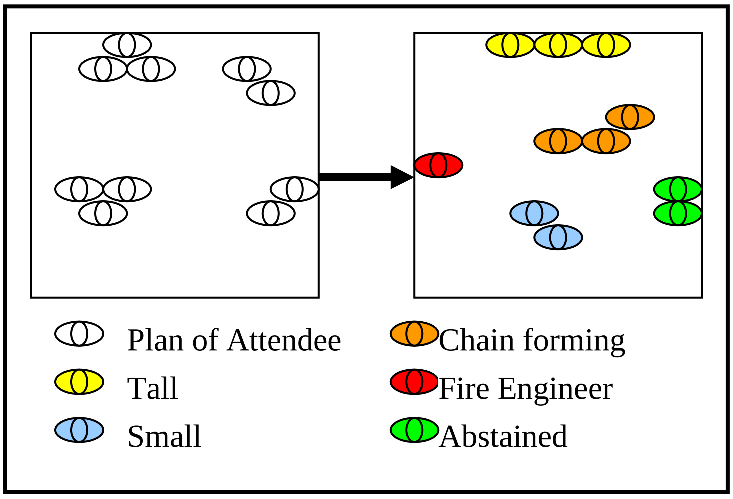


Figure 8.12 Representations of ice-breaker exercise

After a few minutes, the attendees were asked to stop in their current position in the room and assess:

- Whether or not the group had achieved the task.
- The difficulty of the task.
- The different methods employed by individuals.

In addition, an interesting phenomenon happened to one of the attendees. A Fire Engineer (trained in recovering people within smoke filled rooms) traveled sideways to the edge of the room and remained there; this is indicative of methods employed by the fire service to travel along the walls of the room when searching for lost colleagues.

8.5.2 Win-win & Brainstorming Formats

The concept of *Win-Win* was introduced to bring into focus mutual benefits both for the attendees and the presenter (see Table 8.8 Win-Win Goals). Other alternatives include (Covey 2004):

- *Win-Lose* or *Lose-Win* where one party gains advantage over the other.
- *Lose-Lose* where both parties do not achieve their desired goals.
- No Deal where either or both parties decide that they do not wish to be associated with the other party or the venture.

The last point (*No Deal*) was observed in the ice-breaker exercise where some attendees abstained from the challenge.

Reinforcing the benefits of the brain storming exercise as *Win-Win* resulted in all attendees participating in the main exercise.

Attendees	Presenter
Learn industry group solving techniques	Use of seminar time-slot with established reputation and good attendance.
Meet & interact with new people or those in different Departments	Use group as working case study
Use new skills in an actual case study	Examine methods employed by groups & results

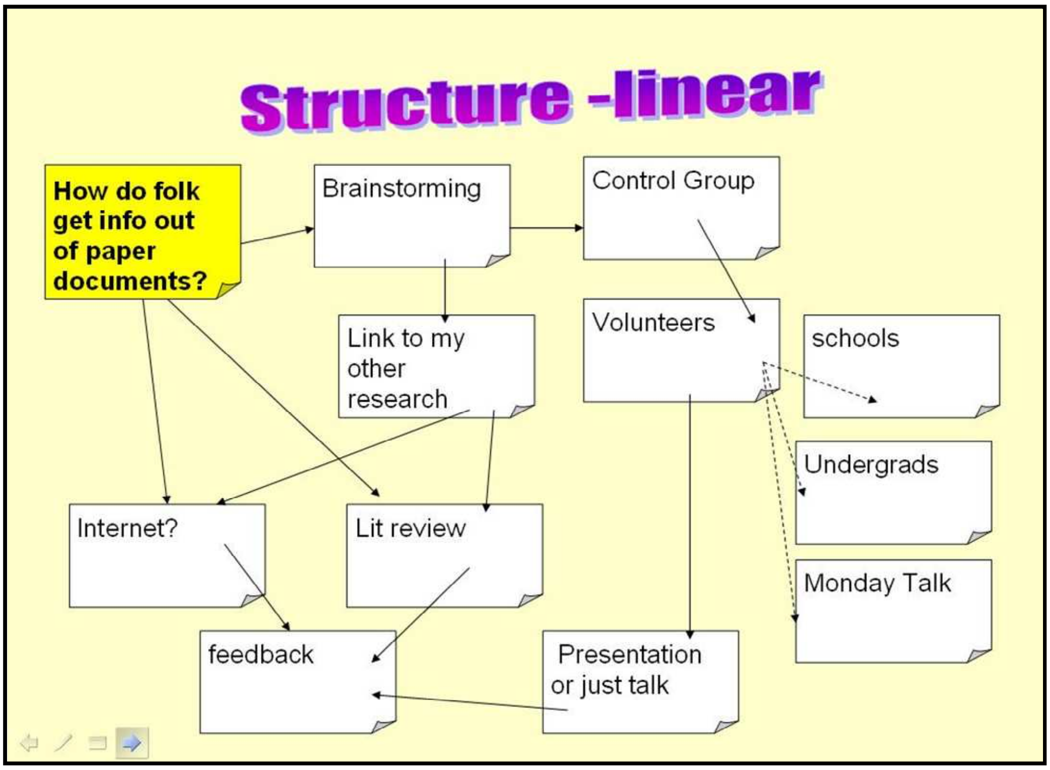
Table 8.8 Win-Win Goals

Three examples of brainstorming formats were presented as linear, spider and input/output.

All formats allow ideas, following from a general theme, to be written down irrespective of whether these are used in any final decision making:

- *Linear* allows re-arranging of the ideas to follow progressive steps.
- *Spider* allows many interconnecting themes to be developed and explored.
- *Output / Input* allows a results oriented approach to be adopted.

These are shown in Figure 8.13, Figure 8.14 and Figure 8.15 respectively.



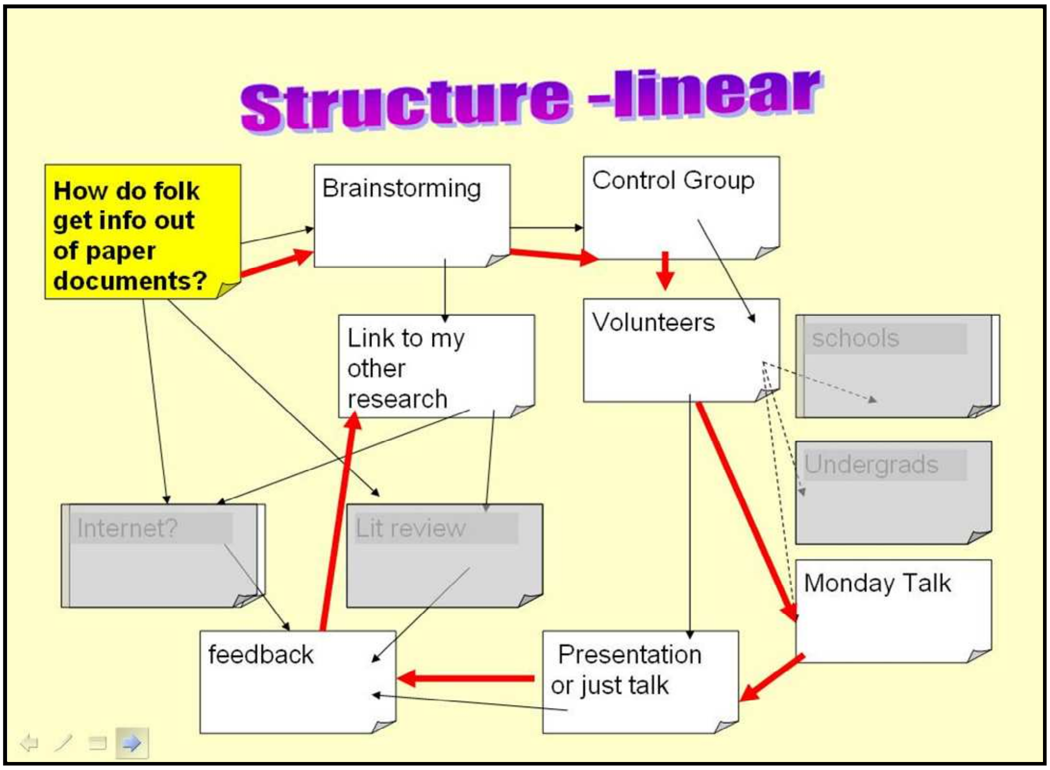
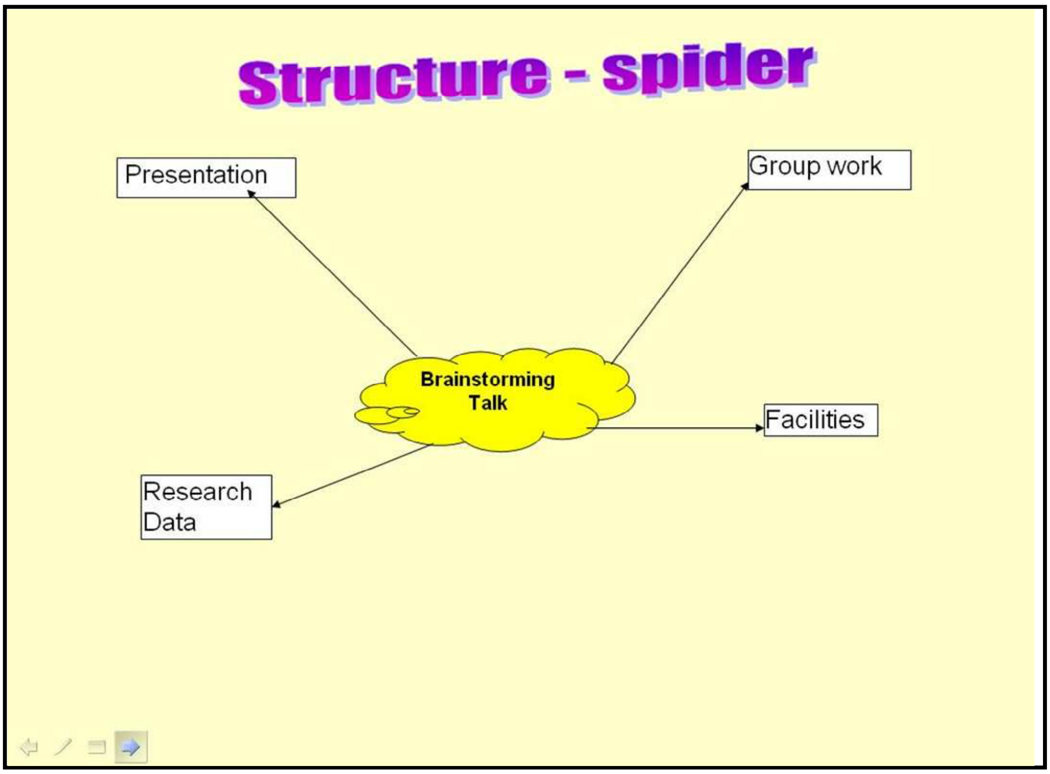


Figure 8.13 Brainstorming - Linear Format



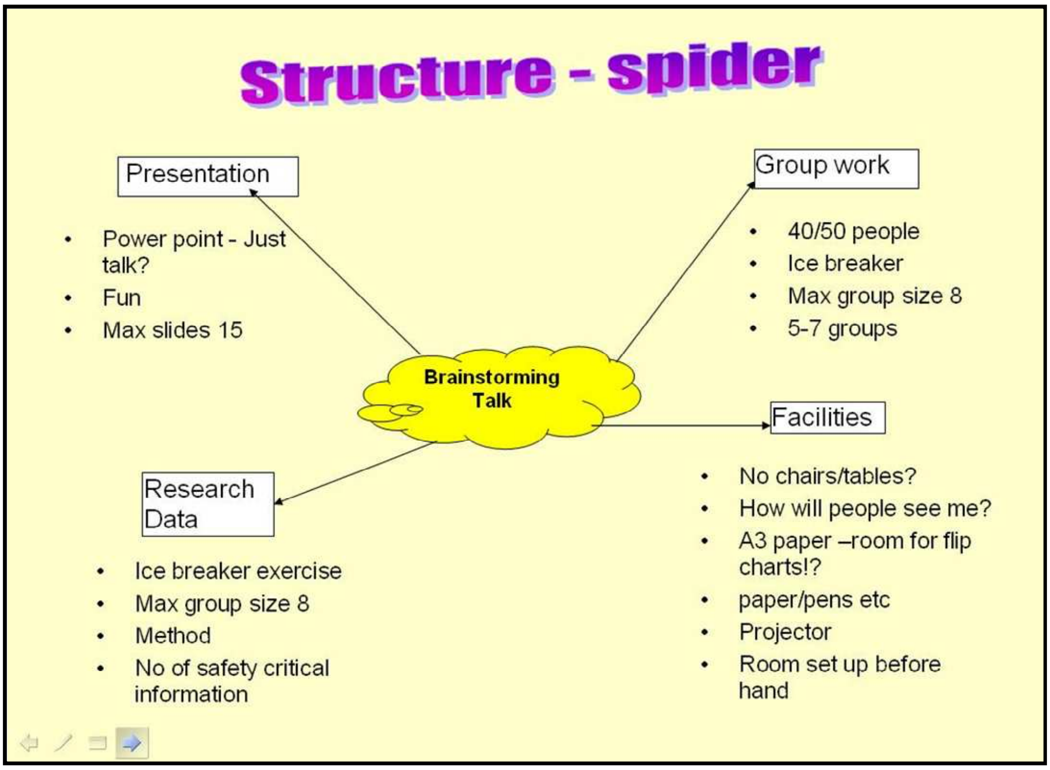


Figure 8.14 Brainstorming – Spider Format

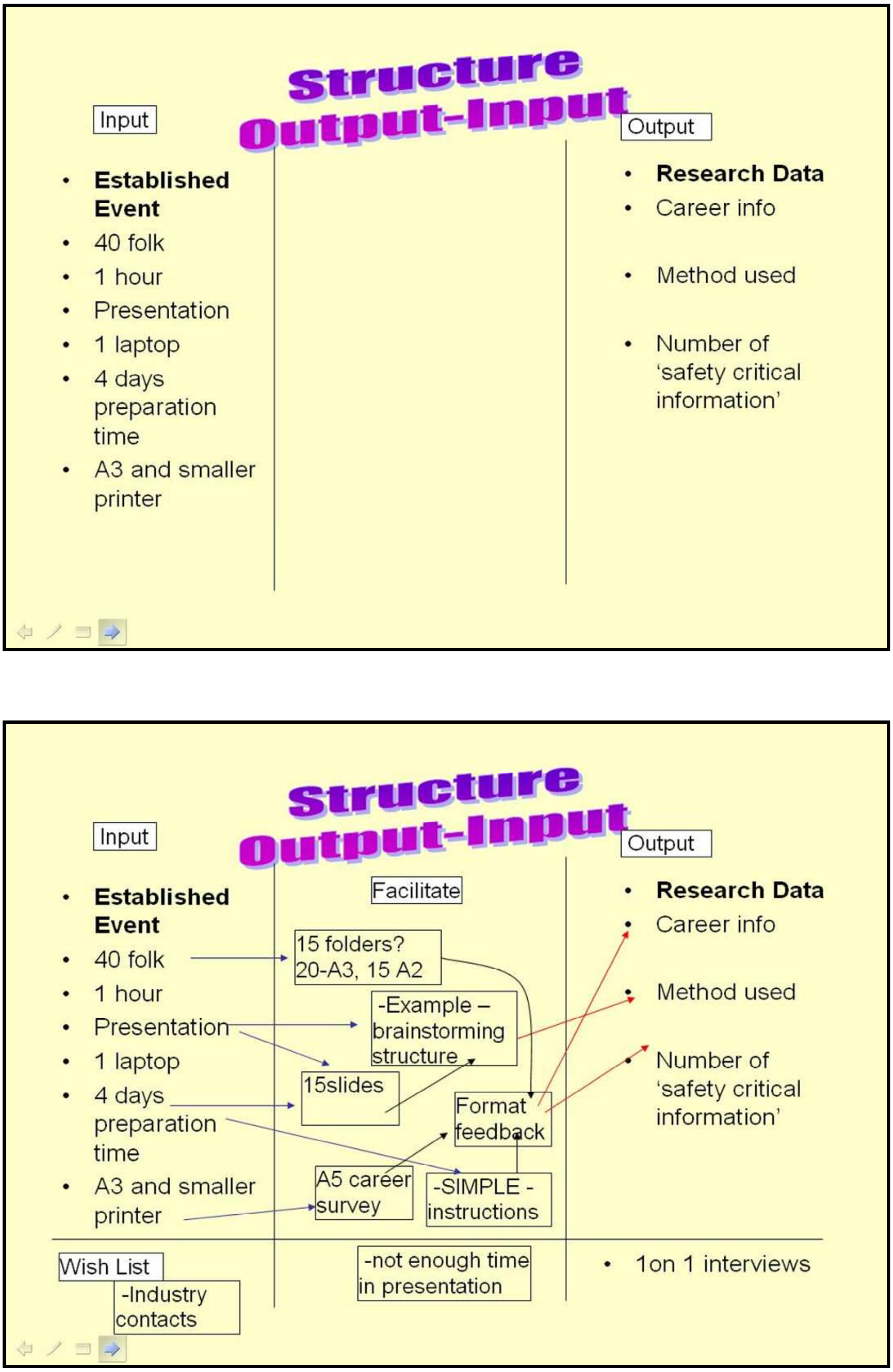


Figure 8.15 Brainstorming -Output/Input Format

8.5.3 The Group Work Task

A brief introduction of the research topic was given to the attendees along with an explanation of documentation such as method statements. The twenty attendees were then split into smaller groups and various resources were made available i.e. paper, pens, highlighters, whiteboard etc.

The task was entitled ***'extract safety related knowledge from paper documents'***. The groups were asked to perform the following in 30 to 40 minute timeslot:

- Brainstorm a method to achieve this goal.
- Use their extraction method on a real method statement.

The groups reported their method of brainstorming at the end of the time limit, along with the individual number of safety information / knowledge items extracted. The brainstorming results are shown in Table 8.9.

Group	Brainstorming Format	Medium	Items extracted
1	**Output / Input** • Led by most experienced member, others acted as scribes • List general areas of hazards • List specific hazards	Flip Chart	**32**
2	**Output/Input** • Produce headings based on the Risk Assessment and COSHH sheets • Explore body of text for more details under these headings • Expand heading list	A3 Paper	**13**
3	**Linear** • Highlight hazards individually • Report and discuss with team • List these statements • Define other useful sections (Risk Assessment & COSHH sheets)	A3 Paper	**25**
4	**Spider** • Reliance on quality assurance checklist • Mine document to produce list of 'key words'	White board	**11**

Table 8.9 Brain-storming Results

			Groups			
			1	2	3	4
Total Number in Group			3	4	6	7
		Male	3	1	6	4
		Female	0	0	0	3
Age Range		<20				
		21-35	1	3	5	5
		36-45	2		1	1
		46-60		1		
		>60				
		Declined				1
Combined Work Experience (Years)		Academia	27	22	30	43
		Consultancy	9	4	8	7
		Contracting	4	3	7	10
		H & S	5	7	25	
		Total	***45***	***36***	***70***	***60***
		Approx. Average	*15*	*9*	*11.5*	*8.5*
Main Discipline	Engineering	Mechanical	1	1	1	3
	Engineering	Civil	1	1		1
	Engineering	Chemical	1	1		
	Engineering	Other			5	1
		None of the Above		1		2

Table 8.10 Demographic of Brain-storming Groups

In addition, a *Career Appraisal Form* is completed as a means of showing the demographic of the group. The results are shown in Table 8.10. This form shows many similarities to the registration questionnaire used in test 2 and is used to compare the two groups and their results; those who use the *Tool* and those who perform brainstorming techniques.

The following photographs (Figure 8.16 to Figure 8.23) show each of the 4 groups during the group task, along with their extraction method.

Figure 8.16 Group 1

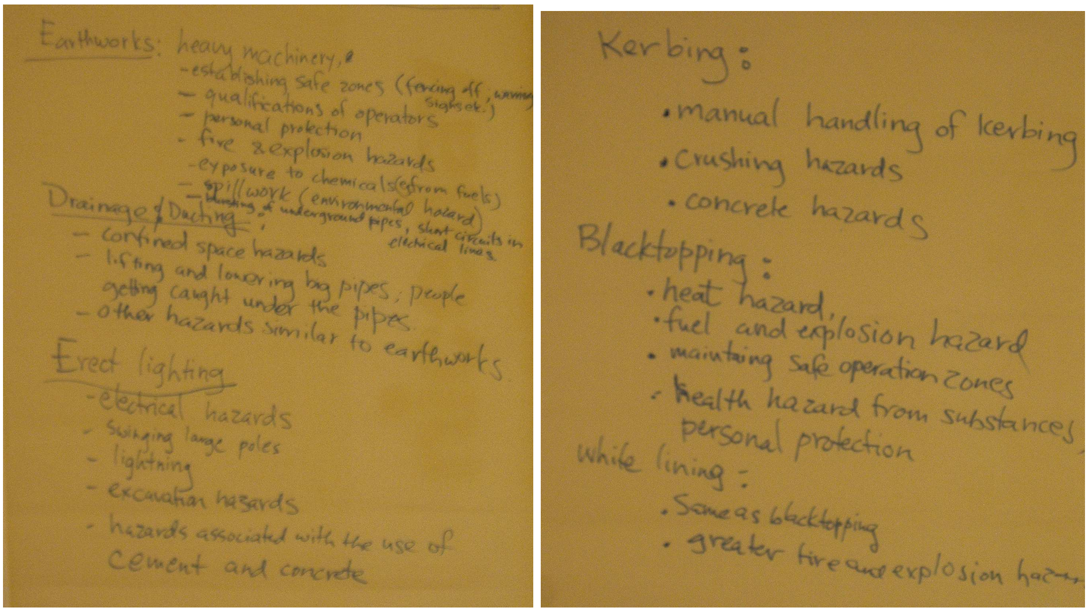


Figure 8.17 Group 1 Extraction Method

Figure 8.18 Group 2

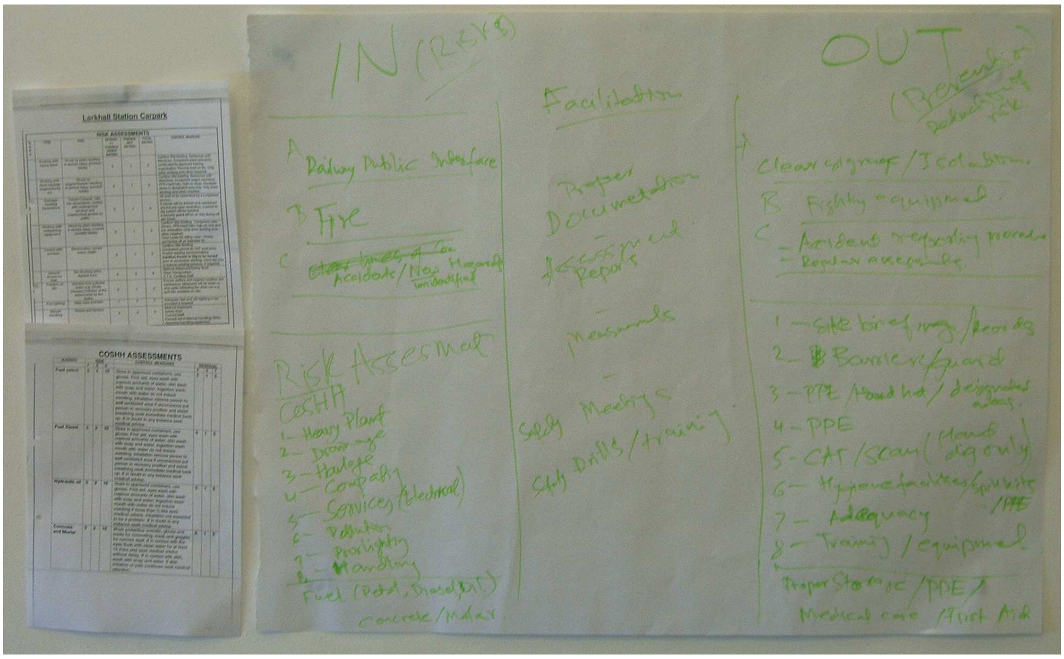


Figure 8.19 Group 2 Extraction Method

Figure 8.20 Group 3

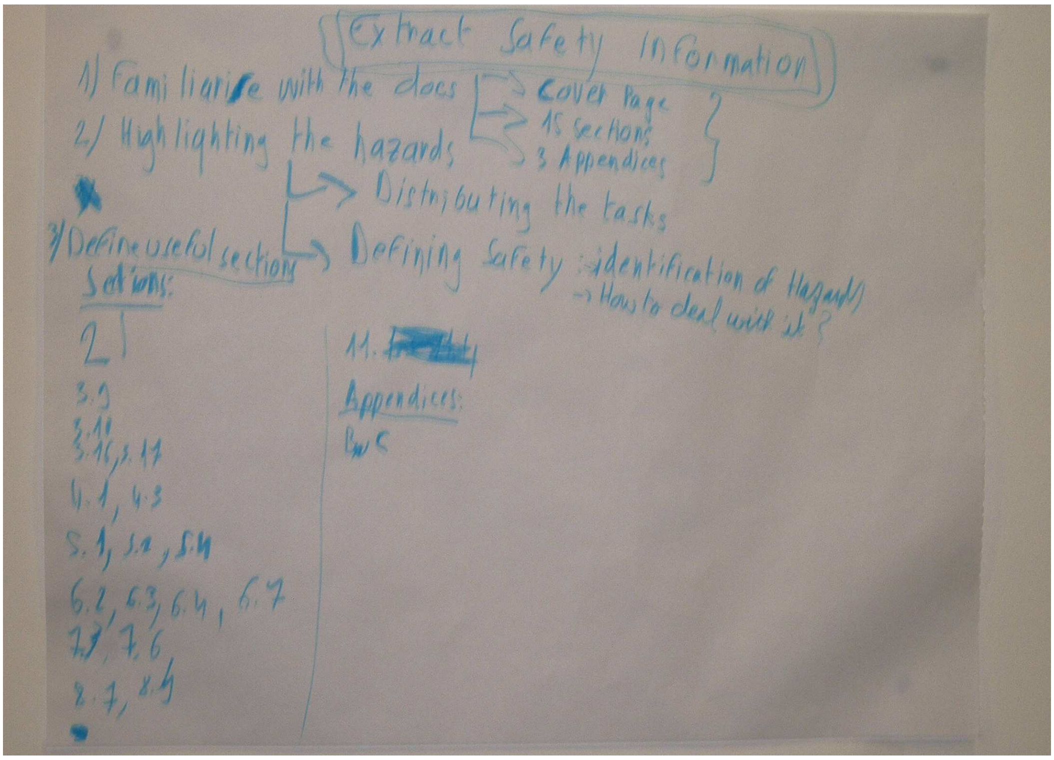


Figure 8.21 Group 3

Figure 8.22 Group 4

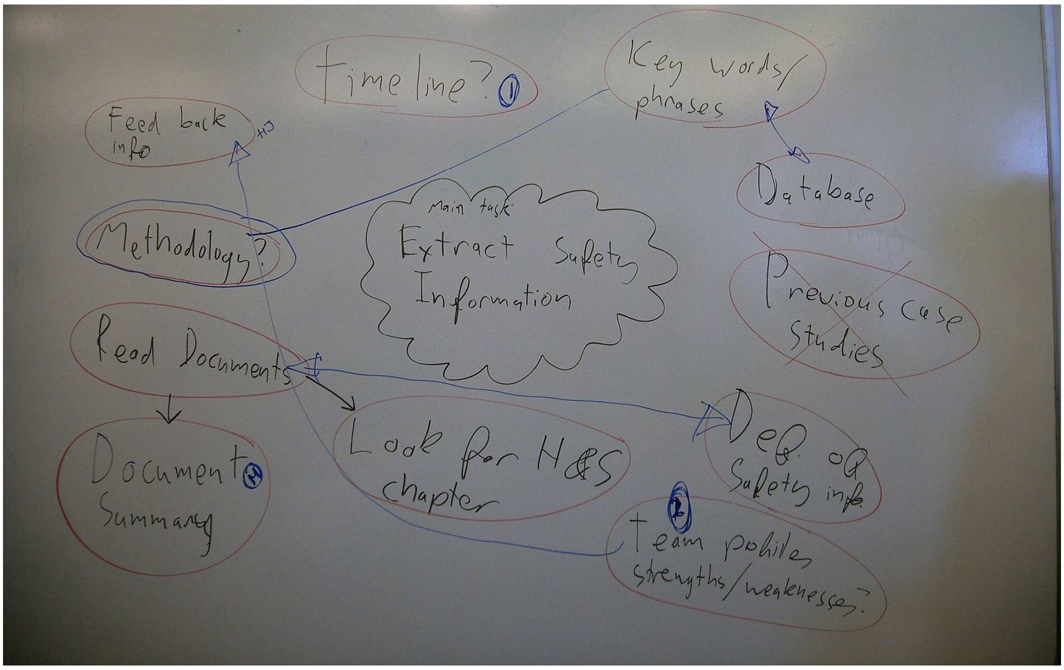


Figure 8.23 Group 4 Extraction Method

Several possible outcomes of the brainstorming exercise relating to work experience are viable, namely:

- No correlation between work experience and number of extracted items. This could signifying past experience has little or no effect in the understanding and extraction of safety knowledge
- A decreasing trend, whereby the number of safety items decreases with increased work experience of the group. This could signify group members are more complacent about the importance of method statement content or rely heavily on competence (i.e. relating either to the capacity of the document originator, or that safety items do not warrant extraction as 'competent' workers would be expected to carry out these duties as part of their normal daily duties).
- An increasing trend in the number of safety items with increased work experience.

The results of the exercise followed this last trend whereby the number of safety items extracted by each of the groups increased with the average work experience (see Table 8.11).

	Group			
	1	**2**	**3**	**4**
Number in Group	3	4	6	7
Work Experience (avg. yrs)	15	9	11.5	8.5
Number of items extracted	32	13	25	11

Table 8.11 Summary of Results

These results are shown graphically in Figure 8.24 in blue, along with red dotted line as a reasonable trend prediction flattening at either end of the distribution.

It must be noted that due to the venue, all groups had predominate work experience in 'academia' in comparison to 'contracting', 'consultancy', and 'health & safety'; no appreciable trend could be assigned to these different types of work experience. None-the-less, Group 3 showed the greatest number of combined years work experience in 'health and safety', yet this did not overly skew the results. This group contained one person from the field of *Mechanical Engineering* and five members from *Fire Engineering* related disciples. Although the 'safety' experience of this group would perhaps be more applicable to evacuation of buildings in service, rather than workers performing construction and maintenance tasks, the group showed their experiences could be applied to different situations.

Lastly, the results showed no trends relating to increased number of group members in the number of safety items extracted; suggesting the old adage that 'quality is better than quantity'.

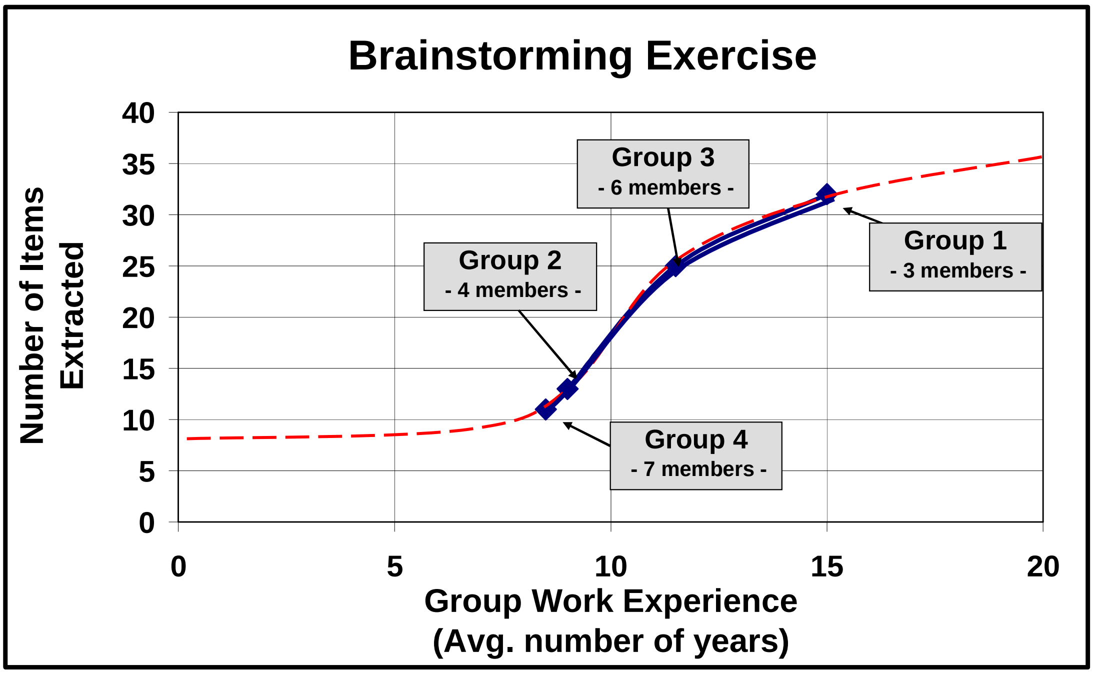


Figure 8.24 Graph showing effect of work experience during the brainstorming exercise

8.5.4 Brainstorming vs. Tool

Figure 8.25 combines and compares the results of the brainstorming exercise (Figure 8.24) with results from test 2 (see also Table 8.5). This graph shows the number of *Tool* solutions (shown in pink) is greater than the number of items identified via brainstorming methods (shown as a blue line) where average work experience is less than ten years,

In addition to these benefits, the *Tool* can also be shown to be good *value-for-money*. Figure 8.26 estimates the cost of the brainstorming workshop aimed to extract safety knowledge from one method statement as around £1,200. This assumes a company 'charge out' rate (or loss of earnings) based on the ages of the brainstorming group i.e. participates aged 21-35 were assumed to be comparable with graduate engineers etc. As a comparison, the cost of extracting the 21 method statements detailed in test 1 (Section 0) would be approximately £25,000, or one third of the overall cost of this research project. Thus the financial benefits of the *Tool* can be seen to compare favorably to group brainstorming techniques, both as data extraction methods for populating the *Case Base* and as a real-time decision support *Tool*.

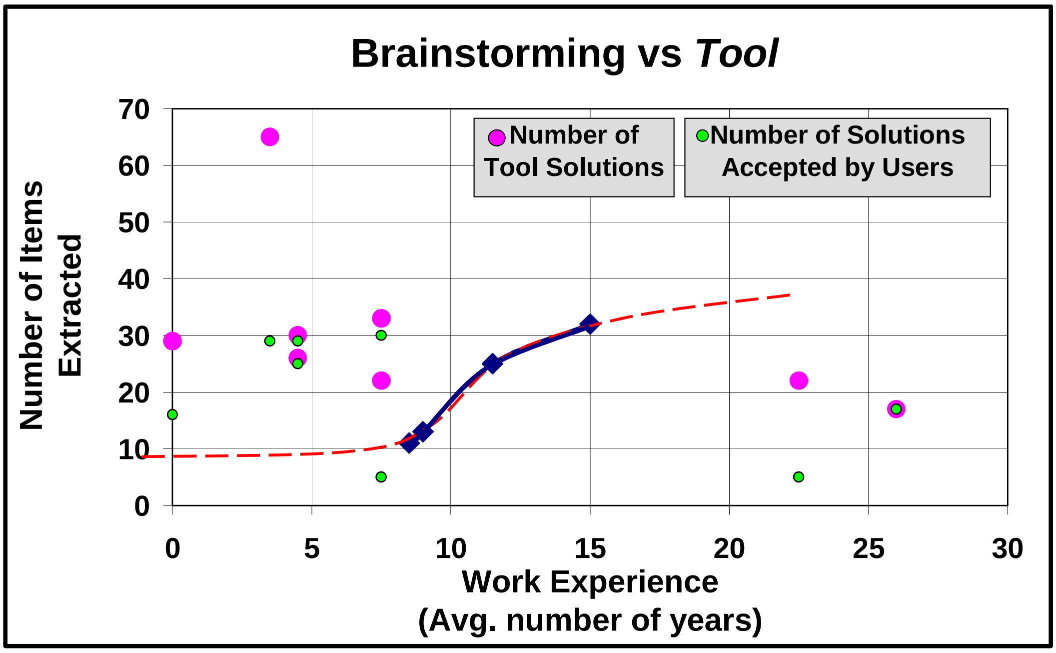


Figure 8.25 Comparison of Brainstorming & Online Survey Results

Participates			
Graduate Engineers	= £30/h	, 14 x £30/h	= 420
Senior Engineers	= £50/h	, 4 x £50/h	= 200
Managing Director	= £60/h	, 1 x £60/h	= 60
Senior Administrator	= £20/h	, 1 x £20/h	= 20
Facilities			
Workshop Facilitator (Plus 5 hours preparation)	= £50/h	, 6 x £50/h	= 180
Room Hire	= £100		= 100
Lunch	= £60		= 60
Miscellaneous items	= £20		= 20
Total	=		**£1,180**

Figure 8.26 Estimated Cost of Brainstorming Workshop

8.5.5 Conclusion

This test demonstrates the following:

- Groups of people, with an average work experience greater than 10 years are better equipped to understand and extract knowledge from paper documents.
- The *Tool* was found to have several benefits over this type of collective group work, namely:
    - o *Tool* users with less than 10 year experience were found to extract a superior number of safety knowledge items in comparison to brainstorming groups with similar work experience.
    - o The cost of the *Tool* was shown to be comparatively good '*value-for-money*'.
- This signifies the *Tool's* potential to provide continual learning in hazard identification and management to relatively new workers, in addition to extracting good safety knowledge from the older working population.

8.6 Test Series Conclusions

The series of tests in this chapter demonstrates the proposed *Tool* as have viable alternative to current methods whereby traditional method statements:

- Do not record 'null' reports.
- Unintentionally hide safety knowledge.
- Reliance upon the interpretation of the reader.
- Allow 'cut & paste techniques' to go unchecked.

To combat these problems, the *Tool* facilitates the capture and re-use of tacit safety knowledge from existing workers and produces clear auditable documents. These documents mirror exiting good practice by providing a communication platform between those *at the sharp end* and those who create safety documentation.

With respect to the *Tool*, this chapter:

- Shows a relatively small *Case Base* can be used to suggest mitigations for new work task situations.
- Proves the prototype version of the *Tool* as functioning and able to make reasonable suggestions of mitigations.
- Proves the web-enabled version of the *Tool* as functioning and able to make reasonable suggestions of mitigations.
- Highlights the quality control and financial benefits of the *Tool*.

In addition, this chapter also highlights the importance of risk perception. Risk perception has been cited as being based on psychology and therefore assurance of complete safety or "zero risk" is practically impossible (The Royal Society 1983; The Royal Society 1992)

The *Tool* quantifies and limits this issue by using a matrix of 9 hazards and 5 harms during the work task classification process, thus limiting the number of risk perception judgements to 45. The results of the tests show users classifying these work tasks based on work experience and competence with those with less work experience appearing to have a range of optimism regarding site dangers. This implies that perhaps these individuals may benefit from collaborative solutions from the *Tool*, rather than insular and personal work experience. The *Tool* therefore demonstrates potential to benchmark company and individual risk perception levels and the effectiveness of targeted training initiatives.

On average 80% of the suggestions by the *Tool* were identified as being correct by volunteers, despite a relatively limited library or *Case Base* of past events. Other findings include:

- Volunteers with more academic work experiences appear to be more optimistic about in the likelihood of site dangers whilst those with contracting / consultancy experience appear more pessimistic.
- Some volunteers rely heavily on the content of the risk assessment and COSHH sheets at the rear of the document, missing important safety issues hidden in prose text. This highlights the need for clear and concise reporting of hazards and improved pro-forma of method statements.
- Those with less than 10 years work experience appear to have a range of optimism of site dangers (*CBR Numbers* are between 58&91). This important finding suggests managers should consider work experience when delegating risk-based tasks to engineers with minimum work experience.

CHAPTER 9: CONCLUSIONS & FURTHER RESEARCH

This thesis has presented the findings of a research project undertaken with the overall aim of understanding and managing hazards within the transportation sector of the construction industry. This chapter, the finale to the thesis, summarises this research and bring together the main conclusions reached. With research of this nature it is important to appreciate that there should not be an end to the investigation of the problems; it is clear there can be much more that can be done to further the cause of protecting the ‘Bobs’ and ‘Andys’ in industry. This chapter will therefore also consider what directions future work in this area should take.

BLANK

9.1 Introduction

This chapter gathers together the conclusions which have been drawn during the course of this research project and is structured in four sections:

- **Section 1 – Introduction**

Brief introduction and chapter structure is given.

- **Section 2 – Conclusions**

The main conclusions of the research are presented. Overall it is concluded that the *Tool* is not only functioning as intended but also has a number of advantages over more traditional methods of safety management.

- **Section 3 – Proposals for Further Work**

Six areas for improvement along with opportunities for future research are highlighted for further discussion:

  - Deployment & Field Testing
  - Parallel Applications
  - Improve Technology
  - Improve Methodology
  - Improve Relationships
  - Multidiscipline / Collaborative Research Opportunities

- **Section 4 – Lessons Learned**

The most important lessons learned include:

- The importance of time management skills.
- The importance of face-to-face contact and strategic networking in user tests.
- Continually testing prototype versions gives an opportunity for improvements to be highlighted in final versions.

9.2 Conclusions

The research presented in this thesis has contributed to the fields of hazard & risk management, and applied artificial intelligence applications:

- The research aims to improve worker safety by providing measures to reduce fatalities and injuries to workers in the field of transportation construction and maintenance tasks. Two hypothetical workers *Bob* and *Andy* are used to demonstrate real-life problems encounters by workers who aim to '*Keep Bob Safe.'*
- This research proposes hazard controls used for a past problem can be applied and / or modified for new work tasks.
- To this end, a fully working decision support *Tool* towards aiding hazard identification in the work place has been developed and tested.
- The *Tool* facilitates the capture and re-use of tacit safety knowledge from existing workers by using a hybrid methodology: *Knowledge Based System* and *Case Based Reasoning*.
    - The development of the '*Think, Plan, Do*' model allowed *Case Based Reasoning (CBR)* research literature to be mapped directly onto the established project lifecycle. Applying this model allowed CBR research within construction and maintenance projects to be identified as the research focus.
    - *Knowledge Based Systems* was identified as a means of facilitating knowledge extraction from corporate memory by concentrating on a '*trial by success*' model. This was achieved by identifying, collecting and transferring knowledge within site documentation relating to non-accident (or null) events within a real infrastructure project.
- The *Tool* produces clear auditable documents or method statements based on specific site conditions, thus providing a communication platform between those *at the sharp end* and those who create safety documentation.

- A new worker group as the target audience – those who act as *Facilitators and Authors of Method Statements* (FAMS). This role challenges and delineates the traditional roles such as *contractor* and *designer* by recognising FAMS as an integral part of work teams irrespective of job title or company structure.

- The *Tool* acts as decision support by suggesting hazard controls that have been used in past similar work task scenarios. This is achieved by identifying similar characteristics in past and current work tasks.

- An innovative method of classifying these characteristics is proposed based on the UK regulatory reporting regulations RIDDOR, thereby linking hazard identification directly to the UK's legal requirements. This is represented as a 9 by 5 matrix whereby those assessing the work task (FAMS) must clarify whether each of the 45 (9 by 5) events are either *likely*, *unlikely* or *not applicable*. This classification process in turn generates a *CBR Number* used to assess the similarity between past and current work tasks.

- Past hazard controls are suggested to the user based on the similarity of the RIDDOR classification. A new method of assessing similarity between stored and new work tasks is presented as the *Range Intersection Algorithm*. This algorithm is linked the Bell curves or distributions of stored hazard controls and is therefore self calibrating. A failsafe algorithm using nearest neighbour technique is used where the *Tool* is queried beyond the boundaries of the stored knowledge.

- The user must accept or decline a list of suggested hazard controls successfully used in past work tasks with a similar classification. Individual hazard controls selected can be searched and selected from the *Case Base* or knowledge library by keyword in addition to new hazard controls uploaded. The hazard controls selected by the user are stored and used to make a more informed suggestions for the next user.

- The *Tool* output is a generated Method Statements with improved layout to allow the effectiveness of hazard identification and management processes to be monitored and assessed. This is achieved by the *site feedback signatory* column whereby the actual hazard controls used on site are recorded.

- In addition to the quality control benefits of the generated method statements the *Tool* has financial benefits in comparison to traditional hazard identification methods such as brainstorming workshops.

- It is proposed that the statistical risks associated with the classification of work tasks and associated hazard management decisions / consequences be collated and analysed by a central specialised risk team. Furthermore it is proposed that this method of splitting risk and hazard management would allow FAMS to concentrate on creating and managing control measures, whilst the statistical risk team can benefit from targeted and centralised risk management training. In short, this method diverges from the established *'jack of all trades and master of none'* persona prevalent in the Industry, with a view to establishing competent workers with diverse skill bases.

- Development testing of the *Tool* allowed the following to be assessed:
    - The weightings used in the generation of the *CBR Number* and the sensitivity of *Tool* suggestions based on these weightings
    - The effect upgrading the RIDDOR classification screen between the prototype and the internet version of the Tool.

- Proof of concept testing involved volunteers using the *Tool* in the prototype and internet form. Both versions were proved to be functioning and able to make reasonable suggestions of hazard controls.
    - The *Tool* compares favourably to a comparative brainstorming workshop for those with less than 10 years average work experience:
    - Significantly higher numbers of knowledge items can be extracted from paper method statements using the *Tool.*

- These results highlighted the issue of risk perception in classifying work tasks based on work experience. This presents an avenue for further study towards investigating perception and worker competence levels based on work experience.

- Lastly, the *Tool* shows potential to provide continual learning in hazard identification / management along with benchmarking company /individual risk perception levels and assessing the effectiveness of targeted training initiatives.

9.3 Proposal for Further Work

This research has shown a means to aid hazard identification and management within Infrastructure Management.

However, the research is by no means all-embracing, and many other areas can be further investigated. Six areas are identified:

- **Deployment & Field Testing**

The *Tool* developed in the thesis is a small-scale *proof of concept* model and full roll-out in an infrastructure project is a long-term goal. Examples of further research include:

  - Developing of deployment strategy and training literature.
  - Assessing the scalability of results with regard to larger *Case Base.*
  - '*Value-for-money'* comparison with safety campaigns and hazard management tools
  - Monitoring user feedback regarding layout and general suggestions for improvements.
  - Statistical comparison of projects using / not using the *Tool*.
  - Investigate link *CBR Number* weightings to real accident studies.
  - Investigate links between risk perception, competence and work experience.

- **Parallel Applications**

Application of the *Tool* to other construction and laboratory settings could be conducted and additional *Case Bases* created. This could enable comparison between industries and weaknesses in hazard identification methods to be identified for future training. An interesting research direction would be the application of the *Tool* to small or medium sized business enterprises (SMEs) or the self-employed.

- **Improve Technology**

It is proposed that later stages of this ongoing research theme will include investigation into small, light hand-held devices that will allow the *Tool* process to become mobile on site. This additional feature will allow site personnel to add (electronically) whether the mitigations proposed were effective or if different methods were required. This would also allow information on how workers' actually carry out the given task to be added to the *Case Base*.

- **Improve Methodology**

Other artificial intelligence or knowledge management methods can be investigated / compared along with other types of documentation and safety communications. Also, retrieval algorithms and investigation into real-life accident distributions could enable improved *Tool* calibration, particularly for hazard weightings.

- **Improve Relationships.**

Academic and industrial collaborations must be actively sought and new projects managed well to enable extended field trials. One suggestion is to approach *Transport Scotland*, created to manage devolved responsibilities for the Scottish Parliament. Contact with such high profile bodies could allow a wider view of industrial practice and give opportunity to be involved with high profile projects, such as the new bridge across the River Forth. Sources of funding in other industry collaborations, such as *Knowledge Transfer Partnerships* (KTPs) could also be investigated and their strategies assessed.

- **Multidiscipline / Collaborative Research Opportunities**

Other avenues for future research could involve collaboration between psychology / education and engineering fields. Some suggested research directions include:

  - The impacts of mental health upon hazard identification and risk management.
  - Risk education to young people and school children, capitalising on the 'Bob the Builder' children's programme. Could Bob & Andy take lessons from this type of media?

- **Improved Relationships –** Seek academic and industrial collaborations for field trials. In addition:
  - Contact with high profile bodies such as *Transport Scotland*, could allow a broader view of industrial practice to be examined.
  - Sources of funding in other industry collaborations, such as *Knowledge Transfer Partnerships* (KTPs) could also be investigated and their strategies assessed.

- **Multidiscipline / Collaborative Research Opportunities**- Other avenues for future research include:
  - The impacts of mental health upon hazard identification and risk management.
  - Risk education to young people and school children, capitalising on the 'Bob the Builder' children's programme

9.4 Lessons Learned

I have gained a vast amount of knowledge throughout the course of this study, both in regard to the research topic and myself. I have found this experience has given me additional confidence by developing communication and presentation skills. These have been further reinforced by presenting my work at seminars and conferences, interacting with people of varying disciplines, and attending appropriate training.

Early identification of the training available through the University of Edinburgh (UoE) enabled a series continuing professional development (CPD) days to be undertaken. A total of 15 CPD days were achieved in the early stages of research project (see ***Appendix I*** for details).

The research was a far greater challenge than I had originally anticipated, especially the development of the *Tool*, both in the prototype and web-enabled versions. This required steep learning curves in server query language (SQL), *ColdFusion* command language and dynamic web-page design. Although not pleasant at the time, these experiences acted as a reality check as to what was achievable within the timescale.

The most important lessons I have learned from undertaking this research are:

- Time management skills are paramount and realistic time scales / planning are required.
- Using the prototype for validation testing enabled the mechanisms to be well-defined before transposition to the web-enabled version.
- Consider the resources available to you, whether it is materials, software, or people. The web-enabled version of the *Tool* would not have come to fruition without the IT support team.
- Face-to-face contact and strategic networking is invaluable. This is demonstrated by the lack of response when testing the online version of the *Tool* when very few people elected to take part.

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