

## CONTENTS

|          |  |    |
|----------|--|----|
|          | ABBREVIATIONS                                | 15 |
|          | GLOSSARY                                     | 17 |
| <b>1</b> | <b>INTRODUCTION</b>                          |    |
| 1.1      | BACKGROUND                                   | 19 |
| 1.2      | RESEARCH PROPOSAL                            | 20 |
| 1.3      | QRA STEPS                                    | 21 |
| 1.4      | MOTIVATION OF THE RESEARCH                   | 22 |
| 1.5      | RESEARCH OBJECTIVES AND SCOPE                | 24 |
| 1.6      | STRUCTURE OF THE REPORT                      | 24 |
| <b>2</b> | <b>LITERATURE REVIEW</b>                     |    |
| 2.1      | OVERVIEW OF RISK ASSESSMENT                  | 27 |
| 2.2      | QRA METHODOLOGY                              | 27 |
| 2.3      | QRA TYPICAL FLOW CHART                       | 29 |
| 2.4      | HAZARD IDENTIFICATION TECHNIQUES             | 30 |
| 2.5      | QUALITATIVE & QUANTITATIVE TOOLS             | 34 |
| 2.6      | CONSEQUENCE MODELLING                        | 34 |
| 2.7      | QRA SOFT WARES                               | 37 |
| 2.8      | FREQUENCY ANALYSIS                           | 37 |
| 2.9      | HISTORICAL DATA BASES ANALYSIS               | 45 |
| 2.10     | RISK RESULTS                                 | 51 |
| 2.11     | SUMMARY                                      | 52 |
| <b>3</b> | <b>RESEARCH METHODOLOGY</b>                  |    |
| 3.1      | INTRODUCTION                                 | 53 |
| 3.2      | STEPS IN METHODOLOGY                         | 53 |
| 3.3      | HAZID STUDY                                  | 55 |
| 3.4      | HAZOP STUDY                                  | 57 |
| 3.5      | LIMITATIONS OF HAZID/HAZOP                   | 62 |
| 3.6      | CONSEQUENCE ANALYSIS                         | 64 |
| 3.7      | SOFT WARES USED                              | 68 |
| 3.8      | INPUT DATA                                   | 69 |
| 3.9      | FREQUENCY ANALYSIS                           | 69 |
| 3.10     | VULNERABILITY CRITERIA                       | 72 |
| <b>4</b> | <b>MODELLING &amp; ANALYTICAL ASSESSMENT</b> |    |

|          |   |     |
|----------|---|-----|
| 4.1      | INTRODUCTION                                | 74  |
| 4.2      | CASE STUDY 1 LPG STORAGE                    | 75  |
| 4.3      | CASE STUDY 2 GASEOUS H <sub>2</sub> STORAGE | 81  |
| 4.4      | CASE STUDY 3 LPG STORAGE                    | 84  |
| 4.5      | CASE STUDY 4 LIQUID H <sub>2</sub> STORAGE  | 88  |
| 4.6      | CASE STUDY 5 LPG STORAGE & DISTRIBUTION     | 96  |
| 4.7      | CASE STUDY 6 NATURAL GAS STATION            | 103 |
| 4.8      | CASE STUDY 7 NATURAL GAS MANIFOLD           | 110 |
| 4.9      | FREQUENCY ESTIMATION                        | 113 |
| 4.10     | PARTS COUNT APPROACH METHOD                 | 114 |
| 4.11     | BAYESIAN NETWORK METHOD                     | 119 |
| 4.12     | PARTS COUNT COMBINED WITH BAYESIAN          | 128 |
| <b>5</b> | <b>RESULTS AND DISCUSSION</b>               |     |
| 5.1      | RESULTS                                     | 129 |
| 5.2      | DISCUSSION                                  | 132 |
| <b>6</b> | <b>CONCLUSION</b>                           |     |
| 6.1      | GENERAL                                     | 134 |
| 6.2      | OIL AND GAS INDUSTRY HSE PERFORMANCE        | 135 |
| 6.3      | CONCLUSION                                  | 138 |
| 6.4      | FUTURE WORK                                 | 139 |
| <b>7</b> | <b>REFERENCES</b>                           |     |
|          | REFERENCES                                  | 140 |
| <b>8</b> | <b>APPENDIX</b>                             |     |
| 8.1      | HAZID CHECKLIST                             | 150 |
| 8.2      | HAZOP SPREAD SHEET                          | 154 |
| 8.3      | NG FLOW DIAGRAM                             | 156 |
| 8.4      | FAULT TREE ANALYSIS                         | 157 |
| 8.5      | EVENT TREE ANALYSIS                         | 160 |
| 8.6      | GENERIC FREQUENCY OGP                       | 162 |
| 8.7      | GENERIC FREQUENCY PCAM                      | 164 |
| 8.8      | PLANT SPECIFIC DATA                         | 166 |
| 8.9      | SAMPLE CALCULATION                          | 167 |
| 8.10     | BAYESIAN NETWORK                            | 168 |
| 8.11     | BAYESIAN SPREAD SHEETS                      | 170 |
| 8.12     | PCAM AND BAYESIAN                           | 175 |
| 8.13     | PAPERS PUBLISHED                            | 176 |
| 8.14     | ABOUT THE AUTHOR                            | 177 |