Preface xvii

About the Author xxiii

About the Website xxv

PART I

An Introduction to Risk Assessment – Its Uses, Processes, Approaches, Benefits and Challenges

CHAPTER 1

The Context and Uses of Risk Assessment 3

1.1 Risk Assessment Examples 3

1.1.1 Everyday Examples of Risk Management 4

1.1.2 Prominent Risk Management Failures 5

1.2 General Challenges in Decision-Making Processes 7

1.2.1 Balancing Intuition with Rationality 7

1.2.2 The Presence of Biases 9

1.3 Key Drivers of the Need for Formalised Risk Assessment in Business Contexts 14

1.3.1 Complexity 14

1.3.2 Scale 15

1.3.3 Authority and Responsibility to Identify and Execute Risk-Response Measures 16

1.3.4 Corporate Governance Guidelines 16

1.3.5 General Organisational Effectiveness and the Creation of Competitive Advantage 18

1.3.6 Quantification Requirements 18

1.3.7 Reflecting Risk Tolerances in Decisions and in Business Design 19

1.4 The Objectives and Uses of General Risk Assessment 19

1.4.1 Adapt and Improve the Design and Structure of Plans and Projects 20

1.4.2 Achieve Optimal Risk Mitigation within Revised Plans 20

1.4.3 Evaluate Projects, Set Targets and Reflect Risk Tolerances in Decision-Making 21
CONTENTS

1.4.4 Manage Projects Effectively 21
1.4.5 Construct, Select and Optimise Business and Project Portfolios 22
1.4.6 Support the Creation of Strategic Options and Corporate Planning 25

CHAPTER 2
Key Stages of the General Risk Assessment Process 29
2.1 Overview of the Process Stages 29
2.2 Process Iterations 30
2.3 Risk Identification 32
   2.3.1 The Importance of a Robust Risk Identification Step 32
   2.3.2 Bringing Structure into the Process 32
   2.3.3 Distinguishing Variability from Decision Risks 34
   2.3.4 Distinguishing Business Issues from Risks 34
   2.3.5 Risk Identification in Quantitative Approaches: Additional Considerations 35
2.4 Risk Mapping 35
   2.4.1 Key Objectives 35
   2.4.2 Challenges 35
2.5 Risk Prioritisation and Its Potential Criteria 36
   2.5.1 Inclusion/Exclusion 36
   2.5.2 Communications Focus 37
   2.5.3 Commonality and Comparison 38
   2.5.4 Modelling Reasons 39
   2.5.5 General Size of Risks, Their Impact and Likelihood 39
   2.5.6 Influence: Mitigation and Response Measures, and Management Actions 40
   2.5.7 Optimising Resource Deployment and Implementation Constraints 41
2.6 Risk Response: Mitigation and Exploitation 42
   2.6.1 Reduction 42
   2.6.2 Exploitation 42
   2.6.3 Transfer 42
   2.6.4 Research and Information Gathering 43
   2.6.5 Diversification 43
2.7 Project Management and Monitoring 44

CHAPTER 3
Approaches to Risk Assessment and Quantification 45
3.1 Informal or Intuitive Approaches 46
3.2 Risk Registers without Aggregation 46
   3.2.1 Qualitative Approaches 46
   3.2.2 Quantitative Approaches 48
3.3 Risk Register with Aggregation (Quantitative) 50
   3.3.1 The Benefits of Aggregation 50
   3.3.2 Aggregation of Static Values 51
   3.3.3 Aggregation of Risk-Driven Occurrences and Their Impacts 52
   3.3.4 Requirements and Differences to Non-Aggregation Approaches 54
Contents

3.4 Full Risk Modelling 56
  3.4.1 Quantitative Aggregate Risk Registers as a First Step to Full Models 56

CHAPTER 4

Full Integrated Risk Modelling: Decision-Support Benefits 59
  4.1 Key Characteristics of Full Models 59
  4.2 Overview of the Benefits of Full Risk Modelling 61
  4.3 Creating More Accurate and Realistic Models 62
    4.3.1 Reality is Uncertain: Models Should Reflect This 62
    4.3.2 Structured Process to Include All Relevant Factors 63
    4.3.3 Unambiguous Approach to Capturing Event Risks 63
    4.3.4 Inclusion of Risk Mitigation and Response Factors 66
    4.3.5 Simultaneous Occurrence of Uncertainties and Risks 66
    4.3.6 Assessing Outcomes in Non-Linear Situations 67
    4.3.7 Reflecting Operational Flexibility and Real Options 67
    4.3.8 Assessing Outcomes with Other Complex Dependencies 71
    4.3.9 Capturing Correlations, Partial Dependencies and Common Causalities 73
  4.4 Using the Range of Possible Outcomes to Enhance Decision-Making 74
    4.4.1 Avoiding “The Trap of the Most Likely” or Structural Biases 76
    4.4.2 Finding the Likelihood of Achieving a Base Case 78
    4.4.3 Economic Evaluation and Reflecting Risk Tolerances 82
    4.4.4 Setting Contingencies, Targets and Objectives 83
  4.5 Supporting Transparent Assumptions and Reducing Biases 84
    4.5.1 Using Base Cases that are Separate to Risk Distributions 85
    4.5.2 General Reduction in Biases 85
    4.5.3 Reinforcing Shared Accountability 85
  4.6 Facilitating Group Work and Communication 86
    4.6.1 A Framework for Rigorous and Precise Work 86
    4.6.2 Reconcile Some Conflicting Views 86

CHAPTER 5

Organisational Challenges Relating to Risk Modelling 87
  5.1 “We Are Doing It Already” 87
    5.1.1 “Our ERM Department Deals with Those Issues” 88
    5.1.2 “Everybody Should Just Do Their Job Anyway!” 88
    5.1.3 “We Have Risk Registers for All Major Projects” 89
    5.1.4 “We Run Sensitivities and Scenarios: Why Do More?” 89
  5.2 “We Already Tried It, and It Showed Unrealistic Results” 89
    5.2.1 “All Cases Were Profitable” 90
    5.2.2 “The Range of Outcomes Was Too Narrow” 90
  5.3 “The Models Will Not Be Useful!” 91
    5.3.1 “We Should Avoid Complicated Black Boxes!” 91
    5.3.2 “All Models Are Wrong, Especially Risk Models!” 91
    5.3.3 “Can You Prove that It Even Works?” 92
CONTENTS

5.3.4 “Why Bother to Plan Things that Might Not Even Happen?” 93
5.4 Working Effectively with Enhanced Processes and Procedures 93
  5.4.1 Selecting the Right Projects, Approach and Decision Stage 93
  5.4.2 Managing Participant Expectations 95
  5.4.3 Standardisation of Processes and Models 95
5.5 Management Processes, Culture and Change Management 96
  5.5.1 Integration with Decision Processes 96
  5.5.2 Ensuring Alignment of Risk Assessment and Modelling Processes 97
  5.5.3 Implement from the Bottom Up or the Top Down? 98
  5.5.4 Encouraging Issues to Be Escalated: Don’t Shoot the Messenger! 99
  5.5.5 Sharing Accountability for Poor Decisions 99
  5.5.6 Ensuring Alignment with Incentives and Incentive Systems 100
  5.5.7 Allocation and Ownership of Contingency Budgets 101
  5.5.8 Developing Risk Cultures and Other Change Management Challenges 102

PART II

The Design of Risk Models – Principles, Processes and Methodology

CHAPTER 6

Principles of Simulation Methods 107

6.1 Core Aspects of Simulation: A Descriptive Example 107
  6.1.1 The Combinatorial Effects of Multiple Inputs and Distribution of Outputs 107
  6.1.2 Using Simulation to Sample Many Diverse Scenarios 110
6.2 Simulation as a Risk Modelling Tool 112
  6.2.1 Distributions of Input Values and Their Role 113
  6.2.2 The Effect of Dependencies between Inputs 114
  6.2.3 Key Questions Addressable using Risk-Based Simulation 114
  6.2.4 Random Numbers and the Required Number of Recalculations or Iterations 115
6.3 Sensitivity and Scenario Analysis: Relationship to Simulation 116
  6.3.1 Sensitivity Analysis 116
  6.3.2 Scenario Analysis 119
  6.3.3 Simulation using DataTables 121
  6.3.4 GoalSeek 121
6.4 Optimisation Analysis and Modelling: Relationship to Simulation 122
  6.4.1 Uncertainty versus Choice 122
  6.4.2 Optimisation in the Presence of Risk and Uncertainty 129
  6.4.3 Modelling Aspects of Optimisation Situations 131
6.5 Analytic and Other Numerical Methods 133
  6.5.1 Analytic Methods and Closed-Form Solutions 133
  6.5.2 Combining Simulation Methods with Exact Solutions 135
6.6 The Applicability of Simulation Methods 135
CHAPTER 7
Core Principles of Risk Model Design 137
7.1 Model Planning and Communication 138
  7.1.1 Decision-Support Role 138
  7.1.2 Planning the Approach and Communicating the Output 138
  7.1.3 Using Switches to Control the Cases and Scenarios 139
  7.1.4 Showing the Effect of Decisions versus Those of Uncertainties 140
  7.1.5 Keeping It Simple, but not Simplistic: New Insights versus Modelling Errors 144
7.2 Sensitivity-Driven Thinking as a Model Design Tool 146
  7.2.1 Enhancing Sensitivity Processes for Risk Modelling 150
  7.2.2 Creating Dynamic Formulae 151
  7.2.3 Example: Time Shifting for Partial Periods 153
7.3 Risk Mapping and Process Alignment 154
  7.3.1 The Nature of Risks and Their Impacts 155
  7.3.2 Creating Alignment between Modelling and the General Risk Assessment Process 156
  7.3.3 Results Interpretation within the Context of Process Stages 157
7.4 General Dependency Relationships 158
  7.4.1 Example: Commonality of Drivers of Variability 159
  7.4.2 Example: Scenario-Driven Variability 160
  7.4.3 Example: Category-Driven Variability 162
  7.4.4 Example: Fading Impacts 168
  7.4.5 Example: Partial Impact Aggregation by Category in a Risk Register 170
  7.4.6 Example: More Complex Impacts within a Category 171
7.5 Working with Existing Models 173
  7.5.1 Ensuring an Appropriate Risk Identification and Mapping 173
  7.5.2 Existing Models using Manual Processes or Embedded Procedures 174
  7.5.3 Controlling a Model Switch with a Macro at the Start and End of a Simulation 175
  7.5.4 Automatically Removing Data Filters at the Start of a Simulation 176
  7.5.5 Models with DataTables 178

CHAPTER 8
Measuring Risk using Statistics of Distributions 181
8.1 Defining Risk More Precisely 181
  8.1.1 General Definition 181
  8.1.2 Context-Specific Risk Measurement 181
  8.1.3 Distinguishing Risk, Variability and Uncertainty 182
  8.1.4 The Use of Statistical Measures 183
8.2 Random Processes and Their Visual Representation 184
  8.2.1 Density and Cumulative Forms 184
  8.2.2 Discrete, Continuous and Compound Processes 186
8.3 Percentiles 187
  8.3.1 Ascending and Descending Percentiles 188
  8.3.2 Inversion and Random Sampling 189
8.4 Measures of the Central Point 190
8.4.1 Mode 190
8.4.2 Mean or Average 191
8.4.3 Median 193
8.4.4 Comparisons of Mode, Mean and Median 193
8.5 Measures of Range 194
8.5.1 Worst and Best Cases, and Difference between Percentiles 194
8.5.2 Standard Deviation 195
8.6 Skewness and Non-Symmetry 199
8.6.1 The Effect and Importance of Non-Symmetry 201
8.6.2 Sources of Non-Symmetry 202
8.7 Other Measures of Risk 203
8.7.1 Kurtosis 204
8.7.2 Semi-Deviation 205
8.7.3 Tail Losses, Expected Tail Losses and Value-at-Risk 206
8.8 Measuring Dependencies 207
8.8.1 Joint Occurrence 207
8.8.2 Correlation Coefficients 209
8.8.3 Correlation Matrices 210
8.8.4 Scatter Plots (X–Y Charts) 212
8.8.5 Classical and Bespoke Tornado Diagrams 212

CHAPTER 9
The Selection of Distributions for Use in Risk Models 215
9.1 Descriptions of Individual Distributions 215
9.1.1 The Uniform Continuous Distribution 216
9.1.2 The Bernoulli Distribution 218
9.1.3 The Binomial Distribution 219
9.1.4 The Triangular Distribution 220
9.1.5 The Normal Distribution 222
9.1.6 The Lognormal Distribution 226
9.1.7 The Beta and Beta General Distributions 232
9.1.8 The PERT Distribution 234
9.1.9 The Poisson Distribution 236
9.1.10 The Geometric Distribution 238
9.1.11 The Negative Binomial Distribution 240
9.1.12 The Exponential Distribution 241
9.1.13 The Weibull Distribution 242
9.1.14 The Gamma Distribution 242
9.1.15 The General Discrete Distribution 244
9.1.16 The Integer Uniform Distribution 245
9.1.17 The Hypergeometric Distribution 245
9.1.18 The Pareto Distribution 246
9.1.19 The Extreme Value Distributions 246
9.1.20 The Logistic Distribution 250
9.1.21 The Log-Logistic Distribution 251
9.1.22 The Student (t), Chi-Squared and F-Distributions 252
9.2 A Framework for Distribution Selection and Use 256
  9.2.1 Scientific and Conceptual Approaches 257
  9.2.2 Data-Driven Approaches 258
  9.2.3 Industry Standards 259
  9.2.4 Pragmatic Approaches: Distributions, Parameters and Expert Input 259

9.3 Approximation of Distributions with Each Other 263
  9.3.1 Modelling Choices 263
  9.3.2 Distribution Comparison and Parameter Matching 265
  9.3.3 Some Potential Pitfalls Associated with Distribution Approximations 267

CHAPTER 10
Creating Samples from Distributions 273
  10.1 Readily Available Inverse Functions 274
    10.1.1 Functions Provided Directly in Excel 274
    10.1.2 Functions Whose Formulae Can Easily Be Created 276
  10.2 Functions Requiring Lookup and Search Methods 277
    10.2.1 Lookup Tables 277
    10.2.2 Search Methods 278
  10.3 Comparing Calculated Samples with Those in @RISK 279
  10.4 Creating User-Defined Inverse Functions 280
    10.4.1 Normal Distribution 281
    10.4.2 Beta and Beta General Distributions 282
    10.4.3 Binomial Distribution 283
    10.4.4 Lognormal Distribution 283
    10.4.5 Bernoulli Distribution 284
    10.4.6 Triangular Distribution 284
    10.4.7 PERT Distribution 284
    10.4.8 Geometric Distribution 285
    10.4.9 Weibull Distribution 285
    10.4.10 Weibull Distribution with Percentile Inputs 285
    10.4.11 Poisson Distribution 285
    10.4.12 General Discrete Distribution 287
  10.5 Other Generalisations 287
    10.5.1 Iterative Methods using Specific Numerical Techniques 287
    10.5.2 Creating an Add-In 289

CHAPTER 11
Modelling Dependencies between Sources of Risk 291
  11.1 Parameter Dependency and Partial Causality 291
    11.1.1 Example: Conditional Probabilities 293
    11.1.2 Example: Common Risk Drivers 293
    11.1.3 Example: Category Risk Drivers 294
    11.1.4 Example: Phased Projects 294
    11.1.5 Example: Economic Scenarios for the Price of a Base Commodity 295
    11.1.6 Example: Prices of a Derivative Product 296
    11.1.7 Example: Prices of Several Derivative Products 297
## CONTENTS

11.1.8 Example: Oil Price and Rig Cost 297  
11.1.9 Example: Competitors and Market Share 298  
11.1.10 Example: Resampling or Data-Structure-Driven Dependence 299  
11.1.11 Implied Correlations within Parameter Dependency Relationships 302  

11.2 Dependencies between Sampling Processes 302  
11.2.1 Correlated Sampling 303  
11.2.2 Copulas 304  
11.2.3 Comparison and Selection of Parameter-Dependency and Sampling Relationships 306  
11.2.4 Creating Correlated Samples in Excel using Cholesky Factorisation 309  
11.2.5 Working with Valid Correlation Matrices 313  
11.2.6 Correlation of Time Series 315  

11.3 Dependencies within Time Series 316  
11.3.1 Geometric Brownian Motion 317  
11.3.2 Mean-Reversion Models 319  
11.3.3 Moving Average Models 321  
11.3.4 Autoregressive Models 321  
11.3.5 Co-Directional (Integrated) Processes 323  
11.3.6 Random State Switching and Markov Chains 323  

### PART III

**Getting Started with Simulation in Practice**

**CHAPTER 12**

**Using Excel/VBA for Simulation Modelling** 327  
12.1 Description of Example Model and Uncertainty Ranges 327  
12.2 Creating and Running a Simulation: Core Steps 328  
12.2.1 Using Random Values 328  
12.2.2 Using a Macro to Perform Repeated Recalculations and Store the Results 330  
12.2.3 Working with the VBE and Inserting a VBA Code Module 330  
12.2.4 Automating Model Recalculation 331  
12.2.5 Creating a Loop to Recalculate Many Times 331  
12.2.6 Adding Comments, Indentation and Line Breaks 332  
12.2.7 Defining Outputs, Storing Results, Named Ranges and Assignment Statements 333  
12.2.8 Running the Simulation 334  
12.3 Basic Results Analysis 335  
12.3.1 Building Key Statistical Measures and Graphs of the Results 335  
12.3.2 Clearing Previous Results 336  
12.3.3 Modularising the Code 338  
12.3.4 Timing and Progress Monitoring 339  
12.4 Other Simple Features 339  
12.4.1 Taking Inputs from the User at Run Time 339  
12.4.2 Storing Multiple Outputs 340
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 Generalising the Core Capabilities</td>
<td>340</td>
</tr>
<tr>
<td>12.5.1 Using Selected VBA Best Practices</td>
<td>340</td>
</tr>
<tr>
<td>12.5.2 Improving Speed</td>
<td>341</td>
</tr>
<tr>
<td>12.5.3 Creating User-Defined Functions</td>
<td>342</td>
</tr>
<tr>
<td>12.6 Optimising Model Structure and Layout</td>
<td>343</td>
</tr>
<tr>
<td>12.6.1 Simulation Control Sheet</td>
<td>343</td>
</tr>
<tr>
<td>12.6.2 Output Links Sheet</td>
<td>344</td>
</tr>
<tr>
<td>12.6.3 Results Sheets</td>
<td>344</td>
</tr>
<tr>
<td>12.6.4 Use of Analysis Sheets</td>
<td>346</td>
</tr>
<tr>
<td>12.6.5 Multiple Simulations</td>
<td>348</td>
</tr>
<tr>
<td>12.7 Bringing it All Together: Examples Using the Simulation Template</td>
<td>350</td>
</tr>
<tr>
<td>12.7.1 Model 1: Aggregation of a Risk Register using Bernoulli and PERT Distributions</td>
<td>351</td>
</tr>
<tr>
<td>12.7.2 Model 2: Cost Estimation using Lognormal Distributions</td>
<td>352</td>
</tr>
<tr>
<td>12.7.3 Model 3: Cost Estimation using Weibull Percentile Parameters</td>
<td>352</td>
</tr>
<tr>
<td>12.7.4 Model 4: Cost Estimation using Correlated Distributions</td>
<td>353</td>
</tr>
<tr>
<td>12.7.5 Model 5: Valuing Operational Flexibility</td>
<td>353</td>
</tr>
<tr>
<td>12.8 Further Possible uses of VBA</td>
<td>354</td>
</tr>
<tr>
<td>12.8.1 Creating Percentile Parameters</td>
<td>354</td>
</tr>
<tr>
<td>12.8.2 Distribution Samples as User-Defined Functions</td>
<td>354</td>
</tr>
<tr>
<td>12.8.3 Probability Samples as User-Defined Array Functions</td>
<td>355</td>
</tr>
<tr>
<td>12.8.4 Correlated Probability Samples as User-Defined Array Functions</td>
<td>356</td>
</tr>
<tr>
<td>12.8.5 Assigning Values from VBA into Excel</td>
<td>358</td>
</tr>
<tr>
<td>12.8.6 Controlling the Random Number Sequence</td>
<td>359</td>
</tr>
<tr>
<td>12.8.7 Sequencing and Freezing Distribution Samples</td>
<td>363</td>
</tr>
<tr>
<td>12.8.8 Practical Challenges in using Arrays and Assignment Operations</td>
<td>364</td>
</tr>
<tr>
<td>12.8.9 Bespoke Random Number Algorithms</td>
<td>364</td>
</tr>
<tr>
<td>12.8.10 Other Aspects</td>
<td>364</td>
</tr>
</tbody>
</table>

### CHAPTER 13

**Using @RISK for Simulation Modelling**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.1 Description of Example Model and Uncertainty Ranges</td>
<td>365</td>
</tr>
<tr>
<td>13.2 Creating and Running a Simulation: Core Steps and Basic Icons</td>
<td>366</td>
</tr>
<tr>
<td>13.2.1 Using Distributions to Create Random Samples</td>
<td>368</td>
</tr>
<tr>
<td>13.2.2 Reviewing the Effect of Random Samples</td>
<td>369</td>
</tr>
<tr>
<td>13.2.3 Adding an Output</td>
<td>370</td>
</tr>
<tr>
<td>13.2.4 Running the Simulation</td>
<td>370</td>
</tr>
<tr>
<td>13.2.5 Viewing the Results</td>
<td>370</td>
</tr>
<tr>
<td>13.2.6 Results Storage</td>
<td>373</td>
</tr>
<tr>
<td>13.2.7 Multiple Simulations</td>
<td>373</td>
</tr>
<tr>
<td>13.2.8 Results Statistics Functions</td>
<td>374</td>
</tr>
<tr>
<td>13.3 Simulation Control: An Introduction</td>
<td>377</td>
</tr>
<tr>
<td>13.3.1 Simulation Settings: An Overview</td>
<td>377</td>
</tr>
<tr>
<td>13.3.2 Static View</td>
<td>377</td>
</tr>
<tr>
<td>13.3.3 Random Number Generator and Sampling Methods</td>
<td>379</td>
</tr>
<tr>
<td>13.3.4 Comparison of Excel and @RISK Samples</td>
<td>381</td>
</tr>
<tr>
<td>13.3.5 Number of Iterations</td>
<td>382</td>
</tr>
</tbody>
</table>
CONTENTS

13.3.6 Repeating a Simulation and Fixing the Seed 382
13.3.7 Simulation Speed 383
13.4 Further Core Features 384
13.4.1 Alternate Parameters 384
13.4.2 Input Statistics Functions 384
13.4.3 Creating Dependencies and Correlations 385
13.4.4 Scatter Plots and Tornado Graphs 385
13.4.5 Special Applications of Distributions 395
13.4.6 Additional Graphical Outputs and Analysis Tools 400
13.4.7 Model Auditing and Sense Checking 405
13.5 Working with Macros and the @RISK Macro Language 405
13.5.1 Using Macros with @RISK 405
13.5.2 The @RISK Macro Language or Developer Kit: An Introduction 407
13.5.3 Using the XDK to Analyse Random Number Generator and Sampling Methods 409
13.5.4 Using the XDK to Generate Reports of Simulation Data 417
13.6 Additional In-Built Applications and Features: An Introduction 417
13.6.1 Optimisation 419
13.6.2 Fitting Distributions and Time Series to Data 420
13.6.3 MS Project Integration 421
13.6.4 Other Features 421
13.7 Benefits of @RISK over Excel/VBA Approaches: A Brief Summary 421

Index 425