

**Robust Intelligent Scenario Planning
for Industrial Systems**

**This Thesis is presented for the degree of
Doctor of Philosophy in Engineering**

**By
Sorousha Moayer**

**B.E. (Industrial Engineering), 2002
M.Sc. (Information Technology Management), 2005**

**School of Engineering and Energy
Murdoch University, Perth, Western Australia
2009**

Declaration

I declare that this thesis is my own account of my research and contains, as its main content, work which has not previously been submitted for a degree at any tertiary education institution.

.....

Sorousha Moayer

Abstract

Uncertainty about the future significantly impacts on the planning capacities of organisations. Scenario planning provides such organisations with an opportunity to be aware of the consequences of their future plans. By developing plausible scenarios, scenario planning methodologies assist decision-makers to make systematic and effective decisions for the future. This research aims to review existing scenario planning methodologies and develop a new framework to overcome the shortcomings of previous methodologies. The new framework has two major phases: a ‘scenario generation phase’ and an ‘intelligent robust optimisation phase’. The scenario generation phase creates future scenarios by applying fuzzy logic and Artificial Neural Network (ANN) concepts. With these concepts, it is possible to deal with qualitative data and also learn from expert data. The intelligent robust optimisation phase identifies the best strategic option which is suitable for working with the most probable scenarios. This second phase includes fuzzy programming and robust optimisation methods to deal with uncertain and qualitative data which usually exists in generated scenarios. The case study for this thesis focuses on Western Australia’s power capacity expansion needs and demonstrates the application of this new methodology in managing the uncertainties associated with future electricity demand. Scenarios which are generated based on different future population trends and industrial growth are used as the basis of determining the best strategic option for the expansion in WA’s electricity industry. Furthermore, transition to renewable energy and technological constraints for WA’s electricity industry are considered in the proposed framework. The result of this case study is an investment plan that satisfies WA’s electricity demand growth and responds to technological and environmental constraints. The new intelligent robust scenario planning framework has the potential to deal with uncertainties in business environments and provides a strategic option that has the ability to work with plausible scenarios for the future.

Contents

Declaration.....	i
Abstract.....	ii
Acknowledgements.....	v
List of Figures.....	vi
List of Tables.....	viii
Publications.....	ix
<i>1 Chapter 1: Introduction</i>	<i>1</i>
1.1 Background.....	1
1.2 Scope of the Study.....	3
1.3 Structure of the Thesis.....	4
<i>2 Chapter 2: Principles of Scenario Planning</i>	<i>6</i>
2.1 Introduction.....	6
2.2 Definition of Scenario Planning.....	7
2.3 History of Scenario Planning.....	7
2.4 The Uncertainty in the Business Environment.....	8
2.5 Scenario Planning and Forecasting.....	13
2.6 Scenario Planning Methodologies.....	16
2.7 Recent Developments in the Scenario Planning Area.....	24
2.8 Comparison of the Existing Methodologies.....	26
2.9 Case Study.....	27
2.10 Discussion.....	36
2.11 Conclusion.....	39
<i>3 Chapter 3: Research Design</i>	<i>40</i>
3.1 Introduction.....	40
3.2 Intelligent Robust Scenario Planning Framework.....	40
3.3 South West Interconnected System (SWIS).....	44
3.4 Research Procedure.....	46
3.5 Conclusion.....	47
<i>4 Chapter 4: Adaptive Neuro-Fuzzy Inference System (ANFIS)</i>	<i>48</i>
4.1 Introduction.....	48
4.2 Principles of ANN and Fuzzy Logic.....	49
4.3 Hybrid Intelligent Systems.....	62
4.4 Neuro-Fuzzy System.....	63
4.5 Adaptive Neuro-Fuzzy System (ANFIS).....	64
4.6 The Application of Soft Computing Techniques in Scenario Planning.....	69
4.7 Discussion.....	76
4.8 Conclusion.....	78
<i>5 Chapter 5: Optimisation Methods Under Uncertainty</i>	<i>79</i>
5.1 Introduction.....	79
5.2 An Introduction to Optimisation Methods.....	79
5.3 Optimisation Methods under Uncertainty.....	81
5.4 Discussion.....	91
5.5 Conclusion.....	92

6	<i>Chapter 6: Development of an Intelligent Scenario Generator Using ANFIS</i>	93
6.1	Introduction.....	93
6.2	ANFIS Methodology for Scenario Generation	93
6.3	Case Study	95
6.4	Discussion.....	107
6.5	Conclusion	108
7	<i>Chapter 7: A Methodology for Robust Intelligent Scenario Planning</i>	109
7.1	Introduction.....	109
7.2	Existing Optimisation Methods in Power System Capacity Expansion	109
7.3	Methodology Overview	113
7.4	Case study	115
7.5	Discussion.....	125
7.6	Conclusion	127
8	<i>Chapter 8: Intelligent Robust Scenario Planning for Power Capacity Expansion in South-West Interconnected System (SWIS), Western Australia (WA)</i>	128
8.1	Introduction.....	128
8.2	Background	128
8.3	The Significant of Developing Intelligent Robust Scenario Planning for SWIS	130
8.4	Case Study	131
8.5	Discussion.....	141
8.6	Conclusion	148
9	<i>Chapter 9: Conclusion</i>	150
9.1	Conclusion	150
9.2	Future Research	152
	<i>Appendix 1 - Micmac Software</i>	154
	<i>Appendix 2 - Mactor Software</i>	157
	<i>Appendix 3 - Smic-Prob-Expert Software</i>	162
	<i>Appendix 4 - SWIS General Information</i>	164
	<i>Appendix 5 - SWIS Electricity Usage (Independent Market Operator, 2009)</i>	168
	<i>References</i>	178

Acknowledgements

Firstly, I would like to thank my supervisor, Professor Parisa A. Bahri, for her support and guidance during this research. I was fortunate and honoured enough to be one of her PhD students. My co-supervisor, Adjunct Associate Professor Ali Nooraii, I thank for his visions and opinions which were essential to the progression of this study.

I am also delighted to express my sincerest gratitude to the staff and PhD students at the School of Engineering and Energy. I would particularly like to thank Bronwyn Phua and Roselina Stone for their help with administrative matters.

Thanks to Dr Sally Knowles for proofreading this thesis. Her useful suggestions really helped me especially in the final stage of this research. I am also grateful to Dr Cecily Scutt who assisted me to improve my academic and writing skills.

Most importantly, I wish to thank my parents who have been a constant source of encouragement and unconditional support. I am also grateful to my family and friends for caring attitude during this period.

Finally, I would like to thank Murdoch University for funding this research.

I apologise to those whose contributions, inadvertently, have not been acknowledged.

List of Figures

Figure 1.1 - The stages of the strategic management process.....	2
Figure 1.2 - Structure of the thesis.....	5
Figure 2.1- The principle of scenario planning (Van Der Heijden, 2005).....	9
Figure 2.2 - Aaker's (1998) strategic uncertainty categories.....	11
Figure 2.3 - The balance of predictability and uncertainty in the business environment (Postma and Lieb, 2005; Van Der Heijden, 2005).....	13
Figure 2.4 - General forecasting steps.....	14
Figure 2.5 - SRI scenario planning methodology (Ringland, 1998).....	17
Figure 2.6 - Future Group methodology.....	17
Figure 2.7 - Global Business Network methodology.....	18
Figure 2.8 - Schoemaker's methodology for scenario planning.....	19
Figure 2.9 - DSLP methodology for scenario planning (Schriefer and Sales, 2006).....	21
Figure 2.10 - Godet (2006)'s methodology and software programs for scenario planning...	24
Figure 2.11 - The chemical processing network and external forces.....	28
Figure 2.12 - The assumed trends of Chemical 4 market demand and price of buying.....	29
Figure 2.13 - Learning scenarios based on the occurrence probability of each uncertainty ..	31
Figure 2.14 - Ranking according to policies taken from Lipsor-Epita-Multipol.....	36
Figure 3.1 - Intelligent robust scenario planning framework phases.....	41
Figure 3.2 - Intelligent robust scenario planning framework for WA power capacity expansion.....	44
Figure 3.3 - South West Interconnected System (SWIS) (ERA, 2009).....	45
Figure 3.4 - Research Procedure.....	46
Figure 4.1 - A biological neural network (Negnevitsky, 2002).....	49
Figure 4.2 - The architecture of a typical ANN (Negnevitsky, 2002).....	50
Figure 4.3 - A single-layer neural network with two inputs.....	50
Figure 4.4 - Perceptron algorithm.....	51
Figure 4.5 - Multi-layer perceptron with two hidden layers.....	52
Figure 4.6 - Fuzzy sets of a fuzzy variable (Height as an example).....	56
Figure 4.7 - The basic structure of Mamdani style fuzzy inference.....	60
Figure 4.8 - The first model of fuzzy neural systems.....	63
Figure 4.9 - The second model of fuzzy neural systems (Fuller, 2000).....	63
Figure 4.10 - Adaptive Neuro-Fuzzy Inference System (ANFIS).....	65
Figure 4.11 - ISG architecture with multi-inputs and single-output (Li <i>et al.</i> , 1997).....	71
Figure 4.12 - The architecture of Li's hybrid intelligent system.....	72
Figure 4.13 - DPM with membership functions.....	74
Figure 4.14 - The modules of Royes and Royes's methodology.....	75
Figure 5.1 - Optimisation methods processes.....	80
Figure 6.1- Adaptive Neuro-Fuzzy Inference System (ANFIS) layers for generating scenarios.....	94
Figure 6.2 - The flowchart of the scenario generation framework using ANFIS methodology	95
Figure 6.3 - The curve of network error convergence.....	97
Figure 6.4 - Membership function of the supplier relationship.....	98
Figure 6.5 - Membership function of the market Share.....	98
Figure 6.6 - Membership function of the supplier relationship.....	99
Figure 6.7 - Li's framework (a) and proposed framework (b) for developing marketing strategy.....	100
Figure 6.8 - DPM with membership functions.....	103
Figure 6.9 - The comparison of two different DPM membership functions.....	104
Figure 6.10 - Initial and final membership functions of the business strength.....	106
Figure 6.11 - Initial and final membership functions of the market attractiveness.....	106
Figure 7.1 - Flow diagram of intelligent robust scenario planning.....	114
Figure 7.2 - The flowchart of intelligent robust scenario planning framework.....	115

Figure 7.3 - Power demand based on load duration curve (Mulvey <i>et al.</i> , 1995).....	116
Figure 7.4 - The initial and final membership functions of fuzzy level and duration of demand.....	118
Figure 7.5 - The total cost of alpha-cuts for each scenario	121
Figure 7.6 - The standard deviation of cost for different λ and ω	123
Figure 7.7 - The expected cost for different λ and ω	124
Figure 7.8 - The excess capacity for different λ and ω	124
Figure 8.1 - The initial and final membership functions of fuzzy variables for population and industry growth.....	134
Figure 8.2 - The standard deviation of cost for different λ and ω	140
Figure 8.3 - The average of cost for different λ and ω	140
Figure 8.4 - The excess capacity for different λ and ω	141
Figure 8.5 - The shares in SWIS electricity generation in 2013 by energy sources	144
Figure 8.6 - The shares in SWIS electricity generation in 2008 by energy sources based on current trend.....	144
Figure 8.7 - GHG emissions for different SWIS resources based on the current trend	145
Figure 8.8 - The shares in SWIS electricity generation in 2008 by energy sources based on sensitivity analysis	146
Figure 8.9 - GHG emissions for different SWIS resources based on sensitivity analysis ...	146
Figure 8.10 - The shares in SWIS electricity generation in 2008 by energy sources based on Disendorf's plan.....	147
Figure 8.11 - GHG emissions for different SWIS resources based on Disendorf's plan.....	148
Figure A1.1 - Matrix of Direct Influence (MDI) taken from Lipsor-Epita-Micmac software	154
Figure A1.2 - Direct influence/dependence map	155
Figure A1.3 - MII taken from Lipsor-Epita-Micmac software	156
Figure A2.1 - MDI taken from Lipsor-Epita-Mactor software	157
Figure A2.2 - Aggregation of the salience and position of actors taken from Lipsor-Epita-Mactor software	157
Figure A2.3 - Direct and indirect influence matrix taken from Lipsor-Epita-Mactor software	158
Figure A2.4 - Actor competitiveness factor (r_a) taken from Lipsor-Epita-Mactor software	158
Figure A2.5 - 3MAO matrix taken from Lipsor-Epita-Mactor software	159
Figure A2.6 - The actors' convergence matrix taken from Lipsor-Epita-Mactor software .	159
Figure A2.7 - The actors' divergence matrix taken from Lipsor-Epita-Mactor software....	160
Figure A2.8 - The actors' convergence diagram taken from Lipsor-Epita-Mactor software	160
Figure A2.9 - The actors' convergence diagram taken from Lipsor-Epita-Mactor software	160
Figure A2.10 - Ambivalence coefficient matrix taken from Lipsor-Epita-Mactor software	161
Figure A4.1 - Shares in Western Australia electricity generation in 2005/06 by energy source (Office of Energy, 2006a).....	165
Figure A4.2 - Shares in Western Australia electricity generation in 2005/06 by renewable energy source (Office of Energy, 2006a).....	165
Figure A4.3 - Energy and cash flow in electricity market (Independent Market Operator, 2006).....	167

List of Tables

Table 2.1 - New terms in the area of scenario planning.....	25
Table 2.2 - The main features of qualitative, quantitative scenario planning methodologies	27
Table 2.3 - Seven key uncertainties in the chemical processing network case	30
Table 2.4 - The outline of scenarios for each sub-system.....	34
Table 2.5 - List of criteria, policies, actions and assumed ranks	35
Table 2.6 - The major differentiations between Godet and Schoemaker’s methodology and	38
Table 3.1 - How the intelligent robust scenario planning framework addresses the issues of previous scenario planning methodologies	43
Table 4.1 - Analogy between biological and artificial neural networks (Negnevitsky, 2002)	50
Table 4.2 - Soft computing constituents (Jang <i>et al.</i> , 1997)	62
Table 4.3 - The application of fuzzy logic and ANN in scenario planning methodologies...	77
Table 5.1 - The benefit and raw material usage coefficients for each product	81
Table 5.2 - Some applications of stochastic programming in different areas	83
Table 5.3 - Some applications of robust optimisation in different areas.....	86
Table 5.4 - Some applications of dynamic programming in different areas	87
Table 5.5 - Some applications of fuzzy programming in different areas	90
Table 6.1 - Fuzzy rules of ANFIS.....	96
Table 6.2 - Training and checking data.....	97
Table 6.3 - The result of sensitivity analysis on ANFIS weight of training data.....	99
Table 6.4 - Fuzzy rules of ANFIS.....	105
Table 6.5 - Training and checking data.....	105
Table 6.6 - Sensitivity analysis based on the initial and final membership function.....	107
Table 7.1 - Fuzzy rules with assumed ANFIS weight	116
Table 7.2 - Different alpha-cuts for the level and duration of demand (L: Low, M: Medium and H: High)	118
Table 7.3 - The details of different scenarios based on the level and duration of demand ..	121
Table 7.4 - The Comparison of intelligent robust optimisation with stochastic programming for the power capacity expansion problem ($\lambda = 0.40$ and $\omega = 200$)	125
Table 7.5 - Robust coefficient for different λ and ω in robust region.....	126
Table 7.6 - The comparison of average run-time for different number of alpha-cuts.....	127
Table 8.1 - The comparison of four possible scenarios for Western Australia in 2029 (Department of Commerce and Trade, 1993)	133
Table 8.2 - The fixed and operational costs of electricity generation resources (Taken from (DOE, 2007))	135
Table 8.3 - The Comparison of intelligent robust optimisation with stochastic programming for the power capacity expansion problem ($\lambda = 0.40$ and $\omega = 400$)	142
Table 8.4 - Robust coefficient for different λ and ω in robust region.....	143
Table 8.5 - The gas emissions for future of Western Australia based on the current trend .	143
Table 8.6 - The gas emissions for future of Western Australia based on sensitivity analysis	145
Table 8.7 - Gas emissions for the future of Western Australia based on Disendorf’s plan .	147
Table A1.1 - The sums of row and columns of the MDI matrix.....	154
Table A1.2 - The sums of rows and columns of the Matrix of Indirect Influence (MII)	155

Publications¹

Journal Publications

- Moayer, S., & Bahri, A., P. (2009). Hybrid Intelligent Scenario Generator for Business Strategic Planning by Using ANFIS. *Expert Systems with Applications Journal*, 36, 4.
- Moayer, S., & Bahri, A., P. (x). Intelligent Robust Scenario Planning framework for Power Capacity Expansion in South-West Interconnected System (SWIS), Western Australia (WA). *European Journal of Operation Research*. Under review.
- Moayer, S., & Bahri, A., P. (x). Fuzzy Robust Optimisation for Capacity Expansion Planning under Uncertainty. *Operation Research Letter*. Under review.
- Moayer, S., & Bahri, A., P. (x). A Methodology for Robust Intelligent Scenario Planning: Power System Capacity Expansion Case Study. *Computers and Operation Research Journal*. Under review.
- Moayer, S., & Bahri, A., P. (x). A Comparative Study between Qualitative and Quantitative Methodologies in Business Strategic Scenario Planning. *Futures*. Under review.

Conference Publications

- Moayer, S., & Bahri, A., P. (2008). Intelligent Robust Scenario Planning Framework for Power Capacity Expansion in South-West Interconnected System (SWIS), Western Australia (WA). *Infirms Annual Meeting*. Washington D.C., USA, October, 2008.
- Moayer, S., & Bahri, A., P. (2008). A Hybrid Optimisation Method for Managing Uncertainty in Capacity Expansion Planning. *International Conference on Principles and Practice of Constraint Programming*. Sydney, Australia, September, 2008.
- Moayer, S., Bahri, A., P., & Nooraii, A. (2007). Adaptive Neuro-Fuzzy Inference System for Generating Scenarios in Business Strategic Planning: *IEEE International Conference on Systems, Men, and Cybernetics*. Montreal, Canada, October, 2007.

¹ Published papers are available on the attached CD.