CHAPTER 1

Preface and Overview

1.1 Motivation

The electricity supply industry (ESI) is one of the most capital intensive of all industries, with huge investments in power stations that are expected to pay off over several decades. Long construction lead times and operating lives imply the need for ***capacity planning*** to determine the ***types***, ***sizes***, and ***timing*** of new plants to be built as older plants are retired. These decisions are made in the face of great uncertainty, and the often irreversible commitments are translated into future costs. In the presence of rapidly changing technology, economics, and shifting social attitudes, new commitments may quickly become obsolete and inadequate. The privatisations of recent years, especially in the UK, have added to the uncertainties by introducing business risk into a previously "safe" market. New responsibilities and priorities in the UK and elsewhere have redefined what constitutes capacity planning, from once an engineering-dominated operational task to the domain of strategic decision making where responsiveness and other measures against complex and uncertain environments are paramount.

A more comprehensive treatment of uncertainty is now necessary given these costly implications. One trend has been to build larger energy models, e.g. NEMS project in the US (DOE, 1994). However, larger models are more difficult for the policy-maker to understand and manage. Indeed, traditional approaches, especially those employing single techniques, have difficulty meeting the conflicting criteria of ***comprehensiveness*** and ***comprehensibility***. One way to resolve this conflict is suggested by combining techniques or models through ***model synthesis*** to overcome the deficiencies of individual techniques and yet exploit the synergies

between them. Other than developing new modelling languages to this end, the literature has little to offer on the method and manner of synthesis.

Elsewhere, the need for ***flexibility*** is frequently mentioned as a response to uncertainty. Flexibility is intuitively appealing as it communicates a practical means of dealing with uncertainty. Rather than modelling uncertainty more comprehensively or accurately, the emphasis is on the ***ability to react,*** such as having different options available. Flexible technologies, such as short lead time, modular, dual-purpose plant, are promoted in the electricity planning literature, e.g. CIGRE (1991, 1993). Under great uncertainty, it has been suggested that flexibility is preferred to optimality as a ***decision criterion*** (Mandelbaum, 1978). In competitive and uncertain environments, like the manufacturing sector, flexibility has become an important ***operational objective***, not only desirable but also necessary (Slack, 1988). This suggests that flexibility may become more important as the electricity industry becomes more deregulated. However, it is still unclear how flexibility can be ***defined***, ***measured***, and explicitly ***modelled*** to be useful to capacity planning under uncertainty.

Although the modelling literature tends to support model synthesis, its ***feasibility*** has not yet been fully established, particularly the conceptual and operational requirements. In the context of the UK ESI, it is also necessary to determine the ***practicality*** of synthesis, as opposed to existing individual approaches. Similarly, while the electricity industry calls for flexibility, its ***usefulness*** in modelling has not been specifically demonstrated. The next section thereby lists a number of specific research questions related to these two themes of ***model synthesis*** and ***flexibility***.

1.2 Research Questions

"How can we deal with the range of uncertainties more completely and adequately than existing approaches in capacity planning, i.e. to meet the conflicting criteria of comprehensiveness and comprehensibility?" This thesis proposes ***model synthesis*** and ***flexibility*** as two ways to answer this question, with emphasis on the conceptual aspects.

Driving the main argument is a list of questions on the issues involved in model synthesis and flexibility. Many of these questions bring up additional questions throughout the thesis.

1) What are the new ***requirements*** for capacity planning in the privatised and restructured UK ESI?

2) What are ***existing approaches*** to this problem and how well do they treat these uncertainties?

3) How can we ***compare*** different modelling appoaches more objectively, systematically, fairly, and in more depth than by reviewing the literature?

4) Is ***model synthesis feasible*** and ***practical*** for these purposes? What are the ***conceptual*** and ***operational*** issues involved in model synthesis?

5) What is ***flexibility***? How is it defined? How does it relate to other words and concepts?

6) In what way(s) can flexibility be useful in addressing uncertainty in electricity capacity planning?

7) When, i.e. under which ***conditions***, is it useful or not useful?

8) How can we ***operationalise*** flexibility?

9) How can we ***measure*** flexibility?

10) How can flexibility be ***modelled*** and ***applied*** to electricity planning?

1.3 Research Methodology

This thesis employs the following research methods: ***literature review***, ***experiment***, ***model replication***, ***conceptual development***, ***synthesis***, and ***comparative theoretical evaluations***.

A ***literature review*** (Chapter 2) of ongoing developments of the UK ESI identifies the new requirements for capacity planning. A ***classification*** of areas and types of uncertainties serves as the basis for a critique of existing approaches to capacity planning. An extensive ***literature review*** (Chapter 3) of capacity planning models and modelling methods used in the UK and elsewhere reveals the limitations of existing approaches. These two reviews also provide the criteria for subsequent evaluation of models.

To investigate the feasibility and practicality of model synthesis and to compare its performance with existing approaches, a ***two-staged case study based modelling experiment*** (Chapter 4) is conducted. This experiment consists of ***pilot studies*** (Appendix A) to establish the feasibility of ***model replication*** and ***evaluation***, development of a hypothetical case study, consolidation of published data pertaining to the UK ESI, replication of three modelling approaches (Appendix B), ***conceptualisation*** of model synthesis (Appendix C), and construction of ***prototypes***. The ***experimental protocol*** offers a systematic and thorough method of model replication and evaluation.

To assess the usefulness of flexibility, a ***cross disciplinary review*** (Chapter 5) of its applications and interpretations is first conducted. A ***conceptual development*** (Chapter 6) of words, relationships, and aspects of flexibility clarifies the confusion found in the literature and unifies the definitions of flexibility. It also provides the basis for subsequent ***identification*** of conditions under which it is useful, ***discussion*** of the downside of flexibility, ***illumination*** of the important concept of

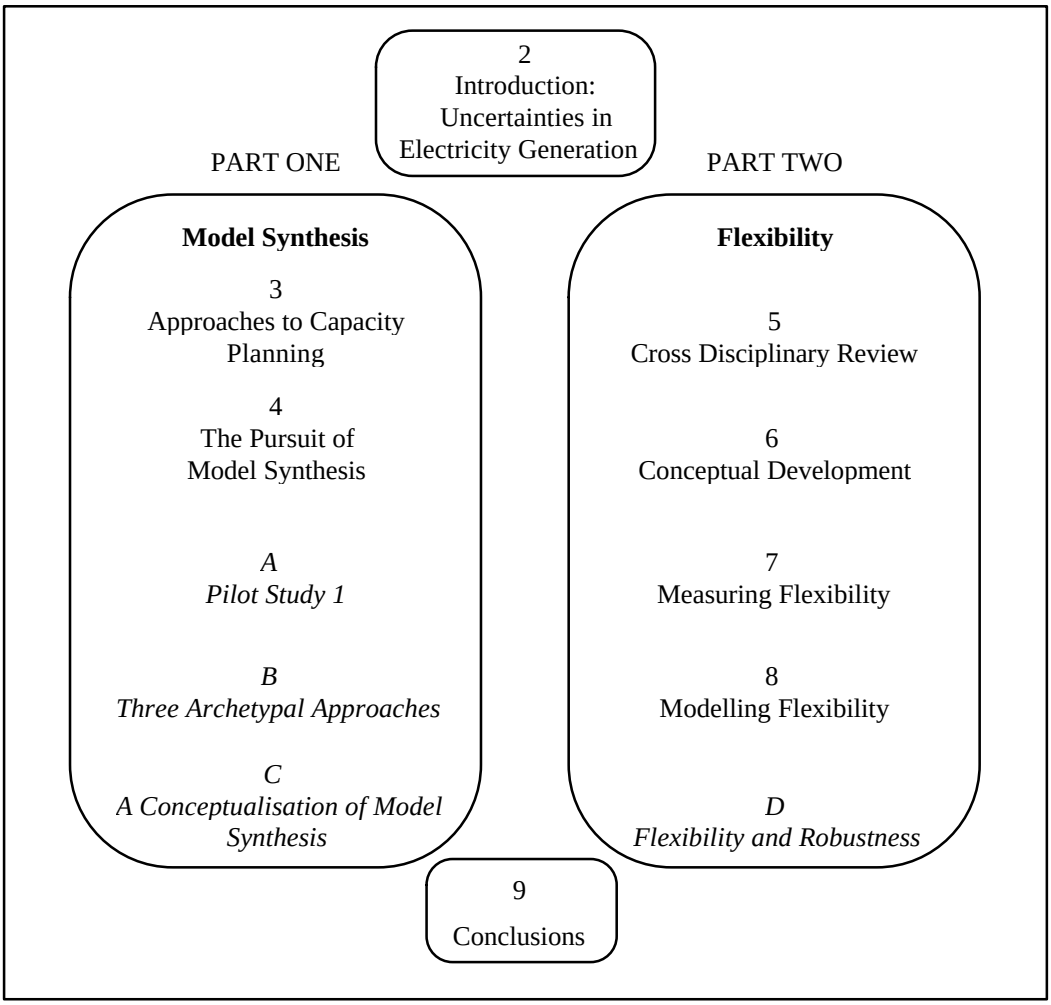
"favourability", ***distinction*** between options and strategies for operationalisation, and ***determination*** of the necessary elements in its definition. The definitional elements translate into indicators for measuring flexibility. Three groups of measures (indicators, expected value, and entropy) are ***evaluated*** (Chapter 7) against criteria based on the conceptual development of Chapter 6. These indicators also provide the basic terminology and framework for modelling flexibility using decision trees and influence diagrams. ***Practical guidelines*** (Chapter 8) for structuring and assessing flexibility are developed. These guidelines facilitate the structuring and assessment of models of strategies for operationalising flexibility in the context of capacity planning in the UK ESI, thus showing the relevance, applicability, and usefulness of flexibility.

1.4 Organisation of Thesis

This thesis consists of ***two independent and separately argued texts*** corresponding to two entirely different ways of approaching the problem. Part One investigates model synthesis as a means to ***completeness*** in modelling the different uncertainties. Part Two investigates flexibility as a means to compensate for ***model unease*** and as a more ***practical means of coping*** with uncertainties. Initially, the two themes seem totally unrelated. It is not until Chapter 9 that they are brought together and resolved.

Figure 1.1 shows the organisation of this thesis in terms of chapters (1 to 9) followed by appendices (A to D in italics). The modelling experiment to establish the feasibility of model synthesis is described in Chapter 4 but documented in the first three appendices. Brief summaries of each chapter and appendix follow.

Figure 1.1 Organisation of Thesis



Chapter 2 Introduction: Uncertainties in Power Generation

This introductory chapter explains the title of this thesis by defining ***electricity capacity planning*** and discussing the ***uncertainties*** which affect it. The background developments in the industry, particularly the privatisation and restructuring in the UK, lead to the current emphasis on uncertainty which motivates this research. The term "uncertainty" is defined and distinguished by ***type***, e.g. internal and external, quantitative and qualitative, etc. Uncertainties that affect capacity planning in the ESI are classified according to ***area***, e.g. demand,

fuel, and environment. It introduces the criteria of ***adequacy***, ***completeness***, ***feasibility***, and ***usefulness***.

PART ONE: Model Synthesis for Completeness

Chapter 3 Approaches to Capacity Planning

Applications of operational research techniques for electricity capacity planning are reviewed. Grouped in the broad categories of ***optimisation***, ***simulation***, and ***decision analysis***, these techniques are briefly defined and evaluated on the basis of ***completeness*** of capturing the areas of uncertainty and ***adequacy*** of modelling treatment. These techniques are either specific to capacity planning or uncertainty analysis. The applications are either based on individual techniques or several techniques. It concludes that models based on two or more techniques, defined as ***model synthesis***, seem to be more capable of achieving completeness through ***complementary*** techniques.

Chapter 4 The Pursuit of Model Synthesis

This chapter documents the research into model synthesis, with supporting details in the first three appendices (A, B, C). The investigation consists of two pilot studies to establish the feasibility of ***model replication and evaluation***, development of a UK ESI-relevant ***case study*** to anchor the data and model content, the first stage of ***three archetypal approaches*** to gain a more indepth, fair, and relevant critique than mere literature review, the second stage of ***conceptualisation*** to identify conceptual issues in synthesis, and the construction of model synthesis prototypes to identify the ***operational*** issues. A ***decision analysis framework*** for organising other techniques is proposed and a "***model of model***" tested to facilitate this framework. A further requirement of ***compatibility*** emerges as an important issue. The results of these experiments cast doubt upon

the general usefulness of model synthesis as a fully comprehensive modelling approach, especially in terms of practicality in the context of the UK ESI. In view of this, flexibility is proposed as a more useful concept to address the modelling goal of completeness (or the lack of it) and as a practical means to cope with uncertainty.

Appendix A Pilot Study 1

This study is a first attempt in this thesis to address a range of uncertainties that affect plant economics, i.e. levelised or marginal costs of electricity generation. It gives critical insight into the use of ***sensitivity analysis*** and ***risk analysis*** to model uncertainty. Data from various OECD countries are consolidated from two different reports to determine the ranges of uncertainty for various parameters. This study establishes the ***feasibility of model replication*** but also shows the ***level of detail*** of subsequent studies.

Appendix B Stage One: Three Archetypal Approaches

This is the first stage of the two staged model experiment. Three representative modelling approaches to capacity planning are replicated and evaluated. 1) The ***deterministic*** approach consists of ***scenario analysis*** and ***sensitivity analysis*** of the capacity planning ***optimisation*** model. 2) The ***probabilistic*** approach is an expanded ***risk analysis*** of the optimisation model. 3) The ***decision analytic*** approach is based on the use of decision trees and influence diagrams. The associated input data and assumptions for the core optimisation model are given.

Appendix C A Conceptualisation of Model Synthesis

Model synthesis is defined as the use of two or more techniques in some integrated fashion towards model completeness. Conceptual issues are developed for

structuring the components and strategies for synthesis. The frequently used terms in this thesis are defined here, e.g. ***technique***, ***model***, and ***approach***.

PART TWO: Flexibility for Uncertainty

Chapter 5 Cross Disciplinary Review

This chapter summarises the extensive cross disciplinary review of definitions, measures, and applications of flexibility since its earliest formal reference in the 1930's and as appeared in various industries and business sectors and academic disciplines. The review is based on two types of sources: 1) journal articles in the last two decades (1970 - 1994), which mention flexibility and closely related words, and 2) specific research studies of flexibility, e.g. previous doctoral dissertations on this topic. It shows the richness of the literature as well as the general confusion in practice of what is meant by flexibility. This review provides the basis for subsequent clarification, analysis, and application in the remaining three chapters.

Chapter 6 Conceptual Development

This chapter clarifies the confusion through analysis. A "conceptual analysis" of flexibility and related words, e.g. adaptability, is applied to flexibility and more established concepts, e.g. uncertainty, commitment, etc. In particular, the contrast between flexibility and ***robustness*** is discussed, with specific application in Appendix D. A distinction is made between the context-dependent ***types*** of flexibility and the context-free ***elements*** of flexibility. An ***uncertainty to flexibility mapping*** is proposed to determine ***types*** of flexibility. The important concept of ***favourability*** inherent in flexibility is highlighted. These conceptual relationships together with ***conditions under which it is useful***, the ***downside of flexibility***, and ***elements in its definition*** provide a conceptual framework to link the theoretical

and practical aspects of flexibility. Two different kinds of ***operationalisation*** of flexibility via ***options*** and ***strategies*** are discussed. The need for measuring flexibility is proposed.

Chapter 7 Measuring Flexibility

Using the four step method of Chapter 4, i.e. criteria, replication, evaluation, and comparison, three groups of measures are critiqued for their consistency with the conceptual development of Chapter 6. For the first group, definitional elements from the conceptual framework are translated into ***indicators***, which support the partial measures found in the literature. The second group is based on the decision analysis notion of ***expected value***. Three different expected value measures and a proposal for an improved measure with features of the previous three are assessed. The third group is based on the scientific concept of ***entropy***, and two types of entropic measures are assessed. This detailed analysis concludes that indicators and expected values may be used to measure flexibility but not entropic measures.

Chapter 8 Modelling Flexibility

This chapter makes use of previously defined indicators and expected value measures to structure and assess options and strategies for operationalising flexibility. ***Practical guidelines*** for this are developed and tested in a ***decision analysis framework***, as a structuring tool for flexibility but not as an organisational tool for synthesis. It gives the circumstances under which to use indicators and different kinds of expected value based measures. Relevance to electricity planning is illustrated by a decision model of ***plant economics***. Relevance to the UK ESI is illustrated by a model of ***pool price***. Four ways to operationalise flexibility are examined with respect to these guidelines.

Appendix D Flexibility and Robustness: Response to Demand Uncertainty

The concepts of flexibility and robustness are applied to an analysis of over and under capacity in production and inventory control, i.e. supply versus demand. Measures of robustness and flexibility are derived with respect to costs of over and under capacity. The original example is extended with additional detail to other applications.

Chapter 9 Conclusions

The final chapter (9) summarises the main conclusions and research contributions. It also suggests directions for further research.

The following table (1.1) provides a simple "location" guide of research questions and methodology.

Table 1.1 Research Questions and Methodology

	Question	**Location**	**Methodology**
1)	What are the new requirements for capacity planning in the privatised and restructured UK ESI?	Chapter 2	literature review, classification
2)	What are existing approaches to this problem and how well do they treat these uncertainties?	Chapter 3, Appendix B	literature review, evaluation critique
3)	How can we compare different modelling appoaches more objectively, systematically, fairly, and in more depth than by reviewing the literature?	Chapter 4, Appendix A, B	proposal, feasibility studies, experiment
4)	Is model synthesis feasible and practical for these purposes? What are the conceptual and operational issues involved in model synthesis?	Chapter 4 Appendix C	experiment, conceptualisation
5)	What is flexibility? How is it defined? How does it relate to other words and concepts?	Chapter 5, 6	literature review, analysis
6)	In what way(s) can flexibility be useful in addressing uncertainty in electricity capacity planning?	Chapter 5, 6	literature review, conceptual development, analysis
7)	When, i.e. under which conditions, is it useful or not useful?	Chapter 6	analysis
8)	How can we operationalise flexibility?	Chapter 6, 7, 8	literature review, application
9)	How can we measure flexibility?	Chapter 7, Appendix D	literature review, analysis, critique
10)	How can flexibility be modelled and applied to electricity planning?	Chapter 7, 8	application, development of guidelines