CHAPTER 5

Cross Disciplinary Review

5.1 Introduction

For flexibility to be of any use to addressing the uncertainties in electricity capacity planning, its practical and theoretical aspects must be understood. Most discussions of flexibility concentrate only on partial aspects of flexibility, and this narrow focus cannot be transported elsewhere. A review of previous studies of flexibility suggests that the best way to allow such portability is to study how flexibility is ***used***, ***defined***, ***classified***, and ***measured*** across disciplines and industries. Such a broad review preserves those aspects or properties of flexibility that are lost or de-emphasized in any single discipline. The last major cross disciplinary review of flexibility was conducted over a decade ago by Evans (1982). Since then, new uses and measures of flexibility have appeared. An update is therefore timely.

The idea of flexibility appears in many disciplines. In banking and finance, investors' preference for flexibility translates into the notion of ***liquidity***, or the ease in which assets can be transformed. In operations management***, flexible manufacturing systems*** replace the function and product-specific machines of the past. In the labour markets, employers allow ***flexible hours*** to attract better skilled workers. In turn, a ***multi-skilled*** worker can entertain more job opportunities. ***Flexible information systems*** offer users more functionality. The so-called "dash for gas" in the present UK Electricity Industry refers to the rapid build-up of a ***flexible technology*** called combined cycle gas turbine which can be quickly built off-site in small but modular unit sizes. In all of these areas, flexibility represents a desirable property or goal.

In spite of its popularity, flexibility has not received the formal recognition worthy of mature and well–defined concepts like optimality or profitability. Although its qualitative importance is obvious, methods of evaluating its quantitative impacts (Orr, 1967) remain elusive. Its usefulness may have been overlooked, particularly its potential contribution to aspects of modelling that are not well served by existing ideas.

This chapter reviews ***definitions***, ***applications***, and ***measures*** of flexibility and related words in the industries covered by the ABI-INFORM (1970 - 1994) CD-ROM. Research implications from this review and specific studies of flexibility are also noted. This review provides the basis for its conceptual development in the next chapter and its operationalisation in chapters 7 and 8 via measuring and modelling.

5.2 Energy Sector and Electricity Planning

As early as the 1970's, utility executives had called for flexibility (Schroeder et al, 1981.) The need for flexibility in power generation planning has been suggested by Berrie and McGlade (1991), Vlahos (1990), Clark (1985), Borison (1982) and others, none of whom have defined nor shown how it can be used. This supports the contention of Hobbs et al (1992) that the importance of flexibility to planning is widely acknowledged, but the concept is rarely defined precisely, much less quantified.

Experience of deviations from plans has convinced Southern California Edison (SCE, 1992), a US utility, of the importance of flexibility in planning. Their method emphasizes planning flexibility by developing built-in "on and off ramps" that allow quick responses to changing conditions by means of first constructing plausible scenarios and then preparing flexible responses to each of them.

Flexibility in planning (Hirst, 1990) comprises the selection of a resource portfolio that can be ***easily adapted to various conditions***, e.g. small unit sizes, short lead times, and demand side management programmes. Approximating discrete supply to continuous demand, small plants could more easily follow load growth than large plants. Extending the argument to the extreme, a series of zero-lead time, infinitesimally small power plants can completely eliminate all periods of excess or deficit capacity. The drawback to maximal flexibility is that small plants cost more per kW of capacity and per kWh of output, i.e. no economy of scale. Another flexible planning approach (Yamayee and Hakimmashhadi, 1984) involves shortening the lead times for different types of plant through the use of option concepts. Such a plan contains flexible elements (options) and uses a decision rule to instil flexibility. CIGRE (1991) define flexibility as ***the ability of the power system to adapt itself quickly to new circumstances to be permanently used in the best way***.

Evans (1982) lists four ways to induce flexibility so that positive consequences occur while avoiding negative ones. He considers them appropriate for research into flexibility in technology assessment. To illustrate their uses, we add our own examples from the electricity industry.

1) Flexibility is the ability to bend or change, as in physical malleability. The flexibility in a class of power plant that is decommissioned but maintained allows it to be reactivated if demand increases. The new type of combined cycle gas turbine plants have short lead times in construction, modular units, small unit sizes, and fast start-up and shut-down times. These characteristics enable the generator to meet shifts in demand more quickly.

2) Flexibility denotes ***yielding to pressure*** or ***change triggered by a shift in environmental conditions***. Pumped hydro generators and night storage space heaters provide peak generating capacity by utilising cheap off-peak supplies of baseload capacity. When peak demand exceeds on-line capacity, water is forced through the turbines by gravity. Off-peak night storage units hold heat in bricks warmed up during the period when demand is lowest.

3) Flexibility is the ***susceptibility of modification*** or ***the ability to effect alterations***, such as the liquidity of an investment, a business, or a technological portfolio. Flexibility is achieved through the overall configuration (via balance, risk diversification, fuel diversification) rather than through the individual properties of various components. The flexibility of a capacity mix is determined by the ease in meeting different conditions of shifting demand levels and load duration curves.

4) Flexibility is the ***capacity for ready adaptation to new situations***. A complex technological system is planned in such a way to accommodate variations in demand. One method is through reserve margins, i.e. surplus capacity. A flexible legal contract contains built-in clauses to enable orders to be cancelled or power to be bought or sold immediately. One flexible strategy suggested by Merkhofer (1975) justifies the cost of keeping options open by the expectation that additional information will permit the decision to be made more effectively later.

5.3 Economics

Since the 1930's, flexibility has been recognised in separate studies as a component of a wide range of economic decisions. Despite the substantial theoretical attention in this area, Jones and Ostroy (1984) claim that it plays a limited role in conventional micro-economic theory due to the difficulty of defining flexibility for universal application. In other words, flexibility is not formal or central to any discipline, as it is ***only desirable but not necessary***.

One of the earliest advocates, Stigler (1939) discusses the relationship between flexibility and ***adaptability*** by analysing average and marginal cost curves in the problem of choosing among alternative plants. Flexibility of operation allows a plant to be ***passably efficient over a range of probable outputs.*** The amount of flexibility built into a plant depends on the costs and gains of flexibility, hence implying that ***flexibility is not a free good***. A plant is flexible if it could produce a wide range of output quantities by incurring relatively small increases in average cost. This translates to a ***flat average cost curve***, i.e. the flatter it is, the more flexible the firm.

From his chronological account of the development of flexibility in the economics literature, Carlsson (1984) concludes that flexibility gives a firm ***the ability to deal with all forms of turbulence or uncertainty in the environment***.

5.4 Corporate Planning / Business Strategy

The firm's need for flexibility directly depends on the stability of the environment in which it operates. Low flexibility is sufficient for stable environments, and high flexibility required for unstable environments. Supporting this argument, Mascarenhas (1981) describes two ways to realise this: increase options (hence its flexibility) or control its environment (make it more stable).

Flexibility is recognised as a key aspect of a firm's response to competitive markets. Flexible specialisation and integration (Gertler, 1988) are strategies for competition between firms, referring to the firm's ability to respond to fluctuations in market demand and to adopt new products quickly. Eppink (1978) notes that the more uncertain the situation, the more an organisation will need flexibility as a complement to planning. As such, it is a characteristic of an organisation that makes it less vulnerable to unforeseen strategic change.

In policy formation, Evans (1982) defines ***strategic flexibility*** as the ***capability which aids repositioning when conditions change***. "Flexible" is propelled as a desirable trait of a planning strategy, structure, and plan. Later, Evans (1991) uses the polymorphous nature of flexibility to develop a framework for strategic flexibility.

In entrepreneurial management, Stevenson (1985) points out the difference between entrepreneurial and administrative decision making styles. Entrepreneurs value flexibility and tend to make commitments in stages thereby limiting the amount of commitment while staying flexible.

5.5 Labour Markets

Labour markets have witnessed the spread of flexibility in ***employment practices***, ***workforces***, and ***career planning***. Against increasing rates of change and volatility of the labour market, ***flexible human resource policies*** have been devised to allow faster responsiveness. A ***flexible workforce*** is multi-skilled, i.e. able to perform various job functions to meet different needs of the organisation. Women are seen as a flexible workforce because of their availability for part-time work. Temporary and contract workers are also part of this group, as their working arrangements can be adjusted to suit the needs of the employing organisation. Career planning advises to ***plan for the unexpected*** by having a number of alternatives and by remaining flexible enough to switch plans in case one strategy does not work out. Flexibility, in this sense, is a contingency.

Specific studies of flexibility in labour markets (Pollert, 1991) convey notions of *responsiveness, matching needs, variety, variability, ability to choose, appealing to many*, *non-restrictive*, and *informal*. Flexibility appears in the restructuring of labour markets and labour processes through increased versatility in design and greater adaptability of new technology in production. ***Flexible specialisation***, for example, refers to a new form of skilled craft production made easily adaptable by programmable technology to provide specialised goods which can supply an increasingly fragmented and volatile market. ***Labour flexibility*** refers to different types of flexibility for employers and employees and has different international contexts. In France and the UK, for example, employers view flexibility as fixed term contracts, the ability to lay off workers, and the introduction of flexible working hours for the employee. "Flexi-time" (Ullrich, 1980) allows employees to vary their hours of work to suit their own preferences. On the other hand, employers in Germany and Sweden emphasize multi-skilling, qualifications, and training as ways to increase flexibility.

Flexibility applies to both employees and employers. Atkinson (1985) identifies three kinds of flexibility that are sought by employers. 1) ***Functional flexibility*** refers to the smooth and quick deployment of employees between activities and tasks. Through multi-skilling and retraining, the same labour force may be redeployed to different job functions as required. 2) ***Numerical flexibility*** allows worked hours to be quickly, cheaply, and easily varied in line with short term changes in the demand for labour. [The author might have equally used the term ***temporal flexibility***.] Contractual relationships govern the kinds of part-time, temporary, and contract arrangements. 3) ***Financial flexibility*** enables a firm to manipulate labour costs according to the state of supply and demand in the external labour market, thereby differentiating between performance-based pay and rate-based pay. Employees, on the other hand, desire two different kinds of flexibility (Atkinson, 1989): ***enhanced mobility*** in the firm and ***transferability*** of accrued benefits, status, and advantages between employers.

The term "flexibility" has been applied in contradictory contexts. On the one hand, flexible means *widely applicable or accommodating*. On the other hand, it also means *tailoring to specific needs*, i.e. matching individual requirements. These opposing connotations are united if flexibility is interpreted as ***the potential to tailor to a wide range of specific needs*.**

5.6 Technology / Information Systems / Telecommunications

Flexible and open systems have the capacity to communicate with other types of technology protocols, i.e. they are responsive to other types of signals. Flexible network routing is intended to accommodate rapidly growing demands that materialise. On the other hand, an inflexible technology is slow and costly to adjust to unexpected events.

In the design of effective decision support systems (DSS), Sprague and Carlson (1982) recognise four levels of flexibility (*changeable*, *modifiable*, *adaptable,*and *evolutionary*.) At the first level, the ***flexibility to solve*** enables the user to confront a problem in a flexible, personal, or creative way. At the second level, the ***flexibility to modify*** allows the configuration of a specific DSS to be modified so that it can handle a different or expanded set of problems. At the third level, the ***flexibility to adapt*** refers to the DSS-builder's ability to adapt to changes that are extensive in an incremental or staged fashion. The fourth and final level of flexibility applies to the long term view, that is, the ***ability of the system to evolve*** in response to changes in the basic nature of the technology on which the DSS is based.

5.7 Manufacturing

The manufacturing sector has seen the greatest proliferation of definitions, classifications, and applications of flexibility. While ***cost*** predominated throughout most of the industrial era, followed by ***quality*** in the 1970's and 1980's, Chandra and Tombak (1992) observe that ***flexibility*** is now the dominant theme in the 1990's because of shorter product life cycles, more competitive markets, and the availability of new technologies known as Flexible Manufacturing Systems. Flexibility is no longer just desirable but vitally necessary, to the extent that it should be part of a competitive strategy (Slack, 1988). Supporting this, Carlsson (1989) argues that flexibility is as important as costs in determining international competitiveness. Recent surveys, e.g. Gerwin (1993), show firms' ranking of flexibility after productivity, delivery, and quality in importance for competitiveness.

In Flexible Manufacturing Systems (FMS), flexibility refers to relaxing the rigidity in scheduling with production volume which may be varied almost instantaneously. The flexibility of FMS, according to Hutchinson and Sinha (1989), provides

economic advantages, such as the ability to rapidly introduce new parts and to change production mix to respond to short-run fluctuations. Flexible couplings give trouble-free service and can accommodate faults. Flexible or robust designs relate to survivability under all types of conditions.

The numerous interpretations of manufacturing, as listed below, have led some researchers to classify different types of flexibility and to develop conceptual frameworks to capture the essential dimensions. Slack (1983) says flexibility refers to how far and how easily you could change what you want to achieve, thus containing the dimensions of ***range*** and ***ease***. Along the same lines, Kumar (1987) says that flexibility in action of an individual or system depends on the decision options or the choices available and on the freedom with which various choices can be made. Similarly, flexibility of a population with respect to a set of alternatives depends not only upon the number of alternatives but also on the extent to which the diversity of choice is determined by certain circumstances. Verter and Dincer (1992) define flexibility as ***the ability of a system to cope with changes effectively.*** Gunasekaran et al (1993) define flexibility as ***the ability of a manufacturing system to cope with changing environments.***

Attempts at unifying manufacturing flexibility are superseded by new reviews, new definitions, and new applications, e.g. Sethi and Sethi (1990), Gupta and Goyal (1989), and Bernardo and Mohamed (1992). A unique, undisputed definition does not yet exist as the concept is manifested in different types of flexibility: operational flexibility, design flexibility, short term, long term, scheduling, job, mix, action, adaptation, adequacy, process, machine, expansion, volume, production, etc. The same term, e.g. ***product mix flexibility***, often has different meanings, e.g. Slack (1983) defines it as *the ability to manufacture a particular mix of products within a minimum planning period*. Meanwhile, Gerwin (1982) defines product mix flexibility as *the ability to manufacture a mix of products simultaneously*.

5.8 Other Areas

In other areas, flexibility communicates the same kind of ***diversity***, ***variety***, and ***desirability***. ***Flexible insurance policies*** target a broad market because of their *specific tailor-made end-products*. The ***resilience of ecological systems*** (Holling, 1973) is a kind of flexibility maintained for *survival in a range of conditions*. ***Flexibility of a production system***, as noted by Zelenovic (1982), is a measure of its capacity to *adapt to changing environmental conditions and process requirements*. Flexible production systems can therefore provide stable functioning of systems under the following conditions seen today: high rate of environmental changes, increasing international competition, and higher quality of technology innovations. In the field of counseling psychology, Anastasi (1990) sees diversity of viewpoints towards testing and assessment as leading to a more comprehensive and flexible model of counseling. In psychological terms, ***a flexible person*** is *open-minded and adaptable*, whereas an inflexible person is unable to deal with ambiguity and uncertainty.

5.9 Observations and Conclusions

As apparent from this review, the literature on flexibility is rich with definitions, measures, and applications. Further analysis is required to resolve the confusion and clarify the following six points.

1) Research on flexibility is fragmented across many disciplines, which together point to the ***versatility of its use*** and also ***a lack of consensus***. For example, manufacturing flexibility is poorly understood because different studies have emphasized ***different aspects of flexibility*** (Kumar, 1986).

2) Identical terms used in different studies do not necessarily have the same meaning. For example, ***decision flexibility,*** according to Heimann and Lusk (1976), is *an alternative criterion to the expectation model*, whereas Merkhofer (1977) defines it as *the availability of alternatives or the size of choice set for a decision*. Clearly, criterion and choice set are not the same.

3) The interpretations of flexibility are often confusing. For example, Mandelbaum (1978) considers ***diversity*** a source of flexibility, i.e. a way to achieve or increase flexibility. On the other hand, DeGroote (1994) says that flexibility is a ***hedge against diversity***. Stirling (1994) says flexibility is a form of diversity, but at the Sizewell B public inquiry, diversity was largely regarded as a ***hedge against uncertainty***.

4) In the extreme, the orthodoxy of flexibility has been criticised by Pollert (1991) as being an ideological fetish. In connection with labour markets, for example, it is ambiguous, multi-form, generic, confusing, and heavily value-laden.

Our intuitive understanding of flexibility is not confined to a single discipline but rather inferred from its uses in a range of disciplines. Previous studies of flexibility, notably Merkhofer (1975), Mandelbaum (1978), Eppink (1978), and Evans (1982), support the six main observations we make from this review.

1) ***Flexibility along with other closely related words is widely used across different areas.*** Although we have only reviewed the uses and definitions of flexibility in business-related fields, we can expect the notion of flexibility to exist everywhere. Table 5.1 lists the main uses of flexibility as covered in this review. It shows that flexibility is a characteristic of the product as well as the process, e.g. plan and planning, decision maker and decision making.

2) ***Reference to flexibility has increased in the last two decades.*** The word "flexibility" or "flexible" is used much more often today than it was a decade ago (ABI-INFORM, 1970 - 1994.) This is due both to new conditions under which flexibility is useful and new ways in which flexibility takes form. This review suggests that the increased reference to flexibility is partly due to the more competitive markets and uncertain environments as well as the greater availability of technological options and increased functionality of systems to meet these needs.

3) ***It is more strongly advocated as a desirable property than a necessary one.*** Flexibility, along with other related words, has been hailed a desirable property of a system, an organisation, a portfolio, a plan, and a process such as planning or decision making. It is advocated as a response to uncertainty as well as to competition, especially in new markets and unstable environments.

4) ***The concept implies having or offering an abundance as well as a variety of choices.*** It is a way of coping with unavoidable uncertainty by having or offering many different choices or functions.

5) ***It also conveys a responsiveness by active behaviour, i.e. reacting to change, as well as inactive behaviour, not having to react by tolerating change.***

6) ***Flexibility seems to fill the gap between planned (intended) and actual outcomes***, especially in situations involving high cost, long lead time, and heavy commitments.

Table 5.1 Uses of Flexibility

Mention or use of flexibility as applied to (column) in area (row)	energy, electricity supply	eco-nomics	corporate planning, business strategy	labour markets	informa-tion and telecom-munica-tion systems	manu-factur-ing	other areas
plan: planning, planning strategy, planning process, planning approach	Y		Y	Y			
decision maker: firm, organisation		Y	Y	Y			person
system, structure, plant	Y	Y	Y	restruc-turing of labour markets	Y	Y	produc-tion system
decision, choice	Y	Y					
Others	model, portfolio, capacity mix			sche-dule, work-force		design	

Five immediate directions for further research arise from this review.

1) Several concepts are closely related, e.g. flexibility increases with increasing number of alternatives, diversity of choices, response to change, etc. These relationships suggest that flexibility may be a function of more established concepts. ***How does flexibility relate to more established concepts?***

2) In all of the sectors reviewed, flexibility is advocated as desirable, albeit not without negative effects and provisioning costs. This begs the question, ***is flexibility always desirable? Under which conditions is flexibility useful?*** What happens when we have too much or too little flexibility? How much flexibility is enough?

3) If flexibility is not always desirable, this poses another question. Under what circumstances is it no longer desirable? Gerwin (1993) warns of the ***downside of flexibility***, to which little, if any, attention has been given. For instance, excess amounts of flexibility, such as quick short-term responses to uncertainty, could lead to wasteful activities.

4) While a unique and formal definition may not yet exist, the manner in which it is used and promoted may help to elaborate the concept. By this, we mean ***identifying necessary elements to define flexibility***, such as Eppink's (1978) designation of type, aspect, and components of flexibility.

5) To harness this concept for practical use, we need to know ***how to operationalise and measure flexibility***.

In addition to the above, specific studies of flexibility have raised research questions that apply to our assimilation of the concept. Most of Mandelbaum's (1978) open research areas still hold today. For example, problems of continuous action space make the range aspect of flexibility difficult to measure. Practical development of flexibility attributes and implications of their use are required, thus highlighting a need to tie together the practical and theoretical aspects. Mandelbaum also suggested using stochastic dynamic programming to study flexibility in traditional multi-period stochastic models. Subsequently, Kulatilaka

(1988) uses this technique as a means to capture the option value of flexibility. Mandelbaum's suggestion raises a further interesting question: do certain modelling approaches facilitate measures of flexibility better than others? In other words, ***is flexibility a feature of the modelling approach?***

Having established the practical importance of flexibility, we now turn to the theoretical side to address the research issues raised above.