ROUTLEDGE REVIVALS

Investment Decisions in Advanced Manufacturing Technology

A Fuzzy Set Theory Approach

Magdy G. Abdel-Kader
David Dugdale
Peter Taylor

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To …

Magda and Mohamed

Catherine

Mary, Tom and Charles

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A fuzzy set theory approach

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Contents

List of Figures

List of Tables

Preface

This book is the outcome of over four years work carried out, principally, by Magdy Abdel-Kader whilst studying for his Doctor of Philosophy at the University of the West of England, Bristol. Thanks are due to the Egyptian Government for the sponsorship Magdy received during his studies and to the University of Cairo which gave Magdy leave of absence during this period.

It was intended that the research should lead to an operational model of AMT decision making that incorporated the mathematics of fuzzy set theory, and this aim was achieved. Magdy's interest in this field was stimulated early in his PhD studies by a period of work in the United States under the supervision of Professor Hamid Parsaei of the University of Louisville, an expert in the application of fuzzy set techniques in advanced technology decisions. Thanks are due to Professor Parsaei for his help during the early stages of Magdy's research.

On joining the University of the West of England in February 1995, Magdy transferred supervision of his work to Peter Taylor and myself, and began his empirical work in earnest. A review of the AMT decision making literature led Magdy to the conclusion that the existing empirical literature did not sufficiently describe the manner in which these decisions were taken in practice, and this naturally led him to consider further work in this area. Two separate approaches were adopted, the first based on a questionnaire survey, and the second based on semi-structured interviews. Triangulation of research methods was adopted in order to minimise the well known weaknesses of either method when used solely.

The research design was established by the three members of the research team, and the field study interviews were carried out by Magdy Abdel-Kader and myself. The authors believe that these studies add considerably to understanding of the important strategic decisions regarding AMT. The particular design of the studies facilitated the relatively sophisticated statistical analysis, and provided insights into the practical issues that surround major investment decisions. Statistical analysis was possible because companies responding to the questionnaire survey could be divided into three categories - those not investing in AMT, those with partly integrated AMT systems and those with fully integrated systems. This part of the research, set out in 'scientific' format and focusing on the testing of a series of hypotheses, has been published in the journal *Management Accounting Research* (see Vol. 9, pp 261-284), and the authors are grateful to the publishers of the journal for permission to publish a version of the study here.

The questionnaire survey and the field study together provided a convincing description of the key features of AMT investment decision making, and this was taken as the basis for further work. This consisted of the development of an empirically grounded model which allows decision makers to use numerical approximations and/or ambiguous or vague concepts in specifying the input data. This is achieved by the use of fuzzy set theory. Through this work the existing literature has been extended by developing a model which can accept *both* numeric and linguistic data, and by proposing a novel method for ranking fuzzy numbers.

Although the authors have all made contributions to the work, the contribution of Magdy Abdel-Kader is paramount. The support of Dr John Pointon of the University of Plymouth must also be acknowledged. John has encouraged us in the preparation of this work, and his help in some of the more mathematical sections is appreciated. The authors also acknowledge the helpful advice of participants at the British Accounting Association conferences held in Plymouth (1995), London (1995), Cheltenham (1996), Birmingham (1997) and Manchester (1998), and the comments of anonymous referees. Despite the efforts of these colleagues, any errors that remain in the text, are of course, the sole responsibility of the authors.

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List of Abbreviations

AGVS	Automated guided vehicles system
AHM	Automated material handling
AHP	Analytic hierarchy process
AMT	Advanced manufacturing technologies
AS/RS	Automated storage and retrieval system
CAD	Computer aided design
CAM	Computer aided manufacturing
CAPM	Capital asset pricing model
CNC	Computer numerical control
Com	Competitiveness
DCF	Discounted cash flow
ES	Existing system
FIRR	Fuzzy internal rate of return
Flex	Flexibility
FMS	Flexible manufacturing systems
FMT	Flexible manufacturing technology
FNFM	Fuzzy non-financial measure
FNPV	Fuzzy net present value
FPB	Fuzzy payback
FRM	Fuzzy risk measure
FROI	Fuzzy return on investment
IRR	Internal rate of return
LS	Linguistic scale
NPV	Net present value
PB	Payback period
R&D	Research and development
RI	Random index
ROI	Return on investment

1 Introduction

Recent years have seen rapid changes in manufacturing, a most important sector in many economies. There is a clear trend from mass production of standard products to the production of a greater variety of custom-made products with shorter product life-cycles, as well as increasing complexity and sophistication of product design. Consumers now demand greater variety, better quality, reliability, and lower prices. To survive, manufacturing firms need to reduce production costs for small batch sizes and greater product-mix complexity, while producing consistently better quality products. Firms must also be able to introduce new products quickly, and cope with shorter delivery cycles (Naik and Chakravarty, 1992). Advanced Manufacturing Technologies (AMT) such as flexible manufacturing systems and robots help to achieve this.

Major investments such as those in advanced manufacturing systems have a significant impact on the long-term performance of the company as a whole. A study conducted by the Institute of Production Engineers (1987) concluded that investments in advanced manufacturing systems should be based on a carefully prepared manufacturing strategy which should form an integral part of overall company strategic planning.

Consider an overall strategy that attempts to achieve a broad range of differentiated products. The company seeks to differentiate its products across the complete range, looking to add unique benefits such as better quality or greater convenience. Here, manufacturing strategy might aim to acquire an advanced manufacturing system that enables the company to produce a variety of top-quality products. This may then lead the company to re-consider other strategic issues such as rationalisation or integration of facilities and improvement of workflow. Consequently, investments in AMT need to be considered as part of the overall corporate strategy, and not simply as a series of incremental capital budgeting decisions (Schroeder, 1989, p. 268).

Advocates of 'strategic' AMT investment have fiercely criticised traditional methods of financial evaluation which, they argue, unfairly disadvantage AMT projects. The flavour of these criticisms is nicely captured in the title of a paper by Robert Kaplan (1986): 'Must CIM be justified by faith alone?' The main theme of this book is the conflict between 'financial' and 'strategic' investment evaluation and efforts to synthesise the two.

This chapter begins with a review of advanced manufacturing technologies and the strategic benefits they can bring, then we turn to the criticisms of traditional investment evaluation methods.

Advanced Manufacturing Technologies

Rapid development in technology has made available a host of automated devices with diverse applications in manufacturing industries. Functional areas such as product design, product testing, process design, fabrication, spray painting, assembly, inspection, material handling, warehousing, and production planning and control have been dramatically affected by automation (Huang et al., 1991). Generally, automation refers to the use of mechanical devices controlled by a host computer that can be programmed and reprogrammed with various operating instructions.

There are many forms of AMT such as Computer Numerical Control (CNC), Robots, Automated Material Handling (AMH), Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Flexible Manufacturing Systems (FMS), and Computer Integrated Manufacturing (CIM). Following Meredith and Suresh (1986), these forms can be categorised as 'stand alone systems' (CNC and robotics), 'partly integrated systems' (AMH, CAD and CAM), and 'fully integrated systems' (FMS and CIM).

Computer Numerical Control

The basic components of an automated manufacturing system are computer numerically controlled (CNC) machine tools. A conventional machine tool, such as a turret lathe, a milling machine, or a grinder, is controlled by an operator who determines the cutting speed of the machine, the depth of cut, the initial and successive locations of the cutting tool and its movement (or alternatively that of the workpiece) to achieve the required dimension and geometry. In a CNC machine tool, the above factors are determined and controlled by a computer according to a set of instructions (part program) prepared for the product being processed. These instructions contain information necessary for machining the product, such as the movement of the tool or the workpiece specified by successive co-ordinates, cutting speed, depth of cut, etc. Each CNC machine is individually controlled by a single computer dedicated to that machine (Hilton, 1991).

Robots

The Robotics Institute of America (RIA) defined a robot as:

> 'A robot is a programmable, multi-functional manipulator designed to move material, parts, tools, or specialised devices through various programmed motions for the performance of a variety of tasks'. (Asfahl, 1992, p. 132)

Groover et al. provided a more general definition of robotics:

> 'An industrial robot is a general-purpose, programmable machine which possesses certain anthropomorphic, or humanlike, characteristics'. (1986, p. 5)

The word 'programmable' in the definitions is very important because the functions of a robot are controlled by a programmable microprocessor-based system that can be linked into a computerised work environment. Not only can it process work automatically but it can also react to a changing work environment, receiving and transmitting data relating to its function. Therefore robotics are an essential part of any computer integrated manufacturing system.

In the past, robotics have been mainly used in stand-alone activities and in the early days, they performed hot, heavy and hazardous jobs previously performed by people. In addition to these socially desirable functions a robot, once programmed, can work at the same rate continuously throughout the day without losing quality. But today the emphasis is changing. Improved productivity and quality, rather than the displacement of people, are the driving forces behind the introduction of robotics in the workplace (Kochan and Cowan, 1986).

Automated Material Handling

Automated Material Handling (AMH) comprises Automated Storage and Retrieval System (AS/RS) and Automated Guided Vehicles System

(AGVS). AS/RS is a computer-controlled stocking system in which items are stored on racks and received and retrieved using computerised robotics, cranes, and/or similar devices. AGVS provides unmanned transportation of materials in the factory and is equipped with automatic guidance devices programmed to follow certain paths.

Koening (1990) suggests that, in flexible manufacturing systems, an AGVS can be loaded by the AS/RS and material delivered via flexible pathways to any one of a number of machining centres.

Computer Aided Design

Computer Aided Design (CAD) is computer software used by engineers in the design of products or production processes. It helps to create or modify engineering designs and stores the information in a computer database. In these applications, the operator constructs a highly detailed drawing on-line using a variety of interactive devices and programming techniques. Facilities are available for replicating basic figures; achieving exact size and placement of components; making lines of specified length, width, or angle to previously defined lines; satisfying varying geometric and topological constraints amongst components of the drawing etc. (Kochan and Cowan, 1986).

Computer Aided Manufacturing

Computer Aided Manufacturing (CAM) is the term commonly used for all computer-controlled activities that are involved in turning raw material into finished products.

Flexible Manufacturing Systems

The concept of Flexible Manufacturing Systems (FMS) was developed in the late 1960s and early 1970s. There is growing interest in the development and implementation of FMS and, to date, hundreds of these systems have been implemented around the world, with Japan leading in terms of the number of applications and associated management and organisational success (Kusiak, 1985).

The United States National Bureau of Standards defines FMS as:

> 'An arrangement of machines (usually numerically controlled machining centres) with tool changers interconnected by a transport system. The transporter carries work to the machines on pallets or other interface units so that work-machine registration is accurate, rapid and automatic. A central computer controls both machines and transport system. Flexible manufacturing systems sometimes process several different workpieces at any one time'. (Nagarur, 1992. p. 799)

The Charles Stark Draper Laboratory defines a FMS as:

> 'Computer-controlled configuration of semi-independent work stations and a material handling system design to efficiently manufacture more than one kind of part at low to medium volumes'. (1984, p. 19)

It can be seen that an FMS consists of three components: work stations (mostly numerically controlled machine tools), an automated material handling system, and a network of supervisory computers and programmable logic controllers.

In FMS environments, parts are brought automatically on pallets to input stations, the material handling system allows the jobs to move from the input stations to any work or storage station, and computers process instructions, ensuring that necessary job tools are available (Medearis et al., 1990). Computers perform several functions in these systems: scheduling and monitoring operations, handling material control, and taking appropriate actions in case of sudden changes in the system.

Industrial Robots in FMS If computers are the 'brains' of FMS, robots are often the 'hands' performing a range of tasks. Robots for handling typically transfer objects from one place to another and load/unload machine tools with parts and tools. Tool-Operating Robots find wide application, for example in coating (painting, underbody protection), spot welding, machining, drilling and trimming. Assembly Robots are used to transfer and fit parts, and are usually designed to cope with variation of parts, variation in the orientation of parts, defective parts and different products assembled on the same flexible assembly line.

Computers, robots and other automated devices can offer great flexibility allowing the system to quickly adjust to any changes in relevant factors like product, process, loads and machine failures. With computer integration, it may even be possible to equip the system with a certain degree of self-diagnostic and adaptive control ability.

Computer Integrated Manufacturing

Koening (1990) sets out seven steps which in a full computer integrated manufacturing (CIM) system would be linked:

1. Obtain product specifications.
2. Design method for producing the product, including design and purchase of equipment and production processes.
3. Construct a production schedule.
4. Purchase raw materials according to the schedule.
5. Produce in the factory.
6. Monitor quality, technical compliance and cost control.
7. Ship the completed product to the customer.

In CIM all NC machines are controlled by a central computer, which also controls movement of parts by the automatic material handling system. This material handling system connects NC machines to each other as well as to the loading and unloading areas. Parts are attached to standard size pallets, which facilitates not only the movement on to the transportation system, but also the mounting of parts on to the NC machines. The dual purpose use of the pallets saves time as part locating jigs and fixtures are not necessary. Various types of automatic material handling systems may be used, including power roller conveyors, shuttle conveyors, automatic guided vehicles and robotics. In addition, the central computer is also used for process design, planning, monitoring and control, shop floor controls, inventory control, and preparation of performance evaluation reports. It can also be used to direct and monitor automatic quality control checks and tests (Dhavale, 1989). In short, when all activities in the factory are linked through a central computer, the factory is considered to have CIM.

Benefits of AMT

The decision to invest in AMT may be motivated by a variety of reasons. O'Brien and Smith (1993) identified the following:

1. Adding capacity to meet increased demand and/or product variety.
2. Meeting the need for constant replacement of old and obsolete technology. Rarely is such new investment an exact replica of the old, and considerable adaptation may be required if the full potential of new technologies is to be exploited.
3. Exploiting wider opportunities in product and process innovation.
4. Obtaining major strategic benefits by improving the competitive advantage of an organisation. Investment could, for example, open up new markets for a company or be the only means of surviving in existing markets. Shortening the time to market, optimising the use of available skills, improving quality, increasing product life through innovation and promoting flexibility in products and processes are all areas which may enhance an organisation's ability to deal with uncertainty and hence survive in an increasingly dynamic and competitive environment.
5. Although innovation and product quality are essential in securing market share, no company can hope to remain competitive without continued attention to the reduction of manufacturing costs. The trend toward "lean production" requires attack on costs in every area of a company's activities.

AMT can provide a range of benefits. The following are commonly cited:

1. Reduced direct labour costs. Direct labour costs are generally reduced when automated equipment is purchased. However, this reduction is rarely sufficient to justify automation.
2. Reduced inventory costs. Automated equipment is more reliable, more consistent, and faster than traditional equipment. Therefore, it can reduce inventory costs by reducing the quantity of inventory on hand, and by releasing space for other uses.
3. Reduced quality costs. Due to greater reliability and consistency of output, automation results in less defects and less waste, scrap, and rework costs. In turn, reduction in defects and related problems lead to reduction in warranty expenses. Also, greater product uniformity and reliability mean that fewer inspections are needed.
4. Faster throughput time. The greater efficiency of an automated process will decrease the production throughput time and can therefore increase the total output for a given period.

5. Increased manufacturing flexibility. Set-up time can be reduced through automation, thereby increasing manufacturing flexibility. Also, the flexibility of automated equipment usually means a longer life than traditional equipment.
6. Faster response to market changes. Due to the flexibility of automated equipment, the firm can respond more quickly to changes in customer tastes and needs.
7. Increased learning effects. Automating a facility or a process is difficult, both in a technical and an operational sense. Firms that hold back, fearing the complexities of automation, soon fall behind their competitors in recognising and in being able to utilise the newer technology as it comes onto the market.
8. Avoiding capital decay. Capital decay can be defined as a loss in market share resulting from technologically obsolete products and operations. Retention of market share, or even an increase in market share, is perhaps the most significant intangible benefit that can be gained from automation. Some firms reject automation after assuming that sales will remain unchanged even if they do not automate. However, if a more efficient process is available, a competitor undoubtedly will invest in it, thereby gaining a competitive advantage (O'Brien and Smith, 1993). The appropriate assumption is that if a firm fails to take advantage of a new technology, it will not be able to maintain the status quo in terms of sales; rather, sales are likely to decline.
9. Higher quality output. Automation allows a higher quality of output that can greatly strengthen the image and competitive position of a company. Higher quality promotes confidence on the part of customers and improved reliability that can provide access to expanding, world-wide markets.

The major difficulty in justifying AMT investment is in accounting for all the benefits which should be gained. Some benefits such as direct labour savings, direct material savings, less frequent set-ups, higher quality output, and the savings from reduced material and in-process inventories can be quantified. However, a second category of more intangible benefits such as: greater manufacturing flexibility, learning effects, and improved employee morale cannot be easily quantified. In the following chapters we shall evaluate the suggestions that have been made to overcome this problem and develop a an appropriate model for investment decision making regarding AMT.

Traditional Investment Appraisal

Traditional investment models based on return on investment (ROI), payback period (PB) and discounted cash flow (DCF) methods are widely used to evaluate potential investment projects in practice (Somers and Gupta, 1991; Wilner et al., 1992; Primrose et al., 1985; Primrose and Leonard, 1986a; and Kulatilaka, 1984). Theoretically, the discounting methods: net present value (NPV) and internal rate of return (IRR), are preferred, and in addition, a US survey (Wilner et al., 1992) reported that a large percentage (70%) of firms specified one of the DCF methods as the primary technique for the evaluation of high technology investments.

To use DCF methods three estimates are required (Chan and Lynn, 1993): a forecast of annual net cash flows, a discount rate (theoretically, the firm's cost of capital), and an estimate of the life of the project. The firm should invest if the NPV of the estimated cash flows is positive or, alternatively, if the IRR exceeds the firm's cost of capital.

The application of traditional appraisal methods to AMT projects usually follows a standard procedure based on the identification of the relevant cash flows, which are the incremental cash flows of the project if adopted. As the subsequent analysis can only be as good as the data on which it is based, every effort should be made to estimate the cash flows as accurately as possible. While projected benefits will often be subjective (and quantification of some benefits may prove impossible), it should be possible to establish fairly accurate cost estimates for the project. We briefly review some of the issues which ought to be considered.

Acquisition (or Initial) Costs

The decision to purchase any form of AMT is different from an investment in conventional technology. AMT cannot be bought off the shelf and plugged into the factory. The system (hardware and software) may be bought from machine tool manufacturers or from vendors, and the interfacing may be designed in-house. The final cost will thus exceed the initial purchase cost due to the costs of interfacing, rearrangement, and modification (Kulatilaka, 1984). In new plants that are *designed* around advanced technology, these costs will be less.

One important factor that may be overlooked is the opportunity cost of existing assets or resources. For example, the opportunity cost that may arise from using an asset which is already owned by the firm in the new system, or from the time lost during the process of transformation from the conventional manufacturing system to the advanced one. Such costs should be considered in the evaluation process.

Annual Operating (or Running) Costs

The operating costs of AMT include all the costs which the system needs to run effectively. These costs mainly consist of factory costs (which include direct material, direct labour, and overhead), and selling and administrative expenses.

Klahorst (1986) indicates that for the economic evaluation of FMS there are 14 cost factors that should be considered:

1. Direct labour costs.
2. Material set-up costs.
3. Tooling costs.
4. Materials handling costs.
5. Part inspection costs.
6. Equipment maintenance costs.
7. Shop supervision costs.
8. Production control costs.
9. Manufacturing engineering costs.
10. Plant facility costs.
11. Inventory costs.
12. Fixturing costs.
13. Prototype and new part costs.
14. Rework and scrap costs.

Investment Decisions for AMT

Although consideration of the acquisition of AMT is an investment decision, AMT systems have special characteristics that make the evaluation process more complex than for conventional types of manufacturing systems. First, advanced systems are capital intensive. They require a huge amount of investment in all stages of implementation - planning, purchasing, installing and operating- even when only a few items are purchased. Second, advanced systems are much more flexible than conventional systems. This flexibility maintains the value of the equipment over the long run, reducing its rate of depreciation. However, the advantages of such flexibility are not easily quantified in traditional appraisal methods. Third, there is synergy when advanced technologies are linked together. Users consistently report qualitative benefits from such linked systems, such as fast response to future customers needs that are deemed more important than the normal cost savings (Meredith and Suresh, 1986 and Garrison, 1991). Finally, lack of experience of high technology systems can make them risky decisions.

The specific nature of AMT projects has caused many authors to criticise the application of traditional investment models in evaluating AMT investments (see, for example, Medearis et al., 1990 and Mensah and Miranti, 1989). The criticisms are of two main kinds. First, traditional investment models emphasise quantitative, financial analysis, but it is argued, fail to capture many of the 'intangible' benefits which should flow from AMT investment. Second, traditional models may militate against AMT investments through high discount rates and short payback targets which systematically penalise long-term investments. Recognition of these issues has led a number of researchers to conclude that traditional investment models should not be used to evaluate investment in AMT.

A major problem when applying traditional investment models to AMT decisions is the failure of these models to quantify all of the benefits of the acquisition of automation. Traditional models focus only on future net cost savings such as reduced labour and energy costs which are easily quantifiable, and they ignore the other benefits such as improved product quality, greater manufacturing flexibility, learning effects, effects on employee morale, and short lead times. Consequently, these models lead to investment myopia, in particular, creating a bias against 'strategic' investment in AMT. This problem is stressed in almost all of the relevant literature (see, for example, Chen and Small, 1996; Accola, 1994; Cheung, 1993; Lavelle and Liggett, 1992; Naik and Chakravarty, 1992; Azzone et al., 1992; Rayburn, 1989; Park and Son, 1988; Srinivasan and Millen, 1986; Kaplan, 1986; ACARD, 1983; and Knott and Getto, 1982).

However, Primrose (1991) dissents from this broad consensus. He denies the existence of the quantification problem claiming that all the benefits of AMT are quantifiable in cash flows through their effect on current sales and costs (see also, Primrose and Leonard, 1986a; 1986b; 1987). This may be true for some benefits such as reduced floor space, reduced inventories and reduction in rework, inspection and warranty costs, but quantifying benefits such as flexibility, learning effects, reduced lead times, employee morale or quality is, at best, a complex task, and, at worst, almost impossible to undertake. Arguably, these benefits are most critical in evaluating the decision of whether to acquire AMT.

The problems inherent in quantifying AMT benefits can be illustrated by trying to estimate the cash flows from increased product quality. Four relevant dimensions of product quality can be identified: product durability, product reliability, product aesthetics, and product performance. These attributes, in turn, depend on three factors: the product design, the materials used in making the components, and the engineering specifications and tolerances observed in product manufacture. The trade-off between these factors and their effects on product costs and market niche has to be assessed as a part of organisational strategy. Also, the savings resulting from reduced raw material and in-process inventories are not easy to estimate because the relationship between organisational costs and the level of inventories is not well-defined. Additionally, these costs vary with the volume of discrete events such as the frequency of set-ups and the number of different types of products, and not with the volume of output. Under these circumstances, cash flow estimates depend on expected future management action with respect to organisational costs (Mensah and Miranti, 1989).

Meredith and Suresh (1986) argue that evaluating AMT investments on the basis of traditional investment models represents a major roadblock to the automation of many factories. There is very little doubt that non-investment in AMT can, in many cases, have serious long-term consequences and that innovation and change are part of our daily business life (Lefley, 1996). Companies failing to recognise the importance of taking opportunities provided by technological improvement in manufacturing can risk their continued profitability and long-term survival (ACARD, 1983; Attaran, 1992; Lefley, 1996; and Chen and Small, 1996). Lefley (1996) summarises the problem as follows:

> '... Management is placed in a dilemma in that on the one hand they wish to invest in new technology, such as AMT, but on the other hand they find it difficult to justify the capital expenditure using traditional financial appraisal techniques. The conventional financial evaluation methods are well-established, well documented, while the methodologies for evaluation of strategic, intangible benefits ... are less formalized and less understood. Evidence suggests that there is a need for a more sophisticated approach to the appraisal of AMT projects, one that will take into account the strategic nature and the full benefits from such investments'. (p. 347)

The need for a more sophisticated approach for the evaluation of AMT investment was also a conclusion of an earlier empirical study conducted by Currie (1994). She stated that:

> '... The study concludes by suggesting that new methods of evaluating AMT should be developed which include a wider array of financial and non-financial benefits. This would improve managements' understanding of some of the key advantages of AMT and, in the process, supplement traditional management accounting techniques (DCF, NPV, payback) by considering the benefits of quality, organisational learning, training and process improvement and innovation'. (p. viii)

The implications of this issue are clear. While DCF methods may be economically sound, their application is often deficient in relation to AMT investment because major qualitative variables are ignored. As both Lefley (1996) and Currie (1994) suggest, new, more sophisticated methods of AMT investment appraisal are needed, extending traditional DCF methods so that *all* costs and benefits associated with AMT proposals are properly evaluated. We begin our discussion of such models in chapter 2.

A further problem in evaluating AMT investments is how to consider a project's risk in the investment decision model. Strictly, there is a difference between the terms 'risk' and 'uncertainty'. The term risk should be used when it is possible to assign objective probabilities while uncertainty implies that it is not possible to assign such probabilities (see, for example, Pike and Dobbins, 1986). However, the term risk is used here to refer to the uncertainty of obtaining the expected benefits (tangible or intangible) from an investment project.

One method often used to account for the high risk inherent in new technologies is the use of an arbitrarily high hurdle discount rate (see, for example, Accola, 1994; Canada and Sullivan, 1990; Kaplan and Atkinson, 1989; and Kaplan, 1986). This method suffers from two main criticisms. First, arbitrarily high hurdle thresholds favour short-term projects over long-term projects which have large cash flows in the latter part of their lives. This is because the discount rate compounds geometrically each time period, so cash flows received five or more years in the future will be penalised severely in the analysis. Also, as pointed out by Kaplan and Atkinson (1989), much of the risk from new technologies will probably be resolved early in the project's life. If there is uncertainty as to whether a new piece of equipment or new technology will work, the outcome will be known in the first or second year. Second, Accola (1994) and Ronen and Sorter (1972) objected to this approach on theoretical grounds because it uses a single measure to reflect both expected cash flows and the riskiness of the expected cash flows. As there are many different determinants of risk, it is difficult to capture all aspects of a project's riskiness through a single modification of the discount rate. Also, adjustments to the discount rate are affected by managers' attitudes toward risk rather than by an explicit representation of the risks inherent in the investment alternatives.

Outline of the Text

The remainder of the text sets out the issues in AMT investment decision making and recommends a new approach that can take account of *all* the decision factors and permits the estimation of input variables in terms such as 'about £2 million' or 'product quality is important'. Often in practice, the inputs to the decision model are specified in exact terms and the inherent vagueness in the basic data is ignored (and forgotten!) in subsequent analysis.

In chapter 2, previous AMT decision models are reviewed. Typically, these are based on multi-attribute scoring and lead to an overall 'score' for each alternative under consideration. The models range from the simple weighting of individual attributes to the relatively sophisticated analytic hierarchy process which allows sub-dimensions to be specified for each decision attribute. We conclude that these models suffer from two major drawbacks. First, there is scant justification for the particular models chosen or for the variables included (and excluded) in the decision process. Second, most of the models require exact estimates of the input data.

The lack of justification for the extant models is addressed in chapters 4 and 5. Chapter 4 reports the findings of a questionnaire survey of major UK manufacturing companies specifically designed to identify the key issues that must be addressed when evaluating AMT projects. Chapter 5 reports the results of a field study of nine UK companies. A series of AMT cases are reported, insights drawn and a number of general conclusions reached. The questionnaire survey and field study support each other and allow the development of an AMT investment model which is empirically grounded and which should therefore find favour with practitioners.

Chapter 6 introduces fuzzy set theory as a means of handling approximate or vague estimates. Much of this chapter is a distillation of the existing literature. However, the analysis reveals some difficulties with existing methods, especially in relation to the ranking of fuzzy numbers. This is a particularly important issue when choosing between competing investment projects and, therefore, a new ranking method is proposed which may be an improvement on previous suggestions.

Chapter 7 develops a model for AMT investment decision making based on the pre-existing descriptive literature and the results of empirical studies reported in chapters 4 and 5. The analytic hierarchy process and fuzzy set theory provide the mathematical tools which form the basis of the model. The model represents a synthesis of several previous models and the authors' empirical work and is designed to address both theoretical issues (such as combining both quantitative and qualitative variables) and the incorporation of variables and features which make the model credible to practitioners.

Chapter 8 provides an overview of the book as a whole, drawing together a number of themes and suggesting possible directions for future research.

2 A Review of Previous Models for the Evaluation of Investment Decisions in AMT

Two major problems in applying traditional models for evaluating AMT investments have been discussed in the previous chapter: the problem of quantifying the intangible benefits of AMT investments, and the problem of measuring and incorporating project risk into the investment model. These problems have led to a growing literature devoted to investigating them and providing possible solutions. This literature can be divided into two major strands. In the first strand researchers attempt to develop theoretical models which aim to overcome the shortcomings of traditional investment decision models based on ROI and cash flow analysis. This type of research can be described as 'normative'. The second strand of literature is based on empirical investigation of the practice of AMT investment decision making by either survey based research or field studies. This type of research can be described as empirical or 'descriptive' research. The major difference between these two strands is that normative researchers seek to formulate decision models that describe *how decisions should be made* while descriptive researchers seek to explore the practice of decision models *as it exists* (see, for example, Ijiri, 1972; Bell et al., 1988; and Ryan et al., 1992). Bell et al. (1988) add a third type of decision making research which they call 'prescriptive' research. They use this term to describe a type of research which combines both normative and descriptive approaches in producing a decision model.

The extensive literature includes numerous normative (theoretical) models specifying how AMT investment decisions ought to be made, but few descriptive (empirical) studies which describe AMT investment decision making practice and no prescriptive research studies. In subsequent chapters an empirically grounded normative model for evaluating AMT investments is developed thus contributing to the 'prescriptive' AMT investment decision making literature.

In this chapter 'normative' models of AMT investment decision making are reviewed. Empirical studies are reviewed in the next chapter.

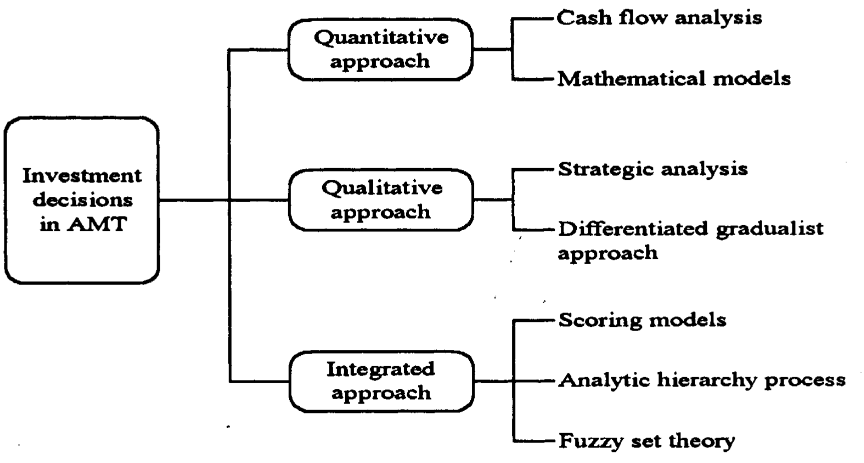

Figure 2.1 A proposed classification scheme

Much of the literature of AMT investment decision making emphasises the problem of quantifying intangible benefits. The literature can be classified into three approaches: quantitative, qualitative and integrated[1], see figure 2.1. Each of these will be considered in turn.

The Quantitative Approach

This approach focuses mainly on easily quantifiable variables. Traditional financial appraisal methods are considered in the next section, and then various mathematical models are reviewed.

Cash Flow Analysis

The most common cash flow based analyses are payback calculations and discounting methods (net present value and internal rate of return)[2]. These methods are widely used. For example, a survey conducted by Klammer et al. (1991) showed that 42% of one hundred US large industrial firms used the payback method as a primary or secondary technique and the discounted cash flow methods, IRR and NPV were used by 57% and 46% of firms respectively in the evaluation of high technology investments.

Payback Period Method The payback period is the time required to recover the initial investment outlay. The project is acceptable if the payback period is equal to or less than a predetermined payback period. The method assumes that the project with the shortest recovery period is the best/lowest risk project. The payback period method has many advantages and is much used in practice. The advantages include: quick and simple to calculate; needs minimal information for computations (Randhawa and West, 1992); and no need to forecast cash flows over the whole project life (Lumby, 1995, pp. 42-43).

However, the payback period method has been criticised for its use in evaluation of investments in general and particularly investments in AMT because: it is short-term as it ignores cash flows after the payback point, and hence is biased against investments with higher returns in their later years, and is inadequate for rigorous analysis of all the variables and for systematic comparison of competing projects.

Primrose and Leonard (1986) also drew attention to the difficulty of determining the required payback period. They considered the relationship between IRR and payback period using a hypothetical example, and showed that companies using a 2 year payback period require an after-tax IRR of 49%, and companies using a 3 year payback period require an after-tax IRR of 31% (see figure 2.2).

The extremely high IRRs calculated were due to two defects in the payback method. First, cash flows after the payback period are ignored, and, second, the time value of money is not taken into account. The latter defect can be overcome by using discounted cash flows instead of 'pure' (non-discounted) cash flows. For example, assume the estimated cash flows of a project during its 5 year life are:

Year	Cash flows (£)
0	(300,000)
1	100,000
2	120,000
3	120,000
4	90,000
5	50,000

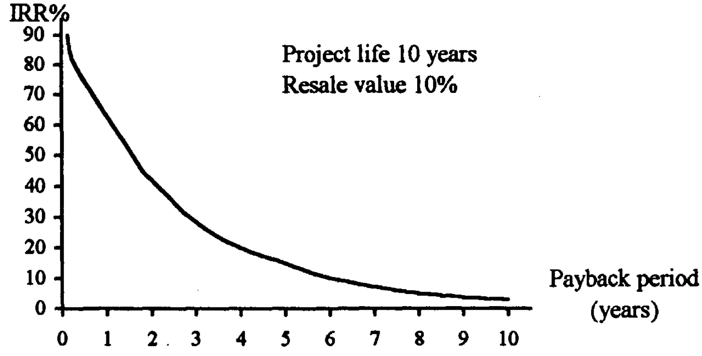

Figure 2.2 A relationship between IRR and Payback period

Source: Adapted from Primrose and Leonard, 1986a, p. 290.

Assuming the cash flows are realised at the end of each year, the payback period is 3 years. However, assuming that 10% is an appropriate discount rate, the discounted payback period is computed as follows:
Discounted cash flows:

Year	Cash flows	× Discount factor	=	Present Value
0	(300,000)	× 1	=	(300,000)
1	100,000	× 0.909	=	90,900
2	120,000	× 0.826	=	99,120
3	120,000	× 0.751	=	90,120
4	90,000	× 0.683	=	61,470
5	50,000	× 0.621	=	31,050

The discounted payback period is 4 years as compared against 3 years for simple payback.

DCF Methods Net present value (NPV) and internal rate of return (IRR) are both discounted cash flow (DCF) methods. The NPV is the figure that represents the sum of future cash flows (positive or negative) discounted to time zero (equation 2.1).