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EVALUATING INVESTMENTS IN ADVANCED MANUFACTURING TECHNOLOGY: A FUZZY SET THEORY APPROACH

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In this paper, a model for the evaluation of investments in advanced manufacturing technology is developed. Many authors have called for an integration of financial and non-financial factors in such evaluations, and this paper demonstrates that it is conceptually possible to do this using the mathematics of the analytic hierarchy process and fuzzy set theory. The development of the model has certain distinguishing features. First, it is based on a conceptual framework that combines the three dimensions of risk, financial return and non-financial factors. The empirical basis for this has been investigated and previously reported by the authors. Second, models previously developed and reported in the literature are shown to suffer from certain flaws relating to the use of linguistic scales, the ranking of fuzzy performance indicators and partiality in the treatment of investment decision variables. These issues are addressed through the development of simpler linguistic scales based on the analytic hierarchy, a revised procedure for ranking fuzzy numbers and an attempt to build a comprehensive model through the three dimensions described above. Triangular fuzzy numbers are used throughout in order to make the mathematics tractable and relatively easy to understand, and to facilitate presentation of a worked example. However, so that the reader is not misled, attention is drawn to some of the complexities in fuzzy arithmetic, especially the important distinction between subtraction/division and deconvolution of fuzzy numbers.

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INTRODUCTION

The use of traditional investment models based on return on investment (ROI) or cash flow analysis, payback, net present value, internal rate of return, for Advanced Manufacturing Technology (AMT) projects has been criticized for failing to capture all relevant information. Arguably these models emphasize quantitative, financial analysis but fail to capture many of the 'intangible' benefits that should flow from AMT investments such as greater manufacturing flexibility, improved product quality and better employee morale (see for example, Abdel-Kader, 1997; Chen & Small, 1996; Dugdale & Jones, 1995; Accola, 1994; Cheung, 1993; Lavelle & Liggett, 1992; Naik & Chakravarty, 1992; Azzone *et al.*, 1992; Rayburn, 1989; Park & Son, 1988; Srinivasan & Millen, 1986; Kaplan, 1986; ACARD, 1983; Knott & Getto, 1982).

It is also argued that the high risk inherent in new technologies often leads to the use of arbitrarily high hurdle discount rates (Accola, 1994; Canada & Sullivan, 1990; Kaplan & Atkinson, 1989; Kaplan, 1986). This disadvantages long-term projects with large cash flows in the later part of their lives, and because there are many different determinants of risk, it is difficult to capture them all through a single modification of the discount rate (Ronen & Sorter, 1972). 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 (Accola, 1994).

Lefley (1996, p. 347) concluded: '*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'. (*emphasis added*). This echoed Currie (1994, p. viii) who argued for: '...*a new method of evaluating AMT should be developed which includes 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' (*emphasis added*). Slagmulder *et al.* (1995) summarized: '... more and more authors are convinced that good investment appraisal requires that strategic and financial considerations be reconciled and integrated'.

In response to this need 'integrated' models that can accept both quantitative and qualitative factors have been suggested. Simpler models are based on a weighted combination of attribute scores (Meredith & Suresh, 1986; Nelson, 1986; Parsaei & Wilhelm, 1989) while more sophisticated models are often based on the Analytic Hierarchy Process (AHP) (Naik & Chakravarty, 1992; O'Brien & Smith, 1993; Srinivasan & Millen, 1986; Putrus, 1990; Accola, 1994; Angelis & Lee, 1996). However, even these relatively sophisticated models can be criticized because the use of precise values does not reflect the qualitative and subjective nature of many factors.