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Fuzzy multi-criteria decision-making procedure for evaluating advanced manufacturing system investments

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Abstract

In this paper, a fuzzy decision algorithm is proposed to select the most suitable advanced manufacturing system (AMS) alternative from a set of mutually exclusive alternatives. Both economic evaluation criterion and strategic criteria such as flexibility, quality improvement, which are not quantitative in nature, are considered for selection. The economic aspects of the AMS selection process are addressed using the fuzzy discounted cash flow analysis. The decision algorithm aggregates the experts' preference ratings for the economic and strategic criteria weights, and the suitability of AMS investment alternatives versus the selection criteria to calculate fuzzy suitability indices. The fuzzy indices are then used to rank the AMS investment alternatives. Triangular fuzzy numbers are used throughout the analysis to quantify the vagueness inherent in the financial estimates such as periodic cash flows, interest rate and inflation rates, experts' linguistic assessments for strategic justification criteria, and importance weight of each criterion. A comprehensive numerical example is provided to illustrate the results of the analysis.

Keywords: Fuzzy decision analysis; Multi-criteria decision-making; Investment analysis; Flexible manufacturing systems

1. Introduction

Investment evaluation methods play an important role in today's competitive manufacturing environment. Shrinking profit margins and diversification require careful analysis of investments, and the decisions regarding these investments are crucial to the survival of the manufacturing firm. Lately, the manufacturing firms have been investing in advanced manufacturing technologies such as group technology, flexible manufacturing systems, computer-integrated manufacturing systems, etc. to improve manufacturing performance in terms of cost, productivity, flexibility and quality, in an effort to compete with other industrialized firms in the global marketplace.

Flexibility in a manufacturing environment can be defined as the capability and ease of accommodating changes in the system. Flexibility ensures that manufacturing can be both cost effective and customized at the same time [1]. A single widely-accepted measure for flexibility does not exist, and thus, there is a continuing research on this subject [2]. Flexibility of advanced manufacturing systems provides faster throughput, reduces cost of retooling for design changes, allows for smoother scheduling, and provides an ability for production volume adjustments to handle unanticipated

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demand changes with low levels of inventory [3]. In summary, flexibility results in considerable enhancement in responding to changes in market demand, product design and product mix.

According to Meredith and Suresh [4], investment justification methods in advanced manufacturing technologies are classified into economic analysis techniques, analytical methods, and strategic approaches. These methods deviate from each other mainly due to the treatment of non-monetary factors. Economic justification methods of manufacturing investments have been discussed thoroughly in the past couple of decades [5]. Economic analysis methods are the basic discounted cash flow techniques such as present worth, annual worth, internal rate of return, etc., and other techniques such as payback period and return on investment which ignore time value of money. The application of these techniques to the evaluation of flexible manufacturing system (FMS) investments is analyzed in [6]. It is well known by engineering economy practitioners that accounting methods, which ignore time value of money, would produce inaccurate or at best approximate results.

Discounted cash flow (DCF) methods appear as the most popular economic justification methodology; however, determining cash flows (revenues, expenses) and discount rates as crisp values can lead to erroneous results in most of the real-life applications. The probabilistic cash flow analysis can be used if the probabilities of the possible outcomes are known. However, when the frequency distribution of the possible outcomes is not known as for the revenues and expenses of a new product line, most decision-makers employ experts' knowledge in modeling cash flows in the evaluation phase [7,8].

The conventional DCF methods do not appear to be suitable on their own for the evaluation of an advanced manufacturing system (AMS) investment due to the non-monetary impacts posed by the system. Sullivan [9] points out the inadequacy of traditional financial justification measures of project worth such as return on investment, payback, net present worth in considering the strategic merits of advanced manufacturing technologies. The results of the surveys conducted by Lefley [10] for justification of advanced manufacturing technology (AMT) in the UK, and by Lefley and Sarkis [11] for appraisal of AMT investments in the UK and US both indicate the support for the difficulty in assessing AMT investments due to their non-quantifiable benefits. Due to this difficulty, over 80% of the respondents in the US and UK point out that not all potential benefits of AMT investments are considered in the financial justification process. Furthermore, the results of the surveys state that subjective assessment of AMT investment with/without financial justification is observed in approximately 60% of the manufacturing firms responding to the questionnaire. Improvements in product quality, reliability, production efficiencies, competitiveness as a result of the versatility and flexibility of the system are the focal points in the justification stage of an AMS investment. Productivity, quality, flexibility and other intangibles should be examined in terms of potential returns through enhancement of long-term business competitiveness as well as in terms of a comprehensive evaluation of internal costs [5].

When flexibility, risk and non-monetary benefits are expected, and particularly if the probability distributions can be subjectively estimated, analytical procedures may be used. Strategic justification methods are qualitative in nature, and are concerned with issues such as technical importance, business objectives, competitive advantage, etc. [4]. When strategic approaches are employed, the justification is made by considering long-term intangible benefits. Hence, using these techniques with economic or analytical methods would be more appropriate. Fig. 1, which is an updated version of the classification initially proposed by Meredith and Suresh [4], resumes the justification methods for advanced manufacturing technologies.

Since certain criteria cannot be expressed in quantitative terms, a number of articles focus on integrating the qualitative and quantitative aspects to evaluate the benefits of AMS. Wabalickis [12] develops a justification procedure based on the analytic hierarchy process (AHP) to evaluate the numerous tangible and intangible benefits of an FMS investment. Naik and Chakravarty [13] point out the need for integrating the non-financial and strategic benefits of AMS with the financial benefits, and propose a hierarchical evaluation