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Quantification of flexibility in advanced manufacturing systems using fuzzy concept

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Abstract

Unlike classical logic which requires a deep understanding of a system, exact equations, and precise numeric values, fuzzy logic incorporates an alternative way of thinking, which allows modeling complex systems using a higher level of abstraction originating from our knowledge and experience. To obtain a sensible result in quantifying the manufacturing flexibility, this paper proposes some fuzzy models based on fuzzy present worth and fuzzy mathematical programming. The fuzzy models based on present worth are basically engineering economics decision models in which the uncertain cash flows and discount rates are specified as triangular fuzzy numbers. Fuzzy present worth formulae of the manufacturing flexibility elements are formed. Using these formulae, more reliable results can be obtained especially for such a concept like flexibility that is described in many intangible dimensions. The fuzzy models based on fuzzy mathematical programming allow decision-makers use upper and lower bounds for the attainment of the objectives and soft constraints. These models allow experts' linguistic predicates about advanced manufacturing systems.

Keywords: Flexible manufacturing systems (FMS); Fuzzy numbers; Manufacturing flexibility; Present worth analysis; Mathematical programming

1. Introduction

The term ‘‘advanced manufacturing systems’’ (AMS) is broadly defined to include any automated (usually computer oriented) technology used in design, manufacturing/service, and decision support. Components of AMS include computer-aided engineering, factory management and control systems, computer-integrated manufacturing processes, and information integration (Canada and Sullivan, 1989).

Many factories have reached an intermediate stage, often called flexible manufacturing system (FMS). At this stage some machine tools, material-handling equipment, and other programmable devices are under the integrated control of a computer. FMSs can manufacture a wide range of products in batch sizes from one to thousands. They provide many important benefits such as greater manufacturing flexibility, reduced inventory, reduced floor space, faster response to shifts in market demand, lower lead times, and a longer useful life of equipment over successive generations of products.

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Manufacturing flexibility may be defined as the ability to cope with changing circumstances or instability caused by the environment (Gupta and Goyal, 1989; Mandelbaum, 1978; Mascarenhas, 1981; Primrose and Verter, 1996). It is a complex, multi-dimensional and difficult-to-synthesize concept. It is not very well understood, and many different terms for various types of flexibility can be found in the literature. This is due to (1) the scope of the flexibility related terms overlap considerably, (2) some terms are aggregates of others, (3) identical terms used by various writers often do not necessarily mean the same thing (Swamidass, 1988).

Application of traditional capital budgeting methods does not fully account for the benefits arising from increased flexibility. In showing how all benefits could be quantified, it was found that the benefits that managers had been ignoring as intangible were often much larger than direct savings such as labor and inventory that they had tended to concentrate on (Primrose and Verter, 1996). Since flexibility is an important intangible evaluation factor in the overall economic justification process for AMS, it is important to refine the existing methods of quantifying flexibility before making any attempt to build the general framework for economic justification.

In the literature, most if not all of the methods quantifying flexibility in monetary terms include deterministic or stochastic approaches. In such methods, the values of parameters are assumed either to be certain or to have a probabilistic distribution. If sufficient objective data is available, probability theory is commonly used in decision analysis. Unfortunately, decision-makers rarely have enough information, since probabilities can never be known with certainty and the decision is attributable to many uncertain derivations. In this situation, for modeling decision problems, most decision-makers rely on experts' knowledge that usually can be expressed only in a linguistic form. For example, the phrase "high flexibility" can be interpreted in many different ways depending on the situation.

Fuzzy Logic is basically a multi-valued logic that allows intermediate values to be defined between conventional evaluations like yes/no, true/false, black/white, etc. By using fuzzy logic, notions like rather warm or pretty cold can be formulated mathematically and processed by computers. In this way an attempt is made to apply a more human-like way of thinking in the programming of computers. Fuzzy Logic was initiated in 1965 by Zadeh (1965), professor for computer science at the University of California in Berkeley. A major contribution of fuzzy set theory is its capability of representing vague knowledge.

This paper aims at evaluating flexibility elements in monetary terms using a couple of fuzzy approaches based on mathematical programming and present worth analysis. To accomplish this aim, the remainder of the paper is organized as follows: Section 2 informs the reader about classification and quantification of flexibility using a literature review. Section 3 introduces fuzzy sets and fuzzy numbers briefly. Section 4 analyzes fuzzy mathematical programming and develops two models for quantifying flexibility. Section 5 defines fuzzy present worth analysis, develops two models based on this analysis, and illustrates the application of one of these models by giving a numeric example. Finally, we conclude by summarizing the findings obtained in this study.

2. Classification and quantification of flexibility

Despite the wide interest, flexibility remains poorly understood in theory and poorly utilised in practice. One of the reasons for this is lack of general agreement on how to define flexibility. Owing to its very nature, any measure of flexibility has to be user or situation specific. This explains the existence of many different measurement schemes (depending upon the viewpoint of the author) and also the lack of universal acceptance of any one scheme. Shewchuk and Moodie (1998) develop a framework and classification scheme to use in defining and classifying the various terms regarding flexibility found in manufacturing. Choi and Kim (1998) propose a new concept of flexibility called comprehensive flexibility. It is an integrated performance measure that covers various types of flexibility in manufacturing systems.