Int. J. Production Economics 129 (2011) 157–168

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

A survey of the application of fuzzy set theory in production and operations management: 1998–2009

Bo K. Wong [a,*], Vincent S. Lai [b]

[a] Department of Computing and Decision Sciences, Lingnan University, Tuen Mun, New Territories, HKSAR, China
[b] Department of Decision Sciences and Managerial Economics, Faculty of Business Administration, The Chinese University of Hong Kong, Shatin, New Territories, HKSAR, China

ARTICLE INFO

Article history:
Received 3 December 2008
Accepted 1 September 2010
Available online 24 September 2010

Keywords:
Production and operations management
Fuzzy set theory
Research
Review

ABSTRACT

The objectives of this research are to identify the research trends in and publication outlets for the applications of the fuzzy set theory technique in production and operations management (POM). The major findings indicate that (1) the most popular applications are capacity planning, scheduling, inventory control, and product design, (2) some application areas make more use of particular types of fuzzy techniques, (3) the percentage of applications that address semi/unstructured types of POM problems is increasing, (4) the most common technologies integrated with the fuzzy set theory technique are genetic/evolutionary algorithms and neural networks, and (5) the most popular development tool is C Language and its extension. Our survey confirms several research trends, some of which are unexpected and some of which contradict previous findings.

1. Introduction

In the 1960s, Professor Lotfi Zadeh created fuzzy set theory to mathematically represent uncertainty and vagueness. This theory reflects human reasoning in its use of approximate information and uncertainty to generate decisions. It has further been used to develop formalized tools to deal with the imprecision intrinsic to a wide variety of problems. Over the past four decades, fuzzy set theory has gained in popularity, and there are now more than 2000 commercially available products that make use of it, ranging from washing machines to high-speed trains. Nearly every application is potentially able to realize some of the benefits of fuzzy set theory, including better performance, higher productivity, better efficiency, and lower cost.

In academia, most of the early fuzzy set theory research focused exclusively on scientific applications. It was not until the late 1980s that this state-of-the-art technique was used to develop a wide variety of business applications and that, as a result, an increase in amount of published research began to appear. In particular, research into the application of fuzzy set theory in the area of production and operations management (POM) has been very successful and thus remains prolific.

Three reviews of the use of fuzzy logic in POM applications have been published in the literature. Du and Wolfe (1997) explored the use of fuzzy logic and neural networks in industry, particularly in the areas of scheduling and planning, inventory control, quality control, group technology, and forecasting, and suggested four types of integration between the two to-stimulate future research. Proudlove et al. (1998) carried out a review of the use of various artificial intelligence (AI) techniques as solutions to eight areas of POM, although fuzzy logic was briefly discussed in only two of these application areas, namely, product design and scheduling. The most recent review was a survey of AI and operational research (OR) in POM conducted by Kobbacy et al. (2007). Their study examined four AI techniques, namely, genetic algorithms (GAs), case-based reasoning, knowledge-based systems, fuzzy logic, and hybrid systems. They then discussed the application of each technique in four areas of operations management, including design, scheduling, process planning and control and quality, maintenance, and fault diagnosis. These reviews presented an overall view of the use of AI techniques in certain POM applications, but did emphasize fuzzy logic techniques and covered only a few POM areas. In addition, two of the reviews are somewhat out-of-date, as they were conducted about 12 years ago. Furthermore, none of them surveyed the historical trends in fuzzy set theory applications or analyzed and identified the potential journal publication channels for related research.

Our study has two objectives. The first objective is to examine the historical trends in published fuzzy set theory research into POM applications, and particularly the trends related to application areas, methods, decision types, AI technology integration, and development tools. The second is to identify the best publication outlets for such research, because although there are many reputable POM journals worldwide, some may not publish work on AI applications. We also consider it worthwhile to determine

* Corresponding author. Tel.: +852 2616 8096; fax: 852 28922442.
E-mail addresses: bokwong@ln.edu.hk (B.K. Wong), sklai@baf.msmail.cuhk.edu.hk (V.S. Lai).

0925-5273/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpe.2010.09.013

whether some journals prefer to publish articles on certain types of POM applications.

By definition, fuzzy set theory encompasses fuzzy logic, fuzzy arithmetic, fuzzy mathematical programming, fuzzy topology, fuzzy graph theory, and fuzzy data analysis. As our surveyed applications cover all of these techniques, the collective term "fuzzy set theory" is used throughout this article, although "fuzzy logic" alone is often used in the literature.

The remainder of this paper begins in Section 2 presenting the data collection method that we adopted to gather information on the published fuzzy set theory applications in the POM literature, including a list of the journals surveyed. Section 3 discusses our classification scheme and the approach used to classify and organize the identified applications. Section 4 provides the results of these classifications, including the historical trends in the main classification categories. A discussion of our findings is presented in Section 5. Section 6 sets out the limitations of the study and makes suggestions for future work. A summary and conclusions are presented in Section 7.

2. Data collection method

Chaudhry and Luo (2005) conducted a study of the applications of GAs in POM, identifying 21 journals for review. Their selection was based on a comparison of three studies of journal rankings and categorizations (i.e., Goh et al., 1997; Soteriou et al., 1999; Barman et al., 2001), from which they elected to adopt the journal list in Barman et al. (2001), as the findings of that study were deemed to be the most comprehensive and representative one. As this list consists of internationally recognized leading POM and business journals, we thus adopt it here.

The most important step in our literature retrieval process was a computer search of the ABI/INFORM and Business Source Premier databases. Our search period covered the 12 years from January 1998 to December 2009. Using the descriptor "fuzzy" and the title of each journal, we retrieved approximately 800 abstracts for review from the specified period. A manual search was then conducted for four journals, *Naval Research Logistics*, *Operations Research*, *Production and Inventory Management*, and *Production and Operations Management*, as these journals or certain issues of them were found to be unavailable in the databases.

Each article retrieved through this process was carefully reviewed before a decision was made on its inclusion in the survey. We required that each article discusses the prototype or development of a fuzzy set theory application for POM. This requirement eliminated many of the articles retrieved from the databases, as the descriptor that we used produced abstracts from numerous articles that did not necessarily describe POM applications.

3. Classification categories

A final total of 402 articles, or 403 applications, were considered to be acceptable for the purposes of this study. As each article was reviewed, it was classified according to the following categories:

(1) Year of publication
(2) Country/institution affiliation of the author(s)
(3) Journal
(4) Application area
(5) Method
(6) Decision type
(7) AI technology integration
(8) Development tool

The classification of most of the categories was quite simple and straightforward, with the exception of application area and decision type. We adopted the approach of Chaudhry and Luo (2005) for the classification of these two categories, which combines the work of Jayaraman and Srivastava (1996) and Keen and Morton (1978), as it was considered to be most appropriate for our review. Readers are referred to their articles for a thorough discussion and justification of the approach. Table 1 presents the application areas and the associated decision types.

Although most of the classifications of application area were reasonably clear, some inevitably required subjective judgment. To ensure accuracy, each of the authors performed the classifications independently, and then compared their results. Any discrepancies were thoroughly discussed until a consensus was reached. If cases remained undecided, then we solicited the expert opinion of a third party.

4. Results

As indicated in Fig. 1, the number of papers published in each year over the 12-year period ranges from 22 to 68. Due to the possible time lag in reviewing and revising the submitted manuscripts and the scheduling of journal publications, it is justifiable to look at a three-year simple moving average for the publications. As expected, the values of the moving averages (23.67, 23.33, 22.67, 24.67, 26.67, 29, 33, 35, 42.67, and 52.67 applications) clearly demonstrate a steadily increasing trend.

Table 2 shows the number of authors by country and membership status of the Organization for Economic Co-operation and Development (OECD). There are a total of 733 researchers affiliated with different institutions in 45 countries. The largest number of authors are from Taiwan (129 or 17.6%), followed by China (including Hong Kong; 98 or 13.37%), the United States (83 or 11.32%), and India (68 or 9.28%). Together, these four countries account for more than half of the total number of authors. As OECD member countries represent more developed economies, Table 2 indicates that 344 of the researchers (46.93%) are from the 20 developed countries, and 389 of the researchers (53.07%) are from the 25 developing countries.

Our review indicates that, of the 402 articles, 42 (10.45%) are collaborations between authors from OECD and non-OECD countries. With regard to the type of affiliated institution, 376 of the articles (93.54%) were written by university professors and researchers, five (1.24%) were authored by industry practitioners and government officials, and 21 (5.22%) were jointly written by authors from both sectors.

As shown in Table 3a, only 10 out of the 21 journals had published articles on fuzzy set theory POM applications. The

Table 1
POM application areas by decision type (adapted from Jayaraman and Srivastava (1996)).

Decision type		
Unstructured	Semi-structured	Highly structured
Environment	Aggregate planning	Distribution
Process choice	Facilities layout	Inventory control
Process design	Facilities location	Maintenance
Product design	Job design	Purchasing
Quality planning	Long-term capacity planning	Quality control
	Long-term forecasting	Scheduling
	Project management	Short-term capacity planning
	Short-term forecasting	