



Multiple criteria decision making combined with finance: A categorized bibliographic study

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Abstract

This paper provides a categorized bibliography on the application of the techniques of multiple criteria decision making (MCDM) to problems and issues in finance. A total of 265 references have been compiled and classified according to the methodological approaches of goal programming, multiple objective programming, the analytic hierarchy process, etc., and to the application areas of capital budgeting, working capital management, portfolio analysis, etc. The bibliography provides an overview of the literature on “MCDM combined with finance,” shows how contributions to the area have come from all over the world, facilitates access to the entirety of this heretofore fragmented literature, and underscores the often multiple criterion nature of many problems in finance.

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Keywords: Bibliographic study; Multiple criteria decision making; Finance; Portfolio analysis; Goal programming; Multiple objective programming; Multi-criteria decision analysis; Discrete alternative methods; Analytic hierarchy process

1. Introduction

Many normative decision models assume that a firm pursues the single objective of stockholder wealth maximization. However, a modern enterprise is a complex organization in which various stakeholders interact with one another, each with its own possible interpretation of wealth maximization, subject to concerns about risk, liquidity, social responsibility, environmental protection, employee welfare, and so forth. Consequently, it may well be appropriate to pursue a multiple objective approach to many financial decision mak-

ing problems. With finance a key functional area and multiple criteria decision making (MCDM) ranked fifth in a recent study [C2] of the most frequently employed tools of operations research and management science, the purposes of this paper are to study the nature of the literature of “MCDM combined with finance” and to facilitate a convenient access to this literature that is only becoming more important as the world of finance becomes more mathematical.

In Section 2 we show the geographic origins of the literature on MCDM combined with finance along with the range of outlets over which its publication, by force or by choice, has been spread. In Section 3 we provide a categorization by methodology of the articles compiled, and in Section 4 we provide a classification by area of

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application. Section 5 consists of concluding remarks.

2. Diversity of origins and dispersion of dissemination

A total of 265 published references on MCDM combined with finance have been compiled.

Of course, judgment is involved in borderline situations, but the *characteristics* we feel most often identify a paper as being as MCDM combined with finance are as follows:

- (a) The title contains both multiple criteria and financial language.
- (b) The abstract conveys both multiple criteria and financial ideas and content (where *financial* is interpreted to include accounting and other related nummular areas of endeavor).
- (c) The content decidedly addresses the paper's MCDM and financial nature in an integrative fashion.
- (d) The list of references at the end shows a blending of the literatures to confirm the paper's orientation.

While most papers demonstrated all characteristics, it was not an absolute requirement that all four be present. For instance, we noticed papers that we felt were clearly finance and MCDM but showed little blending of the literatures in their lists of references. This was apparently the result of work on a financial problem in which the authors recognized the existence and impact of multiple criteria, but were presumably unaware of the extent to which the field of MCDM had been developed. Also motivating this study was the feeling that many people who had worked on projects involving both MCDM and finance were unaware of other MCDM combined with finance papers published perhaps many years before simply because there was no easy way to find out about them.

By MCDM we mean *multiple criteria* with three or more objectives. Finance has traditionally recognized the two-objective situation of risk versus return, the risk-return efficient frontier, and the necessity to tradeoff risk against return in order to

achieve a final solution. Such risk-return aspects have been extensively studied with single-criterion and parametric solution techniques that have long been well-known and are today contained in most corporate and investment finance textbooks. But what is *not* well-known are the new ways of looking at financial problems when three or more criteria exist, the pitfalls the naïve can fall into when attempting to practice MCDM without sufficient experience [C8, Chapters 6 and 7], and the ranges of sophisticated solution procedures that have only been developed relatively recently [C3]. Primarily, the difficulty encountered as we transit from *two* to *more than two* criteria is that the “efficient frontier” is no longer a frontier but becomes a *surface*. While it is possible to parameterize a frontier, it is not possible to parameterize a surface. This then leads to the methods and techniques of MCDM (i.e., MCDA (multi-criteria decision analysis or multiple criteria decision aid) which is a designation often used in Europe) that attempt to intelligently probe and sample the efficient set that may of course exist in up to k dimensions (where k is the number of criteria).

Using the four characteristics above, the articles of this study were collected by first examining the Recent MCDM Journal Articles sections of the issues of *MCDM WorldScan* (the newsletter of the International Society on Multiple Criteria Decision Making). This resulted in 76 refereed journal articles over the period 1986–2001. In examining journals prior to 1986, 82 more refereed articles were identified. Along with significant content in 12 texts, the location of 52 contributions in conference proceedings volumes, and 43 more in books of readings, a total of 265 were obtained for inclusion.

In Table 1, we show the distribution of the 265 articles by the type of volume or journal in which they were published. Of the 265, 101 were published in volumes of various sorts: 35 in specialized books of readings (as in [A6,A22,A27,A37,A41, etc.]); 28 in the Springer-Verlag series *Lecture Notes in Economics and Mathematical Systems*; 15 in individual conference proceedings volumes (as in [A9,A12,A14,A29,A36, etc.]); 12 in texts with significant MCDM combined with finance content [B1,B2,B3,B4,B5,B6,B7,B8,B9,B10,B11,B12]; and

Table 1
Distribution of articles by journal

Journal or type of volume	Number of articles
Specialized books of readings	35
Lecture Notes in Economics and Mathematical Systems	28
Individual conference proceedings	15
European Journal of Operational Research	16
Journal of the Operational Research Society ^a	13
In texts with significant MCDM combined with finance content	12
Advances in Mathematical Programming and Financial Planning	11
Omega	10
Financial Management	8
Computers and Operations Research	8
Decision Sciences	8
Management Science	8
Socio-Economic Planning Sciences	7
The Accounting Review	7
The Engineering Economist	4
Mathematical and Computer Modelling ^b	4
Journal of Bank Research	4
Accounting and Business Research	3
Central European Journal for Operations Research and Economics ^c	3
The Financial Review	3
Journal of Business Finance and Accounting	3
Annals of Operations Research	3
Journal of Financial and Quantitative Analysis	3
Journal of Multi-Criteria Decision Analysis	3
Journal of Business Research	3
Journal of Finance	2
Journal of Risk and Insurance	2
Management International Review	2
Operations Research	2
Water Resources Bulletin	2
31 Other journals	2
Total	265

^a Formerly Operational Research Quarterly until 1977.

^b Formerly Mathematical Modelling until 1988.

^c Formerly Ekonomicko-Matematicky Obzor until 1988, Review of Econometrics until 1992, and Czechoslovak Journal for Operations Research until 1993.

11 in the JAI Press series *Advances in Mathematical Programming and Financial Planning*.

Of the 164 articles published in journals, the most (16) appear in the *European Journal of Operational Research* with the remaining 148 articles broadly dispersed across 55 journals from the fields of operations research, finance, accounting, economics, insurance, engineering economy, water resources, and so forth.

In Table 2 is the distribution of the 265 articles by year in which they were published. We see that the rate has been reasonably constant over the past

three decades. In Table 3 we see how the authorship of the 265 articles is distributed by the countries of the authors. The Weighted and Individual Authorship Counts in the table are explained as follows. Consider an article with four authors, two from country A and one each from countries B and C. With regard to the Weighted Counts, country A would add .50 and countries B and C would add .25 each. With regard to the Individual Counts, country A would add 2 while countries B and C would add 1 each. With the 265 papers dispersed geographically, over time, and by

Table 2
Distribution by year

Year	Number
1955	1
1963	1
1965	1
1971	2
1972	3
1973	8
1974	7
1975	5
1976	5
1977	10
1978	14
1979	6
1980	9
1981	10
1982	7
1983	10
1984	7
1985	10
1986	11
1987	15
1988	4
1989	13
1990	4
1991	11
1992	7
1993	16
1994	13
1995	7
1996	7
1997	8
1998	12
1999	5
2000	14
2001	2
Total	265

publication outlet, along with the fact that up to 25% of the contributions appear in what may be considered often difficult to find volumes and journals, it is not surprising that it has been difficult for authors embarking on MCDM combined with finance projects to know for sure whether they are “re-inventing the wheel” or not.

3. Methodological classification

The 265 articles are classified by methodology employed in Table 4. The most (103) are in the

Table 3
Authorship counts by country

Country	Authorship counts	
	Weighted	Individual
1. USA	128.10	230
2. Netherlands	21.50	44
3. Greece	21.15	45
4. United Kingdom	12.67	23
5. Canada	11.08	25
6. Germany	8.33	11
7. Poland	7.91	13
8. Israel	7.50	11
9. Italy	7.16	13
10. Belgium	6.50	12
11. Japan	4.75	13
12. China	4.00	6
13. Finland	4.00	6
14. France	3.33	8
15. Czech Republic	3.00	4
16. Spain	3.00	4
17. India	2.00	4
18. Turkey	2.00	4
19. Austria	1.00	1
20. Portugal	1.00	2
21. Sweden	1.00	1
22. Taiwan	1.00	2
23. Thailand	1.00	2
24. New Zealand	0.67	2
25. Bangladesh	0.50	1
26. Switzerland	0.50	1
27. South Korea	0.33	1
Total	265	489

category of goal programming (GP), followed by multiple objective programming (83), and so forth.

3.1. Goal programming

GP was first introduced by Charnes et al. [A33] in 1955 in a model for executive compensation. GP is useful in financial planning because many financial criteria can be expressed in terms of goals. A general format for a GP model is

$$\begin{aligned}
 \min \quad & \sum_{i=1}^k P_i(w_i^- d_i^- + w_i^+ d_i^+) \\
 \text{s.t.} \quad & c^1 x + d_1^- - d_1^+ = t_1 \\
 & \vdots \\
 & c^k x + d_k^- - d_k^+ = t_k \\
 & x \in S \\
 & x, d_i^-, d_i^+ \geq 0
 \end{aligned}$$

Table 4
Classification by methodology

Methodology	Number of articles	Authors
GP	103	Ballestero (00), Clewlow, Hodges and Pascoa (98), Dominiak (97), Tamiz, Hasham, Jones, Hesni and Fargher (96), Goedhart and Spronk (95), Bessler and Booth (94), Goedhart and Spronk (94, 91), Khorramshahgol and Okoruwa (94), Vermeulen, Spronk and van der Wijst (94, 93), Lawrence and Marose (93), Lin and O'Leary (93), Schniederjans, Zorn and Johnson (93), Sharda and Wingender (93), Puelz and Lee (92), van den Bergh, Hallerbach and Spronk (92, 91), Giokas and Vassiloglou (91), Zanakis (91), Spronk (90, 88, 85, 82, 81, 81), Booth and Bessler (89), Colson and de Bruyn (89), Goedhart, Peters and Spronk (89), Lee and Eom (89), Eom, Lee, Snyder and Ford (87-88), Fowler and Schniederjans (87), Guerard and Stone (87), Guerard and Lawrence (87), Korhonen (87), Kwak and Diminnie (87), O'Leary and O'Leary (87), Spahr, Deckro and Hebert (87), Ashton (85, 86), Kvanli and Buckley (86), Miyajima and Nakai (86), Guerard and Buell (85), Schaffers and Spronk (86), Sharda and Musser (86), Arthur and Lawrence (85), Gressis, Bacon and Yen (85), Hindelang and Krishnamurthy (85), Spronk and Zambruno (85, 81), Telgen (85, 83), Cook (84), Isermann (84), Philippatos and Christofi (84), Schniederjans (84), Joiner and Drake (83), Spronk and Veeneklaas (83), Steuer (83), De, Acharya and Sahu (82), Lawrence and Reeves (82), Vinso (82), Keown, Taylor, III and Pinkerton (81), Harrington and Fischer (80), Keown and Taylor, III (80), Kvanli (80), Lee and Chesser (80), Hollis (79), Kumar and Philippatos (79), Hannan (78), Keown and Martin (78, 77, 76), Keown (78), Kumar, Philippatos and Ezzell (78), Taylor and Keown (78), Booth and Dash (77), Drandell (77), Fortson and Dince (77), Gleason and Lilly (77), Sheshai, Harwood and Hermanson (77), Welling (77), Ignizio (76), Neely, North and Fortson (76), Wacht and Whitford (76), Orne, Rao and Wallace (75), Hawkins and Adams (74), Klock and Lee (74), Lee and Lerro (74, 73, 71), Sartoris and Spruill (74), Schroeder (74), Callahan (73), Jackman (73), Killough and Souders (73), Osteryoung (73), Jääskeläinen (72), Lee and Clayton (72), Ijiri (65), Charnes, Cooper and Ijiri (63)
Multiple Objective Programming	83	Ballestero (00), Brimberg and ReVelle (00), Klamroth and Wiecek (00), Korhonen (00), Ogryczak (00), Liu and Dauer (00), Schniederjans and Schniederjans (00), Mansini and Speranza (99), Gao and Hu (98), Rustem (98), Trafalis and Mishina (97), Coffin and Taylor, III (96), Kwak, Shi, Lee and Lee (96), Skulimowski (96), Speranza (96, 94, 93), Thizy, Pissarides, Rawat and Lane (96), Chen (95), Costa and Climaco (95), Konno and Suzuki (95), L'Hoir and Teghem (95), Corner, Deckro and Spahr (93), Konno, Shirakawa and Yamazaki (93), Lai and Hwang (93), Lin (93), Mitra and Patankar (93), Weber and Current (93), Farn and Waung (92), Kornbluth (92), Rys and Ziemba (91), Chrisman, Fry, Reeves, Lewis and Weinstein (89), Langen (89, 87), Rosenblatt and Sinuany-Stern (89), Skocz, Zebrowski and Ziemba (89), Sridhar (89), Tayi and Leonard (88), Gonzalez, Reeves and Franz (87), Kornbluth and Salkin (87), Nunamaker and Truitt (87), Kobayashi, Tanino, Wierzbicki and Okumura (86), Kornbluth (86, 86), Lam and Karwan (85), Morse (84), Vetschera (84), Boquist and Moore (83), Morse (83), Nakayama, Takeguchi and Sano (83), Balachandran and Steuer (82), Kornbluth and Vinso (82), Ashton and Atkins (79, 81), Bona, Merighi and Ostanello-Borreani (81), Lawrence and Steuer (81), Olve (81), Zeleny (81), Bernhard (80), Colson and Zeleny (80), Muhlemann and Lockett (80), Wilhelm (80), Bhaskar (79), Eatman and Sealey (79), Keefer (78), Lin (78, 80), Muhlemann, Lockett and Gear (78), Sealey (78), Wallenius, Wallenius and Vartia (78), Zeleny (78), Sealey (77), Shapiro (76), Caplin and Kornbluth (75), Miller and Erickson (75), Stone and Reback (75), Kornbluth (74), Steuer (74), Candler (73), Forsyth and Laughhunn (73), Stone (73), Candler and Boehlje (71), Charnes, Cooper and Ferguson (55)
MCDA	45	Doumpos and Zopounidis (01), Zopounidis and Doumpos (01), Beuthe, Eeckhoudt and Scannella (00), Hallerbach (00), Hallerbach and Spronk (00), Xu and Zheng (00), Zopounidis and Doumpos (00), Jog, Kaliszewski and Michalowski (99), Zopounidis (99), Zopounidis and Doumpos (99), Zopounidis, Doumpos and Zanakis (99), Doumpos, Zopounidis and Anastassiou (98), Greco, Matarazzo and Slowinski (98), Hurson and Ricci-Xella (98), Scarelli (98), Skulimowski (98), Xu (98), Zopounidis, Dimitras and Rudulier (98), Zopounidis and Doumpos (98), Matsatsinis, Sintos and Zopounidis (97), Pardalos, Michalopoulos and Zopounidis (97), Skulimowski (97), Zopounidis and Doumpos (97), Hanne (95), Bergeron, Martel, and Twarabimyenye (94), Hurson and Zopounidis (94), Jog and Michalowski (94), Siskos, Zopounidis and Pouliezios (94),

Table 4 (continued)

Methodology	Number of articles	Authors
AHP	18	Tibiletti (94), Zopounidis (94, 93), Chevalier and Gupta (93), Manas (93), Cerny and Glúckafova (92), Cosset, Siskos and Zopounidis (92), Zopounidis, Pouliezos and Yannacopoulos (92), Danev, Kolev and Slavov (91), Mareschal and Brans (91), Lootsma, Mensch and Vos (90), Wymore and Duckstein (89), Martel, Khoury and Bergeron (88), Siskos and Zopounidis (87), Zopounidis (87), Legrady, Lootsma, Meisner and Schellemans (84), Bernardo and Lanser (77)
MAUT	8	Hogan, Olson and Rahmlow (00), Ossadnik (96), Barbarosoglu and Pinhas (95), Greenberg and Nunamaker (94), Ulengin and Ulengin (94), Jablonsky (93), Fuller (91), Rashid and Tabucanon (91), Saaty and Vargas (91), Tarimcilar and Khaksari (91), Arbel and Orgler (90), Meziani and Rezvani (90), Srinivasan and Kim (89, 88), Vargas and Roura-Agusti (89), Jensen (87), Lockett, Hetherington and Yallup (86), Olson, Venkataramanan and Mote (86)
Survey of Methodologies	8	Chujej and Mount-Campbell (89), Chew and Mao (86), Bodily and White (83), Rios-Garcia and Rios-Insua (83), Bassler, MacCrimmon, Stanbury and Wehrung (78), Keefer and Kirkwood (78), Keefer (78), Schwartz and Vertinsky (77)
		Zopounidis (98), Brockett, Cooper, Kwon and Ruefli (97), Zopounidis, Doumpos and Matsatsinis (97), Thanassoulis (85), Bhaskar and McNamee (83), Zeleny (82), Colson and Zeleny (79), Chateau (75)
Total	265	

in which S is the feasible region; P_i is the priority of the i th goal, $c^i x$ is the i th goal criterion function, and the t_i are the target values of the k goal criteria. The d_i^- and d_i^+ are deviational variables which measure achievements below and above goal. The w_i^- and w_i^+ are relative importance weights attached to the underachievement and overachievement deviational variables.

In early works applied to finance, Lee and Lerro [A135] presented a GP model for portfolio selection in the mutual fund industry; Ignizio [A86] formalized the idea of multiple objectives in capital budgeting with a GP branch and bound algorithm for zero–one variables; and Fortson and Dince [A59] presented a GP model for the management of a country bank in which four competing objectives (profit, capital adequacy, loan-to-deposit ratio, and liquidity) were considered.

Among the many contributions in the 1980s, Spronk [B9] introduced “interactive multiple GP”; and Sharda and Musser [A186] developed a multiperiod GP model as an alternative to the more conventional hedge ratio approaches to financial futures hedging. Korhonen [A112] presented a two-stage GP approach applied to the assets and liability management in a bank. Her model included three one-year planning periods with multiple scenarios to describe uncertainty, chang-

ing priorities, and multiple goals such as expected profit, risk, liquidity, capital adequacy, growth, customer relationships, and other aspects of a bank’s operations. More recently, Bessler and Booth [A17] have studied the use of GP for interest rate management in a commercial bank.

The advantage of GP is that multiple criteria can be incorporated into a model that can be solved using conventional (single criterion) optimization software. GP’s disadvantage is that information about the decision maker’s preferences is required a priori in the form of priority levels, importance weights, and goal target values.

3.2. Multiple objective programming

In contrast to GP, a multiple objective program

$$\begin{aligned}
 \max \quad & \{f_1(x) = z_1\} \\
 & \vdots \\
 \max \quad & \{f_k(x) = z_k\} \\
 \text{s.t.} \quad & x \in S
 \end{aligned}$$

does not require the a priori information of that of a GP formulation. In multiple objective programming, we compute or sample the efficient set and present the results, in whole or in part, to a decision maker for the ultimate selection of a final

solution. Most multiple objective programming procedures are interactive and a review of such interactive procedures is contained in Gardiner and Steuer [C3].

In early works, Sealey [A184] described a multiple objective programming model for a bank's financial planning, and discussed the increased flexibilities that can be obtained with this approach. Lawrence and Steuer [A130] applied an interactive multiple objective programming procedure to capital budgeting to enable a decision maker to gain improved appreciations of how the objectives tradeoff against one another. A book with substantial content on multiple objective programming in finance is Kornbluth and Salkin [B4].

In 1993, Konno et al. [A109] looked at portfolio analysis from a multiple objective perspective and argued for skewness as a third portfolio selection objective. They also commented on the possibility that multiple objectives beyond risk and return may be a reason why market portfolios typically reside deep below the bi-criterion risk-return efficient frontier.

The advantage of multiple objective programming is that we can sample neighborhoods on any multi-dimensional efficient surface to any degree of resolution. A disadvantage is the CPU run time required.

3.3. Multi-attribute utility analysis

In contrast to multiple objective programming in which the decision maker's value function is *implicit* (assumed to exist but otherwise unknown) and the feasible region is continuous or at least contains a large number of points, in multi-attribute utility analysis the effort is to strive for an *explicit* value function to be exercised over a small discrete number of alternatives. Often applied to difficult public policy problems in an environment of risk and uncertainty, multi-attribute utility theory (MAUT) embraces a large body of mathematical theory and a wide range of assessment techniques. As outlined in Keeney and Raiffa [C4], information from the assessments is used to parameterize a value function, rank the alternatives, make a choice, and otherwise provide deeper in-

sights into the problem. As in the Rios-Garcia and Rios-Insua paper [A173], most of the MAUT finance papers deal with applications involving investment project selection.

3.4. Multi-criteria decision analysis

Multi-criteria decision analysis (MCDA) refers to another family of methods, developed mostly in Europe, for addressing multiple criteria problems with a small to moderate number of discrete alternatives. All involving preference modeling, a review of many of the most prominent MCDA methods is found in Olson [C5]. Perhaps foremost among the methods of MCDA is the ELECTRE family of methods of Bernard Roy [C6] based upon outranking concepts ("one solution *outranks* another if it is at least as good as the other in most respects, and not too much worse in any one respect"). For instance, Martel et al. [A149] employ ELECTRE to study the limitations of conventional risk in being able to capture global risk in a portfolio context. Also influenced by ELECTRE is BANKADVISOR by Mareschal and Brans [A148] which has been successful in the banking industry. Another MCDA method that has seen application in the financial arena in MINORA, as described for example in Siskos et al. [A190].

3.5. The analytic hierarchy process

The analytic hierarchy process (AHP), developed by Saaty (initially presented in detail in [C7]), is another approach, extraordinarily elegant in its simplicity, for addressing and analyzing discrete alternative problems with multiple conflicting criteria. Residing upon decidedly different axioms, the AHP has been extraordinarily successful in its application to broad arrays of problems. The AHP starts (in the not unusual way) of subdividing a problem into a hierarchy of an overall objective, criteria, subcriteria, sub-subcriteria, etc., until we have on the bottom level the discrete alternatives as in the tree of Fig. 1.

Then, starting at the bottom level, we conduct pairwise comparisons between the elements immediately below each other element. For example, concerning their importance with regard to

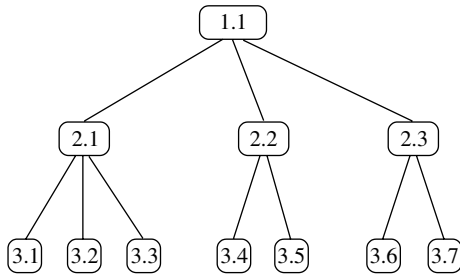


Fig. 1. AHP tree.

element (2.1), we build a 3×3 pairwise comparison matrix containing our comparisons among elements (3.1), (3.2) and (3.3). Then, concerning their importance with regard to element (2.2), we build a 2×2 pairwise comparison matrix containing our comparisons between elements (3.4) and (3.5), and so forth, completing each level and then working up the tree until we are able to establish a priority ranking for each alternative taking all criterion concerns into account.

As a sampler of the AHP in finance, Arbel and Orgler [A1] describe the application of the AHP methodology to the evaluation of a bank acquisitions strategy; Mezzani and Rezvani [A151] develop a four-level AHP model to select a financing instrument for a foreign investment; and Tarimcilar and Khaksari [A216] present an AHP model for capital budgeting in the health care industry. Recently, in an interesting paper by Ossadnik [A167], the AHP is proposed for the allocation of synergies in merger situations.

4. Range of applications

Table 5 categorizes the 265 papers into eight different application categories led by portfolio analysis (77), followed by general financial planning (45), and so forth.

4.1. Portfolio analysis

Representing the range of contributions in portfolio selection, Muhlemann et al. [A157] developed a multiple objective stochastic linear programming formulation of the multiperiod portfolio selection problem under uncertainty; and Har-

ington and Fischer [A79] proposed a simulation model combined with an integer GP model for large-scale portfolio modeling. Also, Jensen [A91] used the AHP to develop a model for international investment risk analysis.

4.2. Capital budgeting

In the early papers in this area, Ignizio [A86] discussed the usefulness of considering capital budgeting problems as a GP within a framework of multiple objectives; and Keown and Taylor [A102] presented a chance-constrained GP approach with De et al. [A50] extending the approach to treat the coefficients in the technological matrix as stochastic. Also, Kwak and Diminnie [A122] presented a zero-one GP model for managing operating budgets at a university, Lin [A141] developed a multiple criteria capital budgeting model (net cash flow, accounting earnings, and dividends) under risk, and Corner et al. [A46] took a multiple objective programming approach involving the three objectives of net present value, risk, and dividend payout.

4.3. General financial planning

In this category, for example, Ashton and Atkins [A5] introduced a multicriteria model to take advantage of both simulation models as financial statement generators and mathematical programming as a flexible search tool; Vinso [A230] presented a stochastic GP model to deal with uncertain exchange rates and other barriers to free capital flows; and Eom et al. [A56] introduced a GP model-based multiple criteria decision support system for global financial planning in a multinational corporation to allow managers to satisfy the multiple financing goals and to effectively analyze the trade-offs among costs, foreign exchange risks, political risks, etc.

4.4. Working capital and commercial bank management

Portraying this area, Eatman and Sealey [A55] developed a multiple objective linear programming model for commercial bank working capital

Table 5
Classification by area of application

Application area	Number of articles	Authors
Portfolio analysis	77	Hallerbach (00), Hallerbach and Spronk (00), Ogryczak (00), Schniederjans and Schniederjans (00), Mansini and Speranza (99), Hurson and Ricci-Xella (98), Rustem (98), Scarelli (98), Brockett, Cooper, Kwon and Ruefli (97), Dominiak (97), Coffin and Taylor, III (96), Skulimowski (96), Tamiz, Hasham, Jones, Hesni and Fargher (96), Speranza (96, 94, 93), Chen (95), Konno and Suzuki (95), L'Hoir and Teghem (95), Hurson and Zopounidis (94), Jog and Michalowski (94), Khorramshahgol and Okoruwa (94), Tibiletti (94), Zopounidis (94), Chevalier and Gupta (93), Jablonsky (93), Konno, Shirakawa and Yamazaki (93), Manas (93), Vermeulen, Spronk and van der Wijst (93), Weber and Current (93), Zopounidis (93), Cerny and Glückaufova (92), Danev, Kolev and Slavov (91), Fuller (91), Rashid and Tabucanon (91), Rys and Ziemba (91), Meziani and Rezvani (90), Chuvej and Mount-Campbell (89), Colson and de Bruyn (89), Skocz, Zebrowski and Ziemba (89), Wymore and Duckstein (89), Martel, Khoury and Bergeron (88), Jensen (87), Siskos and Zopounidis (87), Kobayashi, Tanino, Wierzbicki and Okumura (86), Lockett, Hetherington and Yallup (86), Spronk and Zambruno (85), Schniederjans (84), Bodily and White (83), Nakayama, Takeguchi and Sano (83), Rios-Garcia and Rios-Insua (83), Spronk and Veeneklaas (83), Zeleny (82), Zeleny (81), Spronk and Zambruno (81), Harrington and Fischer (80), Lee and Chesser (80), Muhlemann and Lockett (80), Wilhelm (80), Colson and Zeleny (79), Kumar and Philippatos (79), Bassler, MacCrimmon, Stanbury and Wehrung (78), Kumar, Philippatos and Ezzell (78), Muhlemann, Lockett and Gear (78), Taylor, III and Keown (78), Booth and Dash (77), Sealey (77), Schwartz and Vertinsky (77), Sheshai, Harwood and Hermanson (77), Shapiro (76), Caplin and Kornbluth (75), Orne, Rao and Wallace (75), Stone and Reback (75), Steuer (74), Lee and Lerro (73), Stone (73)
General financial planning	45	Ballesterio (00, 00), Brimberg and ReVelle (00), Xu and Zheng (00), Zopounidis and Doumpos (00), Jog, Kaliszewski and Michalowski (99), Zopounidis (99), Zopounidis, Doumpos and Zanakis (99), Gao and Hu (98), Matsatsinis, Sintos and Zopounidis (97), Trafalis and Mishina (97), Zopounidis, Doumpos and Matsatsinis (97), Costa and Climaco (95), Goedhart and Spronk (94), Siskos, Zopounidis and Pouliezios (94), Vermeulen, Spronk and van der Wijst (94), Lin and O'Leary (93), Mitra and Patankar (93), Kornbluth (92), van der Bergh, Hallerbach and Spronk (91), Goedhart and Spronk (91), Spronk (90), Goedhart, Peters and Spronk (89), Srinivasan and Kim (89), Eom, Lee, Snyder and Ford (87-88), Spronk (88), Kornbluth and Salkin (87), Ashton (86, 85), Kvanli and Buckley (86), Miyajima and Nakai (86), Schaffers and Spronk (86), Lam and Karwan (85), Spronk (85), Isermann (84), Kornbluth and Vinso (82), Spronk (82), Vinso (82), Ashton and Atkins (81), Bona, Merighi and Ostanello-Borreani (81), Kvanli (80), Ashton and Atkins (79), Sealey (78), Neely, North and Fortson (76), Callahan (73), Klamroth and Wiecek (00), Liu and Dauer (00), Kwak, Shi, Lee and Lee (96), Thizy, Pissarides, Rawat and Lane (96), Goedhart and Spronk (95), Corner, Deckro and Spahr (93), Lin (93), Schniederjans, Zorn and Johnson (93), Lootsma, Mensch and Vos (90), Rosenblatt and Sinuany-Stern (89), Gonzalez, Reeves and Franz (87), Kwak and Diminnie (87), Nunamaker and Truitt (87), Spahr, Deckro and Hebert (87), Arthur and Lawrence (85), Thanassoulis (85), Legrady, Lootsma, Meisner and Schellemans (84), Vetschera (84), De, Acharya and Sahu (82), Keown, Taylor, III and Pinkerton (81), Lawrence and Steuer (81), Olve (81), Spronk (81,81), Bernhard (80), Keown and Taylor, III (80), Bhaskar (79), Keefer (78, 78), Keefer and Kirkwood (78), Lin (78), Bernardo and Lanser (77), Ignizio (76), Chateau (75), Hawkins and Adams (74), Lee and Lerro (74), Schroeder (74), Candler (73), Forsyth and Laughhunn (73), Osteryoung (73), Candler and Boehlje (71), Charnes, Cooper and Ijiri (63)
Capital budgeting	42	Doumpos and Zopounidis (01), Zopounidis and Doumpos (01), Hogan, Olson and Rahmlow (00), Zopounidis and Doumpos (99), Clewlow, Hodges and Pascoa (98), Doumpos, Zopounidis and Anastassiou (98), Greco, Matarazzo and Slowinski (98), Zopounidis (98), Zopounidis, Dimitras and Rudulier (98), Skulimowski (98), Xu (98), Zopounidis and Doumpos (98), Skulimowski (97), Bergeron, Martel, and Twarabimene (94), Bessler and Booth (94), Ulengin and Ulengin (94), Sharda and Wingender (93), van den Bergh, Hallerbach and Spronk (92), Cosset, Siskos and Zopounidis (92), Zopounidis, Pouliezios and Yannacopoulos (92), Saaty and Vargas (91), Booth and Bessler (89), Zopounidis (87), Chew and Mao (86), Sharda and Musser (86), Gressis, Bacon and Yen (85), Boquist and Moore (83), Colson and Zeleny (80), Zeleny (78), Miller and Erickson (75)
Interest rate and risk analysis, prediction, and classification	30	Doumpos and Zopounidis (01), Zopounidis and Doumpos (01), Hogan, Olson and Rahmlow (00), Zopounidis and Doumpos (99), Clewlow, Hodges and Pascoa (98), Doumpos, Zopounidis and Anastassiou (98), Greco, Matarazzo and Slowinski (98), Zopounidis (98), Zopounidis, Dimitras and Rudulier (98), Skulimowski (98), Xu (98), Zopounidis and Doumpos (98), Skulimowski (97), Bergeron, Martel, and Twarabimene (94), Bessler and Booth (94), Ulengin and Ulengin (94), Sharda and Wingender (93), van den Bergh, Hallerbach and Spronk (92), Cosset, Siskos and Zopounidis (92), Zopounidis, Pouliezios and Yannacopoulos (92), Saaty and Vargas (91), Booth and Bessler (89), Zopounidis (87), Chew and Mao (86), Sharda and Musser (86), Gressis, Bacon and Yen (85), Boquist and Moore (83), Colson and Zeleny (80), Zeleny (78), Miller and Erickson (75)

Table 5 (continued)

Application area	Number of articles	Authors
Working capital and commercial bank management	21	Hanne (95), Lai and Hwang (93), Giokas and Vassiloglou (91), Mareschal and Brans (91), Langen (89), Sridhar (89), Tayi and Leonard (88), Korhonen (87), Langen (87), Telgen (85), Morse (84), Philippatos and Christofi (84), Morse (83), Telgen (83), Eatman and Sealey (79), Hollis (79), Keown (78), Fortson and Dince (77), Keown and Martin (77), Sartoris and Spruill (74), Lee and Lerro (71)
Auditing, accounting, insurance, and pension fund management	17	Pardalos, Michalopoulos and Zopounidis (97), Farn and Waung (92), O'Leary and O'Leary (87), Kornbluth (86,86), Bhaskar and McNamee (83), Balachandran and Steuer (82), Lawrence and Reeves (82), Lin (80), Drandell (77), Gleason and Lilly (77), Welling (77), Klock and Lee (74), Kornbluth (74), Killough and Souders (73), Ijiri (65), Charnes, Cooper and Ferguson (55)
Government and nonprofit organizations	17	Beuthe, Eeckhoudt and Scannella (00), Barbarosoglu and Pinhas (95), Greenberg and Nunamaker (94), Puelz and Lee (92), Tarimcilar and Khaksari (91), Zanakis (91), Chrisman, Fry, Reeves, Lewis and Weinstein (89), Guerard and Buell (85), Cook (84), Joiner and Drake (83), Hannan (78), Keown and Martin (78), Wallenius, Wallenius and Vartia (78), Keown and Martin (76), Wacht and Whitford (76), Jackman (73), Lee and Clayton (72)
Strategic planning, mergers, and acquisitions	16	Korhonen (00), Zopounidis and Doumpos (97), Ossadnik (96), Lawrence and Marose (93), Arbel and Orgler (90), Lee and Eom (89), Vargas and Roura-Agusti (89), Srinivasan and Kim (88), Fowler and Schniederjans (87), Guerard and Lawrence (87), Guerard and Stone (87), Olson, Venkataramanan and Mote (86), Hindelang and Krishnamurthy (85), Steuer (83), Wallenius, Wallenius and Vartia (78), Jääskeläinen (72)
Total	265	

management; Tayi and Leonard [A217] presented an alternative multi-objective balance sheet management model to allow the explicit incorporation of trade-offs between conflicting objectives and attempts to reduce the cognitive burden; Langen [A126] introduced an interactive decision support system, IDSSBALM, to address bank asset and liability management; and Giokas and Vassiloglou [A63] developed a GP model for the Commercial Bank of Greece to take into account institutional, financial, legal, and bank policy considerations.

4.5. Auditing, accounting, insurance, and pension fund management

Characterizing work in these areas, Killough and Souders [A105] developed a GP model for public accounting firms; Lawrence and Reeves [A129] developed a zero–one GP model for capital budgeting in a property and liability insurance company; Bhaskar and McNamee [A20] discussed the nature of multiple objectives in accounting; and Farn and Waung [A57] presented a multiple criteria Markovian processes system for pension fund and manpower planning.

4.6. Interest rate and risk analysis, prediction, and classification

Here, Sharda and Musser [A186] presented a multiperiod, multiple objective GP model for financial futures hedging as an alternative to the more conventional hedge ratio approaches; Spahr et al. [A195] developed a nonlinear GP approach for controlling systematic and total risk of the firm in capital budgeting; Booth and Bessler [A23] developed a GP model to assist a bank in creating optimal strategies to manage interest-rate risk; and Sharda and Wingender [A187] presented a dynamic GP model with foreign exchange futures to manage foreign currency accounts receivable.

4.7. Government and nonprofit organizations

Covering applications in government and nonprofits, Wacht and Whitford [A231] developed a GP model for capital investment analysis in nonprofit hospitals and applied it to an actual hospital capital budgeting situation; Joiner and Drake [A94] used a GP for developing an application model for a state level public health care

agency; and Zanakis [A239] developed a two-phase approach for library needs assessment and budget allocation. In the first phase, measures of benefits from library services were obtained by a committee using a structured analytic approach to combine judgments with data. In the second phase, a GP model was used to allocate the library budget proportionally to measured benefits while satisfying a variety of other conflicting goals.

4.8. Strategic planning, mergers, and acquisitions

Representing these areas, Fowler and Schniederjans [A60] presented a GP model for strategic acquisition problem solving; and Guerard and Lawrence [A74] used GP model for multi-period strategic planning in a firm.

5. Concluding remarks

Despite the many simplifying single-criterion “bottom line” or bicriterion “risk-return” pronouncements that we may hear, it should be clear from the 265 references of this study that much of the world of finance, particularly in its most important and complex managerial aspects, resides fundamentally within an environment of *multiple* (i.e., more than two) conflicting objectives. One major affected area is, of course, contemporary portfolio selection where, beyond risk and return, additional criteria such as to maximize upper-tail skewness, maximize liquidity, minimize the number of securities in the portfolio, and maximize perhaps a social responsibility quotient may well be present. The significance here, as in any other area whose theory is directly tied to the risk-return efficient frontier, is that the efficient frontier is no longer a curvilinear line segment, but must now be thought of as a *surface*. Because of the challenge posed by multiple objectives to the theory of conventional risk-return efficient-frontier finance [C1, as for instance in], the research opportunities in exploring the application the multicriterion technologies in finance appear at this time to be particularly substantial. One last comment. Although only one MCDM combined with finance reference [A70] has appeared with rough sets, it is

expected that articles using some of the other newer techniques of operational research such as fuzzy approaches and genetic algorithms will begin to appear shortly in MCDM combined with finance as their potential becomes more widely recognized.

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