GOAL PROGRAMMING: METHODOLOGY AND APPLICATIONS

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by

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Printed on acid-free paper.

This book is dedicated to the four individuals
who are most cited in the literature for creating,
nurturing and continuously improving the subject
of *Goal Programming*:

A. Charnes, W. W. Cooper, Sang M. Lee and James P. Ignizio

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PREFACE

If you are a graduate student or researcher who is interested in *goal programming* (GP) research, this book will be of benefit to you. To understand how this book will help you, let me explain the motivation behind its creation.

A few years back I was surprised when I read J. P. Ignizio's 1985 book, *Introduction to Linear Goal Programming* and found not a single reference to the most prolific GP researcher (Sang M. Lee) was cited. For what ever reason relevant GP research is not made available, researchers need a comprehensive source of all GP research publications that they can reference. Without knowing what has been done in GP research, it is impossible to know what is left to do in this very important field of research.

The purpose of the book is to provide the most comprehensive reference guide to GP research that is available to date. This book can be viewed as a very large bibliography but is much more. This book provides the most extensive bibliography of GP books and journal research publications (over a thousand citations) in its appendices that has ever been complied. Recognizing the substantive and maturing nature of the subject of GP, this book's content is devoted to identifying all the available literature on methodology and applications which have been reported during GP's almost forty year history. Having collected GP citations for over twenty years, I have found the volume of existing GP research is presently so substantive that no single book could begin to detail the individual methodologies and applications. As such, this book will focus on overviewing and summarizing the contributions to GP of various research studies, rather than detailing the methodological mechanics and application specifics. The objective of this book is to permit researchers and graduate students to know what has been contributed in the past to GP research so that they will know how best to extend the GP envelop of knowledge into the future. This book also seeks to offer suggestions and ideas to promote further GP research.

This book is not an introductory book on GP and does not contain the basic GP algorithms that are found in such books. Instead, this book seeks to augment basic GP books as a comprehensive guide to finding additional research on those algorithms and applications that are not commonly available in introductory books.

This book is organized into five chapters. Chapter 1 describes GP models and explains their relationships with models other fields of study. This chapter sets a common frame of reference on GP modeling for those who might be not be as familiar with all the conventional forms of the GP models used today. In Chapter 2, subjects on GP modeling strategies are presented. As readers will see in this chapter, issues of conflict are not limited to the GP model alone. Chapter 3 is focused on identifying available GP solution methodologies and Chapter 4 on available applications. These chapters are organized by type of methodology and type of application for quick reference by researchers. Finally, in Chapter 5 a brief discussion is presented on GP past research and trends that exist for future GP research. In each of the these chapters the bulk of the GP journal research studies cited in the literature will be listed for quick reference in the text or in numerous tables throughout this book, with notes to identify the primary purpose of each research study. These tables will help to summarize the content of the articles and serve to allow researchers a means to quickly identify citations that may be of interest to their own research. In Appendix A a listing of over 40 GP textbooks, readings books and monographs is presented. In Appendix B a listing of over 980 GP journal research paper citations are presented. All citations are written in the English language.

The accuracy and completeness of this book is my responsibility. The inclusion criteria for journals and books was simple. If the refereed publication contained the name GP or if it is cited in some other publication as having made a contribution to GP it was eligible to be included. One purposeful omission that I now acknowledge is that paper presentations and nonrefereed publications have, for the most part, been excluded from this book. While the individual citations from readings books have generally not been included in the book, the books themselves that have been cited in the GP literature are cited in Appendix A. The body of knowledge that is contained in this book is refereed and as such has undergone a measure of quality control that nonrefereed presentations and publications do not. The all English requirement (or limitation) is similar to other GP bibliographies. It should be mentioned that many of GP publications that are cited in this book were published in countries other than the US. Despite the fact that the citations in the appendices on which this book represents over 20 years of collecting effort on my part, I acknowledge the possibility that omissions and inaccuracies may exist. For all the errors that this book may contain I apologize for them in advance.

Marc J. Schniederjans

CHAPTER 1. INTRODUCTION TO GOAL PROGRAMMING

This book is designed to provide students, faculty and researchers a perspective and review of the total body of published *goal programming* (GP) research to date. The objective of this book is to present a comprehensive overview of goal programming methodology and applications, past and present, as they are reflected in journal publications and books. It is assumed that readers will have some basic knowledge of GP. With the exception of this chapter, the remaining chapters in this book are fairly independent of each other and can be referenced or read independently of the others.

The purpose of this chapter is to describe the subject called *goal programming* or GP and to distinguish the models, methods and applications as a unique subject of study. Specifically, this chapter seeks to introduce and describe differing types of GP models that will be discussed throughout this book. In addition, the relationship of GP within the fields of *management science/operations research* (MS/OR) and *multiple criteria decision making* (MCDM) will be discussed. This chapter will also introduces the concept of the *life cycle* of GP research as a means of adding to the description of the current state of research on this subject.

DESCRIPTIONS OF GOAL PROGRAMMING MODELS

A Point of Origin

The basic idea of GP has been traced by Romero (1992, p. 2) to a study by Charnes, Cooper and Ferguson (1955) on executive compensation. While the term *goal programming* did not appear in this 1955 article, this paper did present a constrained regression idea that embodies the deviation minimizing approach inherent in GP. According to Romero (1992), it was not until Charnes and Cooper's 1961 linear programming textbook, *Management Models and Industrial Applications of Linear Programming* that the term goal programming appeared. Interestingly, it was not presented as a unique or revolutionary methodology, but as an extension of *linear programming* (LP).

In the Charnes and Cooper (1961, pp. 215-221) book, goal programming was suggested for use in solving unsolvable LP problems (e.g., infeasible LP problems). Indeed, GP was not even cited as a term in the index of the Charnes and Cooper (1961) book.

From this humble beginning as an extension of LP, GP has distinguished itself in the years since as a unique problem solving methodology. Thousands of paper presentations have been given on the subject of GP at annual meetings of professional societies, particularly the *Operations Research Society of America*, the *Institute of Management Science*, the *Institute of Decision Sciences*, and the *International Society of Multiple Criteria Decision Making*. Numerous textbooks, readings books and monographs have been devoted in part or totally to the subject of GP. For a listing of these books see *Appendix A, Textbooks, Readings Books and Monographs on Goal Programming*. Virtually every management science or operations research textbook in the last 20 years has voted a chapter to the subject of GP. Journal research publications on the subject of GP have almost reached the millennia mark. For a listing of these articles see *Appendix B, Journal Research Publications on Goal Programming*.

Goal Programming as an Extension of Linear Programming

Since the origin of GP can be traced to LP, a starting point for the GP model can be found by restating the LP model, its assumptions and modeling notation. One version of the LP model can be stated in what is called the *canonical form*:

$$\text{Minimize: } Z = \sum_{j=1}^{n} c_j x_j$$

$$\text{subject to: } \sum_{j=1}^{n} a_{ij} x_j \geq b_i, \text{ for } i=1, \ldots, m$$

$$x_j \geq 0, \text{ for } j=1, \ldots, n \tag{1.1}$$

Where the $x_1, x_2, \ldots, x_n$ are nonnegative *decision variables* or unknowns and the $c_1, c_2, \ldots, c_n$ are contribution coefficients that represent the marginal contribution to Z for each unit of their respective decision variable. This LP model seeks a single objective or goal of minimizing the *objective function* or Z

function. In the model the objective function is subject to a set of *m* *constraints*. In the constraints, the a_{ij}, where $i=1, 2, \ldots, n$ and $j=1, 2, \ldots, m$, are *technological coefficients* that represent the per unit usage by x_j of the *right-hand-side coefficient* of b_i. In this model the *n* decision variables are required to be non negative.

The LP model implicitly requires the following assumptions (Fang and Puthenpura 1993, pp. 3-4):

1. *Proportionality assumption*: Each unit of each decision variable x_j contributes c_j units to the objective function and a_{ij} units in the ith constraint.

2. *Additivity assumption*: The contribution to the objective function and the technological coefficients in the constraints are independent of the values of the decision variables.

3. *Divisibility assumption*: Decision variables are permitted to be noninteger or have fractional values.

4. *Certainty assumption*: All parameters, a_{ij}, b_i and c_j must be known with certainty.

The LP model in (1.1) permits the possibility of positive deviation (called *surplus* in LP terminology) from the right-hand-side coefficients in the model, since the sum of the products in the left-hand-side can be greater-than any b_i. It is also true that LP constraints can be stated as less-than or equal-to expressions. In this case, the LP model can permit negative deviation (called *slack* in LP terminology) from b_i. Any LP model can include greater-than or equal-to, equal-to and less-than or equal-to types of constraints.

Regardless of the types of constraints included in an LP model, the mathematical requirements represented by the constraints must be satisfied in order to have a *feasible solution*. It must also be remembered that optimization of the objective function is secondary to finding a feasible solution set of the x_j that will satisfy all of the constraints in a model. When one or more constraints in an LP model finds itself outside or in conflict with the *area of feasible solutions,* we have an *infeasible solution*.

What Charnes and Cooper (1961) suggested in their textbook is that each constraint that makes up an LP model is a separate function, called a *functional*. These functionals are viewed as individual *objectives* or *goals* to be attained. In effect, the b_i are a set of objectives or goals that we must satisfy in order to have a feasible solution. If we subtract b_i from both sides of an equality constraint, we can express the functional as the absolute value of an LP constraint, or:

$$f_i(x) = \left| \sum_{j=1}^{n} a_{ij} x_j - b_i \right| \text{ for } i=1, ..., m \tag{1.2}$$

Charnes and Cooper (1961) referring to these functionals as *goals*, suggested that goal attainment is achieved by minimizing their absolute deviation. In those LP problems (i.e., infeasible solutions) where deviation in functionals are inevitable, the best solution occurs by minimizing the deviation. In this way it is possible to obtain a kind of solution where constraints are in conflict with one another. Charnes and Cooper (1961, p. 215) put it this way:

"Whether goals or attainable or not, an objective may then be stated in which optimization gives a result which comes 'as close as possible' to the indicated goals."

Recognizing that deviation from goals will exist in unsolvable LP problems like an infeasible LP problem, Charnes and Cooper (1961, p.217) illustrated how that deviation could be minimized by placing the variables representing deviation directly in the objective function of the model. This allows multiple (and sometimes conflicting) goals to be expressed in a model that will permit a solution to be found. Multiple and conflicting goals are what many scholars use as a distinguishing characteristic to describe how a GP model differs from an LP model. While Charnes and Cooper did not present a general GP model statement in their 1961 book, a generally accepted statement of this type of GP model was presented in Charnes and Cooper (1977):

$$\text{Minimize: } Z = \sum_{i \in m} (d_i^+ + d_i^-)$$

$$\text{subject to: } \sum_{j=1}^{n} a_{ij} x_j - d_i^+ + d_i^- = b_i, \text{ for } i=1, ..., m$$

$$d_i^+, d_i^-, x_j \geq 0, \text{ for } i=1, ..., \text{m; for } j=1, ..., n \tag{1.3}$$

Where d_i^+ is called a *positive deviation variable* and d_i^- is called a *negative deviation variable*. The substantially useless value of Z is the summation of all deviations. The statement in (1.3) that i is an element of the m possible positive and negative deviation variables is to imply that choice in the selection of deviation variables to be included in the objective function is an option. The deviation variables are related to the functionals algebraically where:

$$d_i^+ = 1/2 \left[\left| \sum_{j=1}^{n} a_{ij} x_j - b_i \right| + \left(\sum_{j=1}^{n} a_{ij} x_j - b_i \right) \right]$$

$$d_i^- = 1/2 \left[\left| \sum_{j=1}^{n} a_{ij} x_j - b_i \right| - \left(\sum_{j=1}^{n} a_{ij} x_j - b_i \right) \right] \qquad (1.4)$$

The GP model in (1.3) has an objective function, constraints (called *goal constraints*) and the same nonnegativity restriction on the decision variables (and deviation variables) as the LP model. It should be mentioned that some GP researchers (see Ignizio 1985, pp. 25, 30-1) feel that the term objective function is not an accurate term and the terms *achievement function* or *unachievement function* should used in its place. This book will use the term objective function which, as Ignizio (1985, p. 31) admitted, it is the more traditional terminology and because Charnes and Cooper (as well as most others) still refer to it as an "objective" function (see Charnes, Cooper and Sueyoshi 1988).

The GP model in (1.3) can have LP constraints if desired and requires the same model assumptions as the LP model, with the exception of proportionality for c_j. It is also a requirement that $d_i^+ x d_i^- = 0$ must always hold true. Both the decision variables and the c_j parameters are removed from the objective function. The fact that there are no decision variables in an GP model's objective function is one of the unique characteristics that distinguishes a GP model from other quantitative methods. We will discuss other necessary modeling assumptions, limitations and requirements in Chapter 2.

Extensions of the Goal Programming Model

From the time of the Charnes and Cooper (1961) book to 1966, few scholars published research on GP. The only journal research publications during this time include Chambers and Charnes (1961), Charnes and Cooper (1962), Charnes, Cooper and Ijiri (1963), Joksh (1964), and Charnes and Stedry (1966). A major development in the extension of GP models did occur during this period with the publication of the 1965 book by Y. Ijiri, *Management Goals and Accounting for Control*. According to Lee (1972, p. 17), Ijiri's (1965) book introduced the *generalized inverse* solution approach. We will be discussing GP solution methodology in Chapter 3. Ijiri also introduced *preemptive priority factors* as way of ranking goals in the objective function of the GP model and established the assigning of *relative weights* to goals in the same priority level. The ideas of weighting or ranking goals are two very different concepts and has fostered two different types of GP models.

Charnes and Cooper (1977) stated the *weighted GP model* as:

$$\text{Minimize: } Z = \sum_{i \in m} (w_i^+ d_i^+ + w_i^- d_i^-)$$

$$\text{subject to: } \sum_{j=1}^{n} a_{ij} x_j - d_i^+ + d_i^- = b_i, \text{ for } i=1, \ldots, m$$

$$d_i^+, d_i^-, x_j \geq 0, \text{ for } i=1, \ldots, \text{m; for } j=1, \ldots, n \qquad (1.5)$$

Where w_i^+ and w_i^- are nonnegative constants representing the *relative weight* to be assigned to the respective positive and negative deviation variables. The relative weights may be any real number, where the greater the weight the greater the assigned importance to minimize the respective deviation variable to which the relative weight is attached. This model is a nonpreemptive model that seeks to minimize the total weighted deviation from all goals stated in the model. We will discuss methodologies to develop these relative weights in Chapter 2.

While Ijiri (1965) had introduced the idea of combining preemptive priorities and weighting, Charnes and Cooper (1977) suggested the GP model as:

$$\text{Minimize: } Z = \sum_{i \in m} P_i \sum_{k=1}^{n_i} (w_{ik}^+ d_i^+ + w_{ik}^- d_i^-)$$

$$\text{subject to:} \quad \sum_{j=1}^{n} a_{ij}\, x_j - d_i^+ + d_i^- = b_i, \text{ for } i=1, \ldots, m$$

$$d_i^+, d_i^-, x_j \geq 0, \text{ for } i=1, \ldots, \text{m; for } j=1, \ldots, n \qquad (1.6)$$

Where w_{ik}^+, $w_{ik}^- \geq 0$ and represent the relative weights to be assigned to each of the $k = 1, \ldots, n_i$ different classes within the ith category to which the non-Archimedean treascendental value of P_i is assigned. The P_i are the preemptive priority factors who serve only as a ranking symbol that can be interpreted to mean that no substitutions across categories of goals will be permitted. It is assumed that the ordering of deviation variables in an objective function, will be minimized in order, where $P_i > P_{i+1} > P_{i+2}$ >>> and so on for as many priorities as may exist in a model. It is also assumed that no combination of relative weighting attached to the deviation variables can produce a substitution across categories in the process of choosing the x_j.

Charnes and Cooper (1977) pointed out the fact that the GP model in (1.6) can allow us to move completely away from weighting deviation variables towards an *absolute priority structure*, where each of the functionals or goals are given a separate priority. Sometimes called the *lexicographic GP model* (see Iserman 1982, Sherali 1982, and Ignizio 1983), the model has no weights, only a preemptive ranking for each of the goals in the model, which can be stated as:

$$\text{Minimize: } Z = \sum_{i \in m} P_i \; (d_i^+ + d_i^-)$$

$$\text{subject to:} \quad \sum_{j=1}^{n} a_{ij}\, x_j - d_i^+ + d_i^- = b_i, \text{ for } i=1, \ldots, m$$

$$d_i^+, d_i^-, x_j \geq 0, \text{ for } i=1, \ldots, \text{m; for } j=1, \ldots, n \qquad (1.7)$$

While several other types of GP models have been suggested, the overwhelming majority of the GP models that appear in the journal literature fit into a form similar to (1.3), (1.5), (1.6) or (1.7). Other variants of GP models such as the *MINMAX GP model* (Romero 1991, p. 5), fall as much under the subject of LP as GP. This book seeks to limit its domain of coverage just GP models that have appeared in journal research publications or GP books.

The *nonpreemptive, nonweighted GP model* in (1.3) is a distinct model that has repeatedly appeared in the literature since the publication of the Charnes and Cooper (1961) book. The *nonpreemptive weighted GP model* in (1.5) and the *preemptive lexicographic GP model* in (1.7) can viewed as the two extreme types of GP models in which virtually all GP modeling are derived. The GP model in (1.6) is simply a combined version of the two extreme types. These GP models, or combinations of them, will be the focus of discussion in this book.

RELATIONSHIP OF GP TO MS/OR

Management science (MS) and *operations research* (OR) can both be defined as a field of study for the application of mathematical analysis to solve managerial problems (Kwak and Schniederjans 1987, p. 1). These fields of study consist of a collection of mathematical algorithms and logic structures that are used to solve problems. OR/MS can trace their origin of industrial application of methodology to the development of linear programming in the 1940's (Cook and Russell 1993, p. 5). As stated in the last section, GP can also trace its point of origin from the development of LP. Just as GP extended LP (by solving unsolvable LP problems, adding weighting, adding priorities, etc.), GP extended itself by reengineering many of the prior single objective LP models with multiple objectives.

There is a direct relationship between the topics in MS/OR and GP. MS/OR journal research and books usually contain the use of one or more mathematical or logic methodologies that exists in the field. Typical MS/OR topics covered in such publications included those listed in Table 1-1. It is assumed that readers are familiar with the MS/OR topics listed in Table 1-1. Most of the MS/OR topics are special case LP methodology or LP models. Logically, then as GP developed, many researchers who had used single objective LP models, extended their model's capabilities to include multiple objectives by reformulating it as a GP model. A early illustration of just how this could be accomplished is presented in Clayton and Moore (1972).

Table 1-1. MS/OR Topics and Their Related GP Topics

MS/OR Topic	Related GP Topic
Linear Programming (LP)	Linear Goal Programming (GP)
LP Duality	GP Duality
LP Sensitivity Analysis	GP Sensitivity Analysis
Integer LP	Integer GP
Nonlinear Programming	Nonlinear GP
Transportation and Assignment Models	GP Transportation and GP Assignment Models
Network Models	GP Network Models
Dynamic Programming Models	GP Dynamic Programming Models
Game Theory Models	GP Game Theory Models
Markov Analysis Models	GP Makov Analysis Models

As can be seen in Table 1-1 there is a related GP topic to each of the MS/OR topics. Since much of the methodologies used to solve LP problems, like the *simplex method*, *duality*, *sensitivity analysis*, *nonlinear programming*, etc., could work on GP problems with minor revisions to the algorithms, most LP methodologies were inevitably converted to a GP equivalent. We will be discussing these GP methods in Chapter 3. Special case LP models, like those for the *transportation method* models, *assignment method* models, *network models*, etc., have LP model equivalents. It is, therefore, an easy step to convert the LP models of these special case problems into GP models by simply adding additional objectives to make the resulting models multi-objective. For example, Drandell (1977) for example, converted one of his own prior LP models used to solve an insurance management problem to a GP model with multiple objectives. We will be discussing these special case formulations in Chapters 2 and 4.

One of the problems scientists have in categorizing methodologies is the fact that one method can be categorized in more than one way. This can lead to confusion and the question as to whether GP is a MS/OR methodology or not. The answer is yes, GP is one of a set of MS/OR mathematical techniques that can be used to solve managerial problems when multiple objectives are present. For this reason, GP is included as a unique problem solving methodology in virtually every MS/OR book on the market today.

RELATIONSHIP OF GP TO MCDM

Multiple criteria decision making (MCDM) is a term used to describe a subfield in operations research and management science. Zionts (1992) generally defined MCDM as a means to solving decision problems that involve multiple (sometimes conflicting) objectives. While that definition also applies to GP, MCDM is a substantially broader body of methodologies of which GP is a small subset.

The various points of origin, methodology and future directions for MCDM can be found in Starr and Zeleny (1977), Hwang, Paidy, and Yoon (1980), Rosenthal (1985), Steuer (1986) and more recently in Dyer, Fishburn, Steuer, Wallenius and Zoints (1992). MCDM's mathematical relationship to GP has been substantially described in a variety of publications including Romero (1991) and Ringuest (1992). Readers are encouraged to review these materials if methodological differences between GP and MCDM are the focus of the reader's research. Consider also reading the entire *Management Science* special issue (Vol. 30, No. 1, 1984) and the entire *Computers and Operations Research* special issue (Vol. 19, No. 7, 1994) both on MCDM, or reviewing any issue of *Multi-Criteria Decision Analysis* journal by John Wiley and Sons.

On a conceptual level the relationship of MCDM and GP can be seen in what Zionts (1992) calls the four subareas that make up MCDM. These four subareas that comprise MCDM are listed in Table 1-2. According to Zionts (1992) the subarea of *multiple criteria mathematical programming* refers to

Table 1-2. MCDM Subareas and Their Related GP Topics

MS/OR Subarea	Related GP Topic
Multiple Criteria Mathematical Programming	Linear Goal Programming
Multiple Criteria Discrete Alternatives	Integer Goal Programming and Zero-One Goal Programming
Multiattribute Utilitiy Theory	Linear Goal Programming, Nonlinear GP and Fuzzy GP
Negotiation Theory	Interactive Goal Programming and GP Game Theory Models

solving primarily deterministic, mathematical programming problems that have multiple objectives. Linear goal programming is one of the many methodologies that are considered a significant contributor to this subarea of MCDM. Indeed, Dyer, Fishburn, Steuer, Wallenius and Zoints (1992) suggest that the development of GP was a beginning point for MCDM, particularly this subarea. How can one distinguish a GP model from the other multiple criteria mathematical programming models? In most cases, the MCDM models in this subarea have decision variables in their objective function, while GP models do not.

Multiple criteria discrete alternatives according to Zoints (1992) is used a problem situation characterized by a matrix where the rows are discrete alternatives in which a choice must be made and the columns constitute objectives. One type of GP methodology we will discuss in Chapter 3 is called *integer goal programming*. Integer GP is a collection of GP algorithms that generate integer or binary (all so called *zero-one GP* or 0-1 GP) solutions for GP problems. Many tabular problems have been formulated as an integer GP problem. For example, Schniederjans and Hoffman (1992) formulated a multinational acquisition problem using a zero-one GP model where the decision choice matrix was made up of selecting multi-national firms to acquire (i.e., the alternatives) based on acquisition criteria (i.e., the objectives).

The subarea referred to as *multiattribute utility theory* from Zoints (1992), involves problems that have probabilistic based outcomes. These outcomes are sometimes expressed as utility functions that are in turn used to weight rankings of alternatives. As we will be discussing in Chapter 3, *nonlinear GP* and *fuzzy GP* methods exist to deal with probabilistic or utility based decision making. In addition, many multiattribute utility theory problems can be converted into deterministic problems and modeled using linear GP. One of the best examples that illustrates the conversion process can be found in Ringuest and Gulledge (1983).

The final subarea of MCDM Zoints (1992) calls *negotiation theory*. The type of problem situation that uses this approach to MCDM involves one or more decision makers who will reach a decision involving multi-criteria information using mechanisms like voting or majority rule. Unique to this type of decision making is the characteristic of where interaction and negotiation takes place by the decision makers to include new are altering information on which to reach a decision. In other words, information changes through negotiation and the new information is shared through interaction among the decision makers. *Interactive GP* is one methodology that can be applied to problem solving where decision makers seek to interact based on new information to reach a final decision. There have also been several *GP game theory* models offered in the literature that fit negotiating theory problems that possess gaming elements (see Hannan 1982b).

Each of these four MCDM subareas really represent a collection of methodologies to be used in a highly varied set of decision environments. While GP modeling can contribute to each subarea, not all MCDM methodology or problem situations can be handled by GP. The presentation here is just to make the point that GP is versatile enough to make some contribution to every subareas that makes up MCDM. In summary, GP is a subset methodology that fits substantially in the multiple criteria mathematical programming subarea, but can provide service to a select group of problems found in the other three subareas.

In conclusion, the relationship of GP to MS/OR and MCDM is one of subordination. As can be seen in Figure 1-1, GP is subordinated within the field of MCDM, which in turn is subordinated within the field of MS/OR. In researching GP literature it is necessary to view GP as a methodology that supports decision making in the various subareas within MCDM. Many of the GP citations in *Appendix B* use the title multi-criteria programming rather than GP. Such labeling can, and probably has lead to researchers overlooking relevant GP contributions. It is also necessary and helpful to use the various topical areas within MS/OR as a means of locating relevant GP models. In Chapter 2 will be discuss the formulations of most MS/OR methodologies within the context of a GP model.

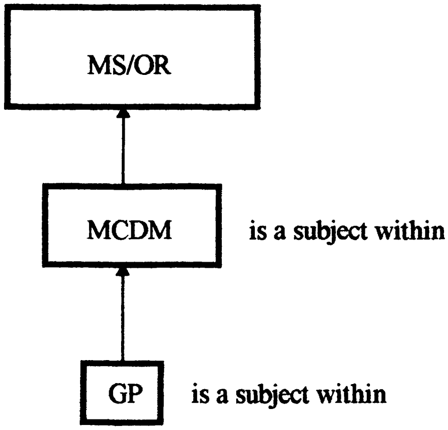

Figure 1-1. Summary Relationship of GP with MS/OR and MCDM

THE LIFE CYCLE OF GP RESEARCH

As previously mentioned, GP's point of origin began with Charnes, Cooper and Ferguson (1955) and now spans 40 years. During that time thousands of GP paper presentations have been made, dozens of papers in reading books have been published and perhaps hundreds of GP papers have been published in non-English journals all over the world. The bibliography of journal publications in *Appendix B* has over 980 citations written in English from journals all over the world. If we plot the frequency of journal publications from 1955 to 1993 (1994 is incomplete as of the writing of this book), their frequency distribution would appear similar to Figure 1-2. The actual numbers of GP journal articles published each year and relevant GP books are listed in Table 1-3.

If we smooth the frequency distribution in Figure 1-2, it appears in the almost exact shape of a classic *life cycle* distribution as pictured in Figure 1-3. Since the distribution being presented consists of GP journal research publications, Figure 1-3 can be viewed as the *life cycle of GP research.* The life cycle of GP research (or any life cycle) goes through four stages of life: Introduction, Growth, Maturity and Decline. The exact positioning of the stages of the life cycle are dictated by the curve's inflection points. Based on these stages, it would appear as though GP research is currently in the Decline stage of its life cycle. If GP research continues in the stage of decline, the subject will cease to exist in a very short period of time. We will revisit the life cycle of GP research in Chapter 5 when we discuss future directions for GP research.

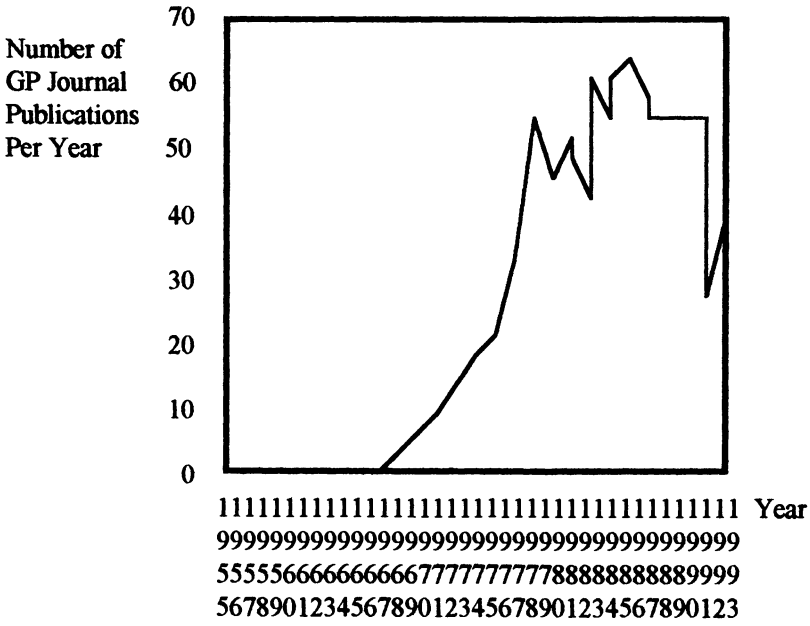

Figure 1-2. Frequency Distribution for GP Journal Publications

Table 1-3. Frequency Listing of GP Journal Publications and Book Titles

Year	No. of Journal Articles	Book Titles with Unique or Significant GP Content*
1955	1	
1956	0	
1957	0	
1958	0	
1959	0	
1960	0	
1961	1	Charnes and Cooper, *Management Models and Ind. Apps. of LP*
1962	1	
1963	1	Graves and Wolfe, *Recent Adv. in Mathematical Programming*
1964	1	
1965	0	Ijiri, *Management Goals and Accounting for Control*
1966	1	
1967	1	Abadie, *Nonlinear Programming*
1968	3	
1969	3	
1970	6	
1971	12	
1972	14	Lee, *Goal Programming for Decision Analysis*
1973	16	Cochrane and Zeleny, *Multiple Criteria Decision Making* Zeleny, *Multiple Criteria Decision Making*
1974	19	
1975	22	Zeleny, *Multiple Criteria Decision Making*
1976	29	Ignizio, *Goal Programming and Extensions* Keeney and Raiffa, *Decisions with Multiple Objectives* Jaaskelainen, *Linear Programming and Budgeting*
1977	32	Starr and Zeleny, *Multi. Crit. Dec. Making-TIMS Studies* Van Delft and Nijkamp, *Multi-Crit. Analy. and Reg. Dec. Mkg.*
1978	55	Zoints, *Multiple Criteria Problem Solving* Cohon, *Multiobjective Programming and Financial Planning*
1979	43	Lee, *GP Methods for Multiple Objective Integer Programs* Fandel and Gal, *Multiple Obj. Dec. Making Theory and Apps.* Hwang and Masud, *Multi. Obj. Dec. Making Meth. and Apps.*

*Complete citation for all books can be found in *Appendix A*.

Table 1-3. (Continued)

Year	No. of Journal Articles	Book Titles with Unique or Significant GP Content*
1980	49	
1981	48	Spronk, *Interactive Multiple GP: Apps. to Fin. Planning*
		Morse, *Org. Multiple Agents with Multiple Criteria*
1982	42	Ignizio, *Linear Programming in Single and Multiple Obj. Sys.*
		Lee, *Management by Multiple Objectives*
1983	63	Lee and Van Horn, *Acad. Adm.:Plan., Budgt. and Dec. Making*
		Chankong and Haimes, *Multiobjective Decision Making*
		Hansen, *Essays and Surveys on Multi. Criteria Dec. Making*
		Rekanitis, Ravindran and Ragsdell, *Eng. Opt.: Meth. and Appl.*
1984	56	Schniederjans, *Linear Goal Programming*
		Depontin, Nijkamp and Spronk, *Macro-Econ. Plan. with Conf.*
		Zeleny, *MCDM: Past Decade and Future Trends*
1985	61	Ignizio, *Introduction to Linear Goal Programming*
		Gal and Wolf, *Solving Stochastic LP's via Goal Programming*
		Fandel and Spronk, *Multi. Criteria Decision Meths. and Apps.*
		Haimes and Chankong, *Dec. Making with Multiple Objectives*
		Sawaragi, Nakayama and Tetsuzo, *Theory of Multiobj. Optim.*
1986	66	Steuer, *Multiple Criteria Opt.: Theory, Comp. and Appl.*
1987	57	Lawrence, Guerard and Reeves, *Adv. in Math. Prog. with Fin.*
		Kwak and Schniederjans, *Intro. to Mathematical Programming*
1988	53	Zoints, *Multi. Crit. Math. Prog.: An Update Overview*
1989	50	
1990	51	Lawrence, Guerard and Reeves, *Adv. in Math. Prog. with Fin.*
		Rios-Insua, *Sen. Anal. in Multi-Obj. Decision Making*
1991	55	Romero, *Handbook of Critical Issues in Goal Programming*
		Lieberman, *Multi-Obj. Programming in the USSR*
1992	30	Ringuest, *Multiobjective Optm.: Behavioral and Comp. Cons.*
1993	38	Lawrence, Guerard and Reeves, *Adv. in Math. Prog. with Fin.*
		Sakawa, *Fuzzy Sets and Interactive Multiobj. Optimization*
1994	3**	

*Complete citation for all books can be found in *Appendix A*.
**Incomplete collection for this year.

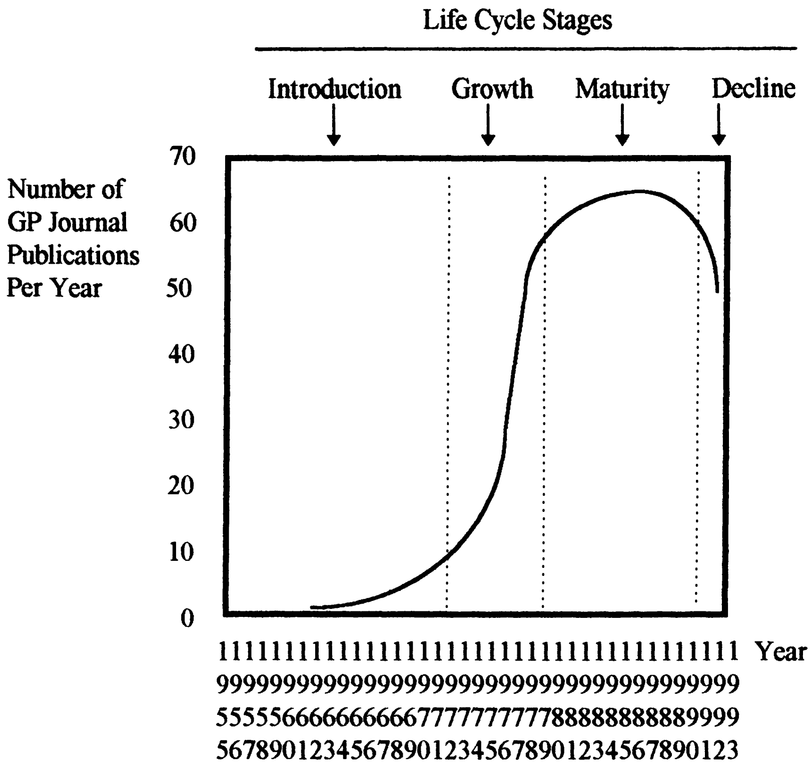

Figure 1- 3. Life Cycle of GP Research

The solution to the problem of declining GP publications is a simple one, that is, to publish more GP research publications. This can only be done by offering journals new and different GP research that makes a significant contribution. To know what is new and different a researcher must know what has been done. To that end this book was created.

SUMMARY

The introductory chapter of any book that deals with an advanced subject usually seems to raise more questions than it answers. This book is no exception. This chapter described several types of GP models (see (1.3), (1.5), (1.6) and (1.7)) that represent the majority of those that appear in GP research. The form and style of modeling notation that will be used throughout this book was introduced in their presentation. This chapter also conceptually described the relationship of GP within the subject areas of MS/OR and MCDM. This book views GP as complementary subset methodology that has application to most multi-objective decision environment subjects discussed in MS/OR and MCDM. The chapter ends with an introduction to the concept of the life cycle of GP research.

It may seem a bit ironic to suggest in an introductory chapter that the life cycle of GP is in decline and may be coming to an end. Others have suggested that GP has already been killed (see Ignizio 1994). The author of this book takes exception with any notion that GP is dead, dying or even has the flu. No body of knowledge or life cycle representing that body of knowledge ever dies. General Dougles MacArthour's put it best when he told the U.S. Congress, "... old soliders never die, they just fade away." GP will never die, but it may fade away if the people who do GP research stop conducting the research. The solution to the problem of declining GP publications is a simple one, that is, to publish more GP research publications. This can only be done by offering journals new and different GP research. To know what is new and different a researcher must know what has been done. To that end this book was created.

To let GP fade away would be a tragic opportunity loss and can be avoided by using some marketing know-how. Product analyst know that a product life cycle can be shifted from a stage of decline to one of growth if something new is added to their products. After almost a thousand journal publications, can there be anything new to add to GP research? You can bet there is! Lets talk about it during the next four chapters.

REFERENCES

All references in this chapter, except those below, can be found in *Appendix B, Journal Research Publications on Goal Programming.*

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Steuer, R. E., *Multiple Criteria Optimization: Theory, Computation, and Application*, John Wiley and Sons, New York, NY, 1986.

Zoints, S., "Some Thoughts on Research in Multiple Criteria Decision Making," *Computers and Operations Research*, Vol. 19, No. 7 (1992), pp. 567-570.

CHAPTER 2. GOAL PROGRAMMING MODEL FORMULATION STRATEGIES

Controversy is a part of any modeling effort, particularly goal programming (GP) modeling. Unfortunately controversy in the way GP models are formulated and presented in the literature has undoubtedly lead to many useful and potentially great models being rejected in the review process for publication. There is need for both the creators of GP models and journal reviewers to understand some of the basics and confusing issues of GP model formulation that exist in the literature.

The purpose of this chapter is to review issues related to GP model formulation strategies that have appeared in the literature. This review of issues and survey of available literature may help researchers to avoid common pitfalls in the practice of GP model formulation. In addition this chapter seeks describe a synergistic approach for GP with other management science/operations research models as a strategy for publication. This chapter also reviews the literature on a number of model structural element methodologies as tactics for improving GP models.

A GOAL PROGRAMMING MODEL FORMULATION PROCEDURE

To formulate any of the GP models presented in Chapter 1 will include some, if not all of the following steps that can be found in any basic management science/operations research (MS/OR) or GP book (see Schniederjans 1984, pp.71-72): (1) define the decision variables, (2) state the constraints, (3) determine the preemptive priorities if need be, (4) determine the relative weights if need be, (5) state the objective function, and (6) state the nonnegativitiy or given requirements. Regardless of whose GP book or article is used, these basic steps should be a part of any GP model formulation strategy. Unfortunately at each step in the formulation process it is possible to misformulate a model. The issues that are often overlooked and give rise to a misformulation are the subject of the next section of this chapter.

ISSUES RELATED TO GOAL PROGRAMMING MODEL FORMULATION

GP model formulations can be in error. Unfortunately, what one researcher may call poor modeling (i.e., modeling error) may be viewed by some other researcher as good modeling. Indeed, anyone can find error in someone else's GP model if they want to. Since those who create GP models are generally the same who review those models, care must be exercised in judging the poorness or goodness of any GP model.

Numerous GP publications have dealt with difficulties and criticisms on the use of GP models. Some of the more notable comments are in Harrald, Leotta, Wallace and Wendell (1978), Hannan (1980), Zeleny (1981), Alvord (1983), Rosenthal (1983), Hannan (1985), Ignizio (1985), Gass (1987), Romero (1991), and Min and Storbeck (1991). From these studies and many others, several modeling issues seem to generate the most controversy. These issues include *dominance* in GP solutions, *inferiority* in GP solutions, *efficiency* in GP solutions, *naive relative weighting* in GP models, *incommesurability*, *naive prioritization* in GP models, *redundancy* and others.

Dominance, Inferiority and Efficiency in GP Solutions

Just as in linear programming (LP), GP models can have multiple solutions. Unlike LP, the GP model can permit a variety of alternative solutions that may allow at least one of the model's goals to be improved without worsening or degrading the others. Zeleny (1981) and other GP researchers feel such a situation represents a major defect in GP modeling.

A *dominated* solution occurs in a GP, if and only if, an alternative feasible solution can be found that will not reduce deviation in an objective function while reducing deviation of some other goal. Cohon (1978, p.70) referred to a *nondominated* solution as one where no other feasible solution existed that would improve one goal without degrading other conflicting goals. A dominated solution can be called an *inferior solution* because other superior solutions that yield better satisfying answers exist. Likewise a nondominated solution can be called a *noninferior solution* because it represents the best solution and not one that is inferior to any other.

This issue of *efficiency* in GP solutions is closely related to dominance and inferiority. According to the Italian economist Vilfredo Pareto (Pareto 1971), efficiency is at an optimal level if the economic situation of a group of people can not be improved without worsening or degrading the economic situation of any one person who makes up the group. This type of optimality is called *Paretian efficiency* (Romero 1991, p. 13). A GP solution is said to be paretian efficient if no other feasible solution can achieve the same or better solution for the group of goals that exist in the objective function, while also being better for one or more other individual objectives that exist in the model. So a GP *efficient solution* must be nondominated solution and a noninferior solution. A GP *inefficient solution* is a dominated solution and a noninferior solution.

One issue in GP model formulation that is directly related to the issues of dominance, inferiority and efficiency concerns the use of LP constraints in GP models to restrict decision variable values. It is certainly a fact that GP permits the inclusion of LP constraints into GP models. Moore, Taylor, Clayton and Lee (1978) referred to the LP constraints included in GP models as *system constraints*. Ignizio (1985, p. 23) calls these constraints a set of *rigid constraints*. Regardless of what they are called they can be included in the formulation of any GP model.

The use of LP constraints may have contributed to confusing GP modeling issues. What appears to be a misrepresentation is how dominance, inferiority and efficiency is represented in the literature. The few tangible examples that appear in the literature seem to require LP constraints that restrict the decision variables in a GP model, in order for dominance, inferiority and inefficiency to be present in a GP solution. For example, Romero (1991, p.15) presented the following GP model formulation:

Minimize: $Z = d_1^- + d_2^- + d_3^-$

subject to:

$$\begin{aligned} x_1 - d_1^+ + d_1^- &= 5 \\ x_2 - d_2^+ + d_2^- &= 2 \\ 0.9x_1 + x_2 - d_3^+ + d_3^- &= 8 \\ x_1 &\leq 6 \\ x_2 &\leq 5 \\ x_1 + x_2 &\leq 9 \\ d_i^+, d_i^-, x_j &\geq 0, \text{ for } i=1, \ldots, 3; \text{ for } j=1, \ldots, 2 \end{aligned} \tag{2.1}$$

The graphic GP solution for this model is presented in Figure 2-1 and numerically presented under the 2.1 Solution column in Table 1-1. In Figure 2-1 the best solution occurs at point *a* on the graph. According to Romero (1991, p. 16) that solution is dominated, inferior and inefficient by all the other points in the shaded region of *a*, *b* and *c*. This dominance can be proved with a test. One test for dominance (which reveals inefficiency and inferiority) in GP solutions by Masud and Hwang (1981) involves maximizing the positive deviation variables. In this case the deviation variables are given a negative weight, which by minimizing a negative weight achieves a maximization of positive deviation. Applying this method to (2.1) we have a revised preemptive model:

Minimize: $Z = P_1\ (d_1^- + d_2^- + d_3^-) + P_2\ [(-d_1^+) + (-d_2^+) + (-d_3^+)]$

subject to:

$$
\begin{aligned}
x_1 - d_1^+ + d_1^- &= 5\\
x_2 - d_2^+ + d_2^- &= 2\\
0.9x_1 + x_2 - d_3^+ + d_3^- &= 8\\
x_1 &\le 6\\
x_2 &\le 5\\
x_1 + x_2 &\le 9\\
d_i^+, d_i^-, x_j &\ge 0, \text{ for } i=1, \ldots, 3; \text{ for } j=1, \ldots, 2
\end{aligned}
\tag{2.2}
$$

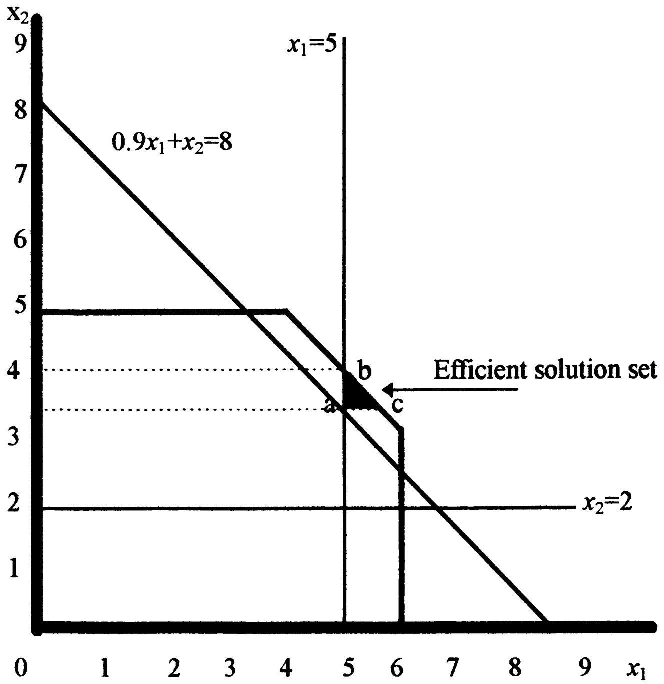

Figure 2-1. Set of GP Efficient Solutions

Table 2-1. Solutions for a Dominated GP Problem

Unknowns	(2.1) Solution	(2.2) Solution	(2.3) Solution*
Z	1.5	2.5	8.4
x_1	5.0	5.0	6.0
x_2	3.5	4.0	5.0
d_1^-	0.0	0.0	0.0
d_2^-	0.0	0.0	0.0
d_3^-	0.0	0.0	0.0
d_1^+	0.0	0.0	1.0
d_2^+	1.5	2.0	3.0
d_3^+	0.0	0.5	2.4

*Other remaining deviation variables not presented.

The solution for this model is also presented in Table 1-1 under the (2.2) Solution column. Since the values for the negative deviation variable are still at zero (an optimal solution for the goals in this model), the (2.2) Solution has not degraded the original problem's goals. Also, we have more positive deviation in variables (i.e., 2>1.5 and 0.5>0.0 for the d_2^+ and d_3^+, respectively) in the (2.2) Solution, and since we seek to maximize deviation in model (2.2) it represents a solution that is better or dominates the (2.1) Solution.

The problem with this argument is that the existence of the LP constraints in this type of GP model is chiefly the cause of the dominated solution. By converting the LP constraints into goal constraints using Table 2-2 as a guide (from Ignizio 1985, pp. 23-24), this problem will not generated a dominated solution. The GP model for this problem is presented in (2.3) and its solution in Table 2-1 in the (2.3) Solution column. If we accepted the notion that more is better as in the (2.2) Solution, then even more is better in the (2.3) Solution. As we an see, the desire to maximize the positive deviation variables has a higher achievement level, while not degrading the negative deviation variables from zero. More over, when the Masud and Hwang (1981) dominance test is applied, the solution for the model in (2.3) is nondominated, efficient and noninferior. Given that the conversion of the LP constraints to goal constraints is correct, how can this outcome be true? It can be true in GP models where all the constraints are goal constraints and that they are included in the objective function. It is also consistent with the observations by Cohon (1978), that GP models that possess some positive deviation, while minimizing negative deviation variables helps to guarantee nondominated solutions.

Table 2-2. Conversion of LP Constraints to Goal Constraints

LP Constraint	Goal Constraint equivalent	Deviation Variable to be Minimized in the Objective Function
$f(x_j) \geq b_i$	$f(x_j) - d_i^+ + d_i^- = b_i$	d_i^-
$f(x_j) \leq b_i$	$f(x_j) - d_i^+ + d_i^- = b_i$	d_i^+
$f(x_j) = b_i$	$f(x_j) - d_i^+ + d_i^- = b_i$	$d_i^+ + d_i^-$

Minimize: $Z = P_1\,(d_1^- + d_2^- + d_3^-) + P_2\,(d_4^- + d_5^- + d_6^-)$

subject to:

$$
\begin{aligned}
x_1 - d_1^+ + d_1^- &= 5 \\
x_2 - d_2^+ + d_2^- &= 2 \\
0.9x_1 + x_2 - d_3^+ + d_3^- &= 8 \\
x_1 - d_4^+ + d_4^- &= 6 \\
x_2 - d_5^+ + d_5^- &= 5 \\
x_1 + x_2 - d_6^+ + d_6^- &= 9 \\
d_i^+, d_i^-, x_j \geq 0, \text{ for } i=1, \ldots, 6;&\text{ for } j=1, \ldots, 2 \qquad (2.3)
\end{aligned}
$$

In summary, it might be advisable to avoid issues of dominance, inferiority and inefficiency by converting LP constraints to goal constraints. This can be accomplished by simply reformulating LP constraints as goal constraints and placing them at the top priority of the model (Ignizio 1985, pp. 23-24). This formulation strategy does not guaranty to prevent all of the problem causing issues discussed here from occurring, only to reduce their occurrence in GP modeling. As such, it might also be advisable to run one or more tests for dominance or efficiency to confirm such problems are not present in the model formulation.

The debate on the seriousness of the presents of dominance, inferiority and inefficiency in GP solutions has lead many GP researcher to question the worthwhileness of GP as a multicriteria method (Romero 1991, p.14). For the single most comprehensive discussion of the prior literature on both the pro's and con's of these issues in GP modeling, see Min and Storbeck (1991). A general listing of citations on these subjects can also be found in Table 2-3.

Table 2-3. GP Citations on Dominance, Inferiority and Inefficiency

Reference	Notes and Comments on What Reference Provides
Cohon (1978)	a variety of perspectives on dominance
Cohon and Marks (1975)	a classic statement on dominance
Hannan (1985)	a basic review of all three issues
Hannan (1980)	a test for efficiency
Ignizio (1981c)	a discussion on GP efficiency
Kornbluth (1973)	a classic argument on efficiency
Masud and Hwang (1981)	a test for inferiority
Min and Storbeck (1991)	pro's and con's on all three issues
Romero (1991, Chapter 2)	illustrative examples and discussion on all three issues with several tests for efficiency and dominance
Romero and Rehman (1983)	a test for efficiency
Zeleny (1981)	states inherent inferiority of GP models

Naive Relative Weighting, Incommesurability, Naive Prioritization, and Redundancy in GP Model Formulations

The four GP model formulation issues of *naive relative weighting*, *incommensurability*, *naive prioritization*, and *redundancy* are often related to one another. In fact, any one of these issues can cause formulation problems that in turn often causes the other issues to brought up as criticisms against GP models. Its even possible for a GP model can actually suffer from all four of these problems at one time.

In any of the weighted GP models in Chapter 1 (see (1.5) and (1.6)) the *relative weights* establish the importance of goals to which they are attached. If the weights do not accurately reflect the true proportioned weight that rightfully exists in the decision environment that is being modeled, then we have a situation of *naive relative weighting*. Since relative weights are often viewed as a type of utility function, Rosenthal (1983) has argued that weights will almost never reflect the true economic environment they are trying to describe.

The negative impact of naive relative weighting can be minimized by putting more effort into their calculation. The use of such weighting methods as the *analytic hierarchy process* (Satty 1980), *conjoint analysis* (Green and Srinivasan 1990), and even multiple regression analysis can help to improve the accuracy of weighting to reflect the true decision environment a model seeks to describe. We will discuss these and other methods further, in a later section of this chapter.

A related issue to relative weighting, though not in a cause-and-effect relationship, is that of *incommensurability* of goal constraints. In a weighted GP model goal constraints are often used to model very different types of goals. Minimizing a budgetary goal constraint whose a_{ij} and b_i are measured in terms of dollars is incommensurable or not in the same measure of units as a human resource goal constraint whose a_{ij} and b_i are measured in terms of humans to hire for job. When both are included in a weighted GP model its like mixing apples and oranges together. Mathematically, the relative magnitudes of measures taken from differing populations (i.e., dollars vs. humans) bias the solution process in favor of the parameters what will yield the largest reduction in deviation. While the relative weights can sometimes used to adjust the model for parameter magnitudes, it is very difficult to validate the nonbias in such GP models. Such bias can also completely render any relative weighting of goals irrelevant since the weighting is used in combination with the parameters to determine the inclusion in the solution process. This point has been well illustrated in the literature (see Romero and Rehman 1984a).

The impact of incommensurability issues in GP modeling can be minimized in a variety of ways. De Kluyver (1979), Zeleny (1982, pp. 315-333) and Romero (1991, pp. 35-43) have all suggested scaling methods that normalize the goal constraints in a GP model. This normalization has the effect of equating the magnitudes of constraint parameters with little or no violation of the proportionality assumption in the model, so the issue of incommensurability is eliminated between goal constraints. We will discuss this method later in this chapter. Another way to over come incommensurability is to simply prioritize the individual goals if the decision environment permits such rankings. When a priority system is used, differing measurement mixtures of constraints can be keep separate. That is to say, the apple constraints can be kept at one priority and the orange constraints can be kept separate at another priority. As long as the groupings of apple or orange constraints at each priority are weighted in a way not to again cause incommensurability, this method will solve this problem. The lexicographic GP model (Chapter 1, (1.7)) can not suffer from this incommensurability. Still another way of defending a GP model on this issue is to rationalize the logic of setting weights in the applied context of the decision environment. See the Romero (1985b) note and the justifying reply by Sutchliffe, Board and Cheshire (1985).

In summary, the noweighted, nonpriority GP model of (1.3), the weighted, nonpriority GP model of (1.5), and the weighted, preemptive GP model of (1.6) tend to suffer from the issue of incommesurability. The nonweighted, preemptive priority or lexicographic GP model (1.7) does not suffer from incommesurability since each of its goals are separated at a different priority level. Unfortunately, the preemptive priorities that protect GP models from incommesurability, can themselves bring modeling difficulties to the formulation.

In the preemptive GP models in Chapter 1 (see (1.6) and (1.7)), the prioritization or ranking of goals in a GP model must accurately reflect the decision environment. Failure to establish a true prioritization of goals in a GP model brings with it a criticism of *naive prioritization* (Romero 1991, Chapter 4). A related issue of naive prioritization is that of *redundancy* in GP models (Amador and Romero 1989). *Redundancy* refers to goal constraints that are not considered or redundant in a given solution for a GP model. For example, in the (2.4) GP model, the resulting solution is where $x_1 = 1$, $x_2 = 1$, $P_1 = 0$,

$P_2 = 99$, $P_3 = 199$, $P_4 = 0.95$, and $P_5 = 0.92$. Only the P_1 goal is fully achieved. The fact is the solution was actually determined at the P_1 goal. This resulted in the other goals being *redundant* or not being considered in the solution. A reviewer might suppose a naive prioritization of goals has caused the redundancy of the other goals. This may or may not be true. If the priorities reflect the actual decision process, then the true decision is determined at the P_1 goal level. The fact that other goals are a part of a GP model and that they are not considered in a solution, should not be considered a poor modeling practice. If this were true, every LP model that has a slack or surplus variable (which includes about every model ever formulated) would be considered misformulated. Similar notions of the inappropriateness of setting a number of priorities in a GP model (see Ignizio 1985, p. 32 who suggests a maximum of 5 or 6 priorities in any GP model) are a questionable suggestion. Every modeling situation is different and will require a differing amount of priorities to adequately describe the decision environment in that situation. It should be remembered that the trade-off information revealed by priorities that are not fully satisfied is often more valuable then the solution values for the decision variables. Without some deviation in the lower priority levels trade-off information is not available, and that deviation would include redundant goal constraints.

Minimize: $Z = P_1\,(d_1^+ + d_2^+) + P_2\,(d_3^-) + P_3\,(d_4^-) + P_4\,(d_5^+) + P_5\,(d_6^+)$

subject to:

$$
\begin{aligned}
x_1 - d_1^+ + d_1^- &= 1 \\
x_2 - d_2^+ + d_2^- &= 1 \\
x_1 - d_3^+ + d_3^- &= 100 \\
x_2 - d_4^+ + d_4^- &= 200 \\
x_1 - d_5^+ + d_5^- &= 0.05 \\
x_2 - d_6^+ + d_6^- &= 0.08 \\
d_i^+, d_i^-, x_j \geq 0, &\text{ for } i=1, \ldots, 6; \text{ for } j=1, \ldots, 2 \qquad (2.4)
\end{aligned}
$$

One reason that does not appear to have been given must discussion time in the literature for all the modeling formulation issues is that of *modeling ethics*. Should a GP researcher accurately model a real world application with all its naiveté or should they exercise some mathematical correctness (i.e., political correctness in modeling) just to get the model through a review process for publication? Many professionals in industry are naive of current state-of-the-art mathematical conventions. Real world situations often reflect a more naive approach to modeling. Researchers seeking to model a real world application can find that decision makers don't always include relevant information, weight the importance of information and/or rank information in a way that the mathematical purist might want them to. Is it wrong then, in structuring a model of the real world, to include naive weighting or naive rankings if that is the way it is actually done? Is it wrong to reflect the real world the way it is observed by the researcher or the way in which a client wants it to be modeled? Should a researcher willfully remove real world naiveté from models in an effort to help them get published? These are ethics questions that experienced GP researchers have to be able to answer for themselves. Most researchers will not change the real world naiveté but instead try to change the client or decision making situation to reflect a less naive situation through education. If the researcher can not change the naive situation, then is advisable to mention the possibility of the GP model possessing some naiveté. It is hoped that reviewers of the same GP papers will not be so quick to reject a real world application simply because it accurately portrays a bit too much naiveté in its formulation.

Citations on relative weighting, prioritization and incommensurability can be found throughout the entire *life cycle* of GP literature. Some of the citations focus on methodology or systems to derive weightings or priorities, while other just provide conceptual material or comments on these issues. Table 2-4 presents a listing of some citations that are repeatedly referenced in the literature.

Table 2-4. GP Citations on Relative Weighting, Prioritization and Incommensurability

Reference	What Reference Provides
Choo and Wesley (1985),Cook and Kress (1988), Gass (1986, 1987), Hotvedt, Leushner and Buhyoff (1982), Knoll and Engelberg (1978), Levary and Avery (1984), Norse and Clark (1975), Ng (1987), Phillips (1987), Steuer (1979)	all provide weighting systems
Romero (1985b), Schenkerman (1991), Sherali (1982), Sutchiffe, Board and Cheshire (1985)	all provide comments on weighting systems

Table 2-4. (Continued)

Reference	What Reference Provides
Gass (1986), Lee and Shim (1986), Rubin and Narasimhan (1984), Tiwari, Dharmar and Rao (1986)	all provide priority systems
Kluyver (1979), De Kluyer (1979b), Fishburn (1974), Hannan and Narasimhan (1981), Hannan (1981d), Rae (1974)	all provide comments on priority systems
Harrald, Leotta, Wallace and Wendell (1978)	discusses limitations of GP on commensurability
Ginguest and Gulledge (1983)	discusses prioritization as a means of dealing with incommensurable goals
Cohon and Marks (1975)	argument that GP is limited to situations where goals or target values must be clearly defined
Min and Storbeck (1991)	provides pro's and con's on all three issues
Romero (1991, p. 35-43)	provides comments and teachable examples of all three issues

Other GP Model Formulation Issues

The number of possible GP model formulation issues far exceeds the content capacity of a single book to be able to do them justice. On the other hand, some mention of these other issues will be briefly offered here to serve as a directory for researchers who need additional information on these sometimes publication blocking issues.

Inappropriateness of predetermined goals or targets (Min and Storbeck 1991): Setting *a priori* right-hand-side b_i values (the model goals or targets) in GP models is viewed by some as being too arbitrary. It is felt that this arbitrary setting may lead to problems like dominance or just limits the information that the GP model can provide (Zeleny 1981). To overcome objections it might be advisable to included a sensitivity analysis of b_i Steuer (1976, 1979) that eliminates the uncertainty in the parameter. Another method (Romero 1985a) involves setting impossibly high target values to force nondominated solutions to occur. Still other methods to resolve this issue include those in Narasimhan (1980), Werczberger (1981), and Rakes and Franz (1985).

Failure of GP to identify unbounded solutions (Min and Stoebeck 1991): As Lee (1972, p.122) points out, unbounded solutions can occur in GP models if they are misformulated. Defending points of view can be found in Ijiri's (1965) book, Iginizo's (1976) book, Schniederjans's (1984) book and repeatedly by others in the literature including Hannan (1980, 1985), and Markowski and Ignizio (1983) and Ignizio (1983). This is not a justifiable reason to reject a GP model formulation.

Equivalence of GP and LP models (Romero 1991, pp. 26-29): As Ignizio (1983) points out, GP models are not LP models. Yet it is the LP base of problem situations that has so fueled the *GP life cycle of publications.* GP models can solve LP model problems for exactly the same solution, but can do much more and in different ways. Romero (1991, p. 29) claims that the equivalence in solutions between an LP model and a GP model is not a desirable situation. This has not been the case in the hundreds of GP models that fill the literature with LP model formulations, expressed with multiple objectives using a GP model. It is quite logical to start with a problem formulation as an LP model, recognize LP's limitations to deal with multiple objectives in the decision environment, and then revise the model in terms of GP. Even in the situation where the solution generated by the GP and the LP model are the same, GP methodology can give trade-off information (such as in the case of preemptive priorities) that does not exist in LP models. This is not really a problem that should be used to reject a GP model formulation.

Logical structure of a goal constraint (Romero 1991, pp. 31-33): Romero (1991, pp. 31-32) and others believe that both deviation variables must be included in goal constraints for a correct formulation. This may be true in some situations, but not all. Most experienced consultants know that in the real world there are boundaries that permit absolutely no deviation. To reflect this extremely hard boundary in a decision environment a single deviation variable constraint can be used. Charnes and Cooper's (1961, p. 217) original GP model includes single deviation variable goal constraints. For those unfamiliar with their formulation Schniederjans (1984, p. 70) illustrates the procedure by which single deviation variable constraints are formulated. Unless leaving the one of the deviation variables out of a formulation leads to some other formulation issue, this omission should not be used to reject a GP model formulation.

Formulation of a model that provides an optimal or satisficing solution: Since the GP solution methods employ the same basic optimization methods used in LP solutions (i.e., *simplex algorithms*), their is a component of optimization at work in any GP model (Ignizio 1982, p. 402). It should not viewed as an incorrect statement that GPmodels seek to optimize solutions or decision making from those solutions. Most GP researchers prefer to consider GP solutions as *satisficing*. The concept of satisficing implies that GP seeks a solution that fully satisfies as many goals as possible rather than just optimizing a single goal as in an LP model (Lee 1972, Chapter 1, Schniederjans 1984, p. 68, Romero 1991, p. 14). Based on the *Simonian philosophy* of satisficing (Simon 1955, 1957), GP models are able to solve complex problems with multiple goals in a way that best satisfies those goals, however they are structured. In summary, the terms optimal, satisficing, best, or even approximately rational (Lee 1972, p. 6) can all be used to describe a GP solution and should be viewed as an acceptable description of what the GP model does.

In concluding this section the concluding remarks by Charnes and Cooper (1961, p. 222) seem most appropriate. At the outset of the creation of GP, Charnes and Cooper where careful to warn users in the formulation of GP models of two main points: "(1) the need for considering all factors, including equivalencies, in setting goals and objectives, and (2) the wisdom of doing this as an integral part of the analysis rather than attempting to think all aspects of the problem through without the aid of explicit models." Care in GP modeling and care in the review of GP models should be exercised by all.

FORMULATION STRATEGIES AND TACTICS FOR IMPROVING GP MODELING

A general strategy for the creation or development of new GP models has often began with a methodology other than GP. In this section we will examine the use of MS/OR models as a point of creation for GP modeling. Once a GP model has been formulated, there is also the need to improve its structure as a means of adding value or literary significance to the model. Tactical methodology that can be used to improve model parameters and structure will also be discussed.

MS/OR Model Formulation Strategies

The synergistic impact of combining two or more MS/OR models to solve a complex decision situation is common place in the literature. LP has been shown to be useful in modeling most of the MS/OR models, including *transportation models*, *assignment models*, *network models*, *dynamic programming models*, *game theory models*, and *markov analysis models* (Kwak and Schniederjans 1987, Fang and Puthenpura 1993). GP is able to model LP problems with multiple objectives. Therefore it is only logical that researchers have chosen to use this connection to structure virtually all of the MS/OR models related to LP, as GP models. In addition, as other quantitative methodologies have found their way into MS/OR books, such as *simulation models*, *heuristic models* and *statistical models* (Hillier and Liegerman 1986), these methodologies were also joined with GP models to provide unique information or analytic power to deal with complex problems. In Table 2-5, available GP research publications are listed by their respective MS/OR topic.

There is still considerable GP modeling that can be done on any of these topics. On each of the MS/OR topic areas in Table 2-5 there are hundreds of articles describing these models that date back almost 50 years. The handfuls of GP models referenced in Table 2-5 representing the multiple goal conversion of the MS/OR topic can not possibly have done justice to still unused potential of each of these topics. For example, the topic of *heuristics* is currently being reinvented and applied in a growing number of areas including *artificial intelligence* and *expert systems*(Ignizio 1991, pp. 29-43). It can be assumed, as such, that the topic of heuristics is in an early stage of its own *life cycle* of research. By combining GP models with heuristic models, the effect will be to move the GP life cycle back in time toward a *maturity* or even *growth stage* in its own life cycle. Combining GP with other MS/OR models becomes not only a strategy a modeling ideas for the researcher, but also a strategy of life cycle renewal for the subject of GP.

Table 2-5. MS/OR Topics and Their Related GP Topics

MS/OR Topic	Related GP Model Reference
Transportation Models	Acharya, Nayak and Mohanty (1987), Bit, Biswol and Alam (1993), Kwak and Schniederjans (1979, 1985d), Lee and Moore (1973), Nayak, Basu and Tripathy (1989), Singh and Kishore (1991), Stewart and Ittman (1979)
Assignment Models	Bailey, Boe and Schnack (1974), Charnes, Cooper, Niehaus and Stedry (1969), Lee and Schniederjans (1983), McClure and Wells (1987b), Mehta and Rifai (1976, 1979), Phillips (1987), Schniederjans and Kim (1987), Zanakis (1983)
Network Models	DePorter and Kimberly (1990), Dieperink and Nijkamp (1987), Ignizio (1983b), Ignizio and Daniels (1983), Jandy and Tanczos (1987), Pentzaropoulos and Giokas (1993), Premachandra (1993), Price and Gravel (1984), Price (1978), Qassim and Silveira (1988), Van Hulle (1991a, 1991b)
Dynamic Programming Models	Acharya, Nayak and Mothanty (1987), Basu, Pla and Ghosh (1991), Charnes, Duffuaa and Al-Saffar (1989), Kornbluth (1986)
Game Theory Models	Charnes, Duffuaa and Intriligator (1984), Cook (1976), Hannan (1982b), Ratick (1983), Schniederjans and Kim (1987)
Markov Analysis Models	Zanakis and Maret (1981a, 1981b)

Table 2-5. (Continued)

MS/OR Topic	Related GP Model Reference
Simulation Models	Ashton (1985, 1986), Clayton, Weber and Taylor (1982), Dobbins and Mapp (1982), Lin (1978), Rees, Clayton and Taylor (1985)
Heuristic Models	Chen and Askin (1990), Gabbani and Magazine (1986), Loucks and Jacobs (1991), Mendoza (1986)
Statistical Models	Bajgier and Hill (1984), Chakraborty (1991b), Hattenschwiler (1988), Charnes and Cooper (1975), Charnes, Cooper and Sueyoshi (1986, 1988), Miyajima and Masato (1986), Sueyoshi (1989)

Tactics for Improving GP Model Formulations

Capturing the modeling complexity in a decision environment with multiple objectives can be difficult even for GP models. GP model formulations are often criticized for a variety of reasons including the logic or mathematical rationale of parameters that are used to make up the model. The relative weights, the number of priorities, the actual values for the technological coefficients of a_{ij} and right-hand-side values of b_i all can contain flaws, where only a single flaw can ruin an entire model formulation.

To help minimize these potential flaws a number of methodologies have been suggested in the literature that are useful in improving GP model formulations. Some of these methods include *scaling* or *normalizing* of goal constraint parameters, the use of *analytic hierarchy process* for determining relative weights or priorities, the use of *conjoint analysis* for determining relative weights or priorities, the use of *regression analysis* for determining relative weighting or goal constraint parameter estimation, the use of *logarithmic transformations* of goals and the use of *input-output analysis* for technological parameter estimation.

Scaling or normalizing goal constraint parameters: The suggestions by De Kluyver (1979), Widhelm (1981), Zeleny (1982, pp. 315-333), Gass (1986, 1987) and Romero (1991, pp. 35-43) on scaling methods that normalize goal constraints in a GP model can be used to reduce the bias caused by the magnitude of parameters in goal constraints. GP models (specifically (1.3), (1.5) and (1.6) in Chapter 1) that permit more than one goal constraint to be weighted or grouped at a single priority level run the risk of *incommensurability* of goal constraints. One way to avoid this problem is to put those goal constraints on the same comparable basis. By scaling to a common measure the of a_{ij} technological coefficients and b_i right-hand-side values, the magnitude of the parameters is adjusted to prevent incommensurability in the model. For example, suppose we have a weighted and preemptive GP model as in (2.5:

$$\text{Minimize: } Z = \text{P}_1\,(d_1^- + d_1^+) + 0.1\text{P}_2\,(d_2^- + d_2^+) + 0.9\text{P}_2\,(d_3^- + d_3^+)$$

$$\begin{aligned} \text{subject to:} \quad & x_1 + x_2 - d_1^+ + d_1^- = 100 \\ & 1{,}000x_1 - d_2^+ + d_2^- = 100{,}000 \\ & x_2 - d_3^+ + d_3^- = 100 \\ & d_i^+, d_i^-, x_j \geq 0, \text{ for } i=1, \ldots, 3; \text{ for } j=1, \ldots, 2 \end{aligned} \tag{2.5}$$

It can be observed in this simple GP model that the values for the decision variables are not determined at the P_1 priority level. This goal only sets a boundary for the sum of the decision variables, such that $x_1 + x_2 = 100$. At P_2 the relative weighting is heavily in favor of making $x_2 = 100$ in the third goal constraint. Unfortunately the relative size of the parameters in the second goal constraint incorrectly causes the solution method seek to minimize the deviation in the second goal constraint, where the solution is obtained. The resulting solution for the (2.5) GP model is where $x_1 = 100$, $x_2 = 0$, $d_3^- = 100$, $\text{P}_1 = 0$, $\text{P}_2 = 90$ with the other deviations variables equaling zero.

To correct this problem (i.e., to make the relative weighting purposeful) Romero and Rehman (1984a) suggest a scaling of the goal constraint parameters. This can be accomplished by dividing the technological coefficients and the right-hand-side values by each goal constraint's respective right-hand-side value and multiplying the ratio by 100 to convert them into percentages of their objectives. So, the new coefficients would be found by:

New technological coefficient= (a_{ij} / b_i)x 100 (2.6)

New right-hand-side values= (b_i / b_i)x 100 (2.7)

Applying this logic to both goal constraints in the (2.5), the resulting revised GP model formulation is presented in (2.8). The resulting solution for (2.8) is where $x_1 = 0$, $x_2 = 100$, $d_2^- = 100$, $P_1 = 0$, $P_2 = 10$ with the other deviation variables equaling zero. In this solution the more heavy weighting of 0.9 on the deviation variables in the third constraint has been included in the solution. Also the goal accomplishment at $P_2 = 10$ is less because of the weighting, and therefore, we have a better solution or less deviation in the solution than in (2.5) where $P_2 = 90$. Unfortunately, scaling to normalize parameters of differing goal constraints can make the interpretation of deviation more difficult and less meaningful. More over, other issues including *naive relative weighting* and *naive prioritization* can be created by changing the actual magnitude of GP model parameters. Other scaling methodologies have been reported in the literature to deal with some of these issues, such as *Euclidean norming* (Romero 1991, p. 40). For the best treatment of these subjects see Romero (1991, pp. 35-43). A review of the references in Table 2-4 is also recommended.

Minimize: $Z = P_1 (d_1^- + d_1^+) + 0.1P_2 (d_2^- + d_2^+) + 0.9P_2 (d_3^- + d_3^+)$

subject to:

$$x_1 + x_2 - d_1^+ + d_1^- = 100$$
$$x_1 - d_2^+ + d_2^- = 100$$
$$x_2 - d_3^+ + d_3^- = 100$$

$$d_i^+, d_i^-, x_j \geq 0, \text{ for } i=1, \ldots, 3; \text{ for } j=1, \ldots, 2 \qquad (2.8)$$

Analytic hierarchy process for determining goal weights and priorities: The *analytic hierarchy process* (AHP) is a statistical methodology (Saaty 1980). AHP can be used to derive relative weighting or priorities based on the weighting for GP models. In modeling situations where numerous qualitative factors are to be considered in establishing relative weighting, AHP may bring a recognized and uniformly fair framework for the assessment of those weights. For those interested in a basic review of the methodology, most introductory level MS/OR books now discuss this methodology (see Cook and Russell 1993, pp. 467-480). For other AHP methodologies and applications that might serve as a basis for combined GP/AHP paper ideas see Zahedi (1986). For specific applications of combined GP/AHP research see Olson, Venkataramanan and Mote (1986), Schniederjans and Wilson (1991), and Dyer, Forman and Mustafa (1992).

Conjoint analysis for determining relative weights or priorities: *Conjoint analysis* is a methodology that can be used to compute relative weighting or technological coefficients in GP models. Conjoint analysis has the ability to take large amounts of attributes that are measured using any type of measurement (i.e., rankings, rating scales, paired comparisons, etc.) and combine them into more a accurate parameter for use in a model. This methodology helps to minimize prediction error in parameters and permits reliability measures and validation statistics to be generated to help lend credibility to GP model structures. For a recent discussion on how conjoint analysis can be used in a variety of different areas see Green and Srinivasan (1990). For a GP model specific study using conjoint analysis see Srinivasan and Shocker (1973).

Regression analysis for determining relative weighting or goal constraint parameter estimation: GP in the form of a *constrained regression* model was used quite some time ago by Charnes, Cooper and Ferguson (1955). By minimizing deviation the GP model can generate decision variable values that are the same as the beta values in some types of multiple regression models. In Charnes, Cooper and Sueyoshi (1986, 1988) it was suggested that their GP model serves a valuable purpose of cross checking answers from other methodologies. Likewise, multiple regression models can also be used to more accurately combine multiple criteria measures that can be used in GP model parameters. Those parameters can include the relative weighting and the goal constraint parameters. The application of multiple regression suggested here is that in situations where the criteria is from the same population, a multiple regression model might be used to group the scores together to form more accurate and justifiable model parameters. For example, in project selection problems, managers often score projects on some scale (like 1 to 10 points). The managers then combine the points together to create a mathematical weighting or utility index on which to base their project selection decision. A multiple regression of the scores for each project will also generate a mathematical weighting that reflects their partial or weighted contribution of the project to some stated goal. The resulting beta coefficients from a regression model would be a more inclusive and in general, more scientifically derived than other simpler methods of estimation. In addition, all of the many beta statistical tests significance for purposes of reliability and significance can also be included in a research study to support the model's construction. One application of the use of regression in estimating goal constraint parameters is in Kwak, Schniederjans and Warkentin (1991).

Logarithmic transformations of goals: In a variety of problem situations the goal constraints must be expressed an nonlinear functions (see Philipson and Ravindran (1978, 1979), Singh (1983) and Sundaram (1978)). We will be discussing *nonlinear GP* in Chapter 3. There is nothing wrong with structuring GP models with nonlinear goal constraints. Unfortunately, such constraints can add complexity to the solution process, which in turn leads to model formulation issues (i.e., dominance, etc.). To avoid the complications of dealing with goals expressed as polynomials many researchers convert the nonlinear functions to linear equivalents using a *logarithmic transformation* (see Romero 1991, pp. 67-71). This can permit a standard linear GP software package to be used to obtain a solution from the model. Romero and Amador (1986) pointed out that such transformations can yield incorrect results because of the unique nature of GP models. They suggested that logarithmic transformations can be used correctly if applied to LP constraints. This leaves open the option of converting goal constraints back into LP constraints for purposes of dealing with the nonlinearity. Where this is not possible, Romero and Amador (1986) suggest that if the logarithmically transformed goal constraints are placed at the P_1 priority level and possess no deviation in their resulting solution (i.e., a fully achieved goal), then the logarithmic transformation is licit.

Input-output analysis for technological parameter estimation: The use of the economics based methodology called *input-output analysis* to generate technological coefficients can be traced to LP model applications by Ijiri (1968), Gambling (1968) and Livingston (1969). What input-output analysis can be used to do in GP models is to transform technological coefficients to reflect real world impact of different types of *posterior* system behavior. For example, in any production process some units of material resources become scrap. If scrap is an important factor in a decision making environment it is necessary to include such allowances in a GP model. In highly complex multi-stage production processes where the flow of production moves in-and-out of various production processes, a simple percentage scrap rate deduction in technological coefficients reflecting usage by a particular production process, generally will not provide a realistic posterior output parameter for the GP model. Input-output analysis, using an inverse matrix procedure, adjusts technological coefficients to take into consideration the interaction and resulting posterior system behavior between all production process. Input-output analysis methodology is illustrated in Kendall and Schniederjans (1983) where a hypothetical example of how this methodology works in a GP model is presented. A real world example of the use of input-output analysis in a GP model of a manufacturing operation is presented in Schniederjans and Markland (1986).

There are almost as many additional tactical methodologies used to improve GP models as there are papers not cited in this section. Some of these methodologies will be discussed in Chapter 3 where the solution method used to generate an answer from a GP model can impact the formulation of that model.

SUMMARY

This chapter is about formulating GP models. It began with a simple GP model formulation procedure. Recognizing that the procedure is not always applied correctly, this chapter discussed issues that can lead to a GP model being misformulated.. Such issues as dominance, inferiority and inefficiency in GP solutions were discussed along with issues of naive relative weighting, incommensurability, naive prioritization and redundancy. Having stated what to avoid or not to do in formulating GP models, the last section of this chapter was devoted to ideas for formulation strategies and tactics that could be used to improve GP models.

The same people who formulate GP models are also the same people who review GP models for publication in journals. It is hoped that this chapter will help the GP researcher who formulates GP models to better understand how to formulate a GP model. It is also hoped that this chapter will help the reviewers of GP models understand that issues raised in the literature that are used to reject GP models for publication purposes may themselves be in error in a particular decision environment. That care by both model builders and model critics is a necessary requirement for the perpetuation of the *life cycle of GP research.*

REFERENCES

All references in this chapter, except those below, can be found in *Appendix B, Journal Research Publications on Goal Programming.*

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CHAPTER 3. GOAL PROGRAMMING SOLUTION METHODOLOGY

When goal programming (GP) was introduced in the mid 1950's there was little computer software (or computers) to help support the growth of this computationally dependent methodology. By the early 1970's both computers and software applications where in place to encourage the development of GP modeling. As the *life cycle of GP research* in Figure 1-3 in Chapter 1 reveals, the real growth period for GP literature began at this very same time. The GP software required the availability of GP algorithms used to generate the primary GP problem solutions. In addition, a collection of supporting algorithms are also necessary to permit a post-solution analysis or secondary consideration of the solutions obtained in the primary solution. Collectively, these *primary* and *secondary* algorithms can be called *GP solution methodologies.*

The purpose of this chapter is to review all of the various types of GP solution methodologies that have appeared in the literature. This review includes the primary GP algorithms and methodology used to generate linear GP, integer GP and nonlinear GP solutions. In addition, secondary GP methodologies including duality and sensitivity analysis used to obtain post-solution information will also be discussed.

PRIMARY GOAL PROGRAMMING SOLUTION METHODOLOGIES

There are many different methodologies and algorithms used to generate solutions for GP models. We will begin by categorizing them into four groups of *linear GP* (which includes all linear based GP solution methods), *integer GP* (which includes methodology used to generate all integer, mixed integer and zero-one integer solutions), *nonlinear GP* (which includes all nonlinear based GP solution methods), and a final *other* group for all methodology that does not fit into the other three groups.

It should be mentioned that applications of GP methodologies add to GP solution methodologies. Some of the methodological improvements that are a part of GP literature have been presented as an application or in a case study. These methodologies will not be included in this chapter since they are presented as applications. These applications will be discussed in Chapter 4 and readers are encouraged to review that chapter's citations of applications to complete their survey of any one type of methodology introduced in this chapter.

Linear Goal Programming Algorithms and Methodology

The first linear GP algorithm is actually an LP algorithm. The methodological proof for solving LP models structured as GP problems can be found in Charnes and Cooper (1961, pp. 210-215). With the improvements of preemption, the *generalized inverse approach* and the illustrative use of the *simplex based algorithm* by Ijiri (1965), as well as the publication of a software program by Lee (1972), substantially increased linear GP research in methodological improvements. While it was assumed the LP proof by Charnes and Cooper (1961) was sufficient to justify the mathematical workings of GP algorithms, it is interesting to note that no mathematical proof of a simplex-based linear GP methodology actually appeared until Evans and Steuer (1973).

In Chapter 2 the distinctions between weighted GP models, preemptive GP models and various combinations were discussed. While some GP algorithms can only be used with a single type of GP model, others have been designed to handle a wider variety of GP models. This logic has been taken to the extreme in MULTIPLEX model and algorithm (Ignizio 1985c), which claims to be able to work with LP, weighted GP, preemptive GP and fuzzy GP models.

The basic algorithms used to solve the weighted GP, preemptive GP and their combinations are available in virtually all basic *management science/operations research* (MS/OR) books (see typical example in Turban and Meredith 1991, Chapter 9). A more detailed discussion of such algorithms can be found in GP books, including Ignizio (1976,1982), Ijiri (1965), Lee (1972) and Schniederjans (1984). Other extensions of methodology can be found in Table 3-1.

Many of the methodological refinements used in weighted GP and preemptive GP models, can be found in applications of these models. These applications are listed in Chapter 4.

Table 3-1. Citations on Weighted/Preemptive GP Methodology

Reference	What Reference Provides
Arthur and Ravindran (1978), Schniederjans and Kwak (1982), Kwak and Schniederjans (1982, 1985c)	reduced size algorithms
Freed and GLover (1981a, 1981b)	used as discriminat analysis
Charnes and Cooper (1977), Evans and Steuer (1973), Hwang, Paidy, Yoon and Masud (1980)	mathematical proofs for GP
Schenkerman (1991)	discussion on weighted GP
Knoll and Engelberg (1978),Kluyver (1979), Sherali (1982),Shim and Siegel (1975), Spivey and Tamura (1970), Steuer (1979), Widhelm (1981)	weighted GP methodologies
Arthur and Ravindran (1980), Charnes and Gooper (1961), Dauer and Krueger (1979), Ignizio (1976 book, 1982 book, 1985c), Iserman (1982), Ijiri (1965 book), Lee (1972 book), Schniederjans (1984 book)	algorithms for both models
Lee (1983), Lee and Rho (1979b, 1983, 1986)	decomposition methodologies
Crowder and Sposito (1987), Ignizio (1985a, 1987)	solution by dual solution
Akgul (1984), Alvord (1983), Clayton and Moore (1972b), Gibbs (1973), Hindelang (1973), Ignizio (1978a, 1983a), Ruefi (1971)	general discussion of issues

Integer Linear Goal Programming Algorithms Methodology

In GP problem situations where decision variables are restricted to integer values, special integer GP methodologies were developed. Most of the GP methodologies are based on integer LP methodologies. For example, in all or mixed integer LP problems one of the most common integer methodologies is the *branch-and-bound solution method.* Arthur and Ravindran (1980) developed their branch-and-bound *integer GP* algorithm on this same LP algorithm. Additional citations for these methods can be found in Table 3-2. In the case of zero-one LP integer solutions the most commonly approach is some type of *enumeration method.* Garrod and Moores (1978) developed their *zero-one GP* solution methodology using the same approach. Other citations for zero-one GP methods can be found in Table 3-3.

It is interesting to note that most of the research in integer GP is applied. In Chapter 4 dozens of application papers are presented using methodologies based on one that is presented in this section. A review of these applied models will reveal additional methodological refinements that are not included in the studies cited in this section.

Nonlinear Goal Programming Algorithms and Methodology

According to Saber and Ravindran (1993) there are four major approaches to nonlinear GP: (1) *simplex based nonliner GP*, (2) *direct search based nonlinear GP*, (3) *gradient search based nonlinear GP*, and (4) *interactive approaches to nonlinear GP.* We will discuss each of these in this section. For additional information on these subjects review the citations presented in Table 3-4.

The *simplex based nonlinear GP* approaches include the method of *approximation programming,* which was developed by Griffith and Steward (1961) adapted by Ignizio (1976) for GP. This methodology permits nonlinear goal constraints to be included in a GP model.

Another simplex based approach to nonlinear GP is called *separable programming.* Originally developed by Miller (1963), this approach was modified for GP by Wynne (1978). This methodology allows nonlinear goal constraints to be included in the GP model by restricting the range of the decision variables into separable functions that are assumed linear. This methodology is based on the logic of *piece-wise linear approximations.* For a review of the mechanics of this methodology see Reklaitis, Ravindran and Ragsdell (1983).

Table 3-2. Citations on Pure/Mixed Integer GP Methodology

Reference	Notes and Comments on What Reference Provides
Arthur and Ravindran (1980)	introduction of branch-and-bound method
Sharif and Agarwal (1976), Lee and Morris (1977)	classical introductions to the subject
Gabbani and Magazine (1986)	a combined methodology with heuristics
Gupta and Sharna (1989)	a combined methodology with quadratic programming
Hallefjord and Jornstern (1988), Ignizio (1989), Sharma and Sharma (1980)	all discuss the pro's and con's of integer programming
Ignizio and Daniels (1985)	a combined methodology with fuzzy GP
Ignizio (1983c, 1984), Ignizio (1985b), Markland and Vickery (1986)	all new methodologies

Table 3-3. Citations on Zero-One GP Methodology

Reference	Notes and Comments on What Reference Provides
Garrod and Moores (1978)	an implicit enumeration method
Lee and Luebbe (1988)	a comparative evaluation of a variety of methods
Lee and Luebbe (1987b)	a methodology utilizing a partitioning method
Rasmussen (1986), Wilson and Jain (1988), Gen, Ida and Lee (1990)	all provide new methodologies or innovations

Table 3-4. Citations on Nonlinear GP Methodology

Reference	Notes and Comments on What Reference Provides
Armstrong, Charnes, and Haksever (1988), Weistoffer (1983)	methodology combined with interactive procedure
Awerbuch, Ecker and Wallace (1976), Charnes, Cooper, Klingman and Niehaus (1975)	a general discussion and comments
Clayton, Weber, and Taylor (1982)	methodology combined with simulation methods to generate a more greedy or efficient solution
Davis and Whitford (1985)	comments on decomposition method

Table 3-4. (Continued)

Reference	Notes and Comments on What Reference Provides
Deckro and Hebert (1988) El-Sayed, Ridgely, Sandgren (1989)	method for polynomial preference structure analysis
Dinklebach (1967)	methodology combined with fractional GP
El-Dash and Mohamed (1992)	methodology combined duality and sequential GP
Gupta and Sharma (1989), Reeves (1978), Shim and Siegal (1975)	methodologies using quadratic GP
Lee (1985a)	methodology combined with chance constraints
Lee and Olson (1985)	methodology combined with chance constraints
Lee and Lerro (1973)	methodology combined with calculus
Masud and Hwang (1989), Shephead(1980)	extensions of basic methodologies
Olson (1992)	review of methodologies
Romero and Amador (1986)	a discussion on nonlinear transformations
Saber and Ravindran (1992)	methodology based on partitioning
Saber and Ravindran (1993)	a survey of methodology
Sakawa (1985)	methodology combined with interactive and fuzzy GP

Still another simplex based approach to nonlinear GP is *quadratic goal programming*. An early discussion of quadratic programming methodology can be found in Beale (1967). The idea of this approach as a GP methodology was originally presented by Gary Reeves at the 1977 Joint Annual Conference of the Operations Research Society and the Institute of Management Science in San Francisco. Quadratic GP permits quadratic goal constraints and quadratic deviation variables in the objective function. For a review of the mechanics of this methodology see Ringuest and Gulledge (1982) and Gupta and Sharma (1989).

Direct search based nonlinear GP methods utilize some type of logical search pattern or methods to obtain a solution that may or may not be the best satisfising solution. The logic process is based on repeated attempts to improve a given solution by evaluating its objective function and/or goal constraints. The basic search idea originated with Box (1965), but was applied to GP by many others including Nanda, Kothari and Lingamurthy (1988). There are many search methods in the literature. Hooke and Jeeves (1961) developed a single objective, continuous variable, unconstrained optimization method, that was later adapted for GP by Ignizio (1976) and Hwang and Masud (1979). An alternative approach that utilizes simulation methods in the search procedure is presented by Clayton, Weber and Taylor (1982).

Gradient based nonlinear GP methods use calculus or partial derivatives of the nonlinear goal constraints or the objective function to determine the direction in which the algorithm is to search for a solution and the amount of movement necessary to achieve that solution. While gradient based methods are generally more efficient in obtaining a solution, they may not be appropriate for GP models whose goal constraints or objective function is nondifferentiable.

Based on Zoutendijk's (1960) algorithm Lee (1985a), Lee and Olson (1985), Newton (1985) and Olson and Swenseth (1987) all developed a version of the gradient method for GP called the *chance constraint method*. The chance constraint method allows parameters to be distributed along a probability distribution. The introduction of the probability distribution is where this methodology obtained its probabilistic or chance name. The use of the chance constraint method requires the assumption that the technological coefficients are normally distributed. There are a dozen applications of chance constraint GP for linear and nonlinear problems listing in Chapter 4. Some of these date back to the 1970's and range up to the 1990's.

Another gradient based method is called the *partitioning gradient method*. Developed for linear GP by Arthur and Ravindran (1978) using a simplex based approach, this methodology can be highly efficient in obtaining nonlinear GP solutions. It works on the basis of finding smaller subproblems that lead to an optimal solution. By solving these smaller problems and eliminating decision variables from the model, the size of the model is reduced. For information on a software application and the methodology itself, see Saber (1991). A special version of the gradient based method is called the *decomposition method*. The decomposition method can solve linear GP or nonlinear GP problems. It is usually based on some version of the Dantzig and Wolfe (1960) LP decomposition method, where large models are decomposed into smaller submodels whose solution will be used to generate the solution to the original larger model. Algorithms and research on the decomposition method for GP can be found in , Ruefi (1971), Sweeney, Winkafsky, Roy and Baker (1978), Lee (1983), and Lee and Rho (1979a, 1979b, 1985, 1986).

One special type of nonlinear GP methodology can be called *stochastic goal programming*. In a stochastic GP model there are probability distributions present to describe model parameters or the model's structure. The chance constraint methodology for example can be used to model and solve some classes of stochastic GP problems. For a good review of the basics see Contini (1968). Other extensions of methodology can be found in Table 3-5.

Interactive approaches to nonlinear GP or *interactive GP* can be defined as a collection of methodologies that are based on progressive articulation of a decision maker's preferences in a decision environment (see Dyer 1972, Benson 1975). The decision maker using interactive GP will be lead to a better solution by interactively comparing a given solution. This makes interactive GP a sequential search process, but one that involves periodic feedback to the decision maker to guide the direction of the search. The term *sequential GP* is often used with the interactive approach to better describe the step-wise nature of this methodology. For additional methodological sources in sequential GP see Table 3-6.

Table 3-5. Citations on Stochastic GP Methodology

Reference	Notes and Comments on What Reference Provides
Ben-Tal and Teboulle (1986)	a discussion on utility, penalty functions and duality
Contini (1968)	classic introduction to the subject
Hussein (1993)	combined methodology with an interative GP approach
Ketzloff-Roberts and Morey (1993)	methodology combined with data envelopment analysis
Odom, Shannon and Buckles (1979)	a commentary of the subject
Reznicek-Roberts and Morey (1993)	combined methodology with data envelopment analysis
Sengupta (1981)	basic review of methodology
Stancu-Minasian and Tigan (1988)	methodology combined with fractional GP
Sueyoshi (1991)	methodology combined with data envelopment analysis
Teghem, Dugrane, Thauvoye and Kunsch (1986)	combined methodology with interative GP

Interative GP has been used for all types of GP models (i.e., linear GP, integer GP and nonlinear GP). Any of the methods that are used to solve GP problems can be used as an interactive, sequential GP search methodology. The combination of these terms appeared in Hasud and Hwang (1981), which may have lead to the often used combination. For an excellent review if the mechanics of the various methods see Van Delft and Nijkamp (1977), Spronk (1981). Additional citations on sequential GP appear on Table 3-7.

Table 3-6. Citations on Interactive GP Methodology

Reference	Notes and Comments on What Reference Provides
Buchanan and Daellenbach (1987)	a comparative evaluation of a variety of methods
DeKluyver and Moskowitz (1984)	a combined methodology to estimate probabilities in forecasting
Dyer (1972), Masud and Hwang (1981), Walker (1978), Zoints and Wallenius (1976)	classic introductions to the subject
Ferreira and Geromel (1990), Fichefit (1976), Gabbani and Magazine (1986), Gass and Dror (1983), Korhonen and Laakso (1986), Reevesand Hedin (1993), Steward (1988) Teghem, Dugrane,Thauvoye and Kunsch (1986) Weistroffer (1982, 1983), Yang, Chen and Zhang (1990)	all provide new methodologies or innovations
Gibson, Bernardo, Chung and Badinelli (1987)	a comparison of various methods
Rustangi and Bare (1987)	discusses how to resolve goal conflicts
Sakawa (1985)	a combined methodology with fuzzy and nonlinear GP

Table 3-6. (Continued)

Reference	Notes and Comments on What Reference Provides
Sakawa and Gen(1985), Sasaki, Gen and Ida (1990)	combined methodology with fuzzy and sequential GP
Shin and Ravindran (1991)	a survey of methods
Tingley and Liebman (1984b)	discusses how to adjust parameters in model

Table 3-7. Citations on Sequential GP Methodology

Reference	Notes and Comments on What Reference Provides
Crowder and Sposite (1991)	usage with a specific computer application
El-Dash and Mohamed (1992), Markowski and Ignizio (1983a)	a combined methodology with duality
Ignizio (1979)	usage with a specific computer application
Masud and Hwang (1981)	an introduction to the basics
Ogryczak (1988a)	a unique discussion and methodology
Saaki and Gen (1992)	a combined methodology with fuzzy and interactive GP

Other GP Algorithms and Methodology

There are at least four other algorithm based methodologies that are extensively represented in GP literature: *interval GP*, *fractional GP*, *duality solution* and *fuzzy GP*. Each of these other methodologies can and often are used with linear GP, integer GP and nonlinear GP models. They also offer unique modeling features that have distinguish them in their own right.

Interval GP: Interval GP allows parameters, particularly the right-hand-side goal values to be expressed on an interval basis. This method is based on interval LP, where an upper boundary, b_u and lower boundary, b_l for the right-hand-side values can be stated as:

$$b_l \leq a_{ij}\, x_j \leq b_u \tag{3.1}$$

So the interval GP equivalence would be accomplished with two goal constraints:

$$a_{ij}\, x_j - d_u^+ + d_u^- = b_u \tag{3.2}$$

$$a_{ij}\, x_j - d_l^+ + d_l^- = b_l \tag{3.3}$$

Where the d_u^+ and d_l^- are both minimized in the objective function and the other deviation variables are free to permit some compromised value for the resulting right-hand-side value. This method can be used to deal with a variety of formulation issues that are used to criticize GP models, such as the inappropriateness of predetermined goals or targets (see Min and Storbeck 1991). For citations on interval GP methodology see Table 3-8.

Fractional GP: Fractional GP is a methodology used when modeling ratios. In a variety of situations, such as modeling return on investment problems, market share problems or percentage type problems, fractional GP maybe the most appropriate of the GP methodologies. As Awerbuch, Ecker and Wallace (1976) noted, there complexities in GP model formulations that make simple multiplication of goal constraints an invalid means for dealing with fractional values. For a review of some of the controversy see Hannan (1977, 1981) and Soyster and Lev (1978). Fractional GP is also an extension of LP, called *fractional LP* (see Marto (1964), Bitran and Novaes (1973). For citations on interval GP methodology see Table 3-9.

Table 3-8. Citations on Interval GP Methodology

Reference	Notes and Comments on What Reference Provides
Charnes and Collomb (1972)	a classic introduction to the basics
Charnes and Cooper (1977)	a mathematical proof and explanation
Ichida and Fujii (1990)	a basic methodological example
Inuiguchi and Yosufumi (1991)	a methodological study of interval parameters
Ishibuchi and Tanaka (1990)	a methodological study of an interval objective function
Steuer (1979)	a combined methodology with sensitivity analysis for weighting

Duality Solution: It has been shown that GP models can be solved more efficiently and without some computational problems by solving the dual formulation of the a GP model (Dauer and Krueger 1977, Ignizio 1985). This method is not without its problems as observed by Crowder and Sposito (1987) and replied to by Ignizio (1987). An interesting extension of this method to sequential nonlinear GP can be seen in El-Dash and Mohamed (1992).

Fuzzy GP: Fuzzy GP is based on *fuzzy set theory*. Fuzzy sets are used to describe imprecise goals. These goals are usually associated with objective functions and are used to reflect both a weighting (with values from zero to one) and range of goal achievement possibilities. For example, if a profit function ranges from \$100 to \$300 in increments of \$100, we might weight our preference for \$100 occurring as 0.0, \$200 occurring 0.5 and \$300 occurring as 1.0. The numerical relationship between the goal of profit and the weighting attached to them, is a fuzzy set of numbers defining the decision makers utility

Table 3-9. Citations on Fractional GP Methodology

Reference	Notes and Comments on What Reference Provides
Agrawal, Swarup, and Garg (1984), Armstrong, Charnes, and Haksever (1987)	basic discussion and select methodology
Awerbuch, Ecker and Wallace (1976), Charnes and Cooper (1962), Hannan (1977, 1981b), Joksh (1964), Kornbluth and Steuer (1981a, 1981b), Soyster and Lev (1978)	all are classical introductions and commentary
Dinklebach (1967)	a combined methodology with nonlinear GP
Lee, Chung, and Tcha (1991)	a combined methodology with fuzzy GP and duality
Pant and Shah (1992)	a new linear approach
Stanu-Minasian and Tigan (1988)	a combined methodology with stochastic GP

in the profit occurrences. The relationship between the weighting and the profit function can be linear or nonlinear. Most importantly, this methodology allows the decision maker who can not precisely define goals to at least express them using a weighting structure that is not limited. This makes fuzzy programming an idea approach when utility function type goals are to be used in the GP model. For citations on fuzzy GP methodology see Table 3-10.

Table 3-10. Citations on Fuzzy GP Methodology

Reference	Notes and Comments on What Reference Provides
Carlsson (1982), Ignizio and Hannan (1982), Llena (1985), Mohandos, Phelps and Ragsdell (1990), Narasimhan (1981)	all provide commentary and criticism of the subject
Hannan (1982a)	explains the difference between fuzzy GP and other fuzzy methodologies
Hannan (1981a, 1981c, 1981d), Narasimhan (1980), Zimmerman (1978), Zimmerman (1983)	all provide basic introductions to the subject
Ignizio and Daniels (1984)	a combined methodology with integer GP
Lee, Chung, and Tchu (1991)	a combined methodology with fractional GP
Rao, Tiwari and Chakraborty (1993)	a combined methodology with chance constraint GP
Rao, Tiwari and Mohanty (1988a, 1988b)	a preference structure analyses
Rubin and Narasimhan (1984)	a combined methodology with Nester priorities
Sakawa (1985)	a combined methodology with interactive and nonlinear GP

Table 3-10. (Continued)

Reference	Notes and Comments on What Reference Provides
Sasaki and Gen (1992)	a combined methodology with interactive GP
Tiwari, Dharmar, and Rao (1986)	a priority structure analysis
Tiwari, Dharmar, and Rao (1987)	an additive model methodology

SECONDARY GOAL PROGRAMMING SOLUTION METHODOLOGIES

Two extensions of LP are duality and sensitivity analysis. These extensions exist in GP as well, but with some unique characteristics.

Duality in GP

In LP models we seek to determine the *marginal contribution* (also called the *dual decision variable*) of each of the right-hand-side values in terms of the single objective function units (Fang and Puthenpura 1993, pp. 56-72). The same basic simplex process is used in GP duality to derive the marginal contribution of each right-hand-side values. A variety of GP concepts and methodologies on duality can be found in Markowski and Ignizio (1983a, 1983b), Ogryczak (1986, 1988b) and Martinez-Legaz (1988). An exception that makes GP duality different is that its interpretation of the resulting marginal contribution is some what different from LP. The marginal contribution of right-hand-side values or goals in GP models take on a *multidimensional characteristic* (Ignizio 1984b). The interpretation of the marginal contribution in GP models has to be in terms of all of other goals in the model. That is, the marginal contribution of one goal in terms of all other goals. An excellent discussion of the mechanics and interpretations can be found in Ignizio (1982, Chapter 18).

Other studies have extended duality analysis in GP. An iterative algorithm with its dual formulation was discussed by Dauer and Krueger (1977). Ben-Tal and Teboulle (1986) added an even greater degree of complexity to the use of duality with a stochastic, nonlinear GP model. Likewise, Lee, Chung and Tcha (1991) combined duality in GP with fuzzy GP and fractional GP. As previously mentioned, dual formulations for GP models have also been shown to enhance computational efficiency for solving GP problems when compared to other standard algorithms (see Dauer and Krueger 1977, Ignizio 1985).

Sensitivity Analysis in GP

According to Ignizio (1982, Chapter 19) there are seven types of changes that can be implemented as a part of sensitivity analysis in GP: (1) changes in the weighting at a priority level, (2) changes in the weighting of deviation variables within a priority level, (3) changes in right-hand-side values, (4) changes in technological coefficients, (5) changes in the number of goals, (6) changes in the number of decision variables, and (7) reordering preemptive priorities. Most of these have been illustrated by application (see Chapter 4). Lee (1972, Chapter 7), Ignizio (1982, Chapter 19), Schniederjans (1984, pp. 105-109.) all provide basic methodologies for undertaking these seven types of sensitivity analyses in GP models. For additional citations on GP sensitivity analysis methodology see Table 3-11.

COMPUTER SOFTWARE SUPPORTING GP SOLUTION ANALYSIS

In S. M. Lee's 1972 GP book, *Goal Programming for Decision Analysis*, the computer coding for a FORTRAN program presented the first published source of software for all the various types of weighted and preemptive linear GP models. The availability of this code and the interest in GP in the early 1970's undoubtedly lead to the greatest growth stage in GP research that this subject has ever had (see Figure 1-3 *Life Cycle of GP Research*). Based on citation counts, Lee's software or versions developed from it are the mostly cited software used to solve GP models during the 1970's and early 1980's. Many of the GP software systems used in the 1990's are based on a version of Lee's GP software program (see Lee, 1972, pp. 140-157). Other mainframe computer based systems, like Ignizio's (1985c) MULTIPLEX code that came later helped to broaden software capabilities to included LP algorithms as a part of a package of software. Being used for mainframe computer systems, both Lee's and Ignizio's software applications could be reprogrammed to handle models equal to the memory of the computer on which they were run.

Table 3-11. Citations on Sensitivity Analysis GP Methodology

Reference	Notes and Comments on What Reference Provides
Gambicki and Haimes (1975)	a basic methodology for changes in goals
Karandikar and Farrokh (1987)	a unique solution methodology
Rifai (1980)	a basic methodology for changes in goals
Shim and Siegel (1980)	a methodology for changes in priorities
Steuer (1979)	a methodology for changes in weighting
Wilson and Jain (1988)	a methodology for use with zero-one GP

Other specialized computer codes whose ability to deal with a smaller subset of GP problem solving have been developed over the years. Unfortunately, most such codes do not end up in journal publications and even their applications are not always reported until years after they appear in the literature. For example a nonlinear GP code called the *Partitioning Gradient Based* (PGB) computer program appeared in Lasdon, Waren, Jain and Ratner (1978). Its coding application to nonlinear GP occurred much later by Saber (1991).

For the purposes of this book, the AB:QM, Version 3.1 (Lee 1993) microcomputer or PC was more than adequate to do solve the small problems presented. The AB:QM software can handle a 50 goal constraint by 50 decision variable or (50 row x 50 column) GP model. It does not handle integer GP problems or nonlinear GP models, unless those models can be converted into the linear GP equivalent. AB:QM also does not provide duality or sensitivity analysis for GP models. This package, like most of those sold with MS/OR books is designed to handle classroom problems for teaching purposes using a wide variety of quantitative methods. While some small GP applications can work within the limitations of this type of microcomputer software, real world applications need much more GP algorithm power.

A telephone survey of existing GP software available through US developers was undertaken in the Fall of 1994 for this book. The purpose of this survey was to locate as many GP software applications for both microcomputers and mainframe computers as were available at that time of the survey. Excluding the MS/OR book software applications, the focus of this survey was on finding packages that would support research and real world sized GP models. A review of other software surveys on MS/OR methodology was used as a baseline for initial survey software developer contacts (Sharda 1992; Saltzman 1994). Other software developer contacts were obtained from advertisements in computer publications and from actual citations in GP articles.

Out of a total of 112 identified developers of LP or some type of mathematical programming software application, only 15 developers actually claimed that GP type models could be processed by their software. The respondents of this survey are presented in Table 3-12. The survey sought to determine the computer system platform or hardware on which the software worked. Platforms included *microcomputer systems*, *mainframe computer systems* or both. The capacity or size of GP models that could be processed by the various computer applications was also determined. In this regard it should be noted that when the word *memory* is used it refers to the size of the individual computer's memory capacity. This feature simply means the software is flexible to adapt to variable computer memory space limitations. In cases where developers offered a variety of packages capable of dealing with a range of differing sized models, only the largest size is reported in Table 3-12. Most importantly, the survey sought to determine which of the various GP methodologies were available on the software applications. The following six options were *linear GP*, *integer GP*, *nonlinear GP*, *duality*, *sensitivity analysis*, and *other*. If any of these six options were present in any form for the computer software application, a *Yes* appears in Table 3-12, other wise a *No* appears. It should be noted that in some cases the solution methodology used to generate GP solutions is based on LP algorithms used in a *sequential* manner to achieve the GP desired solution results.

Like all surveys, this one has some limitations. One limitation is the recognition that more then just those respondents is this survey offer GP software. For example, developers in nations other than the US were not surveyed or included in this study because of cost and time factors. Another limitation on this survey is the inherent bias that comes from accepting information based on the telephone responses of the representatives of the software developers, rather than actual experience with each software system. The claims of software capabilities are what were reported in the telephone survey by representatives of the firms they represent and may not prove out in the actual use of the specific software reported in this survey. In other cases, like with GINO (see Liebman, Lasdon, Schrage and Waren 1986), a general purpose modeling language, the software requires the GP model to be expressed in a slightly different form than those presented in the GP literature. This extra modeling effort may inhibit some applications informational efficacy.

Even given these limitations on a less the complete sampling of computer packages, the results reveal both quantity and quality of GP algorithm support in existing GP software applications. There appears to be more than enough GP algorithm power to solve any type of GP problem situation. Indeed, some of the newer software applications are particularly powerful when combined together. For example, the GAMS and MINOS software systems can be jointed together to overcome their individual limitations (see Brooke, Kendrick and Meeraus 1988). Combined the GAMS/MINOS software application can handle a larger range of problems and provides addition solution analysis information. An interesting capability of a combined software system is illustrated by MINOS and CONOPT, both of which are produced by the same software developer. CONOPT is not a GP software application but adds modeling diagnostic capability to MINOS GP models, such that CONOPT could help diagnose model formulation errors in GP models. Such software combinations are endless in variety and are left to the experimenters to research and report in the literature.

Table 3-12. Computer Software Applications That Support GP Solution Analysis

Software:	AMPL	CPLEX Mixed Integer Optim.	GAMS
Publisher:	Boyd & Fraser Pub. One Corp. Place Ferncroft Village Danvers, MA 01923	CPLEX Optim. Inc. 930 Tahoe Blvd. #802-279 Incline Village, NV 89451	Boyd & Fraser Pub. One Corp. Place Ferncroft Village Danvers, MA 01923
Phone No.:	(508)777-9069	(702)831-7744	(508)777-9069
FAX No.:	(508)777-9068	(702)831-7755	(508)777-9068
System Platforms:	Micro, Mainframe	Micro, Mainframe	Micro, Mainframe
Size Capacity (rows x cols.):	Memory	Memory	Memory
System Features:			
Linear GP	Yes	Yes	Yes
Integer GP	Yes	Yes	Yes
Nonlinear GP	Yes	Yes	Yes
Duality	Yes	Yes	No
Sens. Analy.	Yes	Yes	Yes
Other		Diagnostics	

Table 3-12. (Continued)

Software:	Extended LINDO	Extended GINO	HS/LP
Publisher:	LINDO Systems 1415 N. Dayton Str. Chicago, IL 60622	LINDO Systems 1415 N. Dayton Str. Chicago, IL 60622	Haverly Syst. Inc. P. O. Box 919 Denville, NJ 07834
Phone No.:	(312) 871-2524	(312) 871-2524	(201)627-1424
FAX No.:	(312) 871-1777	(312) 871-1777	(201)625-2296
System Platforms:	Micro, Mainframe	Micro, Mainframe	Micro
Size Capacity (rows x cols.):	32,000x100,000	800x1,600	8,192xMemory
System Features:			
Linear GP	Yes	Yes	Yes
Integer GP	Yes	No	Yes
Nonlinear GP	No	Yes	Yes
Duality	Yes	Yes	No
Sens. Analy.	Yes	Yes	Yes
Other			

Table 3-12. (Continued)

Software:	IBM Optimization Subroutine Library	MINOS, NPSOL and LSSOL	MPSX-MIP/370
Publisher:	IBM Dept. 85BA, MS 658 Neighborhood Rd. Kingston, NY 12401	Stanford Business Software Inc. 2672 Bayshore Pkwy. Mtn. View, CA 94043	Altium, of IBM IBM MS 936 Neighborhood Rd. Kingston, NY 12401
Phone No.:	(914)385-5027	(415)962-8719	(914)385-6408
FAX No.:	(914)383-4239	(415)962-1869	(914)385-4500
System Platforms:	Micro, Mainframe	Micro, Mainframe	Micro, Mainframe
Size Capacity (rows x cols.):	Memory	Memory	3,200xMemory
System Features:			
Linear GP	Yes	Yes	Yes
Integer GP	No	Yes	Yes
Nonlinear GP	No	Yes	Yes
Duality	Yes	No	Yes
Sens. Analy.	Yes	Yes	Yes
Other			Fuzzy GP

Table 3-12. (Continued)

Software:	Optimal Engineer	SAS/OR	Solvers
Publisher:	Transpower Corp. 1 Oak Drive Parkerford, PA 19457	SAS Institute Inc. SAS Campus Dr. Cary, NC 27513	Frontline Systs. Inc. P. O. Box 4288 Incline Village, NV 89450
Phone No.:	(800)OPT-TODAY	(919)677-8000	(702)831-0300
FAX No.:	None given	(919)677-8123	(702)831-0314
System Platforms:	Micro	Micro, Mainframe	Micro
Size Capacity (rows x cols.):	Memory	Memory	8,000x4,000
System Features:			
Linear GP	Yes	Yes	Yes
Integer GP	No	Yes	Yes
Nonlinear GP	Yes	No	Yes
Duality	No	Yes	Yes
Sens. Analy.	No	Yes	Yes
Other			

Table 3-12. (Continued)

Software:	SOPT	STORM	XPRESS-MP
Publisher:	Saitech Inc. 1301 Hwy. 36 Hazlet, NJ 07730	Storm Soft. Inc. 24100 Chagrin Blvd. Cleveland, OH 44122-5535	Resource Optim., Inc. 531 S. Gay Str. Ste 1212 Knoxville, TN 37010-1520
Phone No.:	(908)264-4700	(216)464-1209	(615)522-2211
FAX No.:	(908)888-1704	(216)464-4222	(615)522-7907
System Platforms:	Mainframe	Micro	Micro, Mainframe
Size Capacity (rows x cols.):	Memory	600x50	Memory
System Features:			
Linear GP	Yes	Yes	Yes
Integer GP	Yes	Yes	Yes
Nonlinear GP	No	No	Yes
Duality	Yes	No	Yes
Sens. Analy.	No	Yes	Yes
Other			

SUMMARY

This chapter discussed a variety of GP methodology. Included were algorithms and methodology designed to obtain a basic or primary solution for a problem. These primary types of methods included linear GP, integer GP and nonlinear GP. Each of these types of methodologies were subdivided into various other existing methodologies. This chapter also discussed secondary GP methodologies including duality and sensitivity analysis. This chapter closes with a survey of existing software applications that support GP problems.

Like the enumeration techniques of zero-one GP, this chapter seeks to provide researchers with a basic idea of the uniqueness of each method and a listing of available research where in to obtain a comprehensive understanding of the methodologies. The tables in this chapter provide a quick reference guide that is hoped will facilitate research efforts to local relevant information and extend the GP literature.

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Zoutendijk, G., *Methods of Feasible Directions*, Elsevier, Amsterdam, 1960.

CHAPTER 4. GOAL PROGRAMMING APPLICATIONS

Goal programming (GP) is a very applied methodology. In the over 980 journal citations listed in *Appendix B*, 666 or over 68 percent are applications, case studies or applied models. Indeed, the diversity of application in GP is now so great that just their listing will absorb this entire chapter.

The purpose of this chapter is to help researchers to identify relevant applied GP literature. To accomplish this objective, the chapter will offer users a categorized listing of the GP journal application research. This listing will be organized to permit users an efficient means to identify GP research by type of application.

INTRODUCTION

GP has been used in a wide range of unusually diverse applications, including Christmas tree optimization (Hansen 1978), the pricing of alcoholic beverages (Korhonen and Soismaa 1988), the optimization of fertilizer use (Minguez, Romero and Domingo 1988), and even the rationing of pregnancy (Neal, France and Treacher 1986). GP has also tackled socially serious issues, like busing children for racial equality (Knutson, Marquis and Ricchiute 1980, Lee and Moore 1977, Saunders 1981), the issue of pollution (Nanda, Kothari and Lingamurthy 1988), the social responsibility of business (Kahalas and Satterwhite 1978), and even the philosophical issue of weighting profit vs. social values (Kahalas and Groves 1978).

The magnitude of available applied GP research can make the effort to find relevant research on a particular topic a challenge. Available bibliographies organized by type of GP application are often limited to several dozen categories in which to identify topical areas of application (see Lin 1979, 1980a, Soyibo 1985, Zanakis and Gupta 1985, Romero 1986, 1991, pp. 106-120, White 1990). Also, many of the improvements in methodology appear with or because of their application to real world problems. For many researchers who are interested in research that applies a particular GP methodology (e.g., integer GP, nonlinear GP, etc.), it is particularly time consuming to review the prior literature. Survey contributions by Zanakis and

Gupta (1985) and Romero (1986, 1991, pp. 106-120) have substantially reduced the effort, but are based on a very limited sample of the true population of all GP applied research.

This chapter provides a bibliography of GP application research that is far more substantial than any bibliography of GP applications to date. The studies listed in the tables in this chapter represent actual real world applications or case studies of GP models, as well as applied hypothetical problem applications of GP models.

The listing of the citations in this bibliography are first organized into nine *functional categories* of *accounting, agriculture, economics, engineering, finance, government, international, management* and *marketing*. Each of these nine categories are divided into more than 160 *topical areas* to provide greater detail on the nature of the application. To permit users to identify the type of GP model that is used in each article, a coding system is utilized. Citations that have one asterisk "*" utilize an integer GP model (i.e.., all integer GP, mixed integer GP or zero-one GP). Citations that have two asterisks "**" utilize some type of nonlinear GP model. Citations that have three asterisks "***" utilize one or more of the other methodologies discussed in Chapter 3 (i.e., fuzzy GP, chance constraint GP, etc.). Citations without an asterisk generally utilize a weighted, preemptive or combination type GP model.

To insure that users will be able to find all existing relevant citations under a specific topic, citations in this bibliography have been cross-listed. This cross-listing permits the same article to appear under multiple topic headings and in multiple categories when appropriate.

GOAL PROGRAMMING APPLICATIONS IN ACCOUNTING

The 38 total GP types of applications in accounting are organized into ten different topics. The citations are presented in Table 4-1. The *Other Accounting* topic is used here for citations that could not easily be identified and classified into the other topical areas. The remaining nine topic areas are self explanatory.

Table 4-1. Citations on GP Applications in Accounting

Topic	Available References on Topic
Assets	Hibiki and Fukukawa (1992), Philippatos and Christofi (1984), Rosenbloom and Shiu (1990), Siokas and Vassiloglou (1991)
Auditing	Bailey, Boe and Schnack (1974), Balachandran and Steuer (1982)***, Blocher (1978), El-Sheshai, Harwood and Hermanson (1977)*, Filios (1984), Gardner, Huefner and Lotfi (1990), Ijiri and Kaplan (1971), Tayi and Gangolly (1985)***
Balance Sheet	Eatman and Sealey (1979), Tayi and Leonard (1988)
Budgeting	Buffa (1983)*, Charnes and Stedry (1966), Charnes, Colantoni, Cooper and Kortanek (1972), Charnes, Cooper and Ijiri (1963), Chen (1983)*, Joiner and Drake (1983), Kwak and Diminnie (1987), Lin (1978), Lootsma, Mensch and Vos (1990), Olve (1981), Smith (1978)
Control Systems	Lin (1980b)
Cost	Badran (1984), Charnes, Colantoni and Cooper (1976), Pentzaropoulos and Gilkas (1993), Sheshai, Harwood and Harmanison (1977)*
Other Accounting	Kornbluth (1974), Lin (1979), Welling (1977)
Public Accounting	Garrod (1991), Killough and Souders (1973)
Taxes	Lee, Lerro and McGinnis (1971), Puelz and Lee (1992)
Transfer Pricing	Merville and Tavis (1974)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

GOAL PROGRAMMING APPLICATIONS IN AGRICULTURE

The 63 total GP types of applications in agriculture are organized into ten different topics. The citations are presented in Table 4-2. The *Other Agriculture* topic is used here for citations that could not easily be identified and classified into the other topical areas. The remaining nine topic areas are self explanatory.

Table 4-2. Citations on GP Applications in Agriculture

Topic	Available References on Topic
Aquaculture	Weithman and Ebert (1981), Shepherd (1981), Sandiford (1986), Muthukude, Novak and Jolly (1990), Drynan and Sandiford (1985), Everitt, Sonntag, Puterman and Whalen (1978)
Economics	Bazaraa and Bouzaher (1981), Bouzaher and Mendoza (1987)
Farming	Barnett, Blake and McCarl (1982), Berlo (1993), Dobbins and Mapp (1982)***, Drynan (1985), Eto (1991), Fahmy and El-Shishiny (1991), Flinn, Jayasuriya and Knight (1980), Kang (1983), McCarl and Blake (1983), Minguez, Romero and Domingo (1988), Patrick and Blake (1980), Piech and Rehman (1993), Rehman and Romero (1993), Romero and Rehman (1983, 1984a, 1985), Varshney and Rao (1989)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-2. (Continued)

Topic	Available References on Topic
Forestry	Arp and Lavigne (1982), Buongiorno and Svanqvist (1982)***, Chang and Buongiorno (1981), Dyer, Hof, Kelly, Crim and Alward (1979, 1983), Field (1973), Field, Dress and Fortson (1980), Hotvedt (1983), Hotvedt, Leushner and Buhyoff (1982), Hrubes and Rensi (1981), Kao and Brodie (1979), McKillop and Liu (1990), Mendoza, Bare and Campbell (1987), Mitchell and Bare (1981)***, Pickens and Hof (1991)***, Porterfield (1976), Rensi and Hrubes (1983), Schuler and Meadows (1975), Schuler, Webster and Meadows (1977), Cubbage, Field, Eza and Farkas (1987), Dane, Meador and White (1977)
Land Management	El-Shishiny (1988), Ghosh, Paul, and Basu (1993)
Other Agriculture	Romero and Rehman (1983), Sinha, Rao and Mangaraj (1988)***, Wheeler and Russell (1977)
Pest Control	Brown, McClendon and Akbay (1990), Johnson, Oltenacu, Kaiser and Blake (1991)
Ranching	Barlett and Clawson (1978), Lara and Romero (1992)***, Neal, France and Treacher (1986), Rehman and Romero (1984, 1987)
Regional Planning	De Wit, Van Keulen, Seligman and Spharim (1988)**
Storage	Chang, Chung and Hwang (1983, 1984)**

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

GOAL PROGRAMMING APPLICATIONS IN ECONOMICS

The 28 total GP types of applications in economics are organized into nine different topics. The citations are presented in Table 4-3. The *Other Economics* topic is used here for citations that could not easily be identified and classified into the other topical areas. The remaining eight topic areas are self explanatory.

Table 4-3. Citations on GP Applications in Economics

Topic	Available References on Topic
Exporting	Levary (1986a)
Income Redistribution	Charnes, Duffuaa and Intriligator (1984)***
Industrial Development	Lee, Tang, Olson and Yen (1989)*, Walker and Chandler (1978)
Municipal Planning	Lee and Sevebeck (1971)
Other Economics	Dynan and Sandiford (1985), Kao and Brodie (1979), Lonergan and Cocklin (1988), Schinnar (1976), Shim (1983)**, Spivey and Tamura (1970), Spronk and Veeneklaas (1983)***, Charnes, Colantoni, Cooper and Kortanek (1972), Samouilidis and Pappas (1980), Charnes, Duffuaa and Al-Saffar (1989)
National Policies	Aggarwal and Clark (1978), Budavei (1982), Charnes and Collomb (1972)***, Habeeb (1991), Kalu (1994), Walleniius (1982), Charnes, Cooper, Harrald, Karwin and Wallace (1976)***
Pollution	Nanda, Kothari and Lingamurthy (1988)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-3. (Continued)

Topic	Available References on Topic
Regional Planning	Chen (1986), Lee and Olson (1981), Tyagi and Swarup (1979), Wright, Revelle and Cohon (1983)
Resource Allocation	Charnes, Cooper, Harrald, Karwan and Wallace (1976)

GOAL PROGRAMMING APPLICATIONS IN ENGINEERING

The 25 total GP types of applications in engineering are organized into eight different topics. The citations are presented in Table 4-4. The *Other Engineering* topic is used here for citations that could not easily be identified and classified into the other topical areas. The remaining seven topic areas are self explanatory.

Table 4-4. Citations on GP Applications in Engineering

Topic	Available References on Topic
Automated Systems	Bard (1986)
Design Problems	Bascaran, Mistree and Bannerot (1987), Guven, Mistree and Bannerot (1984), Ignizio and Satterfield (1977), Ignizio (1981a), Ignizio (1987), Ishiyama, Hondoh, Ishida and Onuki (1989), Kornbluth (1986)**, McCammon and Thompson (1980, 1983), Singh and Agarwal (1983), Singh (1983)
Feasibility Study	Ng (1991)

**Nonlinear GP model

Table 4-4. (Continued)

Topic	Available References on Topic
Other Engineering	Qassim and Silveira (1988), Van Crombrugge and Thompson (1985), Wang (1986), Siha (1993)
Production Processing	Acharya, Jain and Batra (1986)
Routing	Elamin, Duffuaa and Yassein (1990)
Reliability	Gen, Tsujimura and Chang (1993)***, Gen, Ida and Lee (1989, 1990)*, Hwang, Lee, Tillman and Lie (1984)**, Jedrzejowics and Rosicka (1983)
Software Application	Svestka (1990)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

GOAL PROGRAMMING APPLICATIONS IN FINANCE

The 112 total GP types of applications in finance are organized into 17 different topics. The topic areas are self explanatory. The citations are presented in Table 4-5.

Table 4-5. Citations on GP Applications in Finance

Topic	Available References on Topic
Acquisition Analysis	Hoffman and Schniederjans (1990), Madey and Dean (1985), Schniederjans and Fowler (1989), Schniederjans and Hoffman (1992)*, Dean and Schniederjans (1991), Hoffman, Schniederjans and Sirmans (1990)
Banking	Bandyopadhyay (1978), Fortson and Dince (1977), Giokas and Vassiloglou (1991), Hibiki and Fukukawa (1992), Hollis and Murray (1985), Keown (1978)***, Siokas and Vassiloglou (1991), Wilstead, Hendrick and Stewart (1975), Zaloom, Tolga and Chu (1986), Zanakis, Mavrides and Roussakis (1986)
Bank Portfolios	Booth and Dash (1977), Booth and Dash (1977)**, Chambers and Charnes (1961), Korhonen (1987)
Bond Portfolios	Alexander and Resnick (1985), Lee and Puelz (1989), Sealey (1977)
Capital Budgeting	Chateau (1975), Choi and Levary (1989)***, De, Acharya and Sahu (1982, 1986)***, Deckro, Spahr and Hebert (1985), Forsyth (1969), Hawkins and Adams (1974), Ignizio (1976), Jackman (1973), Keown and Martin (1977)***, Keown and Martin (1976, 1978)*, Keown and Taylor (1980)***, Keown and Taylor (1981), Lawrence and Reeves (1982b), Lee and Lerro (1974b), Lee and Shim (1984), Taylor and Keown (1981)*, Thanassoulis (1985)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-5. (Continued)

Topic	Available References on Topic
Capital Flow	Arthur and Lawrence (1985), Sartoris and Spruill (1974), Lee and Lerro (1974a)
Credit Analysis	Srinivasan and Kim (1987)
Divestiture	Sueyoshi (1991)***, Charnes, Cooper and Sueyoshi (1988), Evans and Heckman (1988)
Financial Planning	Ashton and Atkins (1979),Callahan (1973),Cook (1984),Jaaskelainen and Lee (1971), Kvanli and Buckley (1986), Kvanli (1980), Lee and Eom (1984, 1989), Lee, Justis and Franz (1979), Linke and Whitford (1983), Merville and Tavis (1974), Miyajima and Nakai (1986)***, Puelz and Lee (1992), Sealey (1978), Vinso (1982)
Finance/Production	Forsyth (1969)
Global Financial Planning	Eom and Lee (1987), Eom, Lee and Snyder (1987), Hoffman and Schniederjans (1990), Merville and Petty (1978), Philippatos and Christofi (1984), Schniederjans and Hoffman (1992)*, Vinso (1982)
Insurance	Drandell (1977), Flock and Lee (1974), Lawrence and Reeves (1982b), Lee and Klock (1974), Lilly and Gleason (1976)
Investment planning	Caplin and Kornbluth (1975), Chae, Suver and Chou (1985), Chen (1987)***, Gleason and Lilly (1977), Hsu (1976), Jose and Tabucanon (1986), Kumar and Philippatos (1979), Leinbach and Cromley (1983), Wacht and Whitford (1976)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-5. (Continued)

Topic	Available References on Topic
Managing Risk	Booth and Bessler (1989), Hibiki and Fukukawa (1992), Hollis and Murray (1985), Lee and Hall (1988), Sharda and Musser (1986)
Mutual Funds Portfolio	Lee and Lerro (1973)
Other Finance	Ashton (1985, 1986), Batson (1989), Hong (1981), Jones (1979), Kornbluth and Vinso (1982)***, Orne and Rao (1975), Walker and Chandler (1978), Joiner (1981)
Portifolio Analysis	Harrington and Fischer (1980)***, Johnson, Zorn and Schniederjans (1989), Kumar and Philippatos (1978), Lee and Chesser (1980), Levary and Avery (1984), Muhlemann and Lockett (1980)***, Muhlemann, Lockett and Gear (1978)***, Schniederjans, Zorn and Johnson (1993), Stone and Reback (1975)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

GOAL PROGRAMMING APPLICATIONS IN GOVERNMENT

The 169 total GP types of applications in government are organized into 27 different topics. The citations are presented in Table 4-6. The broadness of this category required an additional level of categorization. The citations are first divided into three broad categories of government involvement: *Education, Health Care* and *General Government*. The *Education-General* and *Health Care-General* topics are used here for citations that could not easily be identified and classified into the other topical areas. The remaining 25 topic area headings are self explanatory.

Table 4-6. Citations on GP Applications in Government

Topic	Available References on Topic
EDUCATION:	
Education-General	Djang (1993), Joiner (1980), Kennedy (1991), Smith (1978), Thomas (1987), Walters, Mangold and Haran (1976)
Eduation-Library	Beilby and Mott (1983), Hannan (1978a), Schniederjans and Santhanam (1989)*
Education-Secondary	Sutcliffe and Board (1986), Sutcliffe, Board and Cheshire (1984), Cohn and Morgan (1978), Papageorgia (1978)
Education-Students	Bafail (1993), Campbell and Ignizio (1972), Miyaji, Ohno and Mine (1988), Rumpf (1987)
Education-University	Albright (1975), Benjamin, Ehir and Omurtag (1992), Chae, Suver and Chou (1985), Diminnie and Kwak (1986), Feuer (1985), Franz, Lee and Van Horn (1981), Geoffrion, Dyer and Fienberg (1972)***, Ghosh, Paul and Basu (1992), Greenwood and Moore (1987), Harwood and Lawless (1975), Kendall and Luebbe (1981), Keown, Taylor and Pickerton (1981), Kwak and Diminnie (1987), Lawrence, Lawrence and Reeves (1983), Lee and Clayton (1970a,1972, 1980a, 1980b), Lee and Moore (1974b, 1975), Lee and Soyibo (1986), Lee and Van Horn (1978), McClure and Wells (1978b), Min (1988b)***, Ritzman and Krajewski (1979), Schniederjans and Kim (1987)*, Schroder (1974), Soyibo and Lee (1986)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-6. (Continued)

Topic	Available References on Topic
HEALTH CARE:	
Health Care-Blood	Kendall and Lee (1980a, 1980b), Kendall (1980)
Health Care-Budgeting	Keown and Martin (1976)*, Trivedi (1981)*, Mersha, Meredith and McKinney (1987)
Health Care-Dieting	Anderson and Earle (1983), McCann-Rugg, White and Endres (1983), Romero and Rehman (1984b)
Heath Care-General	Christainson (1983), Lee and Lerro (1974a), McGlone and Calantone (1992), Nelson and Wolch (1985), Ozatalay and Broyles (1984), Parker (1983), Rifai and Pecenka (1990), Tingley and Liebman (1984a), Wilson and Gibberd (1990)
Health Care-Hospitals	Chae, Suver and Chou (1985), Ghandfaroush (1993), Lee (1973), Wacht and Whitford (1976), Butler, Karwan, Sweigart and Reeves (1992)
Health Care-Nurse	Arthur and Ravindran (1981), Chen and Yeung (1993), Ozkarahan Bailey (1988), Ozkarahan (1989), Trivedi (1981)*, Moores, Garrod and Briggs (1978), Musa and Saxena (1984)
Health Care-System Design	Charnes and Storbeck (1980), Franz, Baker, Leong and Rakes (1989), Franz (1989), Franz, Rakes and Wynne (1984)***, Parker, Mtango, Koda and Killewo (1986), Specht (1993), Zhu and McKnew (1993), Baker and Fitzpatrick (1986), Baker, Clayton and Taylor (1989)**, Baker, Clayton and Moore (1989)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-6. (Continued)

Topic	Available References on Topic
GENERAL GOVERNMENT:	
Allocating Resources	Buffa and Shearon (1980), Koizumi and Inakazu (1989), Simkin (1977), Cornett and Williams (1991), Donckels (1977)**, Dusansky and Kalman (1981)**, Sinha and Sastry (1987b), Sinha, Sastry and Misra (1988)
Environmental Issues	Cocklin, Lonergan and Smit (1986), Charnes, Cooper, Karwan and Wallace (1979)***, Charnes, Cooper, Harrald, Karwan and Wallace (1976)***, Charnes, Haynes, Hazleton and Ryan (1975), Cocks and Baird (1989), Harrald, Wallace and Wendell (1978), Kambo, Handa and Bose (1991), Lonergan and Cocklin (1988), Ludwin and Chamberlain (1989), Marten and Sancholuz (1982), Panagiotakopoulos (1975), Spronk and Veeneklaas (1983), Werczberger (1976)
Government Budgeting	Joiner and Drake (1983)
Military	Armstrong and Cook (1979), Bres, Burns, Charnes and Cooper (1980), Gallagher and Kelly (1991), Lee, Synder and Brisch (1983), Mellichamp, Dixon and Mitchell (1980), Morey (1985), Nussbaum (1980), Suzuki and Yoshizawa (1994)***, Taylor, Keown and Greenwood (1983)*, Weigel and Wilcox (1993), Collons, Gass and Rosendahl (1983), Gass (1991), Gass and Collins (1988)
Police Allocation	Saladin (1982), Taylor, Moore, Clayton, Davis and Rakes (1985)**, Lee, Franz and Wynne (1979)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-6. (Continued)

Topic	Available References on Topic
GENERAL GOVERNMENT (Continued):	
Policy Evaluation	Chicoine, Scott and Jones (1980), Smith (1980), Piekanen (1970)
Policy Compliance	Taylor, Davis and Ryan (1977)
Postal Service Scheduling	Ritzman and Krajewski (1973)
Prison Management	Dessent and Hume (1990)
Social Issues	Kahalas and Groves (1978), Kahalas and Key (1974), Kahalas and Satterwhite (1978), Knutson, Marquis and Ricchiute (1980), Lee and Moore (1977), Nanda and Lingamurthy (1988), Saunders (1981), Zanakis (1987)*
Transportation	Prakash, Sinha and Sahay (1984), Wilson and Gonzalez (1985)
Urban Planning	Courtney, Klastorian and Reufli (1972)m Ignizio (1980), Kambo, Handa and Bose (1991), Lee and Keown (1979), Stern (1974), Taylor and Keown (1978b), Taylor (1977)
Utility Management	Chetty Mallikarjuna and Subramanian (1988), Linke and Whitford (1983)
Waste Management	Sushil and Vrat (1989), Sushil and Agrawal (1989), Sushil (1993), Mogharabi and Ravindran (1992)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-6. (Continued)

Topic	Available References on Topic
GENERAL GOVERNMENT (Continued):	
Water Resource Mgt.	Can and Houck (1984), Chisman and Rippy (1977), Changchit and Terrell (1993), Dauer and Kruger (1980), Giocoechea, Duckstein and Fogel (1976), Houck (1985), Jain, Soni and Seethapathi (1988), Loganathan and Bhattacharya (1990), Lohani and Adulbhan (1979), Loucks (1977), McGregor and Dent (1993), Monarchi, Kisiel and Duckstein (1973)***, Neely, North and Fortson (1976,1977), Neely, Sellers and North (1980), Nelson (1979), Reznicek, Simonovic and Bector (1991), Szidarovsky and Duckstein (1986), Taylor, Davis and North (1975), Yazadanian and Peralta (1986)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

GOAL PROGRAMMING APPLICATIONS IN AN INTERNATIONAL CONTEXT

The 42 total GP types of applications in an international context are organized into seven different topics. The citations are presented in Table 4-7. The topic areas are structured in terms of the major categories used in this book. Since these citations are cross-listed, their listing here allows users an additional international dimension to sort on for identification purposes.

Table 4-7. Citations on GP Applications an International Context

Topic	Available References on Topic
Accounting	Merville and Petty (1978), Philippatos and Christofi (1984)
Agriculture	Barnett, Blake and McCarl (1982), Bazaraa and Bouzaher (1981), Buongiorno and Svanqvist (1982), Chang, Chung and Hwang (1983)**, Chang, Chung and Hwang (1984)**, Charnes, Duffuaa and Al-Saffar (1989), Kang (1983), Lara and Romero (1992)***, Romero and Rehman (1983)
Economics	Habeeb (1991), Kalu (1994)
Engineering	Guven, Nistree and Bannerot (1984)
Finance	Bandyopadhyay (1978), Eom and Lee (1987), Hoffman and Schniederjans (1990), Lee and Eom (1989), Lee and Eom (1984), Leinbach and Cromley (1983), Levary and Avery (1984), Merville and Petty (1978), Philippatos and Christofi (1984), Schniederjans and Hoffman (1992)*, Vinso (1982), Hollis and Murry (1985), Hollis (1978), Kornbluth and Vinso (1982)***
Government	Anderson and Earle (1983),Chae, Newbrander and Thomason (1989), Cocks and Baird (1989), Everitt, Sonntag, Puterman and Whalen (1978), Jain, Soni and Seethapathi (1988), Marten and Sancholuz (1982), McGregor and Dent (1993), Nelson (1979), Papageorgio (1978), Parker, Mtango, Kado and Killewo (1986)
Management	Al-Faraj, Alidi and Al-Ibrahim (1993),Chang, Chung and Hwang (1983), Chang, Chung and Hwang (1984), Ehir and Benjamin (1993)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

GOAL PROGRAMMING APPLICATIONS IN MANAGEMENT

The 244 total GP types of applications in management are organized into 45 different topics. The citations are presented in Table 4-8. The broadness of this category required an additional level of categorization. The citations are first divided into three broad categories of government involvement: *Human Resource Management, Management Information Systems* and *Production and Operations Management*. The *Other Human Resources* and *Other MIS* topics are used here for citations that could not easily be identified and classified into the other topical areas. The remaining topic areas headings are self explanatory.

Table 4-8. Citations on GP Applications in Management

Topic	Available References on Topic
HUMAN RESOURCE MANAGEMENT:	
Assigning and Scheduling	Charnes, Cooper, Niehaus and Stedry (1969), Jones and Kwak (1982), Koelling and Bailey (1984), Lawrence, Reeves and Lawrence (1984), Loucks and Jacobs (1991), Mehta and Rifai (1976), Min (1987b)*, Zanakis and Lawrence (1977)*, Zanakis and Maret (1981a), Zanakis (1983)***, Organization structure Freeland (1976), Lee and Rho (1985)***, Lee, Luthans and Olson (1982)
Compensation	Charnes, Cooper and Ferguson (1955), Kwak, Allen and Schniederjans (1982), Steuer (1983)
Corporate Evaluation	Sridhar and Raghavendra (1988)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-8. (Continued)

Topic	Available References on Topic
HUMAN RESOURCE MANAGEMENT(Continued):	
Human Resource Planning	Aronson and Thomson (1985), Charnes, Cooper and Niehaus (1975),Henderson (1982),Kornbluth (1983), Martel and Price (1981)**, Min (1990), Price and Gravel (1984), Price and Piskor (1972), Price (1978, 1980), Taylor, Moore and Clayton (1982)**, Whitford and Davis (1983), Wijngaard (1987)
Job Evaluation	Gupta and Ahmed (1988)
Labor Negociation	Schniederjans and Kim (1987)
Organizational Decisions	Bonczek, Holsapple and Whinston (1979), Keown and Taylor (1978)*, Kimory (1978), Lee and Litschert (1976), Lee and Shim (1986)***, Sweeney, Winkofsky, Roy and Baker (1978), Tersine (1976)
Other Human Resources	Bottoms and Bartlett (1975), Kananen, Korhonen, Wallenius and Wallenius (1990), Parker and Kaluzny (1982), Rifai (1978)
Policy Evalution	King (1982), Rivett (1977)
Productivity Measurement	Sardana and Vrat (1987)
R&D Allocations	Keown, Taylor and Duncan (1979)*, Khorramshahgol and Gousty (1986), Khorramshahgol, Dabzie and Akaah (1988), Kwak and Jones (1978), Ringuest and Grayes (1989), Stewart (1991)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-8. (Continued)

Topic	Available References on Topic
Strategic Planning	Jaaskelainen (1972)
MANAGEMENT INFORMATION SYSTEMS:	
Decision Support Systems	Khorramshahgol and Azani (1988)
Design	Henderson and Schilling (1985), Ignizio, Plamer and Murphy (1982), Jain and Dutta (1986), Jain (1984), Lee and Wilkins (1983)
Distributed Data	Chen, Farn and Tsay (1991)*, Ling-Hwie, Kwo-Jean and Ching-Shu (1991)*
Evalution Systems	Chandler (1982), Djang (1993), Parker (1985), Tanner (1991)
Microcomputers	Lee and Shim (1984)
Other MIS	Henderson and Schilling (1985), Gross and Talavage (1979)
Project Selection	Santhanam, Muralidhar and Schniederjans (1989), Schniederjans and Santhanam (1993a, 1993b)*, Schniederjans and Wilson (1991)*
Time Sharing	Dyer (1973)
PRODUCTION AND OPERATIONS MANAGEMENT:	
Acquisition Planning	Utar and Schoenfled (1973)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-8. (Continued)

Topic	Available References on Topic
PRODUCTION AND OPERATIONS MANAGEMENT (Continued):	
Aggregate Planning	Deckro and Hebert (1988)**, Gilgeous (1989), Goodman (1974), Hindelang and Hill (1978), Jaaskelainen (1969), Lockett and Muhlemann (1978), Musud and Hwang (1980), Rakes, Franz and Wynne (1984), Welman (1976)
Assembly Line	Baybars (1985), Fisher, Wei and Dontamsetti (1989), Gunther, Johnson and Peterson (1983), Malakooti (1991b), Decko and Rangachari (1990)
Blending Problems	Arthur and Lawrence (1980), Lee and Olson (1983)***
Design	Osinski, Pokojski and Wrobel (1983), Sankaran (1990), Shafter and Rogers (1991), Shih and Hagels (1989)*, Singh and Verma (1985), Singh, Aneja and Rana (1990), Eilon (1982), Fortenberry, Mitra and Willis (1989), Green, Kim and Lee (1981)
Energy	Bit and Alam (1993), Choobineh and Burgman (1984)
Flexible Manufacturing	Chen and Askin (1990), Dean, Schniederjans and Yu (1990), Frazier, Gaither and Olson (1990), Gangan, Khator and Bahu (1987), Imany and Schlesinger (1989), Kumer, Singh and Tewari (1987, 1991)***, Lee and Jung (1989), O'Grady and Mennon (1984, 1986a, 1986b), Ro and Kim (1990)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-8. (Continued)

Topic	Available References on Topic
PRODUCTION AND OPERATIONS MANAGEMENT (Continued):	
Forecasting	Hattenschwiler (1988), Reeves and Lawrence (1982)
Inventory and Distribution	Brauer and Naadimuth (1992), Buffa (1976, 1983), Chaudhry, Forst and Zydiak (1991), El-Dash (1992)**, Golany, Yadin and Learner (1991), Karmarkar (1979)**, Mehrez and Ben-Arich (1991)***, Padmanabhan and Vrat (1990)**, Rao (1980), Sinha and Sastry (1987a), Wascher (1990)
Kanban/Just-In-Time	Fukukawa and Hong (1993), Kim and Schniederjans (1993), Lee, Chung and Everett (1992)
Loading and Handling	Ng (1992), Osleeb and Ratick (1983)
Location and Layout	Al-Faraj, Alidi and AL-Ibrahim (1993), Alonso and Devaux (1981), Barda, Dupuis and Lecioni (1990), Benito and Devaux (1981), Bhattachary, Rao and Tiwari (1992,1993)***, Current, Min and Schilling (1990), Davis, Stam and Grzybowski (1992), Dieperink and Nijkamp (1987), Kwak and Schniederjans (1985a, 1985b), Lee and Franz (1979), Lee and Lubbe (1987a), Lee and Schniederjans (1983), Lee, Green and Kim (1981), Min (1988a), Mohanty and Rathnakumar (1984), Nijkamp and Spronk (1979), Rosenblatt (1979), Schniederjans, Kwak and Helmer (1983), Venugopal and Mothanty (1982), Solomon and Haynes (1984), Solanki (1991)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-8. (Continued)

Topic	Available References on Topic
PRODUCTION AND OPERATIONS MANAGEMENT (Continued):	
Logistics and Routing	Arthur and Lawrence (1982), Gingrich and Soli (1984), Johnson (1976), Lawrence and Burbridge (1976), Park and Koelling (1986), Srinivasan and Thompson (1972)
Lot-Sizing	McKnew and Sauydan (1991)*, Vickery and Markland (1985, 1986)*
Maintenance	Armstrong and Cook (1981)
Materials Management	Mohanty and Chandran (1984)
Production/Finance	Forsyth (1969)
Production/Marketing	Hansen (1978), Taylor and Anderson (1979)
Production Planning	Chanda (1990), Ehir and Benjamin (1993), Fisk (1979), Golovanov, Zotov, Maikov and Pushnyak (1987), Green, McCarthy and Pearl (1983), Kendall and Schniederjans (1985), Mackulak, Moodie and Williams (1980), Malakooti (1989, 1991a)***, Miller and Davis (1978), Mohanty and Govindrajan (1989), Mohanty and Singh (1992), Philipson and Ravindran (1978), Ray (1986), Ruefli and Storbeck (1984), Salvia (1979), Sarma, Sellami and Houam (1993), Schniederjans and Markland (1986), Sullivan and Fitzsimmons (1978), Sundaram (1978), Tabucanon and Mukyangkoon (1985)***, Utar and Schoenfled (1973), Zanakis and Smith (1980)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-8. (Continued)

Topic	Available References on Topic
PRODUCTION AND OPERATIONS MANAGEMENT (Continued):	
Project Planning	Deckro and Hebert (1984), Hannan (1978b), Moore, Talyor, Clayton and Lee (1978), Rakes and Franz (1985), Taylor and Keown (1978a), Lee, Park and Economides (1978)
Purchasing	Buffa and Jackson (1983)
Quality	Bardaro and Mutmansky (1986), Bishop, Narayanan and Greney (1977), Ebrahimpour and Ansari (1988), Hindelang (1973), Irani, Mittal and Lehtihet (1989), Kalro, Chaturvedi and Sengupta (1983), Klimberg, Revelle and Cohon (1991), Rifai and Dey (1990), Sengupta (1981), Tayi (1985)**, Williams and Zigli (1987)
Sampling	Chakraborty (1986, 1988a, 1988b, 1991a, 1991b)***, Drezner and Wesolowsky (1991), Ravindran, Shin, Arthur and Moskowitz (1986)**
Scheduling Production	Chen (1988)*, Crouch (1984), Daniels (1990), Dary-Dowman and Mitra (1985)***, Deckro, Hebert and Winkofsky (1984), Fisk (1980), Hershauer and Gowens (1977)*, Jacobs and Wright (1988), Lashine, Foote and Ravindran (1991)**, Lee and Clayton (1970b), Lee and Moore (1974a), Lee and Olson (1984)*, Lee, Clayton and Taylor (1978), Selen and Hott (1986)*, Utar and Schoenfled (1973), Van Hulle (1991b)*, Wilson (1989)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

Table 4-8. (Continued)

Topic	Available References on Topic
PRODUCTION AND OPERATIONS MANAGEMENT (Continued):	
Transportation	Acharya, Nayak and Mohanty (1987), Al-Faraj, Alidi and AL-Ibrahiam (1993), Hemaida and Kwak (1994), Kwak and Schniederjans (1979, 1985d), Lee and Moore (1973), Moore, Taylor, Clayton and Lee (1978), Morse and Clark (1975), Nayak, Basu and Tripathy (1989), Singh and Kishore (1991), Stewart and Ittman (1979), Turshen and Wester (1986)

*Integer GP model
**Nonlinear GP model
***Other specialized GP model

GOAL PROGRAMMING APPLICATIONS IN MARKETING

The 24 total GP types of applications in marketing are organized into eleven different topics. The citations are presented in Table 4-9. The *Other Marketing* topic is used here for citations that could not easily be identified and classified into the other topical areas. The remaining ten topic areas are self explanatory.

Table 4-9. Citations on GP Applications in Marketing

Topic	Available References on Topic
Distribution Channels	Kim (1983), Kwak, Schniederjans and Warkentin (1991)
Marketing/Production	Hansen (1978), Taylor and Anderson (1979)

Table 4-9. (Continued)

Topic	Available References on Topic
Market Segmentation	McGlone and Calantone (1992)
Media Planning	Charnes, Cooper, DeVoe, Learner and Reinecke (1968), Charnes, Cooper, Learner and Snow (1968), Clayton and Moore (1972a), De Kluyver (1978, 1979a), Dyer, Forman and Mustafa (1992), Keown and Duncun (1979)*
Other Marketing	Lee and Nicely (1974), Mehta and Riafai (1979), Wilson (1975)
Pricing	Brown and Norgaard (1992), Korhonen and Soismaa (1988)
Product Development	Bard (1990)
Purchasing	Williams (1987)
Retailing	Kim (1983), Min (1987a)
Sales Management	Lee and Bird (1970), Mahajan and Valharia (1990), McClure and Wells (1987a)
Warranty Estimation	Mitra and Patankar (1988, 1990, 1993)

*Integer GP model

SUMMARY

This chapter lists the GP applied publications that have appeared in the literature since GP was first created in 1955. The listing is this chapter is based on those journal citations that appear in *Appendix B* of this book. The fact that only journal citations are being used is a possible limitation on the comments that follow.

As can be seen in this chapter, a lot of GP applied research has been done. This chapter should also be viewed as a call for a lot more GP research to be done. Of the 666 actual citations listed in *Appendix B*, a total of 745 cross-listed applications appear in the tables in this chapter. If the number of citations observed in these tables represent the true proportions in the population of all GP applied research, then the relative creation of research into the nine major categories is as stated in Table 4-10.

Table 4-10. Citation Counts, Ranking and Proportion of GP Applications

Category	Citation Counts	Ranking	Proportion (%)*
Management	244	1	32.8
Government	169	2	22.7
Finance	112	3	15.0
Agriculture	63	4	8.5
International	42	5	5.6
Accounting	38	6	5.1
Economics	28	7	3.7
Engineering	25	8	3.4
Marketing	24	9	3.2
Total	745		100.0

*Based on proportion of total citation counts.

A point is worth mentioning on the relative proportions of publications in Table 4-10. One way of viewing this table is in its presentation of possible publication opportunities. The opportunities for a GP publication in each category area (i.e., in the respective journals in each area) can possibly be viewed in a type of inverse relationship. That is, journals in the areas of marketing and engineering might whole the greatest opportunity for a publication, over journals in management. This doesn't mean that all management journals should not be considered as possible outlets, only that in general it may be easier to get publications in nonmanagement journals where virgin ideas for applications are still more plentiful.

Since many of the researchers who work with GP are *management science* or *operations research* faculty, it is not surprising to find the largest number of publications is in the *management* area. The fact that one has to publish in one's own departmental areas to become tenured or promoted is also no surprise. Interestingly enough, most college and university accreditation organizations want colleagues from differing departments to work together on research and teaching. They feel that such cross-pollination will help to generate better researchers and teachers. It might also help to generate more GP publications.

CHAPTER 5. FUTURE TRENDS IN GOAL PROGRAMMING

Goal programming (GP) research has had a great past and will have a great future in helping to improve decision making. Trends in the types of GP research that appear in the literature are important to observe in order to take part in making contributions to that future.

The purpose of this chapter is summarize and conclude this book's presentation on GP. This is accomplished with commentary and suggestions on trends in GP research. This chapter will present a commentary on how GP is currently positioned for growth in research. This section will be followed by a presentation on suggestions for future GP research.

GP IS POSITIONED FOR GROWTH

To provide for continual growth, the *life cycle of GP research* must be able to demonstrate an ability to overcome obstacles to grow and maintain the interest of individuals who will contribute to that growth. This section focuses on these two issues to help researchers understand just how well the life cycle of GP research is positioned for a growth stage.

Overcoming Past Obstacles to Growth

Two major obstacles to the GP research growth that are commonly repeatedly in the literature concern a lack of theoretical developments and the lack of computer software. Zanakis and Gupta (1985) claimed that a lack of sufficient new theoretical developments was possibly a major reason for a decline in GP publications in the mid-1980's. The reality was that GP in 1984 when Zanakis and Gupta were researching their paper had not even reached its peak of publications which occurred in 1987. Their call for more theoretical and empirical work on GP was substantially answered by dozens of studies on priority preferences, goal trade-off analyses and weightings methodologies (see Tables 2-3 and 2-4). The result on total GP research publications was a substantial and sustained increase of GP publications running through the year 1991 (see Table 1-3). The theoretical contributions currently available, but not always used, is more than adequate to deal with the justification of most research applications.

Zanakis and Gupta (1985) also claimed that there was a lack of reliable computer codes or software to handle large-scale problems and nonlinear problems. Based on the survey research of computer software presented in Table 3-12 this is no longer the case. The availability of the GP computer software is helping GP literature to grow in two ways. First, the availability of software allows the developers of new methodologies to compare prior methodology with their own newly developed methodology. In reviewing the integer GP (see Tables 3-2 and 3-3), nonlinear GP (see Tables 3-4 and 3-5), interactive GP (see Table 3-6), sequential GP (see Table 3-7) and fuzzy GP (see Table 3-10) methodology citations, half or more of the citations have occurred in just the last ten years (since 1984). In most of these studies some form of software application was utilized to provide a comparative analysis to help confirm the significance of the new GP methodology that was being proposed. A second contribution of GP computer software can be seen in the new applications that are increasingly appearing in the literature. An examination of the dates of GP application citations in the tables in Chapter 4 reveals that over 50 percent of all GP applications occurred since 1984 and virtually all of these studies were run on computer software developed during this time.

Neither GP theory or computer software is lacking in the 1990's. More can always be used, but neither should be used as a reason to keep researchers from doing GP research.

Growing Interest in the Subject

There are a great many optimistic trends that can be observed about GP research. The growth in interest in *multiple criteria decision making* (MCDM) is one positive trend since GP is viewed as a subject within the field (see Figure 1-1). As MCDM grows to increased dominance in the fields of *management science and operations research* (MS/OR), it helps to bring with it increased interest and research opportunities for GP research.

In a survey by the *Operations Research Society of America* and the *Institute of Management Sciences* respondents were asked their opinions about what they thought were the most useful OR/MS methodologies (Dyer 1993). Both professional researchers and recently graduated students were polled in the survey. In the resulting ranking, MCDM was ranked 5th by the professionals and 7th by the recent graduates. The only other category that GP might have fallen into is *mathematical programming*, in which case the professionals ranked this category 6th and the recent graduates ranked it 5th. In either case, this was the first time MCDM had made it into the top ten rankings and a growing sign of GP's relative importance as a decision making methodology.

Another trend that is positioning MCDM for growth in recent years is the increased number of conferences devoted to this subject. The *International Conference on Multiple Criteria Decision Making* which is sponsored by the *International Society on Multiple Criteria Decision Making* held its 12th annual meeting in Hagen, Germany in 1995. The 1st *International Multi-Objective and Goal Programming Theories and Applications* conference took place in Portsmouth, England in 1994. The 1st *International Conference on Multiple Objective Decision Support Systems for Agricultural and Environmental Management* held its conference in Honolulu, Hawaii in 1995.

Perhaps one of the most promising signs of the potential for publications in MCDM occurred when The *Journal of Multi-Criteria Decision Making*, which is published by John Wiley and Sons of New York, started in 1992. In addition to an entire journal being devoted to the subject of MCDM, there have been a variety of international journals that have devoted a special issue to MCDM methods, including GP. In the last five years some of these journals have included *Computers and Operations Research, INFOR, Agricultural Systems* and *Journal of Advanced Transportation*.

Even in the way GP is taught in schools has been the subject of interest and research. Prior research by Hannan (1976) and Lee, Shim and Lee (1984) helped to present basic ideas or strategies for teaching GP to undergraduate students. Recent research on teaching GP by Kennedy (1991), Kim and Kim (1992), and Lee and Kim (1992a, 1992b) is enhancing the understanding of newer *interative GP* methodologies and the use of computer graphic systems. While the potential impact of these newer teaching methods has not yet had a chance to show up in the literature, they will undoubtedly help to increase the interest in GP in a new generations students. According to dissertation research on GP the less recent generation of GP researchers also have quite some interest in GP research (see Lee and Shim 1987a).

SHIFTING THE LIFE CYCLE OF GP RESEARCH TO GROWTH

The *life cycle of GP research* introduced in Chapter 1 and whose depiction is presented in Figure 5-1 appears to portent a rather ominous future trend. The apparent *decline stage* in the life cycle of GP research we find ourselves in can be shifted back into a *maturity* or even *growth stage* by increasing the number of GP publications. But increasing GP publications just for publication sake is not going to lead to a long life. Indeed, it can be argued from a production standpoint, that cheapening a product just to produce more units with less material, will lead to a decline in sales in the long-term because of poor quality.

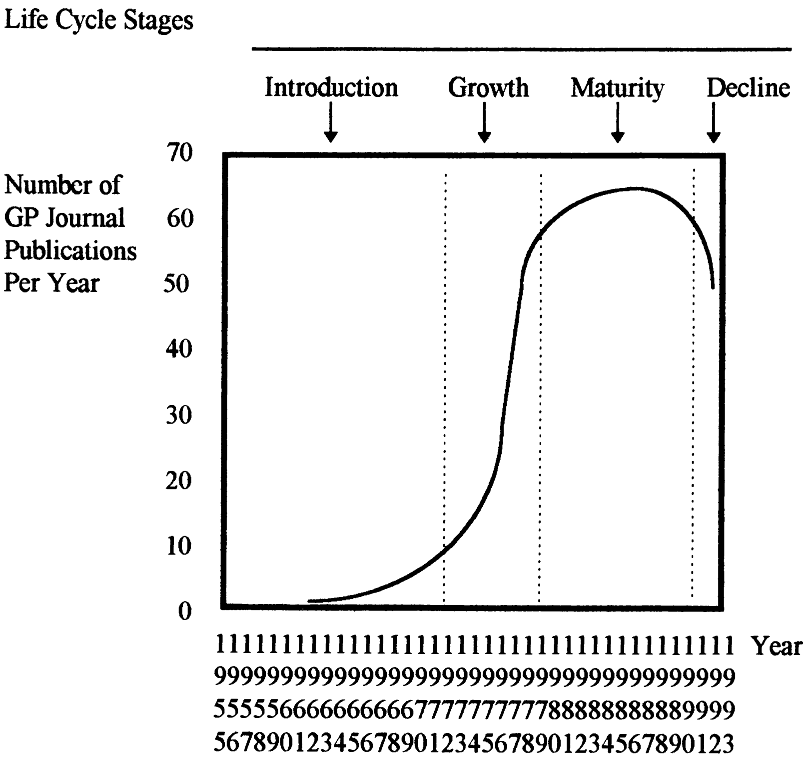

Figure 5-1. Life Cycle of GP Research

To shift the life cycle of GP research back to a growth stage without sacrificing quality can be achieved by valued-added innovation in both methodology and application. Researchers who use linear programming (LP) to model problems still find ways of having their work published when they offer an innovative idea in modeling methodology or application. The same logic can apply to even the most mature GP models. By finding innovative ideas for GP models will lead to value-added, high quality contributions that make a significant contribution to this field of study. The problem is where to find ideas for innovative ideas.

Based on observations of the total body of GP journal research presented in *Appendix B*, a number of possible innovation suggestions can be summarized. These suggested innovative ideas may be known to the experienced GP researcher but are not always articulated or practiced by them. These ideas are particularly meant to challenge and stimulate idea creation for less experienced researchers. Indeed, some of these suggested innovations in GP research may help graduate students come up with an idea for a thesis or dissertation.

1. *New technologies can lead to new applications, particularly in the areas of agriculture, engineering and management*: For example the development of flexible manufacturing systems (FMS) has helped to generate several applications (see Table 4-8, Flexible Manufacturing). New technologies are constantly being invented and introduced into agriculture, engineering and management environments. Each introduction represents a possible area of application. One additional point of opportunity that can be mentioned is the fact that automated systems that reduce variability in the application environment (like a robot replacing a human on an assembly line), improves the use of deterministic methodologies like GP. As variability in production processing is removed, more deterministic modeling methodologies can be applied because of the manufacturing consistency of the automation.

2. *New approaches and philosophy can lead to new GP model opportunities.* For example, the introduction of the production philosophy of *just-in-time* (JIT) management has helped to generate a few new studies using GP modeling (see Table 4-8, Kanban/Just-In-Time) and *total quality management* (TQM) has also generated some research (see Table 4-8, Quality). Considering that there are hundreds of articles on JIT and TQM, the potential for combinations with GP modeling are endless. It should also be remembered that there many other fairly recent and new approaches being introduced that can be used in a similar way in just about every functional area in business.

3. *New government legislation can lead to new GP model opportunities.* For example, the enactment of the *North American Free Trade Agreement* (NAFTA) in 1993 represents one of the greatest change agents to impact business in both North America and the world with which it trades. International contractual economic and environmental impact studies can be under taken using GP. Also, countless studies using management methodologies within the multiple goal framework inherent in NAFTA can be

undertaken on topics including logistics, lot-sizing, maintenance, materials management, project planning, purchasing, quality, sampling, scheduling production and transportation. With the available GP models in Table 4-8, Production and Operations Management as a guide, the opportunities for new NAFTA related GP models are substantial.

4. *Innovations in finance can lead to new GP modeling opportunities.* For example, the development of *junk bonds* for allocating debt was one of the most significant innovations of the 1980's. This finance innovation did not appear in any GP model, even though finance applications related to bonds and mutual funds exist and finance represents the third highest number of GP publications (see Table 4-10). New finance related innovations are being created all the time that could and should be optimized with multiple objectives using GP.

5. *Changes in accounting practices can lead to new GP modeling opportunities.* For example, anyone of the many tax changes each year can be viewed as a possible candidate for a GP model (see Table 4-1, Taxes).

6. *Innovations in marketing practices can lead to new GP modeling opportunities.* For example, consideration of new advertising systems, like the placing of advertisements on the floors of food stores can involve a large number of marketing planning variables. Media mix, layout design and location models that already exist can be reapplied to bring into consideration multiple marketing factors that are not yet considered with this media innovation (see Table 4-9, Media Planning, Retailing, Sales Management).

7. *Seeking better social issue correctness can lead to new GP modeling.* This is an almost undiscovered area (see Table 4-6, Social Issues). For example, military officer accession models (see Table 4-6, Military) can be adjusted to take into consideration the desire for better representation of women and minority groups.

8. *Changes toward international globalism can lead to new GP modeling.* This area more than the others will be one of the most fruitful areas of GP modeling. Previously not identified in other GP bibliographies (Lin 1980, Zanakis and Gupta (1985), Romero (1986, 1991, pp. 96-97), international applications of everything that has been applied nationally represents the greatest possible opportunity for those who are actively involved in research in foreign countries. This includes more than the simple explanations of how something like logistics is done in a foreign country, but how that country and other countries can combine their systems to achieve multiple objectives.

9. *The MS/OR and GP combined strategy (as discussed in Chapter 2) can create new opportunities for GP modeling.* Each time a new MS/OR methodology is developed that can be used in combination with GP, a new potential GP model and application are created. When a new GP methodology is created, the increase in possible publications where that methodology can be combined with all the other MS/OR methodologies is dramatically increased.

10. *Looking on the brighter side of criticism can create new opportunities for GP modeling.* One additional area for research that can be proposed will help undo some of the negative comments and cynicism that exists in the study of GP. The development of examples of GP modeling that counter all the defects in GP modeling that have been reported in the literature over the years is one area of possible future research. Examples that show that GP models don't suffer, or under what situations they may suffer from dominance, inferiority, nonefficiency, naive relative weighting, incommesurability, naive prioritization or redundancy will help others to defend their work from the critics (who are us).

The suggestions for research presented here are a small portion of what is left to be done with GP. It is up to every researchers to find other areas of application. For those who can not find any other innovated areas for GP research, the above suggestions are hereby offered as a challenge to implement.

SUMMARY

This chapter presented a discussion on how GP research is positioned to enter a growth stage in its life cycle of research. Suggestions on how researchers can help contribute to the growth of the research were also presented.

GP is currently positioned well to be a major contributor to the fields of MCDM and MS/OR. There is a more than a sufficient body of knowledge in GP methodology and application to support any use of the model that fits its basic assumptions. There is also sufficient computer software to aid in the application of GP in small, medium and large scale problems solving in industry and academia. There also appears to be a sufficiently growing interest in the subject by students and researchers. Sufficient interest to be enthusiastic about a possible resurgence in GP modeling research and related MCDM methodologies.

It is interesting to note that more than 50 percent of the methodology papers and application papers have been published in the last ten years of the forty year run since the introductory paper by Charnes, Cooper and Ferguson (1955). Interest in GP is not coming to an end, it is slowing down to shift gears for an even greater run. The life cycle of GP research is waiting to be reborn all over again.

REFERENCE

Dyer, J. S., "Suggestions for an OR/MS Master's Degree Curriculum," *OR/MS Today*, Vol. 20, No. 1 (1993), pp. 18-31.

APPENDIX A. TEXTBOOKS, READINGS BOOKS AND MONOGRAPHS ON GOAL PROGRAMMING

The alphabetical by author listing of books in this appendix are those cited in GP research publications and/or having made a significant contribution to GP literature. While some of these books are focused on subjects other than GP, they contain relevant or substantial GP material.

Abadie, J., ed., *Nonlinear Programming*, North-Holland, Amsterdam, 1967.

Chankong, Vira and Haimes, Yacov Y., *Multiobjective Decision Making*, North-Holland Publishing, New York-Amsterdam, 1983.

Charnes, A. and Cooper, W. W., *Management Models and Industrial Applications of Linear Programming*, John Wiley and Sons, New York, NY, 1961.

Cochrane, J. L. and Zeleny, M. eds., *Multiple Criteria Decision Making*, Springer-Verlag, Berlin, 1973.

Cohon, J. L., *Multiobjective Programming and Financial Planning*, Academic Press, New York, NY, 1978.

Depontin, M., Nijkamp, P. and Spronk, J., *Macro-Economic Planning with Conflicting Goals*, Springer-Verlag, Berlin, 1984.

Fandel, G. and Gal, T. eds., *Multiple Objective Decision Making Theory and Applications*, Springer-Verlag, Berlin, 1979.

Fandel, G. and Spronk, J. eds., *Multiple Criteria Decision Methods and Applications*, Springer-Verlag, Berlin, 1985.

Gal, Thomas and Wolf, Hartmut, *Solving Stochastic Linear Programs via Goal Programming*, Springer, Berlin, 1985.

Graves, R. L. and Wolfe, P., eds., *Recent Advances in Mathematical Programming*, McGraw-Hill, New York, NY, 1963.

Haimes, Y. Y. and Chankong, G. V. eds., *Decision Making with Multiple Objectives*, Springer-Verlag, Berlin, 1985.

Hansen, P. ed., *Essays and Surveys on Multiple Criteria Decision Making*, Springer-Verlag, Berlin, 1983.

Hwang, C. L. and Masud, A. S. M. eds., *Multiple Objective Decision Making-Methods and Applications*, Springer, Berlin-Heidelberg, 1979.

Ignizio, James P., *Goal Programming and Extensions*, Heath (Lexington Books), Lexington, MA, 1976.

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Ijiri, Y., *Management Goals and Accounting for Control*, Rand-McNally, Chicago, IL, 1965.

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Keeney, R. L. and Raiffa, H., *Decisions with Multiple Objectives: Preference and Value Tradeoffs*, John Wiley & Sons, New York, 1976.

Kwak, N. K. and Schniederjans, M. J., *Introduction to Mathematical Programming*, Kreiger Publishing, Malabar, FL, 1987.

Lawrence, Kenneth D., Guerard, J. B. Jr. and Reeves, G. D. eds., *Advances in Mathematical Programming and Financial Planning*, Vol. 1, JAL Press, Greenwich, CN, 1987.

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Lawrence, Kenneth D., Guerard, J. B. Jr. and Reeves, G. D. eds., *Advances in Mathematical Programming and Financial Planning*, Vol. 3, JAL Press, Greenwich, CN, 1993.

Lee, Sang M. and Van Horn, James, *Academic Administration: Planning, Budgeting and Decision Making by Mutliple Objectives*, University of Nebraska Press, Lincoln, NE, 1983.

Lee, Sang M., *Goal Programming for Decision Analysis*, Auerbach Publishers, Philadelphia, PA, 1972.

Lee, Sang M., *Goal Programming Methods for Multiple Objective Integer Programs*, American Institute of Industrial Engineers, Atlanta, GA, 1979.

Lee, Sang M., *Management by Multiple Objectives*, Petrocelli Books, Princeton, NJ, 1982.

Lieberman, Elliot R., *Multi-Objective Programming in the USSR*, Academic Press, Boston, MA, 1991.

Morse, J. N. ed., *Organizations Multiple Agents with Multiple Criteria*, Springer-Verlag, Berlin, 1981.

Rekanitis, G., Ravindran, A. and Ragsdell, K., *Engineering Optimization: Methods and Applications*, Wiley and Sons, New York, NY, 1983.

Ringuest, Jeffrey L., *Multiobjective Optimization: Behavioral and Computational Considerations*, Kluwer Academic Publishers, Boston, MA, 1992.

Rios-Insua, David, *Sensitivity Analysis in Multi-Objective Decision Making*, Springer-Verlag, Berlin, 1990.

Romero, Carlos, *Handbook of Critical Issues in Goal Programming*, Pergamon Press, Oxford, England, 1991.

Sakawa, Masatoshi, *Fuzzy Sets and Interactive Multiobjective Optimization*, Plenun Press, New York, NY, 1993.

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Zoints, S. ed., *Multiple Criteria Problem Solving*, Springer, Berlin-Heidelberg, 1978.

Zoints, S., *Multiple Criteria Mathematical Programming: An Updated Overview and Several Approaches*, Springer, Berlin-New York, 1988.

APPENDIX B. JOURNAL RESEARCH PUBLICATIONS ON GOAL PROGRAMMING

The alphabetical by author listing of journal research publications in this appendix represents the largest collection to date of citations from journals written in English on the subject of GP. While some of these publications are focused on subjects other than GP, they contain relevant or substantial GP material.

Acharya, B., Jain, V. K., and Batra, J. L., "Multi-Objective Optimization of the ECM Process," *Precision Engineering*, Vol. 8, No. 2 (1986), pp. 88-96.

Acharya, B., Nayak, N. N. and Mohanty, D. N., "Dynamic Programming Models with Goal Objectives in Transportation Problems," *Journal of Orissa Mathematical Society*, Vol. 6, No. 2 (1987), pp. 75-88.

Aggarwal, S. C. and Clark, D. J., "A Model for National Planning Policies," *Omega*, Vol. 6, No. 2 (March 1978), pp. 161-171.

Agrawal, U., Swarup, K. and Garg, K. C., "Goal programming Problem with Linear Fractional Objective Function," *Cahiers du Centre-d' Etudes-de Recherche Operationnelle*, Vol. 26, Nos. 1-2 (1984), pp. 33-41.

Akgul, M., "A Note on Lexicographic Linear Programming," *INFOR*, Vol. 22 (1984), p. 343.

Albright, S. C., "Allocation of Research Grants to University Research Proposals," *Socio-Economic Planning Sciences*, Vol. 9 (1975), pp. 189-195.

Alexander, Gordon J., and Resnick, Bruce G., "Using Linear and Goal Programming to Immunize Bond Portfolios," *Journal of Banking and Finance*, Vol. 9, No. 1 (1985), pp. 35-54.

Al-Faraj, T. N., Alidi, A. S. and Al-Ibrahim, A. A., "A Planning Model for Determining the Optimal Location and Size of Traffic Centers: The Case of Damman Metropolitan, Saudi Arabia," *European Journal of Operational Research*, Vol. 66, No. 3 (1993), pp. 272-278.

Alonso, M. A. B. and Devaux, P., "Locations and Size of Day Nurseries--A Mulitple Goal Approach," *European Journal of Operational Research*, Vol. 6, No. 2 (February 1981), pp. 195-198.

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