

**MEASURING AND EVALUATING EFFICIENCY AND
EFFECTIVENESS USING GOAL PROGRAMMING AND DATA
ENVELOPMENT ANALYSIS IN A FUZZY ENVIRONMENT**

by
Nimish Sheth

**Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State
University in partial fulfillment of the requirements for the degree of**

**MASTER OF SCIENCE
in
Industrial and Systems Engineering**

APPROVED:

Konstantinos P. Triantis, Ph.D., Chairman

Barbara Hoopes, Ph.D.

Ken Harmon

John Kobza, Ph.D.

Olivier Girod, Ph.D.

**April 1999
Falls Church, Virginia**

Key Words: Fuzzy GoDEA, DEA, Goal Programming

© Nimish Sheth 1999

MEASURING AND EVALUATING EFFICIENCY AND EFFECTIVENESS USING GOAL PROGRAMMING AND DATA ENVELOPMENT ANALYSIS IN A FUZZY ENVIRONMENT

by

Nimish Sheth

Konstantinos P. Triantis, Ph.D., Chairman

Department of Industrial and Systems Engineering

(ABSTRACT)

Crisp mathematical programming techniques have shortcomings when used for measuring and evaluating achievement of organizational goals in a decision-making environment. Generally, in most real-life situations optimal achievement of multiple goals is rarely possible. In such cases, a compromise achievement of goals that leads to a *satisficing* solution rather than an *optimal* solution bears more relevance.

The present research introduces a framework to measure and evaluate the goals of efficiency and effectiveness in a fuzzy environment and is developed using Goal Programming, Data Envelopment Analysis and Fuzzy Set Theory. The proposed framework is called Fuzzy GoDEA and uses surrogate constraints to represent the efficiency and effectiveness goals. DEA type constraints are used to model the efficiency goal. The effectiveness goal is represented by the aggregate efficient contribution of the individual decision-making units toward achievement of the global organizational targets. Concepts of fuzzy set theory and goal programming are used to model the imprecision in goal achievement and the relative importance between goals. Additionally, the concept of minimal operational viability is introduced, though not included in the application due to unavailability of suitable data.

The Fuzzy GoDEA framework accommodates crisp input and output data but allows imprecise specification of the aspiration levels for the efficiency and effectiveness goals. The imprecision in goal achievement is allowed through the specification of an interval of acceptable achievement rather than a crisp value. A membership function is defined for each fuzzy constraint associated with the efficiency and effectiveness goals and represents the degree of achievement of that constraint. Further, the Fuzzy GoDEA framework is extended into several variations that (i) allow the assignment of relative importance to the goals of efficiency and effectiveness and (ii) model scenarios where one of the goals of efficiency and effectiveness is crisp and the other fuzzy.

The applied component of the research involves the application of the Fuzzy GoDEA framework to a newspaper preprint insertion process (NPIP). Detailed analyses of the results are presented to describe the information available from the Fuzzy GoDEA methodology that can be used in conjunction with conventional DEA analysis to assess and improve the efficiency and effectiveness performance of the NPIP system.

“With the sword-of-Knowledge, cut asunder the doubt-of-the-Self, born of ‘ignorance,’ residing in your heart...”

(The Bhagvad Gita)

ACKNOWLEDGEMENTS

*To my parents, Niharika and Mahendra,
You gave me the knowledge of life.*

It is the romance of the journey that gives the destination an aura. On completion of my present scholastic venture I cannot but reminisce about the journey.

My father, Mahendra, who instilled in me the relentless desire for knowledge and integrity on the road of life, who I grew up admiring as the definitive role model. To this day, he continues to be a source of inspiration. My mother, Niharika, who exemplifies patience and sacrifice as none I have seen. Her devotion to our family represents the foundation of any success that I achieve. My older brother, Manish, and sister-in-law, Prochi, whose hard-work and foresight afforded me the very opportunity to embark on this journey.

It is the formative years that mould the individual. The many teachers, whose instruction I have had the privilege of acquiring, provided a more than worthy education. A true friend should, above all, be a source of self-realization and growth. André, Marushka, and Ranjan, with their remarkable personalities have left an eternal mark on me and although we live in different parts of the world, I will always cherish our times together and keep them in my heart.

An academic endeavor demands discipline and mentoring that helps achieve scholastic excellence while maintaining the relevance to reality. My diversely talented committee members delivered the required guidance and inspired me to meet the challenge. Their collective contribution and graciousness to serve on the committee defined the research experience. I will affectionately remember "the Greek professor", my advisor, Kostas Triantis, who has been a source of consistent encouragement in the face of frustration and kind commendation for achievement. Most notably, he allowed

complete freedom of thought but provided invaluable direction in an area of inquiry that resulted in a significant contribution to the literature. It has been an honor and privilege to have been under his most capable tutelage that extended my horizons beyond the classroom and textbooks.

Any arduous journey requires much more than individual effort. It is in this spirit that I acknowledge the various people who have influenced me. Looking back on the quest for accomplishing the present academic manuscript I note the need for encouragement, support and understanding that were essential to my confidence and sense of purpose. My soul mate, Jackie, for who I would not even have had the courage or motivation to set out on this journey, has been the embodiment of endurance and caring for every day of the past three years, across the thousands of miles that separate us. Above all, she believed in me when I myself faced inner doubt. I dedicate this effort to her. I now propose to take her hand in marriage and look forward to our journey together.

SPECIAL THANKS

I would like to express my sincere gratitude to the following people and organizations at Virginia Tech whose gracious assistance facilitated completion of this thesis.

- *System Performance Laboratory*: (Ken Harmon and Kostas Triantis for giving me the opportunity to be part of a wonderful team in an exceptional environment of professional and personal growth).
- *College of Engineering, Northern Virginia Center*: (Nora Vasquez and Eddie Haggins for easing the administrative maze and ensuring the perennial flow of caffeine).
- *Northern Virginia Center Library*: (Pat Murphy and Cindy Neyland for providing excellent library support despite their limitations).
- *Newman Library*: (for the prompt delivery service of the numerous reference materials requested).
- *Manufacturing Systems Integration Laboratory*: (for providing the use of CPLEX).
- *Northern Virginia Center*: (for a memorable stay at Virginia Tech).
- *Scott Clarke* (for interesting conversations of baseball, cricket, Industrial Engineering and Kingfishers) and *Rina Sadia* (for sharing a little of Israel and her generous hospitality at a very difficult time).

TABLE OF CONTENTS

LIST OF TABLES	xii
LIST OF FIGURES	xiii
LIST OF ACRONYMS.....	xiv
1. INTRODUCTION.....	1
1.1. OBJECTIVE OF THE RESEARCH	1
1.2. MOTIVATION	2
1.3. OVERVIEW OF THE RESEARCH METHODOLOGY	3
1.4. ORGANIZATION OF THE DOCUMENT	5
2. LITERATURE REVIEW	6
2.1. DEFINITIONS AND CONCEPTS.....	7
2.1.1. Production Technology	7
2.1.2. Production Function	8
2.1.3. Isoquant	8
2.1.4. Radial And Non Radial Measures Of Efficiency.....	10
2.1.5. Returns To Scale	11
2.1.6. Definitions Of Technical Efficiency	13
2.2. TECHNICAL EFFICIENCY	14
2.2.1. Input-Reducing and Output-Increasing Orientations of Technical Efficiency	17
2.3 DATA ENVELOPMENT ANALYSIS (DEA).....	27
2.3.1. The CCR Model	28
2.3.2. The BCC Model.....	35
2.3.2.1. BCC: Input Orientation	38
2.3.3. Färe-Lovell Input Reducing Technical Efficiency Model.....	41
2.3.4. DEA Applications.....	44

2.4. MULTI-LEVEL PROGRAMMING.....	45
2.5. GOAL PROGRAMMING.....	49
2.6. GOAL PROGRAMMING AND DATA ENVELOPMENT ANALYSIS	
(GODEA).....	51
2.7. FUZZY DECISION-MAKING	55
2.7.1. Fuzzy Set Theory.....	55
2.7.2. Decision-Making In A Fuzzy Environment.....	59
2.7.3. Fuzzy Linear Programming.....	60
2.7.4. The Zimmermann Model.....	61
2.7.5. The Carlsson and Korhonen Model	63
2.7.6. Fuzzy Goal Programming (FGP).....	65
2.7.7. Fuzzy DEA.....	67
2.7.7.1 The Sengupta Fuzzy DEA Model.....	68
2.7.7.2 Fuzzy Radial And Non-Radial Models.....	70
3. METHODOLOGY.....	72
3.1. REFORMULATION OF THE ATHANASSOPOULOS (1995)	
GODEA MODEL.....	73
3.2. MEMBERSHIP FUNCTIONS FOR THE INPUT AND OUTPUT	
SPACES.....	78
3.2.1. Assumptions	79
3.2.2. The Input Space	79
3.2.3. The Output Space.....	82
3.3. FUZZY GOAL PROGRAMMING AND DEA (Fuzzy GoDEA) MODEL....	86
3.3.1. The Conceptual Model.....	86
3.3.2. The Mathematical Formulation.....	88
3.4. INTERPRETATION OF THE MEMBERSHIP FUNCTIONS.....	94
3.4.1. Membership Functions For The Constraints.....	94
3.5. ILLUSTRATION.....	96
3.6. VARIATIONS OF THE FUZZY GODEA MODEL.....	98

4. APPLICATION.....	114
4.1. OVERVIEW OF THE NEWSPAPER PREPRINT	
INSERTION PROCESS (NPIP).....	114
4.1.1. The Newspaper And NPIP Elements.....	115
4.1.2. The Newspaper Preprint Insertion Process.....	116
4.2. THE PACKAGING LINE.....	117
4.2.1. Organization.....	117
4.2.2. Operation.....	118
4.2.3. Fault Detection And Management.....	119
4.2.3.1. NNSS Faults.....	119
4.2.3.2. Preprint Faults.....	119
4.3. THE PACKAGING LINE MODEL.....	119
4.3.1. Purpose.....	120
4.3.2. Definition Of The Input Variables.....	121
4.3.2.1. Direct Labor (DLR).....	121
4.3.2.2. Rework (RWK).....	123
4.3.2.3. Raw Material (RML).....	125
4.3.3. Definition Of The Output Variable.....	129
4.3.3.1. Packages (PCF).....	129
4.3.3.2. Complexity Factor (CF).....	132
4.3.4. Definition Of The Global Targets.....	135
4.3.5. Conceptual Model.....	137
4.4. APPLICATION PROCEDURE FOR THE PACKAGING	
LINE ANALYSIS.....	137
4.4.1. Model Specification For The Packaging Line.....	137
5. RESULTS AND DISCUSSION.....	140
5.1. APPLICATION DATA.....	140
5.2. FUZZY GODEA MODELS SUMMARY.....	141
5.3. EFFICIENCY GOAL.....	144
5.4. EFFECTIVENESS GOAL.....	152

5.5. RESULTS FOR THE FUZZY GODEA MODEL VARIATIONS.....	154
5.5.1. Fuzzy GoDEA Base Model.....	154
5.5.2. Fuzzy GoDEA: Variation 1.....	158
5.5.3. Fuzzy GoDEA: Variation 2.....	158
5.5.4. Fuzzy GoDEA: Variation 3.....	159
5.5.5. Fuzzy GoDEA: Variation 4.....	159
5.5.6. Fuzzy GoDEA: Variation 5.....	163
5.5.7. Fuzzy GoDEA: Variation 6.....	166
5.5.8. Fuzzy GoDEA: Variation 7.....	170
5.5.9. Fuzzy GoDEA: Variation 8.....	170
5.5.10. Fuzzy GoDEA: Variation 9.....	174
5.6. EFFICIENCY ACHIEVEMENT ACROSS FUZZY GODEA VARIATIONS.....	179
5.7. EFFECTIVENESS ACHIEVEMENT ACROSS FUZZY GODEA VARIATIONS.....	182
5.8. ACTIVITY LEVELS ACROSS FUZZY GODEA VARIATIONS.....	183
5.9. EVALUATION OF THE PACKAGING LINE PERFORMANCE	185
6. CONCLUSION.....	189
6.1. SUMMARY.....	189
6.2. RESEARCH CONTRIBUTION AND CONCLUDING REMARKS.....	192
6.3. RECOMMENDATIONS FOR FUTURE RESEARCH.....	193
REFERENCES.....	195
APPENDICES.....	200
VITA	316

LIST OF TABLES

Table 4.1.	Example of a Work Order for the Packaging Line	118
Table 5.1.	Average Input/Output Data for the Packaging Line	141
Table 5.2.	Summary of the Fuzzy GoDEA Model Variations	141
Table 5.3.	Fuzzy Peer Table for Production Days 1-24	148
Table 5.4.	Fuzzy Peer Table for Production Days 25-48	149
Table 5.5.	Fuzzy Peer Table for Production Days 1-48	150
Table 5.6.	Output/Input Global Target Achievement for Fuzzy GoDEA Models	182
Table 5.7.	Symptoms and Root Causes for Inefficient DMUs	187

LIST OF FIGURES

Figure 2.1.	Isoquant for Output Level Y^0	9
Figure 2.2.	Constant and Variable Returns to Scale	12
Figure 2.3.	Input and Output Vectors for the n^{th} month	17
Figure 2.4.	Input-Reducing Isoquant Orientation	20
Figure 2.5.	Output-Increasing Isoquant Orientation	21
Figure 2.6.	Input-Reducing Technical Efficiency	24
Figure 2.7.	Output-Increasing Technical Efficiency	25
Figure 2.8.	CCR Production Function	32
Figure 2.9.	Technical Efficiency and Scale Efficiency	36
Figure 2.10.	CCR and BCC Production Functions	39
Figure 2.11.	Färe-Lovell Input Reducing Technical Efficiency Measure	42
Figure 2.12.	A Multi-Level System	46
Figure 3.1.	Membership Function μ for the Input Space	81
Figure 3.2.	Membership Function μ for the Output Space	84
Figure 3.3.	Conceptual Model	87
Figure 3.4.	Membership Function μ for the “ \leq ” Type Fuzzy Goal	95
Figure 3.5.	Membership Function μ for the “ \geq ” Type Fuzzy Goal	95
Figure 4.1.	NPIP Elements	115
Figure 4.2.	Newspaper Preprint Insertion Process	116
Figure 4.3.	NPIP Organization Flow Diagram	117
Figure 5.1.	Output/Input Global Target Achievement: Fuzzy GoDEA Base Model	157
Figure 5.2.	Output/Input Global Target Achievement: Fuzzy GoDEA Variation 4	162
Figure 5.3.	Output/Input Global Target Achievement: Fuzzy GoDEA Variation 5	165
Figure 5.4.	Output/Input Global Target Achievement: Fuzzy GoDEA Variation 6	169
Figure 5.5.	Output/Input Global Target Achievement: Fuzzy GoDEA Variation 8	173
Figure 5.6.	Output/Input Global Target Achievement: Fuzzy GoDEA Variation 9	178
Figure 5.7.	Number (Percentage) of Inefficient Units by Variation	181

LIST OF ACRONYMS

APSp	Average Number of Preprints per package
BCC	Banker, Charnes and Cooper
CCR	Charnes, Cooper and Rhodes
CF	Complexity Factor
CDMU	Central Decision Making Unit
CP	Complete Packages produced per day
DEA	Data Envelopment Analysis
DLR	Direct Labor
DMU	Decision Making Unit
GoDEA	Goal Programming and Data Envelopment Analysis
HR	Hourly Rate
IP	Incomplete Packages
HE	Number of Hourly Employees
NoPT	Number of Preprint Types
NSS	News Sensitive Section
NNSS	Non-News Sensitive Section
NPIP	Newspaper Preprint Insertion Process
MUL	Multiple NNSS
PCF	PP x CF
PLOT	Packaging Line Output
PMIS	Preprint Misses
PMOT	Preprint Insertion Machine Output
PMUL	Preprint Multiples
PP	Packages
PST	Preprint Shortages
PT	Total Production Time
REJ	Rejected NNSS
RML	Raw Material
RWK	Rework

SCP	Scrapped NNSS
TRH	Trashed NNSS
TPZ _p	Total Number of Production Zones Activated during the day
UON	Unopened NNSS
WR	Hourly Wage Rate