DYNAMIC SUSTAINABLE PROCUREMENT PROBLEM: MODELS AND METHODOLOGIES

HARPREET KAUR

DEPARTMENT OF MANAGEMENT STUDIES

INDIAN INSTITUTE OF TECHNOLOGY DELHI

AUGUST 2017

DYNAMIC SUSTAINABLE PROCUREMENT PROBLEM: MODELS AND METHODOLOGIES

by

HARPREET KAUR
Department of Management Studies

Submitted
in fulfilment of the requirements of the degree of **Doctor of Philosophy**

to the

Indian Institute of Technology Delhi

AUGUST 2017

CERTIFICATE

This is to certify that the thesis entitled "**Dynamic Sustainable Procurement Problem: Models and Methodologies**" being submitted by **Harpreet Kaur** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is a bonafide record of original research work carried out by him. She has worked under my supervision and has fulfilled the requirements for the submission of the thesis, which has reached the requisite standard.

The results contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

(Dr. Surya Prakash Singh)
Department of Management Studies
Indian Institute of Technology Delhi
New Delhi-110016, India

Date:

ACKNOWLEDGEMENTS

Completion of this doctoral dissertation was possible with the support of several people. I would like to express my sincere gratitude towards all of them. First and foremost, I am extremely grateful to my research supervisor, Dr. S. P. Singh for his valuable guidance, scholarly inputs, consistent encouragement and motivation I received throughout my research work, even during tough times in the Ph.D. pursuit. I consider it as a great opportunity to do my doctoral programme under his guidance and to learn from his experience and expertise. I thank my supervisor for all the help and kind support I have received during this programme. I would also like to thank my Student Research Committee for their encouragement and support during various phases of the programme. I am also thankful to Prof. Remy Glardon for guiding me during 3 months of research stay at EPFL Lausanne. I gratefully acknowledge my colleagues at Optimization lab who have contributed to my personal and professional development at over all these years. I would also like to thank my roommate and friends at hostel for being there in all good and bad times.

A special thanks to my parents. This dissertation would not have been possible without the unconditional love and support of my parents. I also thank my siblings for their love and encouragement. Finally, I thank god for leading me through all difficulties, whose guidance I have experienced day by day and to whom I trust for my future. Thank you.

(Harpreet Kaur)

ABSTRACT

Procurement is the process of buying goods or services from an external source. It is an important business function which ensures procurement of quality goods in the right amount at right time within right cost. With increased market competition globally post 1990's, business organizations have finally realized that procurement is a strategic and tactical level activity than a simple clerical one. Since procurement is an initial and the most crucial step in the entire supply chain, effective procurement can enhance a firm's competitive advantage and overall business performance. Hence, an effective and efficient procurement strategy is required for any industry to minimize costs, maintain quality of end products, avoid delays and improve overall supply chain performance.

Selection of suppliers and carriers based on various criteria important for the manufacturing firm is the first step towards efficient procurement. In this research, different qualitative models are applied to prioritize suppliers and carriers considering various traditional and non-traditional parameters. However, different qualitative models provide different supplier/carrier rankings causing a difficulty in final decision making. This research work develops an ILP based model for consensus ranking of suppliers and carriers considering ranks obtained from various qualitative models. In addition to this, the dynamic procurement models are also proposed by integrating lot-sizing, supplier selection and carrier selection. These procurement models are developed for carbon trading market using carbon emission constraint. It is referred as dynamic sustainable procurement (DSP) model. The proposed procurement models are either mixed integer linear programs (MILP) or mixed integer non-linear programs (MINLP) type and optimal solution cannot be obtained in realistic time for large size problems. Therefore, a heuristic (H-1) based solution methodology is also proposed to solve large sized

MILP and MINLP models. The optimal and heuristic solutions obtained are also statistically compared to show the efficiency of proposed heuristic (H-1) approach.

These proposed models are further extended to capture uncertainties in the form of fluctuations in demand, supplier capacity and carrier capacity using fuzzy and stochastic parameters. These procurement models are referred as fuzzy sustainable procurement (FSP) using triangular fuzzy numbers and stochastic sustainable procurement (SSP) model using chance-constrained programming. Besides uncertainties, the research work also propose goal based procurement models considering various goal targets prioritized by the firms, thus, to address firm's targets into procurement modelling. These models are referred as goal based dynamic sustainable procurement (GDSP) model and goal based stochastic sustainable procurement (GSSP) model

Finally, the research proposes a flexible dynamic sustainable procurement (FDSP) model to integrate quantitative and qualitative models to develop a procurement plan taking care of both qualitative and quantitative parameters desired by the firm. A case study is also conducted to validate the proposed models for real-time industry data.

Keywords: Dynamic procurement, Sustainability, Flexibility, quantitative modelling (Stochastic, fuzzy, goal based, ILP, MILP, MINLP, Heuristic), qualitative modelling (AHP, TOPSIS, Fuzzy-AHP, Fuzzy-TOPSIS, IRP, Weighted IRP, DEMATEL, BAK)

सार

प्रापण एक बाहरी स्रोत से माल या सेवाओं को खरीदने की प्रक्रिया है यह एक महत्वपूर्ण व्यवसाय कार्य है जो सही कीमत पर सही मात्रा में गुणवत्ता वाले सामान की खरीद को सही कीमत के भीतर सुनिश्चित करता है। 1 99 0 के बाद विश्व स्तर पर बढ़ती प्रतिस्पर्धा के साथ, व्यापार संगठनों ने अंततः यह महसूस किया है कि खरीदारी एक सरल कारकुनी एक की तुलना में एक रणनीतिक और सामरिक स्तर की गतिविधि है। चूंकि खरीद पूरी आपूर्ति श्रृंखला में एक प्रारंभिक और सबसे महत्वपूर्ण कदम है, इसलिए प्रभावी खरीद एक फर्म के प्रतिस्पर्धात्मक लाभ और समग्र व्यापार प्रदर्शन को बढ़ा सकती है। इसलिए, किसी भी उद्योग के लिए लागत कम करने, अंत उत्पाद की गुणवत्ता बनाए रखने, देरी से बचने और समग्र आपूर्ति श्रृंखला प्रदर्शन में सुधार के लिए एक प्रभावी और कुशल खरीद रणनीति आवश्यक है।

विनिर्माण फर्म के लिए महत्वपूर्ण मानदंडों के आधार पर आपूर्तिकर्ताओं और वाहकों का चयन कुशल खरीद की ओर पहला कदम है। इस शोध में, विभिन्न पारिवारिक और गैर पारंपरिक मापदंडों पर विचार करने वाले आपूर्तिकर्ताओं और वाहकों को प्राथमिकता देने के लिए विभिन्न गुणात्मक मॉडल लागू किए गए हैं। हालांकि, विभिन्न गुणात्मक मॉडल विभिन्न सप्लायर / वाहक रैंकिंग प्रदान करते हैं जिससे अंतिम निर्णय लेने में कठिनाई होती है। यह शोध कार्य विभिन्न गुणात्मक मॉडल से प्राप्त रैंकों पर आपूर्तिकर्ताओं और वाहकों की सर्वसम्मति रैंकिंग के लिए एक आईएलपी आधारित मॉडल विकसित करता है। इस के अलावा, गतिशील प्रापण मॉडल भी प्रस्तावित हैं, बहुत-आकार, सप्लायर चयन और वाहक चयन को एकीकृत करके। कार्बन उत्सर्जन की कमी का उपयोग करते हुए ये खरीद मॉडल कार्बन ट्रेडिंग बाजार के लिए विकसित किए जाते हैं। इसे गतिशील स्थायी खरीद (डीएसपी) मॉडल के रूप में संदर्भित किया जाता है। प्रस्तावित खरीद मॉडल या तो मिश्रित पूर्णांक रैखिक कार्यक्रम (एमआईएलपी) या मिश्रित पूर्णांक गैर-रैखिक कार्यक्रम (मिनलिप) प्रकार हैं और बड़े आकार की समस्याओं के लिए वास्तविक समय में इष्टतम समाधान प्राप्त नहीं किया जा सकता है। इसलिए, बड़े आकार के एमआईएलपी और मिनलिप मॉडलों को हल करने के लिए एक अनुमानी (एच -1) आधारित समाधान पद्धति भी प्रस्तावित है। प्राप्त इष्टतम और शोधिक समाधान भी सांख्यिकीय रूप से प्रस्तावित अनुमानी (एच -1) दृष्टिकोण की दक्षता दिखाने के लिए तुलना में हैं।

इन प्रस्तावित मॉडल को फजी और स्टोचैस्टिक मापदंडों का उपयोग करते हुए मांग, सप्लायर क्षमता और वाहक क्षमता में उतार-चढ़ाव के रूप में अनिश्चितताओं को पकड़ने के लिए आगे बढ़ा दिया गया है। इन खरीद मॉडल को फजी टिकाऊ खरीद (एफएसपी) के रूप में त्रिकोणीय फजी संख्या और स्टेचैस्टिक टिकाऊ खरीद (एसएसपी) मॉडल के माध्यम से मौका-विवश प्रोग्रामिंग का उपयोग कर कहा जाता है।

अनिश्चितताओं के अलावा, शोध कार्य फर्मों द्वारा प्राथमिकता के विभिन्न लक्ष्य लक्ष्यों को ध्यान में रखते हुए लक्ष्य आधारित खरीद मॉडल का प्रस्ताव भी करता है, इस प्रकार, प्रापण मॉडलिंग में फर्म के लक्ष्य को संबोधित करने के लिए। इन मॉडलों को लक्ष्य आधारित गतिशील स्थायी खरीद (जीडीएसपी) मॉडल और लक्ष्य आधारित स्टोचैस्टीक टिकाऊ खरीद (जीएसएपी) मॉडल के रूप में संदर्भित किया जाता है

अंत में, अनुसंधान एक लचीला गतिशील स्थायी खरीद (FDSP) मॉडल मात्रात्मक और गुणात्मक मॉडल एकीकृत करने के लिए फर्म द्वारा वांछित दोनों गुणात्मक और मात्रात्मक मानकों की देखभाल करने के लिए एक खरीद योजना विकसित करने का प्रस्ताव है। वास्तविक समय उद्योग डेटा के लिए प्रस्तावित मॉडल को मान्य करने के लिए केस स्टडी भी आयोजित किया जाता है।

कीवर्ड: गतिशील खरीद, स्थिरता, लचीलापन, मात्रात्मक मॉडलिंग (स्टोकेस्टिक, फजी, लक्ष्य आधारित, आईएलपी, MILP, MINLP, अनुमानी), गुणात्मक मॉडलिंग (AHP, TOPSIS, अस्पष्ट-AHP, अस्पष्ट-TOPSIS, IRP, भारित IRP, DEMATEL, BAK)

TABLE OF CONTENTS

CERTIFICATE	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
सार	v
LIST OF INDICES, VARIABLES AND PARAMETERS	xiii
LIST OF ABBREVATIONS	xvi
LIST OF FIGURES	xviii
LIST OF TABLES	xx

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND	1
1.2 1PROCUREMENT: AN IMPORTANT SUPPLY CHAIN FUNCTION	2
1.3 DRIVING FACTORS FOR PROCUREMENT	3
1.3.1 Procurement process	3
1.3.2 Supplier selection	3
1.3.3 Logistics and carrier selection	4
1.4 SUSTAINABLE PROCUREMENT	5
1.4.1 Carbon trading	6
1.5 SCOPE OF RESEARCH	6
1.6 ORGANIZATION OF THE THESIS	7
1.7 CONCLUDING REMARKS	11

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION	12
2.2 REVIEW ON SUPPLIER SELECTION	13
2.3 REVIEW ON CARRIER SELECTION	21
2.4 REVIEW ON DYNAMIC PROCUREMENT	23
2.5 REVIEW ON PROCUREMENT UNDER UNCERTAINTY	27
2.5.1 Fuzzy based procurement models	27
2.5.2 Stochastic procurement models	28
2.6 REVIEW ON GOAL-BASED PROCUREMENT MODELS	32

2.7 GAPS IDENTIFIED 32
2.8 RESEARCH OBJECTIVES 33
2.9 CONCLUDING REMARKS 34

CHAPTER 3: SUSTAINABLE SUPPLIER AND CARRIER SELECTION

3.1 INTRODUCTION 35
3.2 PROPOSED METHODOLOGY 37
3.2.1 Qualitative models 37
3.2.2 Integer linear model for Consensus ranking 39
3.3 MODELLING SUPPLIER SELECTION 40
3.3.1 Criteria identification and filtration through expert opinion 40
3.3.2 Criteria weights identification using DEMATEL 41
3.3.3 Qualitative modelling for Supplier selection 43
3.3.4 ILP for consensus supplier selection 46
3.4 **MODELLING CARRIER SELECTION** 46
3.4.1 Criteria weight identification 47
3.4.2 Qualitative modelling for carrier selection 49
3.4.3 ILP for consensus carrier selection 50
3.5 COMPARISON BETWEEN PROPOSED ILP AND BAK 53
3.6 CONCLUDING REMARKS 54

CHAPTER 4: DYNAMIC SUSTAINABLE PROCUREMENT MODELS

4.1 INTRODUCTION 56
4.2 DYNAMIC PROCUREMENT MODEL 57
4.2.1 List of assumptions 57
4.2.2 Deterministic Procurement Model 57
4.3 NUMERICAL ILLUSTRATIONS 58
4.3.1 Illustration 1: (4T-8P-8S-4M) Problem 59
4.3.2 Illustration 2: (7T-7P-8S-4M) Problem 60
4.4 CARBON EMISSIONS FRAMEWORK 62
4.5 DYNAMIC SUSTAINABLE PROCUREMENT MODEL WITHOUT LEAD TIME 63

4.6 NUMERICAL ILLUSTRATIONS 64
4.6.1 Illustration 1: (3T-10P-10S-5M) Problem 65
4.6.2 Illustration 2: (5T-7P-8S-4M) Problem 67
4.6.3 Illustration 3: (7T-4P-5S-3M-1) Problem 70
4.6.4 Illustration 4: (7T-4P-5S-3M-2) Problem 70
4.6.5 Illustration 5: (15T-3P-5S-3M) problem 73
4.6.6 Cost comparison between proposed MINLP (with carbon) and relaxed MILP (without carbon) 73
4.7 DYNAMIC SUSTAINABLE PROCUREMENT MODEL WITH LEAD TIME 79
4.8 SOLUTION METHODOLOGY AND COMPUTATIONAL TRIALS 80
4.8.1 Exact approach 81
4.8.2 Axiom development 81
4.8.3 Heuristic (H-1) approach 83
4.8.4 Hypothesis Testing 88
4.9 NUMERICAL ILLUSTRATIONS 89
4.10 GOAL-BASED DYNAMIC SUSTAINABLE PROCUREMENT MODEL 93
4.11 NUMERICAL ILLUSTRATION 94
4.11.1 Illustration 1: (4T-8P-8S-4M) problem 95
4.11.2 Illustration 2: (7T-7P-8P-4M) problem 99
4.12 CONCLUDING REMARKS 103

CHAPTER 5: DYNAMIC SUSTAINABLE PROCUREMENT MODELS UNDER UNCERTAINTY

5.1 INTRODUCTION 105
5.2 FUZZY SET THEORY AND FUZZY PROGRAMMING 106
5.2.1 Fuzzy Set Theory 106
5.2.2 Fuzzy Linear Programming 107
5.3 FUZZY SUSTAINABLE PROCUREMENT (FSP) MODEL 108
5.3.1 List of assumptions 108
5.3.2 Model formulation 108
5.4 NUMERICAL ILLUSTRATIONS 110
5.1 Illustration 1: (3T-3P-5S-3M) Problem 110

5.2 Illustration 2: (7T-4P-5S-3M) Problem 112
5.5. CHANCE-CONSTRAINT PROGRAMMING 114
5.6 STOCHASTIC SUSTAINABLE PROCUREMENT MODEL 114
5.6.1 List of Assumptions 115
5.6.2 Model formulation 115
5.7 NUMERICAL ILLUSTRATIONS 117
5.7.1 Illustration 1: (4T-8P-8S-4M) problem 117
5.7.2 Illustration 2: (9T-10P-10S-5M) problem 121
5.8 GOAL BASED STOCHASTIC PROCUREMENT PROBLEM 128
5.8.1 Problem statement 128
5.8.2 Model formulation 128
5.9 NUMERICAL ILLUSTRATIONS 129
5.9.1 Illustration 1: (4T-8P-8S-4M) problem 130
5.9.2 Illustration 2: (7T-7P-8P-4M)Problem 135
5.10 CONCLUDING REMARKS 139

CHAPTER 6: FLEXIBLE DYNAMIC SUSTAINABLE PROCUREMENT MODEL

6.1 INTRODUCTION 140
6.2 FLEXIBLE DYNAMIC SUSTAINABLE PROCUREMENT FRAMEWORK 140
6.3 MODELLING FLEXIBLE DYNAMIC SUSTAINABLE PROCUREMENT 142
6.3.1 Phase I: Qualitative models 143
6.3.2 Phase-II: Quantitative model 145
6.3.3 Phase-III: Flexible Dynamic Sustainable Procurement (FDSP) model 146
6.4 NUMERICAL ILLUSTRATION 148
6.4.1 Phase-I: Qualitative modelling 149
6.4.2 Phase-II: Dynamic Sustainable Procurement (DSP) model 151
6.4.3 Phase-III: Flexible Dynamic Sustainable Procurement (FDSP) model 153
6.5 CONCLUDING REMARKS 163

CHAPTER 7: CASE STUDY

7.1 CASE OVERVIEW 164

7.2 DATA COLLECTION 164

7.3 CASE STUDY 1: DSP MODEL 171

7.4 CASE STUDY 2: SSP MODEL 172

7.5 CONCLUDING REMARKS 174

CHAPTER 8: DISCUSSIONS AND FUTURE SCOPE

8.1 INTRODUCTION 175

8.2 SUMMARY OF RESEARCH WORK 175

8.3 THEORETICAL CONTRIBUTIONS 177

8.4 RESEARCH IMPLICATIONS 179

8.4.1 Implications for Academicians 179

8.4.2 Implications for Industry Practitioners 181

8.5 LIMITATIONS AND FUTURE SCOPE 183

8.6 CONCLUDING REMARKS 183

REFERENCES 184

APPENDICES 196

Appendix A-I: Importance of each criterion based on Survey 196

Appendix A-II: Conversion scale for converting crisp numbers into a triangular fuzzy number 196

Appendix A-III: Pair-wise comparisons for each supplier criteria using AHP 197

Appendix A-IV: Pair-wise comparison for each supplier criteria using fuzzy- AHP 199

Appendix A-V: Average Matrix for supplier criteria (DEMATEL) 202

Appendix A-VI: Weighted Normalized Matrix for TOPSIS 203

Appendix A-VII: Interpretive Ranking process for supplier selection 203

Appendix A-VIII: Mode of DEMATEL responses obtained for carrier criteria 204

Appendix A IX: Pair-wise comparison matrices between carriers (AHP) 205

Appendix A-X: Comparison matrix for TOPSIS 207

Appendix A-XI: Dominating interaction matrix (IRP and W-IRP) 207

Appendix B-I: Data set of (4T-8P-8S-4M) Problem. 208

Appendix B-II: Data set of (7T-7P-8S-4M) Problem 209
Appendix B-III: Randomly generated data for (3T-10P-10S-5M) problem. 211
Appendix B-IV: Randomly generated data for (5T-7P-8S-5M) problem 213
Appendix B-V: Randomly generated data for (7T-4P-5S-3M -1) problem 214
Appendix B-VI: Randomly generated data for (7T-4P-5S-3M-2) Problem 215
Appendix B-VII: Randomly generated data for (15T-3P-5S-3M) problem 216
Appendix B-VIII: Randomly generated fuzzy-data for (3T-3P-5S-3M) Problem 218
Appendix B-IX: Randomly generated Fuzzy-data for (7T-4P-5S-3M) Problem 219
Appendix B-X: stochastic data set for (4T-8P-8S-4M) problem 220
Appendix B-IX: Stochastic data set for (9T-10P-10S-5M) problem 221
Appendix B-XII: Stochastic Data set for (7T-7P-8S-4M) problem 223
Appendix B-XIII: Data set for (3T-10P-6S-5M) Problem 225
Appendix C-I: LINGO code of the proposed MINLP 227
Appendix C-II: LINGO code of the proposed MILP 228
Appendix C-III: LINGO code of the proposed heuristic (H-1) 229
Appendix C-IV: LINGO code of the FSP Model 230
Appendix C-V: LINGO code of the SSP Model 232
Appendix C-VI: LINGO code of the Goal SSP Model 233

AUTHOR’S PROFILE 233
PUBLICATIONS FROM THE THESIS 234

LIST OF INDICES, VARIABLES AND PARAMETERS

List of indices

t Index for time periods

i Index for parts

j Index for suppliers

m Index for carriers

List of variables

X_{tijm} Order allocation in t^{th} period of i^{th} part procured from j^{th} supplier in using m^{th} carrier

U_{tijm} 1 if in t^{th} period the i^{th} part is procured from j^{th} supplier using m^{th} carrier ELSE 0

Y Extra or spare carbon emissions sold or bought over entire planning horizon

I_{ti} Inventory carried from t^{th} period to $t^{(t+1)h}$ period for i^{th} part

List of parameters/notations

D_{ti} Demand in t^{th} period for i^{th} part

PC_{tij} Cost of purchasing in t^{th} period of i^{th} part from j^{th} supplier

TC_{tjm} Cost of transportation in t^{th} period from j^{th} supplier using mth carrier

OC_{ti} Cost of ordering in t^{th} period of i^{th} part

HC_{ti} Cost of holding inventory in t^{th} period for i^{th} part

SC_{tij} Capacity in t^{th} period of j^{th} supplier for i^{th} part

Ω_{jm} Available truck load capacity of m^{th} carrier with j^{th} supplier.

V_{tjm} Total number of m^{th} carriers available in t^{th} period with j^{th} supplier.

α Carbon emissions quota (in tons) for entire planning horizon.

C Carbon price per unit (ton).

F_{tm}, F'_{tm} Amount of carbon emission in executing a lot size of x units in t^{th} period of i^{th} part from j^{th} supplier using m^{th} carrier. F_{mt} is the carbon emissions produced when m^{th} carrier is empty. F_{omt} is the variable emission factor in time t^{th} period.

E_t Amount of carbon emissions caused during placing an order in t^{th} period.

E'_t Amount of carbon emissions caused in holding a unit of part at warehouse for t^{th} period.

UL_{ti} Upper tolerance of lead time in t^{th} period for i^{th} part.

LL_{ti} Lower tolerance of lead time for t^{th} period for i^{th} part.

L_{tjm} Lead time in t^{th} period of j^{th} supplier using m^{th} carrier.

dj Distance (Kms)of j^{th} supplier from the buyer.

mil_m Mileage (Kms/litre) of m^{th} carrier.

CHAPTER 3

j Index for MCDM techniques

i Index for supplier/carriers

X_{ij} Rank of i^{th} supplier/carrier using j^{th} MCDM technique

Y_i Aggregated/integrated final rank of the i^{th} suppliers/carriers.

CHAPTER 5

$\widetilde{D_{it}}$ Fuzzy demand in t^{th} period for i^{th} part expressed as TFN $(D_{it_{(l)}}, D_{it_{(m)}}, D_{it_{(u)}})$,

$\widetilde{SC_{ijt}}$ Fuzzy supplier capacity in t^{th} period with j^{th} supplier of i^{th} part expressed as TFN $(SC_{ijt_{(l)}}, SC_{ijt_{(m)}}, SC_{ijt_{(u)}})$

$\widetilde{\Omega_{jmt}}$ Fuzzy carrier capacity of m^{th} carrier with j^{th} supplier in t^{th} period expressed as TFN $(\Omega_{jmt_{(l)}}, \Omega_{jmt_{(m)}}, \Omega_{jmt_{(u)}})$

F_{Dti}^{-1} Constant inverse cumulative distribution function for random demand for given α_{ti} having mean (μ) and standard deviation (σ)

$F_{SC_{tij}}^{-1}$ Constant inverse cumulative distribution function for random supplier capacity for given α_{tij} having mean (μ) and standard deviation (σ)

$F_{V_{tij}}^{-1}$ Constant inverse cumulative distribution function for random carrier capacity for given α_{tjm} having mean (μ) and standard deviation (σ)

α_{tjm} Level of probability in t^{th} period that units supplied by j^{th} supplier using m^{th} carrier meets capacity of m^{th} carrier

α_{ti} Level of Probability that unit supplied satisfies the demand of i^{th} product in t^{th} period

α_{tij} Level of probability in t^{th} period that units supplied by j^{th} supplier for i^{th} product meets capacity of j^{th} supplier

CHAPTER 4 AND 5

Z_1* Goal value for purchasing cost

Z_2* Goal value for ordering cost

Z_3* Goal value for transportation cost

Z_4* Goal value for holding cost

Z_5* Goal value for carbon emission cost

Z_6* Goal value for supplier capacity i.e. minimization of capacity overutilization

Z_7* Goal value for carrier capacity i.e. minimization of capacity overutilization

d_1^+, d_1^- Positive and negative deviational variable for Z_1*.

d_2^+, d_2^- Positive and negative deviational variable for Z_2*.

d_3^+, d_3^- Positive and negative deviational variable for Z_3*.

d_4^+, d_4^- Positive and negative deviational variable for Z_4*.

d_5^+, d_5^- Positive and negative deviational variable for Z_5*.

d_{ijt6}^+, d_{ijt6}^- Over-utilization and under-utilization of supplier capacity $\forall\ i,j,t$.

d_{jmt7}^+, d_{jmt7}^- Over-utilization and under-utilization of carrier capacity $\forall\ j,m,t$.

LIST OF ABBREVATIONS

AHP: Analytic Hierarchy Process

ANP: Analytic Network Process

BAK: Borda and Kendall method

CV: Coefficient of Variation

DEA: Data envelopment analysis (DEA)

DEMATEL: Decision Making Trial and Evaluation Laboratory

DSP: Dynamic Sustainable Procurement

ELECTRE: Elimination and Choice Expressing Reality

FDSP: Flexible Dynamic Sustainable Procurement

FSP: Fuzzy Sustainable Procurement

Fuzzy QFD: Fuzzy Quality Function Deployment

GDSP: Goal based Dynamic Sustainable Procurement

GSSP: Goal based Stochastic Sustainable Procurement

ILP: Integer Linear Program

IRP: Interpretive Ranking Process

ISM: Interpretive Structural Modelling

JIT: Just-in-Time

MAUT: Multi-Attribute Utility Theory

MCDM: Multi-Criteria Decision Making

MILP: Mixed Integer Linear Program

MINLP: Mixed Integer Non-Linear Program

PROMETHEE: Preference Ranking Organization Method for Enrichment Evaluation

QFD: Quality Function Deployment

SAP-LAP: situation-actor-process- learning-action-performance

SD: Standard Deviation

SSP: Stochastic Sustainable Procurement

TFN: Triangular Fuzzy Number

TOPSIS: Technique for Order of Preference by Similarity to Ideal Solution

Weighted IRP: Weighted Interpretive Ranking Process

LIST OF FIGURES

Figure 1.1 Generic procurement procedures	3
Figure 1.2: Organization of thesis	9
Figure 2.1: Frequency distribution of supplier selection criteria.	15
Figure 2.2: Percentage distribution of MCDM techniques used in supplier selection	18
Figure 2.3: Research trend in stochastic supply chain and procurement	30
Figure 3.1: Generic framework of supplier and carrier selection process	36
Figure 3.2: Proposed sustainable supplier and carrier methodology	38
Figure 3.3: Average supplier criteria ratings based on industry survey	41
Figure 3.4: Causality diagram of supplier criteria	43
Figure 3.5: Causality diagram of carrier criteria	49
Figure 4.1: Carbon emissions Framework.	62
Figure 4.2: Cost distribution for proposed MINLP and relaxed MILP	77
Figure 4.3: Trend analysis of procurement, carbon emission and total cost between proposed MINLP (with carbon emission constraint) and relaxed MILP (without carbon emission constraint)	78
Figure 4.4: Solution Methodology Flowchart for DSP Model	82
Figure 4.5: Distribution of optimality gap for all 30 tests for medium size instances	87
Figure 4.6: Distribution of optimality gap for all 12 tests for large size instances	87
Figure 4.7: Supplier capacity distribution and its deviations for (4T-8P-8S-4M) problem	97
Figure 4.8: Carrier capacity distribution and its deviations for (4T-8P-8S-4M) problem	98
Figure 4.9: Supplier capacity distribution and its deviations for (7T-7P-8S-4M) problem	101
Figure 4.10: Carrier capacity distribution and its deviations for (7T-7P-8S-4M) problem	102

Figure 4.11: Distribution of goal targets and deviation for (4T-8P-8S-4M) and (7T-7P-8S-4M) problems 103

Figure 5.1: Triangular Fuzzy number 107

Figure 5.2: Lot-sizing schema for (3T-3P-5S-3M) problem 111

Figure 5.3: Lot-sizing schema for (7T-4P-5S-3M) problem 113

Figure 5.4: Distribution of order allocation for (4T-8P-8S-4M) problem 120

Figure 5.5: Distribution of order allocation for (9T-10P-10S-5M) problem 125

Figure 5.6: Lot sizing pattern for (4T-8P-8S-4M) and (9T-10P-10S-4M) problem 126

Figure 5.7: Supplier capacity distribution and its deviations for (4T-8P-8S-4M) problem 133

Figure 5.8: Carrier capacity distribution and its deviations for (4T-8P-8S-4M) 134

problem

Figure 5.9: Supplier capacity distribution and its deviations for (7T-7P-8S-4M) problem 137

Figure 5.10 Carrier capacity distribution for (7T-7P-8S-4M) problem 138

Figure 6.1: Flexible Dynamic Sustainable Procurement (FDSP) framework 142

Figure 6.2: Framework for supplier/carrier selection 144

Figure 6.3: Framework for DSP model 146

LIST OF TABLES

Table 2.1: Frequency of journals referred for review 12

Table2.2: Summary of supplier selection criteria appeared in literature 16

Table 2.3: Summary of popular MCDM techniques for supplier selection 19

Table 2.4 Summary of carrier selection criteria appeared in literature 22

Table 2.5: Summary of past work on dynamic procurement models 26

Table 2.6: Summary of papers on fuzzy procurement models 28

Table 2.7: Summary of widely referred papers on stochastic procurement models 31

Table 3.1: Supplier criteria weights using DEMATEL 42

Table 3.2: Priority vectors for suppliers for each criteria using AHP 44

Table 3.3: Priority vectors for suppliers for each criteria using fuzzy-AHP 44

Table 3.4: Separations from Ideal and negative ideal solution and relative closeness index using TOPSIS and fuzzy-TOPSIS 45

Table 3.5: Calculation of Net Dominance for suppliers using IRP and Weighted IRP 45

Table 3.6: Final Ranks obtained by using different qualitative models and ILP 46

Table 3.7: Types of carriers 47

Table 3.8: Criteria weights for carrier selection using DEMATEL 48

Table 3.9: Priority vectors for carriers for each criteria using AHP 51

Table 3.10: Priority vectors for carriers for each criteria using fuzzy-AHP 51

Table 3.11: Separations from Ideal and negative ideal solution and relative closeness index using TOPSIS and fuzzy TOPSIS 52

Table 3.12: Net dominance of carriers using IRP and weighted IRP 52

Table 3.13: Carrier ranks obtained using different qualitative models and ILP 53

Table 3.14: Comparison of ranks using ILP and BAK technique 53

Table 3.15: Comparison of ranks using ILP and BAK for bigger data set 54

Table 4.1: Optimal solution using dynamic procurement model for (4T-8P-8S-4M) problem 59

Table 4.2: Optimal solution using dynamic procurement model for (7T-7P-8S-4M) problem 61

Table 4.3: Data sets considered for numerical illustrations 65

Table 4.4: Optimal solution using MINLP and MILP for (3T-10P-10S-5M) 66

Problem

Table 4.5: Optimal solution with and without carbon emission constraint for (5T-7P-8P-4M) problem 68

Table 4.6: Optimal solution with and without carbon emission constraint for (7T-4P-5S-3M-1) problem 71

Table 4.7: Lot-size schema with and without carbon emission constraint for (7T-4P-5S-3M-2) Problem) 72

Table 4.8: Lot-size schema with and without carbon emission constraint for data set 15T-3P-5P-3M 75

Table 4.9: Cost comparison between DSP model with carbon constraint (proposed MINLP) and without carbon constraint (relaxed MILP) 76

Table 4.10: Comparison between solution quality and CPU time for proposed MINLP, MILP and proposed heuristic (H-1) on medium scale problem 85

Table 4.11: Comparison between solution quality and CPU time for proposed MINLP, MILP and proposed heuristic (H-1) on large scale problems 86

Table 4.12: t-test significance between objective function value of MINLP/MILP and heuristic (H-1) 89

Table 4.13: Optimal dynamic sustainable procurement solution for (4T-8P-8S-4M) problem 90

Table 4.14: Optimal dynamic sustainable procurement solution for (7T-7P-8S-4M) problem 91

Table 4.15: Optimal results for goal based sustainable procurement model for (4T-8P-8S-4M) problem 96

Table 4.16: Optimal solution for goal based sustainable procurement model for (7T-7P-8S-4M) problem 100

Table 5.1: Optimal fuzzy sustainable procurement solution for (3T-3P-5S-3M) problem 111

Table 5.2: Optimal fuzzy sustainable procurement solution for (7T-4P-5S-3M) problem 113

Table 5.3: Optimal stochastic sustainable procurement solution for (4T-8P-8S-4M) problem 119

Table 5.4: Optimal stochastic sustainable procurement solution for (9T-10P-10S-5M) problem 123

Table 5.5: Comparative statics of stochastic sustainable model for thirty problem instances of varying datasets 127

Table 5.6: Goal deviations and Procurement plan obtained for (4T-8P-8S-4M) problem 132

Table 5.7: Goal deviations and Procurement plan obtained for (7T-7P-8S-4M) problem 136

Table 6.1: List of criteria and criteria weights derived using DEMATEL. 150

Table 6.2: Final supplier ranking 150

Table 6.3: List of criteria for carrier selection and corresponding weightages derived using DEMATEL 151

Table 6.4: Final carrier ranking 151

Table 6.5: Optimal solution of DSP model 152

Table 6.6: Possible elimination strategies to formulate FDSP 157

Table 6.7: Objective function value of FDSP considering all elimination strategies 158

Table 6.8: Percentage deviational for FDSP 159

Table 6.9: FDSP optimal solution corresponding to 4.69% deviation 160

Table 6.10: Comparison between order allocation of DSP and FDSP 161

Table 7.1: Demand calculation for part (P_1 -40.5) 165

Table 7.2: Demand calculation for part (P_2 -41.2) 165

Table 7.3: Demand calculation for part (P_3 -41.5) 166

Table 7.4: Demand calculation for part (P_4 -42.2) 166

Table 7.5: Demand calculation for part (P_5 -43.9) 167

Table 7.6: Demand calculation for part (P_6 -45.5) 167

Table 7.7: Demand calculation for part (P_7 -45.6) 167

Table 7.8: Demand calculation for part (P_8 -50) 168

Table 7.9**:** Demand calculation for part (P_9 -54) 168

Table 7.10: Demand calculation for part (P_{10} -58) 168

Table7.11: Supplier information 168

Table 7.12: Secondary data for manufacturing firm located at Jalandhar, Punjab (for DSP) 169

Table 7.12: Secondary data for manufacturing firm located at Jalandhar, Punjab (for SSP) 170

Table 7.13: Optimal procurement plan for DSP model 172

Table 7.14: Optimal procurement plan for SSP model 173