# TABLE OF CONTENTS

1. **INTRODUCTION**  
   1.1 OBJECTIVES OF THE RESEARCH  
   1.2 MOTIVATION  
   1.3 OVERVIEW OF THE PROPOSED RESEARCH METHODOLOGY  
   1.4 ORGANIZATION OF THE DOCUMENT  

2. **BACKGROUND**  
   2.1 TECHNICAL EFFICIENCY  
     2.1.1 BASIC CONCEPTS OF TECHNICAL EFFICIENCY  
     2.1.1.1 Production Functions  
     2.1.1.2 Isoquant  
   2.2 DATA ENVELOPMENT ANALYSIS  
     2.2.1 BASIC DEA MODELS  
     2.2.1.1 The BCC Model  
     2.2.1.1.1 Input Reducing Model (IRM)  
     2.2.1.1.2 Output Increasing Model (OIM)  
     2.2.2 FURTHER INSIGHTS INTO TECHNICAL EFFICIENCY  
     2.2.2.1 RADIAL MEASURES  
     2.2.2.1.1 Input Reducing Model (IRM)  
     2.2.2.1.2 Output Increasing Model (OIM)  
     2.2.2.2 NON-RADIAL MEASURES  
     2.2.2.2.1 THE FÄRE-LOVELL NON-RADIAL MEASURE  
   2.3 LINEAR GOAL PROGRAMMING  
     2.3.1 TERMINOLOGY AND CONCEPTS  
     2.3.1.1 Objective  
     2.3.1.2 Aspiration Level  
     2.3.1.3 Goal  
     2.3.1.4 Goal Deviation  
     2.3.1.5 Goal Formulation
2.3.1.6 The Achievement Function 22
2.3.1.7 Lexicographic Minimum 22
2.3.2 STEPS IN MODEL CONSTRUCTION 22
2.3.3 METHODS OF SOLUTION 23

3. EXISTING MULTIPLE OBJECTIVE-DEA TYPE METHODOLOGIES 26
3.1 THANASSOULIS AND DYSON (1992) 26
3.2 ATHANASSOPOULOS (1995) 31

4. PROPOSED MODEL FOR THE RESEARCH 39
4.1 MULTIPLE OBJECTIVE FRAMEWORK 39
4.2 THE SERIAL-MANUFACTURING GOAL PROGRAMMING MODEL 42 (SMGP)

5. OVERVIEW OF THE MANUFACTURING PROCESS 47
5.1 INTRODUCTION 47
5.2 INNER LAYER PROCESS 49
  5.2.1 Inner Layer Material Prep 49
  5.2.2 Surface Scrub and Photo Resist Lamination 49
  5.2.3 Print Inner Layer 49
5.3 ETCH PROCESS 49
  5.3.1 Develop Resist, Etch Copper, Strip Resist 49
  5.3.2 Automated Optical Inspection 100% 49
5.4 MULTILAYER PROCESS 50
  5.4.1 Surface Prep and Black Oxide 50
  5.4.2 Lay-up, Press, Break Down 50
  5.4.3 Route and Bevel Panels 50
5.5 DRILL PROCESS 50
  5.5.1 Drill Panels (Sample Inspection) 50
5.6 COPPER ELECTROLESS PROCESS 51
5.6.1 Electroless Copper Deposition 51

5.7 ELECTROLYTIC PANEL PROCESS 51
  5.7.1 Electrolytic Panel Plate (100% Inspection) 51

5.8 LAMINATION PROCESS 51
  5.8.1 Scrub and Photo Resist Lamination 51

5.9 SOLDER PROCESS 52
  5.9.1 Develop Resist & Solder Plate (Sample Inspection) 52
  5.9.2 Strip Resist, Etch Copper, Strip Solder (Sample Inspection) 52
  5.9.3 Scrub, Apply Solder Mask (100% Inspection) 52
  5.9.4 Hot Air Solder Leveling - HASL (100% Inspection) 53

5.10 GOLD-NICKEL PLATING PROCESS 53
  5.10.1 Strip Solder, Plate Gold (Sample Inspection) 53

5.11 MACHINE PROCESS 53
  5.11.1 Route and Bevel, Wash (Sample Inspection) 53
  5.11.2 Electrical Test (100%) 54
  5.11.3 100% Inspection, Audit, Lot Conformation, Report, Ship 54

5.12 DEFINITION OF VARIABLES 54
  5.12.1 Input Variables 55
    5.12.1.1 Direct Labor Hours 55
    5.12.1.2. Material Inputs Costs 55
  5.12.2 Output Variable 56
    5.12.2.1 Number of Boards 56

6. ANALYSIS OF RESULTS 57

6.1 THE DEA EVALUATION 57
  6.1.1 The BCC Input Reducing Model 58
  6.1.2 The BCC Output Increasing Model 59
  6.1.3 The Two Stage Radial Model 61
  6.1.4 The Input Reducing Färe-Lovell Non-Radial Model 61
  6.1.5 The Output Increasing Färe-Lovell Non-Radial Model 62
  6.1.6 The Aggregate Input Reducing BCC Model 63
6.1.7 The Aggregate Output Increasing BCC Model 64
6.1.8 The Two Stage Radial Model 65
6.1.9 The Input Reducing Färe-Lovell Non-Radial Model 65
6.1.10 The Aggregate Output Increasing Färe-Lovell Non-Radial Model 65
6.1.11 Disposability Tests 66
6.1.11.1 Output-Based Test for Input Disposability 66
6.1.11.2 Input-Based Test for Output Disposability 67

6.2 THE SMGP EVALUATION 69
6.2.1 The First Strategy 70
6.2.1.1 Convexity Assumption (sum of the z’s equal to one) 70
6.2.1.2 Activity Parameters constrained between zero and one 82
6.2.1.3 Activity Parameters Unrestricted 84
6.2.2 The Second Strategy 86
6.2.3 The Third Strategy 87
6.2.3.1 Convexity Assumption (sum of the z’s equal to one) 87
6.2.3.2 Activity Parameters constrained between zero and one 89
6.2.3.3 Activity Parameters Unrestricted 92
6.2.4 Alternate Strategy to Compare against Actual Outputs 94
6.2.4.1 The First Strategy 94
6.2.4.2 The Third Strategy 97
6.2.5 Sensitivity Analysis 100
6.2.5.1 Dual Prices (Shadow Pricing) 100
6.2.5.2 Perturbations to the Objective Function Coefficients and the Right-Hand-Sides 101

7. CONCLUDING REMARKS 103
LIST OF OBJECTS

Figure 2.1 Isoquant 7
Figure 2.2 Radial and Non-Radial Measures of Efficiency 7
Figure 2.3 Comparison of DEA and Regression 10
Table 2.1 Goal Formulations 21
Figure 3.1 Centralized Planning System 33
Fig 4.1 Contribution of the Individual Processes to the Global Targets 41
Figure 5.1 Printed Circuit Board Manufacturing Process 48
Figure 6.1 Average Efficiency of each Process across all Months 58
Figure 6.2 Average Efficiency of each Month across all Processes 59
Figure 6.3 Average Efficiency of each Process across all Months 60
Figure 6.4 Average Efficiency of each Month across all Processes 60
Figure 6.5 Average Efficiency of each Process across all Months 61
Figure 6.6 Average Efficiency of each Month across all Processes 62
Figure 6.7 Average Efficiency of each Process across all Months 63
Figure 6.8 Average Efficiency of each Month across all Processes 63
Figure 6.9 Average Efficiency of each Month across all Processes 64
Figure 6.10 Average Efficiency of each Month across all Processes 64
Figure 6.11 Average Efficiency of each Month across all Processes 65
Figure 6.12 Average Efficiency of each Month across all Processes 66
Figure 6.13 Output Trend Plotted against Increasing Labor 68
Figure 6.14 Output Trend Plotted against Increasing Raw Materials 68
Figure 6.15 Percent Positive Deviations from Global Output Target 71
Table 6.1 Percent Deviations from Output Targets for Plant and Process Levels 72
Figure 6.16 Cumulative Process Output Deviations 73
Table 6.2 Percent Deviations from Labor (Input) Targets for Plant and Process Levels 75
Table 6.3 Percent Deviations from Raw Materials Targets for Plant and Process Levels 76
Table A.23 Output Based Output Disposability- Aggregate Technical Efficiency Scores 132
Table A.24 Input Reducing Non-Radial- Aggregate Technical Efficiency Scores 133
Table A.25 Output-Increasing Non-Radial- Aggregate Technical Efficiency Scores 134
Table A.26 Percent Deviations from Output Targets for Plant and Process Levels (Z>0) 135
Table A.27 Percent Deviations from Labor (Input) Targets for Plant and Process Levels (Z>0) 136
Table A.28 Percent Deviations from Output Targets for Plant and Process Levels (Z>0) 137
Table A.29 Percent Deviations from Process Line Balance (Z>0) 138
Table A.30 Percent Deviations from Output Targets for Plant and Process Levels (Z<1) 139
Table A.31 Percent Deviations from Labor (Input) Targets for Plant and Process Levels (Z<1) 140
Table A.32 Percent Deviations from RM (Input) Targets for Plant and Process Levels (Z<1) 141
Table A.33 Percent Deviations from Process Line Balance(Z<1) 142
Table A.34 Percent Deviations from Output Targets for Plant and Process Levels (SUMZ=1, Strategy III) 143
Table A.35 Percent Deviations from Labor (Input) Targets for Plant and Process Levels (SUMZ=1, Strategy III) 144
Table A.36 Percent Deviations from RM (Input) Targets for Plant and Process Levels (SUMZ=1, Strategy III) 145
Table A.37 Percent Deviations from Process Line Balance (SUMZ=1, Strategy III) 146
Table A.38 Reference Observations - Peers (SUMZ=1, Strategy III) 147
Table A.39 Percent Deviations from Output Targets for Plant and Process Levels (Z>0, Strategy III) 148