Thesis
v.1

MICHIGAN STATE UNIVERSITY LIBRARIES
3 1293 01090 7545
LIBRARY
Michigan State
University

This is to certify that the

dissertation entitled

The Effect of a Dynamic Bill of Material on Material Planning and Control Systems in Process Industries

presented by

David Michael Lyth

has been accepted towards fulfillment
of the requirements for
Ph.D. degree in Production/Operations Management

Major professor

Date August 14, 1987

MSU is an Affirmative Action/Equal Opportunity Institution

0-12771

RETURNING MATERIALS:
Place in book drop to remove this checkout from your record. FINES will be charged if book is returned after the date stamped below.

THE EFFECT OF A DYNAMIC BILL OF MATERIAL ON MATERIAL PLANNING AND CONTROL SYSTEMS IN PROCESS INDUSTRIES

By

David Michael Lyth

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Management

1987

ABSTRACT

One of the problems faced by the material planning and control system of batch process manufactures is the need to respond to variability in the quality characteristics of some of their raw material inputs. Because physical properties of acceptable raw material can vary, the actual quantity of raw material required in production depends not only on the size of the order being produced, but on the actual properties of those raw materials. The result is a dynamic bill of material which is defined as a listing of all raw materials required for a product's manufacture where the quantity of each raw material is stochastic, with a known probability distribution, rather than deterministic.

This research assumes that a raw material's physical properties will affect its usage in blending all products the same way, that is, if twice as much raw material is needed to make a particular product, then all products using that raw material will require twice as much of that raw material during production. This shifts the source of variability from the input-output coefficients in the bill of material to variability in the effective quantity of raw material received from the supplier. The problem addressed here becomes one of lot size determination when ordering

raw material with varying quality characteristics, or as it is more commonly known, variable yield lot-sizing.

Three basic methods were identified for the material planning and control system to order raw material from the supplier. They were a variation to the basic economic order quantity model, lot-for-lot ordering with varying service levels, 50%, 70% or 90%, and the use of stochastic dynamic programming. Another response involved the service level of finished goods safety stock.

The basic research question posed in this study dealt with the performance characteristics of each of the five raw material ordering methods. Based on raw material and finished goods inventory levels, raw material ordering cost, setup time, units placed on backorder and total cost, the performance of each planning response was identified.

A simulation model was developed to compare the performance of the planning responses to raw material variability. It was a single machine blending process with feedback to the planning system for corrective action.

Endogenous factors, those factors under the control of the planning system, included the service level of finished goods safety stock and the choice of raw material planning method. Exogenous, or environmental, variables were also identified and incorporated in the experimental design of this research. They included the holding cost for finished goods and raw materials, the penalty assigned to units placed on backorder, the cost of ordering raw materials, the

setup time required by the production process and a measure of raw material variability. A full factorial experimental design was employed and resulting data was analyzed using multivariate analysis of variance.

The results of this study indicate relatively poor performance of the modified economic order quantity method and ineffectiveness of finished goods safety stock as a way of responding to raw material variability. The remaining raw material planning methods, modified lot-for-lot and stochastic dynamic programming provided comparable performance. For each possible combination of exogenous factors, a planning system design was specified indicating recommended service level of finished goods safety stock and raw material planning method to be employed.

ACKNOWLEDGMENTS

When reading dissertations by other authors in the course of this research, I was amazed at the varied content of their acknowledgments. It was only when my dissertation was completed did I understand the authors' logic in writing their acknowledgments. A dissertation and doctorate is a joint effort, faculty, family and friends all have contributed to the completion of this research and my degree. It is through the acknowledgment section of this dissertation, I am able to recognize and thank those individuals.

Dr. Phillip L. Carter, Chairman of the Dissertation Committee, provided much insight into the initial development of this research question and its subsequent refinement and investigation. His insight, encouragement and constructive criticism allowed for the successful completion of this dissertation. He has provided support and assistance throughout my stay at Michigan State University, his advice and counseling contributed significantly to my professional development and success in the program.

The remaining members of the committee, Dr Richard F. Gonzalez and Dr. Gary L. Ragatz, also were instrumental in the completion of this work. Their aid in all phases of this research, problem formulation and editing through seemingly countless revisions was invaluable. Their support and advice aided my progress through the doctoral program, and their efforts are recognized and greatly appreciated.

Other faculty providing counsel, advice and aid included Dr. David M. Dilts and Dr. Steven A. Melnyk.

Another group of people contributing to the completion of the degree were my fellow doctoral students by aiding in the development and refinement of research ideas and providing moral support throughout the doctoral program and commiserating on that program's perceived hardships. I would expressly like to thank Barbara E. Taylor, her friendship allowed me keep my career at Michigan State University it in proper perspective. Finally, Robert Landeros merits special mention. His friendship throughout the program provided a lasting friendship that allowed me to complete this degree and maintain both my sanity and sense of humor. To our fathers . . . and their sons.

A different type of support is provided by one's family. Many times, the intricacies of a doctoral program are not fully appreciated by the family members but their love and support is there without asking for it. My family, especially my mother, provided the strong base necessary to complete this program.

A special note of thanks to two people who helped me to have the courage to start, and the perseverance to finish this degree, my father, Leo F. Lyth, and my father-in-law, Omar A. Caylor.

As I have seen many people do, I have saved the best for last. Without the support of my wife, Joyce, this journey to my doctorate would not have been started, let alone completed. Her love, support and sacrifices were instrumental in the completion of this research and this degree . . . Thank you Joyce.

Copyright by
DAVID MICHAEL LYTH
1987

TABLE OF CONTENTS

		Page
CHAPTER 1 - INTRODUCTION		
1.1	Introduction	1
1.2	Manufacturing Environment	1
1.3	Variability	2
1.4	The Management of Variability	9
1.5	Management Responses to Variability	11
1.6	Research Objectives	12
1.7	Organization	13
CHAPTER 2 - LITERATURE REVIEW		
2.1	Introduction	15
2.2	Process Industries Overview	16
2.3	Uncertainty in Manufacturing	29
2.4	Decision Making under Uncertainty	31
2.5	Dynamic Bill of Material	33
2.6	Variable Yield Lot Sizing	37
2.7	Chapter Summary	39
CHAPTER 3 - THE MODEL		
3.1	Introduction	41
3.2	Production and Inventory Planning Framework	41
3.3	The General Model	44
3.4	Planning and Control System Logic	47
3.5	Raw Material and Product Structure	50
3.6	Cost Structure	51
3.7	Assumptions of the Model	54
3.8	Variation in Quantity Supplied	54
3.9	The Simulation Model	56
3.10	Experimental Factors	59
3.11	Chapter Summary	66
CHAPTER 4 - RESEARCH DESIGN		
4.1	Introduction	67
4.2	Endogenous Factor Levels	67
4.3	Exogenous Factor Level Settings	70
4.4	Performance Measures	75
4.5	Data Collection	78

4.6 Statistical Analysis Experimental Design . 79
4.7 Chapter Summary 83

CHAPTER 5 - STATISTICAL RESULTS

5.1 Introduction 84
5.2 Statistical Analysis Methodology . . . 85
5.3 Multivariate Analysis of Variance Main Effects Results 90
5.4 Two-way Interactions 95
5.5 Three-way Interactions 113
5.6 Significant Four Factor Interactions . . 137
5.7 Significant Five Factor Interactions . . 159
5.8 Six Factor Interaction 169
5.9 Chapter Summary 170

CHAPTER 6 - ANALYSIS OF RESULTS

6.1 Introduction 172
6.2 Statistical Analysis Overview 172
6.3 Six Factor Interaction Analysis . . . 179
6.4 Dependent Variable Trends 321
6.5 Overall Rank of Planning System Methodologies. 334
6.6 Backorder Units and Replanning . . . 342
6.7 Chapter Summary 346

CHAPTER 7 - SUMMARY, MANAGERIAL IMPLICATIONS, AND FUTURE RESEARCH

7.1 Introduction 347
7.2 Summary 348
7.3 Environmental Factors 349
7.4 Contribution of Research 349
7.5 Suggestions for Future Research . . . 352

APPENDIX A:

Census of Manufacturers Data 353

APPENDIX B:

Program Flowcharts 355

APPENDIX C:

Program Listings 369

LIST OF REFERENCES 430

LIST OF TABLES

TABLE		Page
2.1	Planning/Control Functions and Factors Affecting System Design	19
2.2	Material Planning Module Design Considerations	24
4.1	Range of Raw Material Quantity Variability	73
4.2	Exogenous and Endogenous Factor Level Settings	82
5.1	Multivariate Analysis of Variance Statistical Analysis Design	86
5.2	Multivariate Analysis of Variance--Main Effects and Interactions Investigated	88
5.3	Multivariate Analysis of Variance Overall Equality Test Main Effect--Planning Method	92
5.4	Multivariate Analysis of Variance Univariate F-Tests Main Effect--Planning Method	93
5.5	Multivariate Analysis of Variance Overall Equality Test Main Effect--Finished Goods Safety Stock	94
5.6	Multivariate Analysis of Variance Univariate F-Tests Main Effect--Finished Goods Safety Stock	95
5.7	Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method and Safety Stock Interaction	96
5.8	Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method and Safety Stock Interaction	97
5.9	Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method and Capacity Utilization Interaction	98
5.10	Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method and Capacity Utilization Interaction	99
5.11	Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method and Cost of Capital Interaction	100
5.12	Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method and Cost of Capital Interaction	101
5.13	Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method and Activity Ratio Interaction	102
5.14	Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method and Activity Ratio Interaction	103

5.15 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method and Coefficient of Variation Interaction . . 104
5.16 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method and Coefficient of Variation Interaction 105
5.17 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock and Average Capacity Utilization Interaction . 106
5.18 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock and Average Capacity Utilization Interaction . . . 107
5.19 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock and Cost of Capital Interaction 108
5.20 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock and Cost of Capital Interaction 109
5.21 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock and Activity Ratio Interaction 110
5.22 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock and Activity Ratio Interaction 110
5.23 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock and Coefficient of Variation Interaction . . 111
5.24 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock and Coefficient of Variation Interaction 112
5.25 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock and Average Capacity Utilization Interaction 113
5.26 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock and Average Capacity Utilization Interaction 114
5.27 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock and Cost of Capital Interaction 115
5.28 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock and Cost of Capital Interaction 116
5.29 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock and Activity Ratio Interaction 117

5.30 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock and Activity Ratio Interaction 117
5.31 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock and Coefficient of Variation Interaction 118
5.32 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock and Coefficient of Variation Interaction 119
5.33 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Average Capacity Utilization and Cost of Capital Interaction 120
5.34 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Average Capacity Utilization and Cost of Capital Interaction 120
5.35 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Average Capacity Utilization and Activity Ratio Interaction 121
5.36 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Average Capacity Utilization and Activity Ratio Interaction 122
5.37 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Average Capacity Utilization and Coefficient of Variation Interaction 123
5.38 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Average Capacity Utilization and Coefficient of Variation Interaction 123
5.39 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Cost of Capital and Activity Ratio Interaction 124
5.40 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Cost of Capital and Activity Ratio Interaction 125
5.41 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Cost of Capital and Coefficient of Variation Interaction 126
5.42 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Cost of Capital and Coefficient of Variation Interaction 126

5.43 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Activity Ratio and Coefficient of Variation Interaction 127
5.44 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Activity Ratio and Coefficient of Variation Interaction 128
5.45 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Average Capacity Utilization, and Cost of Capital Interaction 129
5.46 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Average Capacity Utilization and Cost of Capital Interaction 129
5.47 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Average Capacity Utilization, and Activity Ratio Interaction 130
5.48 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Average Capacity Utilization and Activity Ratio Interaction 131
5.49 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Average Capacity Utilization, and Coefficient of Variation Interaction 132
5.50 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Average Capacity Utilization and Coefficient of Variation Interaction 132
5.51 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Cost of Capital and Activity Ratio Interaction 133
5.52 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Cost of Capital and Activity Ratio Interaction 134
5.53 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Cost of Capital and Coefficient of Variation Interaction 135
5.54 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Cost of Capital and Coefficient of Variation Interaction 135
5.55 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Activity Ratio and Coefficient of Variation Interaction 136

5.56 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Activity Ratio and Coefficient of Variation Interaction 137
5.57 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Cost of Capital Interaction 138
5.58 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Cost of Capital Interaction 139
5.59 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Activity Ratio Interaction 140
5.60 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Activity Ratio Interaction 140
5.61 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Coefficient of Variation Interaction 141
5.62 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Coefficient of Variation Interaction 142
5.63 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital and Activity Ratio Interaction 143
5.64 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital and Activity Ratio Interaction 143
5.65 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital and Coefficient of Variation Interaction 144

5.66 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital and Coefficient of Variation Interaction 145
5.67 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Activity Ratio and Coefficient of Variation Interaction 146
5.68 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Activity Ratio and Coefficient of Variation Interaction 146
5.69 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Average Capacity Utilization, Cost of Capital and Activity Ratio Interaction 147
5.70 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Average Capacity Utilization, Cost of Capital and Activity Ratio Interaction 148
5.71 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Average Capacity Utilization, Cost of Capital and Coefficient of Variation Interaction 149
5.72 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Average Capacity Utilization, Cost of Capital and Coefficient of Variation Interaction 149
5.73 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Interaction 150
5.74 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Interaction 151
5.75 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 152
5.76 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Cost of Capital Activity Ratio and Coefficient of Variation Interaction 152

5.77 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Activity Ratio Interaction 153
5.78 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Activity Ratio Interaction 154
5.79 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Coefficient of Variation Interaction 155
5.80 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Coefficient of Variation Interaction 156
5.81 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Interaction 157
5.82 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Interaction 157
5.83 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 158
5.84 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 159
5.85 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Activity Ratio Interaction 160
5.86 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Activity Ratio Interaction 160

5.87 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Coefficient of Variation Interaction 161
5.88 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Coefficient of Variation Interaction 162
5.89 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Interaction 163
5.90 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Interaction 164
5.91 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 165
5.92 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 165
5.93 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 166
5.94 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 167
5.95 Multivariate Analysis of Variance Overall Equality Test--Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 168
5.96 Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 168

5.97 Multivariate Analysis of Variance Overall Equality Test--Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 169
5.98 Multivariate Analysis of Variance Univariate F-Tests Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction 170
6.1 Planning System Responses to Raw Material Variability 174
6.2 All Possible Exogenous Factor Settings . . . 176
6.3 Tukey HSD Test Critical Difference Values . . 178
6.4 Dependent Variable Means--First Exogenous Factor Setting 181
6.5 Dependent Variable Means--Second Exogenous Factor Setting 190
6.6 Dependent Variable Means--Third Exogenous Factor Setting 199
6.7 Dependent Variable Means--Fourth Exogenous Factor Setting 208
6.8 Dependent Variable Means--Fifth Exogenous Factor Setting 217
6.9 Dependent Variable Means--Sixth Exogenous Factor Setting 225
6.10 Dependent Variable Means--Seventh Exogenous Factor Setting 234
6.11 Dependent Variable Means--Eighth Exogenous Factor Setting 243
6.12 Dependent Variable Means--Ninth Exogenous Factor Setting 252
6.13 Dependent Variable Means--Tenth Exogenous Factor Setting 260
6.14 Dependent Variable Means--Eleventh Exogenous Factor Setting 269
6.15 Dependent Variable Means--Twelfth Exogenous Factor Setting 278
6.16 Dependent Variable Means--Thirteenth Exogenous Factor Setting 287
6.17 Dependent Variable Means--Fourteenth Exogenous Factor Setting 295
6.18 Dependent Variable Means--Fifteenth Exogenous Factor Setting 304
6.19 Dependent Variable Means--Sixteenth Exogenous Factor Setting 313
6.20 Raw Material Inventory Means 322
6.21 Raw Material Order Cost Means 323
6.22 Finished Goods Inventory Means 328
6.23 Average Backorder Units 329
6.24 Setup Time Means 331

6.25 Total Cost Means 333
6.26 Average Rank Using MSE 336
6.27 Overall and Average Rank of Planning Systems . . 338
6.28 Individual and Average Total Cost for all Exogenous Factor Settings 340
6.29 Average Number of Replans 344

LIST OF FIGURES

FIGURE		Page
1.1	Variability in Batch Processing	7
1.2	Manufacturing Control System Framework	10
3.1	Process Industries Framework	42
3.2	Production Planning and Control Framework	46
5.1	Null hypothesis testing in ANOVA and MANOVA	89
6.1	Raw Material Inventory--First Exogenous Factor Setting	182
6.2	Finished Goods Inventory--First Exogenous Factor Setting	183
6.3	Raw Material Ordering Cost--First Exogenous Factor Setting	184
6.4	Production Setup Time--First Exogenous Factor Setting	185
6.5	Backordered Units--First Exogenous Factor Setting	186
6.6	Total Cost--First Exogenous Factor Setting	187
6.7	Raw Material Inventory--Second Exogenous Factor Setting	191
6.8	Finished Goods Inventory--Second Exogenous Factor Setting	192
6.9	Raw Material Ordering Cost--Second Exogenous Factor Setting	193
6.10	Production Setup Time--Second Exogenous Factor Setting	194
6.11	Backordered Units--Second Exogenous Factor Setting	195
6.12	Total Cost--Second Exogenous Factor Setting	196
6.13	Raw Material Inventory--Third Exogenous Factor Setting	200
6.14	Finished Goods Inventory--Third Exogenous Factor Setting	201
6.15	Raw Material Ordering Cost--Third Exogenous Factor Setting	202
6.16	Production Setup Time--Third Exogenous Factor Setting	203
6.17	Backordered Units--Third Exogenous Factor Setting	204
6.18	Total Cost--Third Exogenous Factor Setting	205

6.19 Raw Material Inventory--Fourth Exogenous Factor Setting 209
6.20 Finished Goods Inventory--Fourth Exogenous Factor Setting 210
6.21 Raw Material Ordering Cost--Fourth Exogenous Factor Setting 211
6.22 Production Setup Time--Fourth Exogenous Factor Setting 212
6.23 Backordered Units--Fourth Exogenous Factor Setting 213
6.24 Total Cost--Fourth Exogenous Factor Setting 214
6.25 Raw Material Inventory--Fifth Exogenous Factor Setting 218
6.26 Finished Goods Inventory--Fifth Exogenous Factor Setting 219
6.27 Raw Material Ordering Cost--Fifth Exogenous Factor Setting 220
6.28 Production Setup Time--Fifth Exogenous Factor Setting 221
6.29 Backordered Units--Fifth Exogenous Factor Setting 222
6.30 Total Cost--Fifth Exogenous Factor Setting 223
6.31 Raw Material Inventory--Sixth Exogenous Factor Setting 226
6.32 Finished Goods Inventory--Sixth Exogenous Factor Setting 227
6.33 Raw Material Ordering Cost--Sixth Exogenous Factor Setting 228
6.34 Production Setup Time--Sixth Exogenous Factor Setting 229
6.35 Backordered Units--Sixth Exogenous Factor Setting 230
6.36 Total Cost--Sixth Exogenous Factor Setting 231
6.37 Raw Material Inventory--Seventh Exogenous Factor Setting 235
6.38 Finished Goods Inventory--Seventh Exogenous Factor Setting 236
6.39 Raw Material Ordering Cost--Seventh Exogenous Factor Setting 237
6.40 Production Setup Time--Seventh Exogenous Factor Setting 238
6.41 Backordered Units--Seventh Exogenous Factor Setting 239
6.42 Total Cost--Seventh Exogenous Factor Setting 240
6.43 Raw Material Inventory--Eighth Exogenous Factor Setting 244
6.44 Finished Goods Inventory--Eighth Exogenous Factor Setting 245

6.45 Raw Material Ordering Cost--Eighth Exogenous Factor Setting 246
6.40 Production Setup Time--Eighth Exogenous Factor Setting 247
6.47 Backordered Units--Eighth Exogenous Factor Setting 248
6.48 Total Cost--Eighth Exogenous Factor Setting 249
6.49 Raw Material Inventory--Ninth Exogenous Factor Setting 253
6.50 Finished Goods Inventory--Ninth Exogenous Factor Setting 254
6.51 Raw Material Ordering Cost--Ninth Exogenous Factor Setting 255
6.52 Production Setup Time--Ninth Exogenous Factor Setting 256
6.53 Backordered Units--Ninth Exogenous Factor Setting 257
6.54 Total Cost--Ninth Exogenous Factor Setting 258
6.55 Raw Material Inventory--Tenth Exogenous Factor Setting 261
6.56 Finished Goods Inventory--Tenth Exogenous Factor Setting 262
6.57 Raw Material Ordering Cost--Tenth Exogenous Factor Setting 263
6.58 Production Setup Time--Tenth Exogenous Factor Setting 264
6.59 Backordered Units--Tenth Exogenous Factor Setting 265
6.60 Total Cost--Tenth Exogenous Factor Setting 266
6.61 Raw Material Inventory--Eleventh Exogenous Factor Setting 270
6.62 Finished Goods Inventory--Eleventh Exogenous Factor Setting 271
6.63 Raw Material Ordering Cost--Eleventh Exogenous Factor Setting 272
6.64 Production Setup Time--Eleventh Exogenous Factor Setting 273
6.65 Backordered Units--Eleventh Exogenous Factor Setting 274
6.66 Total Cost--Eleventh Exogenous Factor Setting 275
6.67 Raw Material Inventory--Twelfth Exogenous Factor Setting 279
6.68 Finished Goods Inventory--Twelfth Exogenous Factor Setting 280
6.69 Raw Material Ordering Cost--Twelfth Exogenous Factor Setting 281
6.70 Production Setup Time--Twelfth Exogenous Factor Setting 282

6.71 Backordered Units--Twelfth Exogenous Factor Setting 283
6.72 Total Cost--Twelfth Exogenous Factor Setting 284
6.73 Raw Material Inventory--Thirteenth Exogenous Factor Setting 288
6.74 Finished Goods Inventory--Thirteenth Exogenous Factor Setting 289
6.75 Raw Material Ordering Cost--Thirteenth Exogenous Factor Setting 290
6.76 Production Setup Time--Thirteenth Exogenous Factor Setting 291
6.77 Backordered Units--Thirteenth Exogenous Factor Setting 292
6.78 Total Cost--Thirteenth Exogenous Factor Setting 293
6.79 Raw Material Inventory--Fourteenth Exogenous Factor Setting 296
6.80 Finished Goods Inventory--Fourteenth Exogenous Factor Setting 297
6.81 Raw Material Ordering Cost--Fourteenth Exogenous Factor Setting 298
6.82 Production Setup Time--Fourteenth Exogenous Factor Setting 299
6.83 Backordered Units--Fourteenth Exogenous Factor Setting 300
6.84 Total Cost--Fourteenth Exogenous Factor Setting 301
6.85 Raw Material Inventory--Fifteenth Exogenous Factor Setting 305
6.86 Finished Goods Inventory--Fifteenth Exogenous Factor Setting 306
6.87 Raw Material Ordering Cost--Fifteenth Exogenous Factor Setting 307
6.88 Production Setup Time--Fifteenth Exogenous Factor Setting 308
6.89 Backordered Units--Fifteenth Exogenous Factor Setting 309
6.90 Total Cost--Fifteenth Exogenous Factor Setting 310
6.91 Raw Material Inventory--Sixteenth Exogenous Factor Setting 314
6.92 Finished Goods Inventory--Sixteenth Exogenous Factor Setting 315
6.93 Raw Material Ordering Cost--Sixteenth Exogenous Factor Setting 316
6.94 Production Setup Time--Sixteenth Exogenous Factor Setting 317
6.95 Backordered Units--Sixteenth Exogenous Factor Setting 318
6.96 Total Cost--Sixteenth Exogenous Factor Setting 319
6.97 Average Total Cost 341

CHAPTER ONE

VARIABILITY IN PROCESS INDUSTRIES

1.1 Introduction

The purpose of this research is to investigate the methods by which inventory and planning systems in batch process industries deal with significant variation in the processing of raw materials into finished products.

This chapter introduces the environment, identifies the problems caused by variations in raw materials, discusses management responses to variability, presents the objectives of this research and provides an overview of the remaining chapters of this dissertation.

1.2 Manufacturing environment

Although variation affects all types of manufacturing firms, this research is interested in one type of manufacturing process, the batch process industry. An example of a batch process industry manufacturer is a processor of food flavorings. Materials move through the production facility in batches and each product has a fixed routing it follows each time it is produced. Another member of the batch process industry is a pharmaceutical

manufacturer. Its products follow the same routing and are assigned lot numbers for testing and documentation.

Process manufacturing is defined as "production which adds value by mixing, separating, forming and/or chemical reactions. It may be done in either batch or continuous mode." (Wallace, 1984, p. 23) A batch process manufacturer is further defined as a process industry manufacturer "where products are produced in discrete measurable lots or batches." (Hyman, 1981, p. 215) Batch process manufacturers follow the classical definition of a flow shop, in which, during manufacturing, production facilities and personnel "tend to perform the same operations for each production run. The shop layout ... is designed to facilitate a product 'flow' ... each product, though variable in material specifications, uses the same flow pattern through the shop." (Wallace, 1984, p. 12)

1.3 Variability

The production process is subject to variation in all aspects of its operation, including planning, design, and execution. Variation in the production process can cause many types of problems, all of which can result in a waste of time, energy, or material. (Hall, 1983) This variation is a function of the manufacturing environment, not of inadequacies in the components of that process.

There are many sources of variation in the batch processing manufacturing environment, including variation in

raw material inputs, processing procedures, processing time, product quality, and process yield. This study focuses on one of the stochastic elements in batch production, raw material variability.

Variation in raw material inputs can appear in different forms. It can manifest itself as either differences in quantity or timing of deliveries, or may occur as variation in the quality characteristics of the raw materials. Quality characteristics can be either variables or attributes. (Juran, Gryna, and Bingham, 1976).

If quality characteristics are classified as attributes, quality specifications are written in such a way that simple classification of a product as either acceptable or defective can be made. An example of this type of quality would be found in the manufacture of ceramic insulators for sparkplugs. Acceptable insulators have product characteristics meeting the quality standards for ceramic insulators. An acceptable insulator has no cracks in the porcelain. During the inspection process, it is determined if the insulators are cracked. Defective insulators, which are cracked, are rejected because they do not meet the quality specifications for that item. The quality characteristics do not vary. A standard is established and the insulators are either acceptable or do not meet that standard of quality. Once the insulator is accepted, it becomes part of the inventory of these raw

materials, and those items in stock are homogeneous. Subsequently, all insulators are acceptable and meet established quality standards. The planning and execution system assumes all acceptable insulators in stock are identical.

Variables of quality characteristics are viewed differently. Specifications are stated in terms of continuous measurements of individual characteristics of raw materials. An acceptable product is one whose quality measurement falls within an established range of values for that characteristic. An example of this type of quality would be found in fruits. When a processor purchases grapes, the sugar content of the grapes meets the minimum established for that type of grape. However, grapes from different vineyards will have different levels of sugar content. As a result, grapes in inventory are not homogeneous, in terms of sugar content.

When examining raw material variability, a variety of methods exist to specify the type of raw material required. If the raw material description is adequately precise, raw materials can be classified as defective or acceptable when they are received for processing (Juran and Gryna, 1980). Raw materials can be sorted prior to manufacturing to assure only acceptable items are put into the production process. This type of variation can be resolved through normal purchasing and quality procedures, and is of little concern to the planning system once it has been resolved. The

planning system assumes that its inventory is homogeneous and all items in inventory are acceptable.

A different problem exists when measured quality characteristics are variable, and different batches of acceptable products do not exhibit identical quality characteristics. This can occur when raw materials are ordered to meet market grade specifications. "Grading is generally limited to natural products such as lumber, . . . food products, etc. The value of grades as a description of quality depends on the accuracy with which the grades can be established and the ease with which they can be recognized upon inspection . . . there can be a significant difference between the upper and lower grade limits of many commodities." (Dobler, Lee, and Burt, 1984, p. 47 - 48) This affects the planning system because allowances for varying raw material characteristics must be made by the planning and execution system during the production process.

This type of variability is present in process industries and has been labeled as a dynamic bill of material and was discussed by Taylor, Seward and Bolander (1981). They stated:

> Variations in raw material quality often lead to variations in bills of material. For example, variations in the moisture content, acidity, color, viscosity or concentration of active ingredients in raw material may cause variation in the ingredient proportions required to make finished product quality specifications.

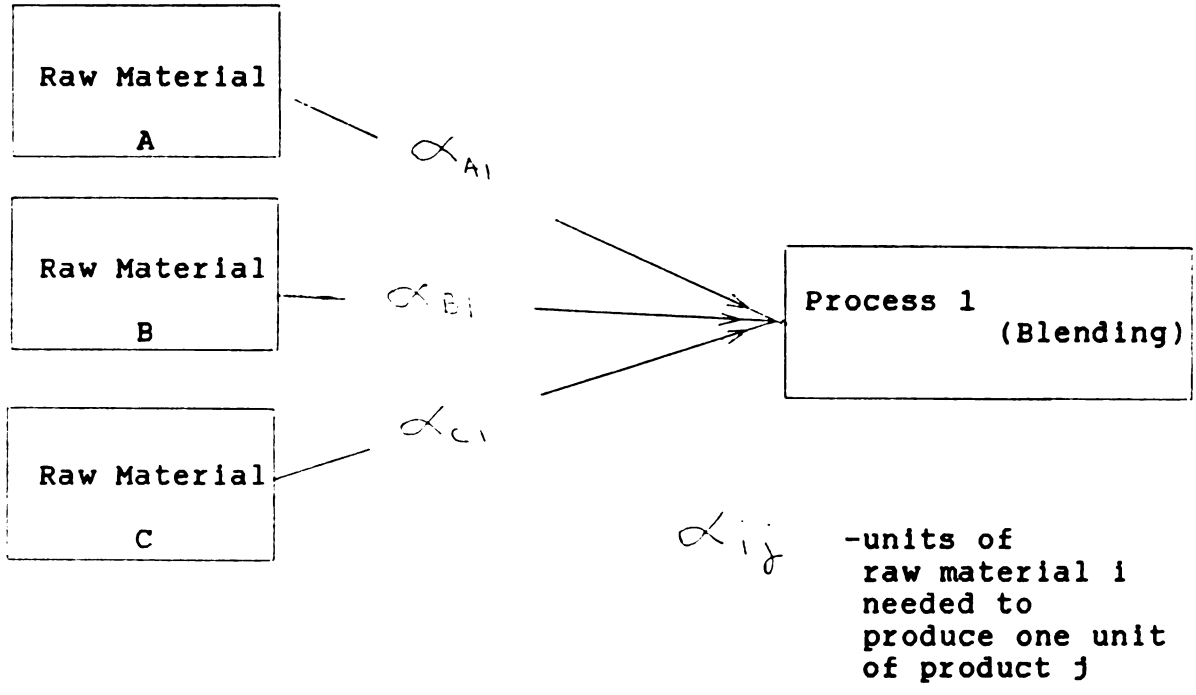
> Another factor which causes variations in bills of materials is the price of alternate ingredients. For example, a pet food may have specifications for the minimum amount of proteins, carbohydrates, and fats per pound of pet food; however the proportions of various ingredients may be varied depending on their current price and availability. (Taylor, Seward and Bolander, 1981, pp. 13 - 14)

This problem affects the planning system of the manufacturing process. Due to this variability in the bill of material, the demand for raw materials is no longer strictly deterministic, as is usually assumed in material requirements planning systems. The demand for raw materials becomes stochastic and depends on the quality characteristics of those raw materials. As a result, ranges for raw material requirements must be planned. Specific quantities to be used cannot be accurately determined from the master production schedule due to the variability in raw material characteristics.

An example of this type of variability was provided by Bolander, Heard, Seward, and Taylor (1981). One of the case studies in their book discussed McCormick and Company, a processor and distributor of food flavorings. A major problem affecting the production process

> comes from the variability or inconsistency of the raw materials. This variability results from seed variety, agricultural practices and Mother Nature. Variable raw materials in particular and to a lesser degree control of the consistency of the manufacturing process result in low predictability of finished product coming out of the process. (Bolander, Heard, Seward and Taylor, 1981, p. 82)

The effect of this type of variability in the bill of material is shown in Figure 1.1. Raw materials are blended to form a batch of product which is then available for subsequent processing. The actual quantity of raw material required to form a batch of product varies due to order size and raw material characteristics.



Variability in Batch Processing

FIGURE 1.1

A typical material requirements planning system would be able to adjust raw material requirements for varying lot sizes, but this type of planning system cannot make adjustments for varying raw material requirements because of raw material characteristics.

Variability in the bill of material occurs during the initial stage of processing when the raw materials are

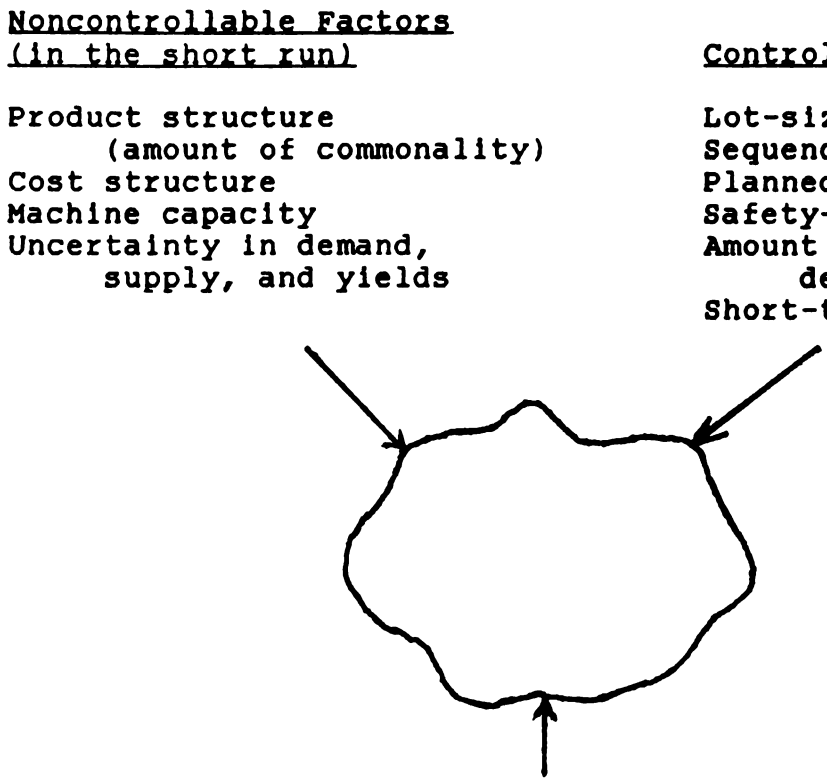
combined to form a batch of product that is ready for further processing. The quantities of raw materials required for each batch of product is variable and is determined based on the quality characteristics. The properties of the raw materials which affect quantity requirements can be determined through analysis or by running a test batch of the product. In this situation, one of two states will occur. There will be enough raw materials on hand to make a batch of product, or there will not be adequate quantities of one or more of the raw materials on hand to produce the entire batch of product. If there are adequate quantities of raw materials, no problem exists and the batch is produced. If there is a shortage of one or more raw materials, it is necessary to identify the raw material limiting the process. The production order quantity would be reduced until all of the limiting raw material would be exhausted and as much product would be blended as raw material inventory and characteristics would allow.

When the quantity of raw material required for a product is variable, this creates a problem for the planning system. The variability in raw material characteristics causes the production system to alter the number of raw material units per product from the standard bill of material during the blending process. If distributions of raw material usage are continuous, the number of possible

bills of material is infinite. Even if the distributions are discrete, the number of bills of material is usually large enough that they are unmanageable. Whether the number of bills is infinite, or just unwieldy, the planning system still faces the dilemma of which bill of material to use.

1.4 The Management of Variability

Although different manufacturing processes require planning and control systems with different attributes, the environment has a greater effect on the overall system. The performance of the planning and control system is a function of a set of controllable and noncontrollable factors in its environment. Some of these factors were identified during a panel discussion by active researchers in the field of Production/Operations Management. (Miller and Graham, 1981) A simplified diagram of some of the elements that affect system performance are shown in Figure 1.2. Included in this diagram are controllable and noncontrollable factors, and system parameters.



Source: Miller, Jeffrey G., and Margaret B. W. Graham, "Production/Operations Management: Agenda for the '80s", Decision Sciences, Vol. 12, No. 4, October, 1981, p. 557

MANUFACTURING CONTROL SYSTEM FRAMEWORK

FIGURE 1.2

One of the major research problems this panel identified was the necessity to recognize uncertainties in the production planning process and the need to develop operations control systems to overcome or minimize the problems these uncertainties created. (Miller and Graham, 1981)

An uncontrollable factor that Miller and Graham (1981) identified, uncertainty in supply, is the focus of this research. Some production planning and control systems deal with significant variation in the processing of raw materials into finished products. Mazzola, McCoy and Wagner (1985) identified yield variability in the silicon chip industry. These manufacturers can experience yields as low as 3 to 4% and as high as 100% with no identifiable change in the production process or raw materials.

There are many sources of variation in this type of manufacturing environment, such as, variation in raw material inputs, processing procedures, product quality or variation in process yield. This research is concerned with variation in the quality characteristics of raw materials.

1.5 Management Responses to Variability

One of the key propositions formulated by Thompson in his discussion of organizational structure was, "under norms of rationality, organizations seek to seal off their core technologies from environmental influences" (Thompson, 1967, p. 19). This implies that organizations will attempt to reduce the effect of uncertainty on the manufacturing system in order to improve the performance of that system.

Scott (1981) identified a variety of strategies an organization may pursue to reduce the effect of an unknown and uncertain environment. Two of the general strategies, bridging and selection, are geared toward a larger issue of

organizational structure. The third class of strategies, buffering, applies to the problem being investigated in this research. Buffering strategies are techniques specifically aimed at reducing uncertainty for the technical core. These strategies include:

1. Coding -- classification of inputs prior to their entry into the system.
2. Stockpiling -- holding large quantities of inputs in order to limit their effect on system performance
3. Leveling -- identifying patterns in input environments.
4. Forecasting -- anticipating changes in supply and adapting to them.

By applying a buffering strategy to raw material variability, the effect of that uncontrollable factor can be reduced.

1.6 Research Objectives

The need to reduce the effect of variability has already been shown in this chapter. When variation is caused by the production process, reduction of that variance can be accomplished by eliminating its sources. When variation is part of the environment of an industry, it is more difficult to reduce the actual variation. Instead, it is necessary to reduce the effects of that variation. (Hall, 1983)

The objective of this research is to identify and evaluate a set of planning system responses to variability in raw material quality characterisitics. Specifically, the research question being posed by this research is as follows:

> For a given set of responses to raw material variability available to the planning and control system of a process industry manufacturer, what are the performance characteristics of each response and which responses result in the best performance?

As one can tell from the research question, the focus of this research is not descriptive, but normative or prescriptive. For a set of planning system responses to raw material variability, this research will identify the performance characteristics of each of the responses to raw material variability and recommend one or more of the responses with the best performance.

1.7 Organization

This chapter presents a general overview of the research. Chapter 2 reviews past research on the process industries, the stochastic nature of manufacturing, variability in raw material requirements, and, a related issued, variable yield lot sizing.

The third chapter begins with a description of the planning and control framework used in this research, identifies normal operation, and identifies corrective action procedures of the system.

Chapter 4 describes the experimental design employed in this investigation. A justification of the methodology used, a list of exogenous and endogenous research factors and performance measures are provided. This chapter also includes a discussion of the performance measures and data collected during the course of the research.

The fifth chapter contains a description of the statistical analysis performed and provides the results of those analyses.

Chapter 6 analyzes the results presented in the previous chapter in order to identify the performance characteristics of each planning system response to raw material variability and identifies that response with the best performance.

Finally, a summary of the conclusions of the research are provided in addition to suggestions for future research are located in Chapter 6.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

There has been very little research investigating variability in process industry environments. For the most part, literature dealing with process industries describes how the planning and control function is performed at one plant or location. It is important, however, to read, discuss, and be cognizant of past research in this area identifying the unique nature of process industries.

The framework being used for the discussion of the literature review is as follows:

1. Process Industries Overview -- literature discussing process industries, the unique problems they face, and their general characteristics.
2. Uncertainty in Manufacturing -- literature dealing with manufacturing variability.
3. Decision Making under Uncertainty -- literature deliberating stochastic decision making and Markov decision models.

4. Dynamic Bill of Material -- literature dealing specifically with the problem of variability in the bill of material or raw materials.

5. Variable yield lot sizing -- literature looking into adjusting lot size or order quantity to handle variable process yield.

This review of past research shows the unique nature of process industries. It identifies the problems caused by variability in raw materials and how the problem of variability has been resolved in the past. The literature also provides a basis for the planning system responses used in this research.

2.2 Process Industries Overview

Process industries constitute approximately fifty percent of all manufacturing firms. (Novitsky, 1983) However, past research indicates the environment in which they operate creates problems and poses requirements on the planning system different from other types of manufacturers. The discussion of the literature to follows highlights those requirements and problems focusing on differences between process industries and the rest of the manufacturing world.

An integrative framework for production and planning systems was developed during a seminar of process industry representatives sponsored by the American Production and Inventory Control Society (Bolander, Heard, Seward and

Taylor, 1981). This model does not vary significantly from previous frameworks for manufacturing, but it does use other models as a basis for creating a framework for process industries accepted by practitioners and subsequent researchers. The actual framework developed by Bolander, et al., will be presented in Chapter 3 during the discussion of the model used in this research. By patterning the model for this investigation after an accepted framework, this research is consistent with previous process industry research.

Subsequent to the conference, Taylor, Seward and Bolander (1981) expanded on their research. They compared system requirements of process industries with fabrication and assembly industry groups to show why process industry groups require different planning and control systems. One point of interest was specification of the process industry manufacturing environment. It is characterized as follows:

* Variability in raw material quality
* Variability in bill of material
* Product yields may vary widely
* May have large demands for intermediate products
* Co-product demands must be balanced
* Products or raw materials may have a limited shelf life

Due to these environmental differences, the requirements for process industry planning and control systems are not the same as fabrication and assembly industries.

Bolander and Taylor (1982) investigated the manufacturing environment of process industries to identify unique characteristics impacting planning and control system design. Because the raw materials used in process industries tend to be natural resources, the quality of those raw materials vary resulting in bill of material variability and stochastic process yield. Other researchers reiterated these environmental characteristics in a variety of process industry settings. (Kiekhaefer and Williams (1982) and Novitsky (1984).)

Recent empirical research by Finch (1986) identified methods used by process industry firms to accomplish planning and control functions. He classified these planning and control functions into five basic categories. He also identified eleven important factors that impact the choice of appropriate planning and control techniques. These five planning and control functions and the factors that affect their design are presented in Table 2.1.

The primary similarity between Finch's model and this research is the significant effect yield variability has on the components of the material planning and control system.

Finch's research is valuable to this investigation because it identifies the need to design planning and control systems based on environmental factors.

Planning and Control Function	Affected by:
Master Production Scheduling	Demand Stability Demand Information Source Plant Autonomy
Priority Planning	Per cent of Work-in Process to Total Inventory Levels in Bill of Material Manufacturing Lead Time Fixed Routings Commonality of Raw Material
Capacity Planning	Number of Work Centers Capacity Flexibility Demand Stability Yield Variability
Priority Control	Per cent of Work-in Process to Total Inventory Levels in Bill of Material Manufacturing Lead Time Demand Stability
Capacity Control	Fixed Routings Number of Work Centers Yield Variability

PLANNING/CONTROL FUNCTIONS AND
FACTORS AFFECTING SYSTEM DESIGN

TABLE 2.1

Haglund (1981) discussed the different requirements placed on a particular subset of process industries, primary metal processors. This research recognized the differences between process industries and other manufacturing firms identified by Taylor, Seward, and Bolander (1981) earlier in this chapter, and also discussed the impact of environmental characteristics on planning and control systems. Haglund stressed the importance of the design of a process industry

manufacturer's planning and control system. It needs to be configured meet the needs of the firm's environment in order for the firm to compete effectively.

Process industries, specifically primary metal fabricators, operate in a capacity based, forward scheduling environment. In Haglund's opinion, this characteristic places more responsibility on the planning function in an organization's planning and control system. How the production plan is determined and implemented will decide the level of work-in-process inventory and subsequent profitability. In other manufacturing environments which rely on a material based backward scheduling system, such as a job shop, the execution and control phase of the planning and control system has a greater effect on system performance.

Haglund further stated the process industries are truly different and material requirements planning and master scheduling are not useful or needed because these techniques were designed for non-process industry manufacturers. He identified the major difference, process industries must control the actual manufacturing process rather than focusing on production and inventory.

This research points out the importance of planning and its relationship to the success of a firm in a process industry. It also identified some of the unique characteristics of a process industry environment.

Williams, Minnimch, Rohlfing and Chmelewski (1983) also investigated the needs of metals processors by exploring the application of Manufacturing Resource Planning to this type of process industry. They took a position opposite Haglund. In their opinion, standard manufacturing planning and control systems could work in process industries with only minor modification. They felt the major difference separating process industries from other manufacturing was the process industry's focus on capacity control rather than material planning. This point of view necessitates modifications to the planning and control system to respond to their environment and compete effectively. Process industries have a high incremental cost of added capacity and their capacity is relatively inflexible. More importantly, product demand is primarily independent rather than dependent, that is, customers order both a firm's finished products and its work-in-process, or intermediate, products. As a result, more emphasis is placed on the master production scheduling module of the planning system. In order to operate effectively, the production and inventory planning system must respond# to different inherent characteristics in process industries. Their major concerns are to

- plan and manage capacity
- plan and manage yield by operation
- treat scrap from trimming as a part of the process and as a required raw material

The authors felt, with modification, standard planning systems would work for process industries enabling them to compete more effectively by taking advantage of recent developments in the field of production and inventory planning.

Nelson (1983) discussed the problems faced by process industries and contrasted them with problems faced by firms in different manufacturing environments. In process industries, end products are more closely related to raw materials rather than production processes. Scheduling jobs to specific machines is important due to the heterogeneous performance characteristics of different machines performing the same production process. Batch quality can assume go/no-go characteristics resulting in either the acceptance or rejection of a complete production lot. Manufacturers in job shops and repetitive manufacturing environments rarely, if ever, encounter this type of problem with batch quality or yield. Nelson elaborated further, stating that material requirements planning can, and has been, used successfully in process industries to solve some of its unique problems.

Kochalka (1978) also explored the application of material requirements planning to process industries. His research minimized the problems caused by using material requirements planning in process industries while enthusiastically identifying the benefits of using this material management system in a process industry environment.

He identified some specific requirements for process industry planning and control systems. These included the need to have process sheets for all final and intermediate products regardless of size or unit of measurement. Another requirement specifically relevant to this research is the environmental characteristic of significant differences between planned and actual yield. Kochalka's recommendation is to use average yield for planning purposes and to supplement production with safety stock if yield is less than planned.

Kochalka's investigation is quite important to this research. It demonstrates the importance of responding to variable process yield and provides a method for dealing with that uncertainty.

Taylor, Seward, Bolander and Heard (1981) presented a framework for process industry production and inventory planning. Although most of this work was a repetition of their conference proceedings, Bolander, Heard, Seward and Taylor (1981), they specifically addressed the problem of material planning which is the topic of this research.

The objective of the material planning segment of the production and inventory planning system is to determine timing and quantity of raw material purchases and production orders. It uses stock status and bill of material information to determine these raw material requirements. Some of the design considerations that Taylor, et al, identified are shown in Table 2.2.

What items should be included in the material plan?

What time horizon should the material plan cover?

What time intervals should be used?

How frequently should the plan be updated?

Should a net change or regenerative approach be used?

Should forward or backward scheduling be used?

What techniques should be used for lot sizing and sequencing products on machines?

How should safety stocks be determined?

Where in the processing sequence are inventories required to buffer sequential operations?

Should material planning be computerized?

Who should be responsible for material planning activities?

MATERIAL PLANNING MODULE DESIGN CONSIDERATIONS

TABLE 2.2

This framework provides a guide in the development of a material planning module for a process industry production and inventory planning system. By answering the questions posed, the resulting system should perform its intended functions effectively and efficiently.

Research identifying some of the differences between process industries and job shop industries was presented by Taylor, Seward, and Bolander (1981). This article provided some general characteristics for process industries, specifically, their manufacturing environment, marketing and

manufacturing strategies, planning system characteristics, planning processes and scheduling system characterisitics. It also reinforced the need for planning systems to respond to variability in bills of material.

The authors pointed out the process industry products are largely commodity items rather than custom products. Therefore, marketing emphasis is on product availability and price rather than product features. In order to compete effectively, the planning and control system must respond to raw material variability so price is competitive and the product is available.

Taylor, et al, reiterated the fact the internal manufacturing environment of a process industry is of a flowshop. A flowshop is defined as

> A shop in which machines and operators handle a standard, usually uninterrupted material flow. The operators tend to perform the same operations for each production run . . . The process industries (chemicals, oil, paint, etc.) are extreme examples of flowshops. Each product, though variable in material specifications, uses the same flow pattern through the shop. (Wallace, 1984, p. 12)

Apart from having different approaches to capacity when compared with other manufacturing firms, a flowshop also differs in its approach to work-in-process inventory. Whereas a job shop requires work-in-process inventory to buffer variation in work center loads caused by variation in product mix, the flowshop requires a balanced process with low work-in-process levels.

Another area that Taylor, et al., identified as a source of difference between process industries and other manufacturers was their external environment. Process industries usually rely on raw materials from the mining or agricultural sectors and are subject to natural variation in quality. This leads to variability in a product's bill of material as more or less of a raw material is added to meet product specification or alternate raw materials are used to supplement standard raw materials.

The final area that the authors identified as important to process industry manufacturers is a source of variability, product yield. Taylor, et al, felt the source of the problem was variability in the environment, not the production process or management, and the effects of that variability needed to be minimized.

This piece of research was valuable because it identified two important characteristics to which process industry management must respond; a varying bill of material and process yield variability. It also pointed out some of the environmental properties which make the process industries truly different from other types of manufacturers.

Some of the distinctive characteristics of process industries, as experienced by meat packers, were listed by Duvall and Hoffman (1983). It was their contention that there are four main areas where process industries differ from job shop and assembly manufacturers.

The first element is in raw material orientation rather than end product orientation. Most process industries are based on the conversion of a single group of raw materials into a multitude of end products. As a result, management is more concerned with material processing than are managers in other environments.

A second difference is the measurement of production activity. The basis for performance measurement is time rather than batch oriented.

The relationship between production yield and labor productivity is a third area of distinction. The nature of process industries is such that process yield affects productivity. Raw material variation or equipment breakdown will reduce labor productivity even though labor's actions may not change. Although yield is more closely related to raw material variability, it is not separable from labor productivity.

A fourth characteristic is the scheduling of production without work orders. Production is measured on a time or total output basis rather than specific units of raw materials.

This article is of value because it points out some of the environmental differences between process industries and other manufacturers while identifying sources of variation planning and control systems.

Swann (1984) discussed criteria for the implementation of a management information system in a process industry. He was concerned with the installation of existing job shop oriented software into a process industry environment, specifically, a paper processor. The major difference between process industries and job shops were job shops benefited from a material requirements planning orientation, but process industries did not need materials requirements planning. Frequently, process industries have 90 percent of raw material cost concentrated in two or three items and processing time can be measured in hours rather than days or weeks. Production work orders are a complication that is unnecessary in a process environment. Authorization to produce goods can be handled through a dispatch list. Finally, a process industry focuses on efficiency of production rather than a precise quantity. As a result, the quantity produced usually will not equal the planned production quantity.

The implementation of a management information system implies the system should employ process oriented software. Reports and analyses should be by product or department, not work order. The system should be on-line due to the short decision making time frame in process industries. The final consideration is the system's stand-alone capability to improve performance and utilization.

Swann has identified demands placed by the information system of a process industry. By designing responses to raw

material variability to respond to these demands, system performance should be improved.

Further investigations of the research showed that many authors, including, Bialous (1983), Galligan and Hazarika (1982), Hoffman (1981), Hyman (1981), Novitsky (1984) and Thompson (1983) verified these characteristics and differences in process industries, but reported on them in the context of a specific firm or type of manufacturer in the process industry environment. They agreed with the research previously discussed, on the need to respond environmental variability occurring in changing bills of material and process yield. In general, the planning system in process industries have different characteristics and must be designed with their environment in mind.

2.3 Uncertainty in Manufacturing

Very little research investigating uncertainty in manufacturing from an overall perspective exists. Most research is narrow in its scope and focuses on a specific type of uncertainty and a method of either eliminating or minimizing the effects of that uncertainty.

Whybark and Williams (1976) investigated the variability affecting all manufacturing industries. The research focused on the response of a material requirements planning (MRP) system to variability. This research compared the ability of safety stock or safety lead time to

deal with variability in the production process. Four types of variability were identified:

1. Demand timing uncertainty
2. Supply timing uncertainty
3. Demand quantity uncertainty
4. Supply quantity uncertainty

Through simulation, they determined that variability in timing is best handled through the use of safety lead time, while variation in quantity is managed best through safety stock. Whybark and Williams showed that regardless of the type of uncertainty, be it length of lead time, uncertainty level or coefficient of variation, uncertainty in either quantity demanded or supplied is best managed through safety stock. Whybark and Williams's research is important because it identifies responses to variability in raw materials. It provides measures of that variability and performance characteristics for the evaluation of managerial responses to that variability.

A recent investigation into uncertainty in manufacturing systems was conducted by Schmitt (1984). The paper examined three methods used to respond to uncertainty in multi-stage manufacturing systems: (1) safety stock with regenerative material requirements planning; (2) safety capacity with regenerative material requirements planning; and (3) net change material requirements planning variability. Sources of uncertainty were errors in demand

forecast and errors in production time standard. This research is important in establishing the need to respond to environmental stability, but the results achieved were dependent on the source of uncertainty and costs related to regular time employment, employment changes, equipment set ups and materials investment.

As one can see, there are a variety of sources of uncertainty in the manufacturing environment. This uncertainty is uncontrollable, but must be addressed so the stability in the system can be achieved and performance improved.

2.4 Decision Making under Uncertainty

Dantzig (1955) provided one of the first discussions of the application of linear programming to situations where variability in either the cost coefficients, resources or input-output coefficients existed. In this article, he showed a series of decisions can be divided into two or more stages. First stage decisions are based on an existing environment. Subsequent decision stages can not be made initially because they either depend on decisions made in an earlier stage, or depend on random values in the model which become known prior to that stage. In further discussion in the article, Dantzig provided a method of solving a particular class of problems of linear programming under uncertainty. While the method of solution is not applicable

to this research, it establishes an approach to solving the problem in more than one stage.

In a later discussion of linear programming under uncertainty, Madansky (1961), listed some of the common methods of dealing with the effect of uncertainty in linear programming models. These included (1) replacing random elements with their expected values, (2) using pessimistic estimates of random elements, and (3) reformulating the problem into a multi-stage decision process allowing the decision maker to correct any inaccuracies, or deficiencies, in prior stages. Madansky's discussion is important to this research for two reasons; it reiterates Dantzig's discussion of multi-stage decision making, but more importantly, establishes the concept of average and pessimistic values replacing stochastic elements in the planning system.

An introduction to Markov decision models and stochastic dynamic programming was provided by Moder and Elmaghraby (1978). In a situation where sequential decisions must be made and future states of a system cannot be predicted, responding to uncertainty in the system is very important. By examining the state (n), or condition, of a system during certain stages (i), or time periods, a flexible model for sequential decision making under uncertainty can be created. The components of this model are:

$R_i^k(n)$ - the reward earned if state (n,i) is observed and if decision k is selected.

$P_{ij}^k(n)$ - the probability that transition occurs to state (n+1,j) given these conditions: state (n,i) is observed and decision k is selected.

The objective of this model is to optimize the expected value of the performance measure over the planning horizon. By choosing k such that the following quantity is optimized,

$$R_i^k(n) + \sum_{\text{all } j} P_{ij}^k(n)\, f(n+1,j) \qquad (2.1)$$

the decision k is then optimal for the state n and stage i where f(n+1,j) is defined as the optimum performance obtainable starting in state n+1 at stage j.

Because stochastic dynamic programming is one of the responses to variability in raw material properties that will be evaluated, this research is important because it outlines the method to be employed in creating a Markov decision model.

2.5 Dynamic Bill of Material

The first research that coined the phrase "dynamic bill of material" was done by Tiber (1981). His research investigated the production of chlorine from electricity and brine. It addressed the problem of adjusting electricity as

one of the process inputs based on the other inputs and the apparatus used to produce chlorine. Depending on the brine concentration, the condition of the production cell and the process temperature, electricity requirements will vary. The article provided a basis for the definition of a dynamic bill of material in which the quantity requirements of one raw material, or input, varies depending on the characteristics of the other raw materials used to make the product.

Tiber's discussion of a dynamic bill of material is pertinent to this research. It introduces the concept of a dynamic bill and provides some planning system responses to variability. He did not test the performance of any of the responses to this problem, but only commented on their feasibility and appropriateness.

Tiber's first choice was to create a bill of material for the product using standard, or average, requirements. This was equivalent to ordering raw material on a lot-for-lot basis at a 50% service level. In his opinion, this was the simplest and best response.

A second alternative involved the creation of multiple bills of material for every possible combination of raw materials used in creating the product. He only identified this as a possible solution, but did not create a full set of bills of material for chlorine. It would have created a

"cumbersome," unmanageable set of bills for this product with none being better than the other.

A third response was to drop the bill of material structure and deal with raw material requirements through the use of an equation representing the relationship between chlorine and electricity used. The third solution is unique to this type of industry (chlorine production) and Tiber recognized its feasibility, but did not recommend it.

Liberatore (1979) investigated the value of two techniques, material requirements planning and economic order quantity with safety stock, to order raw materials for FMC Corporation, a member of the chemical process industry. Although the economic order quantity model can be used as a lot sizing within material requirements planning, Liberatore discussed the use of this model as an independent inventory model, thus making the two techniques mutually exclusive. Occasionally, raw materials in this segment of the economy are available only in truck or rail car loads. Consequently the raw material ordering system needs to respond to that additional constraint. By using the economic order quantity with safety stock method instead of material requirements planning, inventory levels and stockouts were reduced.

Liberatore recommended application of ABC analysis to identify raw materials where usage merits their inclusion in the more detailed analysis and planning procedure. If all assumptions were met, the raw material levels and stockouts would be reduced using his method. This research is

valuable in identifying another legitimate planning response to raw material ordering.

The blending problem was investigated by Golovin (1979). The blending problem has been investigated by others, but Golovin dealt with the blending problem when a dynamic bill of material exists. He was concerned with gasoline production and the fact that raw material properties vary, thus creating a dynamic bill of material for the production of the product. The research discussed the use of a simulation model to minimize production costs while meeting physical and chemical requirements for products produced. The advantage of Golovin's research was it formalized the types of variability in the blending process and logic dealing with raw material variability in process industries.

A subset of this problem is the variable demand for raw materials and components faced in some industries dealing with the teardown and rebuild of complex components. This problem was mentioned by Meyer (1980). He discussed the problems faced in rebuilding and reworking alternators, yet this is applicable to rework shops in general. The purchase of raw materials (alternators requiring rebuilding) provides a group of either good or bad parts. When the alternator is rebuilt, the demand for parts can be expressed on a zero-one basis. This situation is similar to what aircraft

industries face during the maintenance and rebuild of airplane engines.

2.6 Variable yield lot sizing

This research views variability in raw material characteristics as a variation in quantity received. A discussion of the transition from varying raw material demand to variable yield will be presented in Chapter 3.

One of the first discussions of the variable yield lot sizing problem was done by Karlin (1958). His was an investigation into single and multiple period versions of a variable yield lot sizing problem. This article started a flurry of investigations into a problem lasting approximately ten years. The problem was viewed as how to determine allowances for rejection or shrinkage and was formulated using dynamic programming. Most research subsequent to Karlin's focused on varying cost functions and different probability distributions including work by Goode and Saltzman (1961), Hillier (1963), Levitan (1960), Llewellyn (1959) and Wadsworth and Chang (1964). Interest in the topic waned until recent concerns over high variability in process yield in the electronics circuits industry. Mazzola, McCoy and Wagner (1985) stated the variable yield lot sizing problem is important to certain

high technology manufacturers with low or varying yields. This problem forces the firm to maintain excess inventory and incur subsequent carrying cost in order to meet demand.

A recent paper by New and Mapes (1984) investigated process yield fallout when the process yield is a stochastic variable. Their research developed strategies for continuous and batch schedules in either make-to-stock or make-to-order environments that relied on the use of average yield to determine production requirements. They also suggested the planning system rely on the integration of statistical distributions of past yields to set up a lot size that would provide the quantity required at a 90% or 95% service level. It identified the expected yield of the process at the specific service level to determine quantities and buffer stocks to deal with yield fallout.

Very little work has been done on the issue of supply quantity uncertainty. Silver (1976) determined the best order quantity based on mean and standard deviation of the ratio# of quantity delivered to quantity ordered. This research provides a formula to determine the economic order quantity for independent demand products based on ordering, holding, and shortage costs. This work was limited to backordering of shortfalls. Kalro and Gohil (1982) expanded this work to handle a mixture of lost sales and backorders. Both pieces of research provide information to this investigation by identifying specific planning system responses to supply variability.

Mazzola, McCoy and Wagner (1985) recently summarized past research by identifying algorithms and heuristics for variable yield lot sizing. They identified the dynamic programming formulation to optimize performance and tested a set of four heuristics in comparison with the dynamic programming formulation. One heuristic was Wagner-Whitin based, another Silver-Meal based, and the final two involved reorder points and reorder quantities.

Recent research by Sepehri, Silver, and New (1986) tested a heuristic to deal with variable yield, multiple lot sizing. The heuristic was based on the incremental cost of increasing the lot size by one unit. The heuristic was found to out perform some of the rules of thumb currently in use.

The literature dealing with variable yield lot sizing is important to this research because a set of responses to the raw material variability will be developed from this literature and will be presented in Chapter 3.

2.7 Chapter Summary

The review of the literature has shown process industries place different requirements on their production and inventory planning system. In order to optimize the planning and control system's performance, the system must respond to the unique requirements, deal with raw material

variability and plan for variation in the production process.

CHAPTER THREE

THE PRODUCTION MODEL

3.1 Introduction

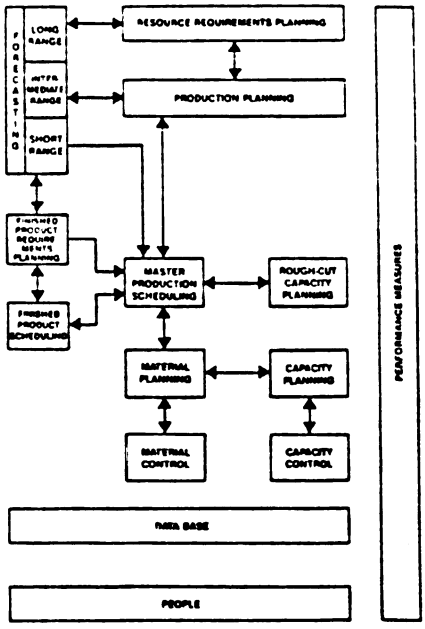
This chapter presents a discussion of the overall framework to be utilized in analyzing raw material variability. It also discusses specific characteristics of the model, and explains the logic of the planning and control system, raw material and product characteristics, cost structure, assumptions of the model and a discussion of the overall planning process and control system logic. The experimental factors under consideration in this study are also identified and discussed.

3.2 Production and Inventory Planning Framework

Rather than develop the model for this research so it mirrors a specific type of manufacturer in a process industry, the model was developed so it would possess the characteristics of a variety of process industries whether they produce food flavorings, aluminum, pharmaceuticals or any variety of products made by batch process manufacturers. The hypothetical batch process model is patterned after a model for the process industry accepted by practitioners and academicians.

A workshop was held in 1979 bringing together a group of industry representatives, consultants and academicians. A planning system framework for process industries was

developed using models proposed by other researchers including Brown (1977), Buffa and Miller (1979), Hax (1976), Holstein (1968), Magee and Boodman (1967), Mize, White, and Brooks (1971), Putnam, Barlow, and Stilian (1963) and Wight (1974). It is recognized that this framework is not significantly different from the models used in its development, however, this framework and its supporting documents reflect the demands placed on a planning system by process industries, demands that are different from other manufacturing and assembly operations. The model was developed by the conference participants and is shown in Figure 3.1.



PROCESS INDUSTRIES FRAMEWORK

Source: Bolander, Steven F., Richard C. Heard, Samuel M. Seward and Sam G. Taylor, Manufacturing Planning and Control in Process Industries, American Production and Inventory Control Society, 1981, p.2.

FIGURE 3.1

This research is interested in a relatively small portion of the planning system framework of a process industry and its scope is not as extensive as the work done by Bolander, et al. In order to properly reflect the depth of the proposed research, it was necessary to focus on the master production scheduling, material planning and material control components of the model shown in Figure 3.1. Since the other components of the model did not deal with the type of variability being studied, they have been eliminated without reducing the effectiveness of the model used to investigate raw material variability. During the discussion of their model, Bolander, et al., recognized the need to include only those components of the model that are required. They stated:

> A firm may not require all of the modules in the general framework or may execute several modules simultaneously. An addition, specific techniques used will vary widely among firms and within plants of the same firm. In many cases techniques must be tailored to fit the needs of a particular manufacturing facility. (Bolander, Heard, Seward and Taylor, 1981, p. 19)

In discussing the degree of uncertainty and level of detail be expected in the varying levels of the model, Bolander, et al, pointed out how the degree of uncertainty is high and level of detail is low during the production planning stage of the model. As one moves down the model through master production scheduling to material planning, the degree of uncertainty decreases and level of detail

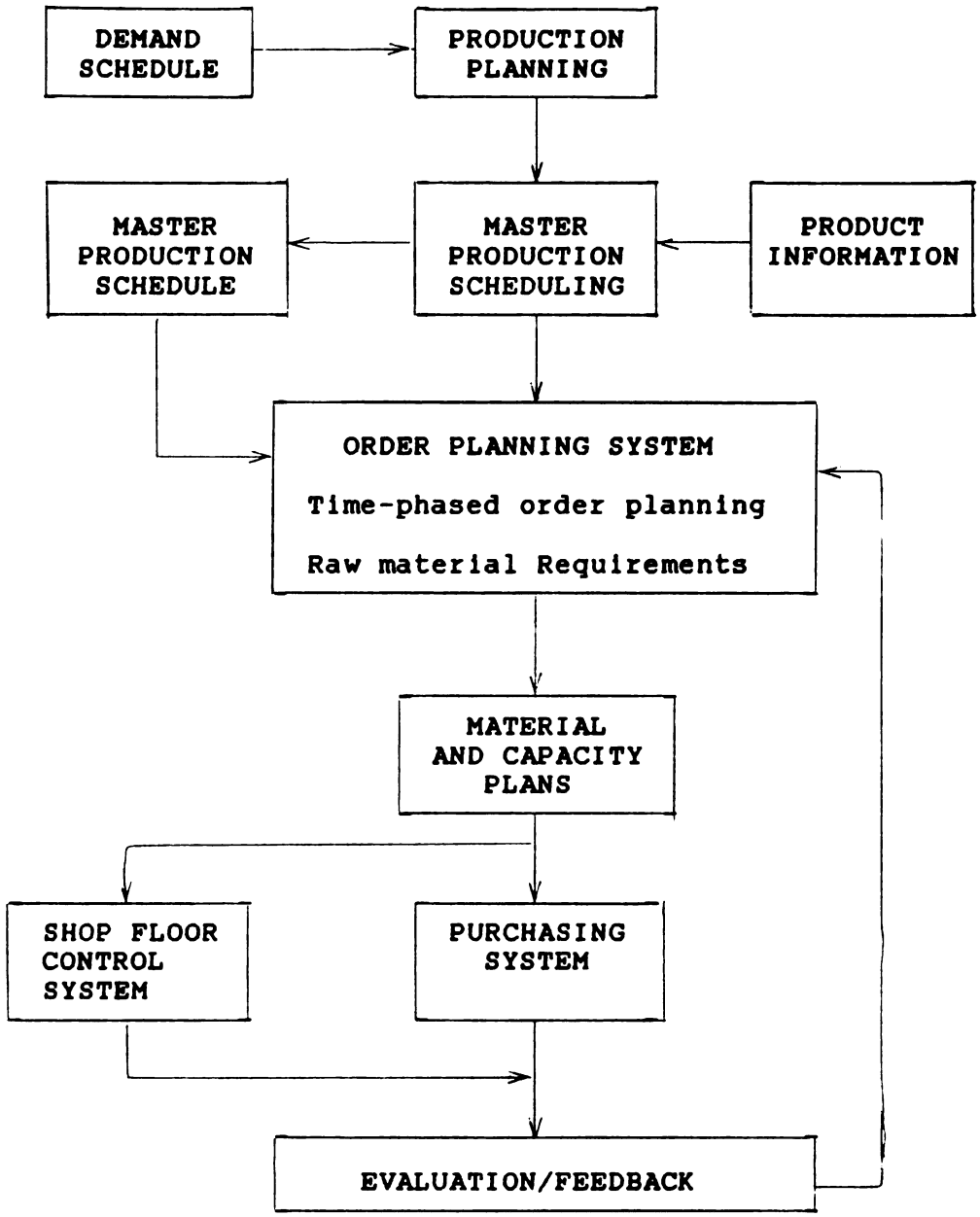
increases. Raw material variability would be an item of relatively high detail and managed when overall variability of the production plan was relatively low. Therefore, raw material variability would not be considered during the production planning and master production scheduling phases of the planning process. As a result, elimination of variability from these steps in the planning process from the proposed model should not cause problems with this model's effectiveness. The variability would be considered implicitly when raw material is ordered and if finished goods safety stock levels are assigned.

3.3 The General Model

At this point, the production and inventory planning model for this research can be created. This model is based on the work done by Bolander, et al, and a framework developed by Vollmann, Berry, and Whybark (1984). The framework is divided into three parts. The top third, or "front end", is the component providing direction for the production process. It creates a master production schedule based on product demand. The next section, the "engine," is the set of planning systems performing detailed production and material planning. The master production schedule is a direct input into this module and the planning system determines period-by-period production and raw material requirements for the production system. Lot sizing, time-phased order planning and raw material planning are

performed. The last third, or "back end," is responsible for the execution of the engine's plans. Orders are released and processed, raw materials are ordered and received, and evaluation and feedback of performance is made. Based on the information provided, the planning system evaluates these inputs and takes corrective action as required.

The resulting model for this research is shown in Figure 3.2.



Production Planning and Control Framework

FIGURE 3.2

Although the model used in this research, shown in Figure 3.2, is reduced in scope when compared with Bolander, Heard, Seward and Taylor's (1981) framework, shown in Figure 3.1, it allows for adequate investigation into the research question posed.

3.4 Planning and Control System Logic

The logic presented here is similar to other process manufacturing planning and control systems. A time phased demand schedule is provided to the production planning system. Using product information such as run times and inventory costs, production lot sizing is done with the use of the Wagner-Whitin algorithm and a master production schedule is generated. The master production schedule provides the planning system with a time phased production schedule stating quantity of product required and its due date. Through the use of a backward finite loading capacity management process, a release date for the order is calculated and the resulting master production schedule is provided as further input to the order planning system.

Raw material requirements are calculated using bill of material files and deliveries are scheduled.

Orders are placed into queue for processing according to their release date. If raw material on hand is adequate, the order is produced and all inventories are adjusted. If

raw material is inadequate, the order quantity is reduced until the limiting raw material is exhausted.

After production is completed on the order, feedback on the performance is provided to the planning system for corrective action if required.

If the production quantity is equal to the order quantity, no problem exists. It is only when the production quantity has been reduced due to lack of raw material, that the planning system must take action. The options open to the planning system depend on the service level of finished goods safety stock. If no safety stock is being held, a service level of 50%, two alternatives are open to the planning system; (1) it can adjust the master production schedule and create a new order to fill the unmet demand, or (2) it can allow the backorder to exist until the next time the product is made. The alternatives will be evaluated on a least-cost basis.

The backorder cost, the cost incurred by meeting the demand with the next scheduled production order, is equal to the cost of having the unmet demand on backorder until the next order is made. If a new order is introduced into the system, material must be ordered and the process setup for the product, so the cost of introducing a new order is the sum of the raw material ordering cost and production setup cost. If it is necessary to introduce a new order, the master production schedule must be adjusted. Based on the new demand for a production order in the next time period,

the production and raw material delivery schedules are replanned in the same manner as the schedules were initially established.

If the service level for finished goods safety stock is higher than 50%, a different logic is used. When finished goods inventory falls below the established level for the product, the planning system takes the same action it would if backorder cost exceeded setup and production cost. An order is initiated for the next time period to cover the shortage. Again, based on the new demand for a production order in the next time period, the production and raw material schedules are replanned in the same manner as the schedules were initially established.

A different situation exists if a shipment of raw material is less than expected. The shortage is evaluated in the same way as production shortages at the time of receipt. Since raw material is not pegged to a particular product or order, the planning system must evaluate reordering on the basis of the expected value of the shortage. The cost of ordering raw material is compared with the expected backorder cost. This expected cost is calculated using the magnitude of the raw material shortage, the time until the next scheduled order for the raw material and the average backorder penalty for all products manufactured using the raw material. The average backorder penalty is calculated using the following equation.

$$RBO_i = \left(\sum_j PBO_j * A_{ij} \right) / \left(\sum_j A_{ij} \right) \qquad (3.1)$$

where RBO_i - back order penalty per unit of raw material i

PBO_j - back order penalty per unit of product j

A_{ij} - units of raw material i used in one unit of product j

If the expected backorder cost exceeds order cost, more raw material is ordered; if not, the next shipment of raw material is increased.

3.5 Raw Material and Product Structure

Characteristics of raw materials and products are established based on normal process industries. Bills of material in process industries are normally very shallow. Since this research is concerned with a single machine process corresponding to the blending operation, a two level bill of material is being used.

A second concern in the creation of products for use in this study was the number of raw materials required per product. Based on the study done by Bolander, et al, (1981), the number of raw materials per product in process industries is relatively low. For this study, the number of raw materials per product was randomly set at two, three, or four. The quantity of raw material per product was also

randomly assigned to each raw material. The quantity of raw material required per product was also randomly assigned.

3.6 Cost Structure

The purpose of the planning system is to control inventory cost, it is therefore necessary to assign costs to different components of the production system.

Cost components include raw material cost, ordering cost, holding cost for both raw materials and finished goods, production set-up cost and a penalty cost for units on backorder. The total cost, which is the sum of all of the individual costs, also measures the performance of the planning and control system.

Due to the stochastic nature of raw material properties, delivery quantities of a raw material are not equal to the quantity ordered, therefore, an excess quantity of raw material will be ordered to cover possible shortages. Raw material safety stock is not kept in inventory, but takes form as an excess order quantity.

The cost assigned to the raw materials was done randomly based on process industry manufacturers. The Census of Manufacturing (1980), provided total cost of raw materials and total revenues for process industries based on SIC code. This provided a probability distribution of the ratio of cost of raw materials per dollar of revenue. Since all firms have a total raw material cost less than total revenue, this ratio is less than 1.0. This probability

distribution was randomly sampled to provide cost ratios which were then assigned to each raw material as a per unit cost. The cost ratios are presented in the Appendix.

Connected with the process of acquiring raw material for production is the ordering cost for making an acquisition. One of the problems with assigning a cost to ordering raw materials is cost varies between industries. There have been precedents for the use of ratios to measure these costs. Berry (1972), and Ritzmann, King, and Krajewski (1984) recommend the use of ratios to measure costs. For this study, raw material ordering cost will be measured as a multiple of unit cost of raw materials.

Product revenue and profit were determined based on raw material cost, input-output coefficients and marginal revenue of raw materials. To calculate product revenue, the revenue contribution per unit of raw material is calculated.

$$RRC_i = 1.0 - RC_i \qquad (3.2)$$

where RC_i - unit cost of raw material i

RRC_i - revenue contribution per unit of raw material i

Total cost of each product was then calculated based on raw material unit cost and input-output coefficients from the bills of material.

$$PC_j = \sum_i RC_i * A_{ij} \quad (3.3)$$

where PC_j - unit cost of product j

A_{ij} - units of raw material i used in one unit of product j

The revenue contribution for each product was calculated based on the revenue contribution of each raw material and input-output coefficients.

$$PRC_j = \sum_i RRC_i * A_{ij} \quad (3.4)$$

where PRC_j - revenue contribution per unit of product j

The final step involved calculation of the price of each product based on its cost and revenue contribution.

$$PP_j = PC_j + PRC_j \quad (3.5)$$

where PP_j - price of product j

These product prices and raw material costs are used in calculating the performance measures mentioned earlier.

Holding cost is determined based on the dollar value of inventory being held at any given time period multiplied by a factor to measure that cost.

Back order cost, the penalty for not shipping product in the time period it was scheduled, is based on the dollar value of the units on backorder.

3.7 Assumptions of the Model

For this study, assumptions about the normal operation of a batch process manufacturer needed to be made. Some of these assumptions have been mentioned already, The following assumptions also apply. Those assumptions are:

1. Each machine is continuously available for assignment. There are no shutdowns or breakdowns.
2. Order release is by product number.
3. Once a job is started, it must be finished before another job can be worked on. (i.e., no preemption)
4. A job cannot be split into two or more smaller jobs, but must move through the shop as one job. (i.e., no lot splitting)

3.8 Variation in Quantity Supplied

The variation in raw material requirements is due to the stochastic nature of the quality characteristics of the raw materials, not the process or product. It can then be assumed, that this type of variability affects all products the same way. That is, raw material properties are such that if twice as much of the raw material in inventory is needed to make a particular product than is normally required, then all products using that raw material will require twice as much of raw material during production.

Each product manufactured will have a "standard" bill of material which is a formal expression of the identity and quantity of raw materials required for the production of the

product. Reasons for variation in actual quantities of raw material used for a given product have been previously stated. Standard usage, calculated using Equation 3.6, is usually an average usage of a raw material for a particular product, and usage can be expressed as a quantity variance of actual units used divided by the standard units for that product (Horngren, 1967)

$$A_{ij} = \sum (R_i / P_j) \qquad (3.6)$$

where A_{ij} - units of raw material i used in one unit of product j

R_i - actual number of units of raw material i used in a given production run

P_j - actual number of units of product j manufactured in a given production run

If the raw material requirements for a given product are expressed in terms of standard units of a raw material rather than actual units of measurement, the quantity of raw material required to produce specific products does not change. For example, if ten standard units of a raw material are required to produce one unit of a certain product and the raw material in stock is twice as effective as a standard unit of that raw material, then only one half the normal amount of raw material is required. When expressed in standard unit terms, one half of the normal amount of raw material provides ten standard units of that raw material. The input-output coefficient of ten standard units of raw material per unit of product is unchanged even

though the actual quantity, in physical units, is different.

As a result, the variation is not in the input-output coefficients for production, but in the quantity of raw materials provided. When a shipment of raw material is received, it has particular quality characteristics that can be compared with the standard properties of that type of raw material. By converting the actual units received to standard units of raw material, a more accurate statement of inventory status can be made. If a shipment is received that is twice as potent as normal, the shipment provides twice as much standard units of raw material that was ordered. By expressing raw material inventory in standard units, the effectiveness of that raw material can be stated and the material planning and control system can represent the true status of raw material inventory.

The stochastic nature of raw material variability can be shifted from variable input-output coefficients to variation in the quantity of raw material received. The result of this analogy is a fixed demand for raw material, expressed in standard units, and a variable quantity of raw material received.

3.9 The Simulation Model

Although this research is investigating a relatively simple, single machine process, the material planning and

control system is complex. The choice of a simulation model as the research method for this investigation merits some discussion. Simulation has been used in response to a multitude of research questions, reasons given for its use by Law and Kelton (1982) include:

> 1. Most complex real world systems with stochastic elements cannot be accurately described by a mathematical model which can be evaluated analytically. Thus, a simulation is often the only type of investigation possible.
>
> 2. Simulation allows one to estimate the performance of an existing system under some projected set of operating conditions.
>
> 3. Alternative proposed system designs (or alternative operating policies for a single system) can be compared via simulation so see which best meets a specified requirement.
>
> 4. In a simulation we can maintain much better control over experimental conditions than would generally be possible when experimenting with the system itself.
>
> 5. Simulation allows us to study a system with a long time frame, e.g., an economic system, in compressed time, or alternatively to study the detailed workings of a system in expanded time. (Law and Kelton, 1982, p. 8)

Simulation has been recognized as the appropriate methodology to employ when realistic experiments are not possible, time compression is necessary or real experimentation is too complex or too costly to perform (Rosenthal and Rosnow, 1984).

In this case, all conditions dictating the use of simulation are met. The system can be modeled analytically, but each response to raw material variability is a different

model. Some of the planning system responses to raw material variability, in the form of either planning or corrective action, require the use of real time information. As a result, analytical approaches to the solution of this problem are inappropriate.

This research is interested in comparing the performance of more than one response to raw material variability and real life experimentation would not be feasible. The need to control exogenous, or environmental factors, and the need for time compression all indicate the use of simulation as the appropriate methodology. For these reasons, simulation can be used to test the effectiveness, and more importantly, compare the performance of the different planning system responses variability in raw materials.

The simulation model created to investigate the questions being posed is a discrete event simulation model of a single machine production system. The simulation model was written in SLAM (Pritsker and Pegden, 1978) with FORTRAN subroutines. SLAM is a specialized simulation language that provides event scheduling, random variable generation, data collection, file handling and statistical calculations.

The Wagner-Whitin algorithm is based on an efficient computer implementation and FORTRAN code of this algorithm provided by Evans (1985).

Flowcharts of the logic of the simulation model and a program listing are provided in the Appendix.

3.10 Experimental Factors

In analyzing the model created for this study, a number of factors were expected to have an effect on the performance of the planning and control system. These factors can be classified as either exogenous or endogenous. The exogenous, or environmental, factors are assumed to have an effect on the performance of the system but are not under the control of the planning system. The endogenous, or managerial, factors are those entities that are controlled by the planning system. The specific values of the factors will be given in Chapter 4.

3.10.1 Exogenous Factors

Exogenous factors are those elements in the environment of the production process over which the planning system has no control. Exogenous factors include raw material variability, capacity utilization and the cost structure of the process. A recent manufacturing simulation study by Ritzman, King, and Krajewski (1984), and a survey of process industry manufacturers by Taylor (1979) provided input in the establishment of factor levels.

3.10.1.1. Raw Material Variability

The variability experienced by the process is a factor that could impact the planning system's performance. Bill of material variability is realized through the variation in the order quantity received. The coefficient of variation will be used to measure this variability. Coefficient of variation is defined as the ratio of variance over mean. Different levels of raw material variability will be tested.

3.10.1.2 Capacity Utilization

The desired level of capacity utilization may affect system performance. If raw material variability is such that the planned sequence of production is disrupted often, necessitating rescheduling of jobs, the ability of the planning system to correct that condition may be limited as capacity utilization increases. Different levels of utilization will be tested.

3.10.1.3 Cost Structure

Costs incurred by the planning system can originate from a variety of sources. Two exogenous cost factors are defined. The first factor is the ratio of raw material order cost to raw material unit cost and setup time to run time per product. The second factor is the ratio of holding cost to unit cost and the ratio of backorder cost to product

cost. Both factors will be set at different levels in the study.

These factors are not under the control of the planning system. However, the level of the ratios should affect the performance of the production planning and control system.

3.10.2 Endogenous Factors

Since this study is concerned with how a planning system can control and plan for the effects of raw material variability, it is important to discuss the nature of the set of responses under consideration. These include the use of finished goods safety stock, a modification of the economic order quantity rule, a modified lot-for-lot ordering system and the application of stochastic dynamic programming to raw material variability.

3.10.2.1 Finished Goods Safety Stock

Liberatore (1979), Whybark & Williams (1976), New & Mapes (1984), and others have advocated the use of safety stock to deal with variability. Safety stock will be used for finished products.

The use of safety stock to deal with bill of material variability will be based on product demand. Average demand and variance for all products will be determined, and using traditional inventory management techniques, a level of safety stock will be calculated for those finished products. Any time an order uses the safety stock to make up for

production shortfalls, the production planning system will initiate a production order to replenish the safety stock as soon as possible. Different service levels for finished goods safety stock will be tested.

3.10.2.2 Economic Order Quantity

The second response involves separating demand from raw material requirements and treating that demand independently rather than using individual product demand in any time period to determine raw material requirements. Using the master production schedule, raw material requirements for a year will be determined. Silver (1976) provided a formula to modify the economic order quantity based on quantity variability of raw materials delivered. Silver's modifications to the traditional EOQ calculation provided the following formulas. The derivation of these formulas from Wilson's EOQ model is based on minimizing expected costs per unit time as a function of the order quantity.

When the expected value of the quantity of raw material delivered based on raw material ordered is

$$DQ_{it} = RD_{it} * b \qquad (3.6)$$

where i - raw material

t - time period

RD_{it} - quantity of raw material ordered

DQ_{it} - quantity of raw material delivered

b - bias, the expected value of the ratio of amount received to amount ordered

and the standard deviation is independent of order quantity

$$\sigma_{X/Q} = \sigma \qquad (3.7)$$

where σ - standard deviation of the delivered quantity given that Q is ordered.

then the economic order quantity is

$$EOQ = (1/b) * (2KD/Ch + \sigma^2)^{1/2} \qquad (3.8)$$

where K - ordering cost
Ch - annual holding cost per unit
D - annual demand rate

Alternatively, when the standard deviation is

$$\sigma_{X/Q} = k * Q \qquad (3.9)$$

where k is a constant, then the economic order quantity is

$$EOQ = (2KD/(Ch(b^2 + k^2)))^{1/2} \qquad (3.10)$$

Raw material requirements are calculated based a schedule of production orders based on release date. The result is a time-phased demand schedule for raw materials. Orders are placed for raw material to meet this demand schedule with

order quantities being integer multiples of the calculated economic order quantity for a given raw material.

3.10.2.3 Modified Lot-for-Lot Ordering

In this response, raw materials will be ordered based on three different service levels. These levels correspond, in part, with discussions of this problem by Dantzig (1955), Madansky (1962), Elmaghabry (1959) and Elmaghabry (1960). The use of the 50% and 90% service level correspond with his expected value and pessimistic approach, respectively. The third level, 70%, provides a compromise between the optimistic and pessimistic service levels.

Raw material requirements will be determined based on the previously generated master production schedule. Depending on the raw material variability, these requirements will be adjusted to meet the specified service level. The resulting raw material requirements schedule is calculated as shown.

$$RN_{it} = RN_{it} * CF \qquad (3.11)$$

where CF - correction factor based on service level
RN$_{it}$ - quantity of raw material i required in time t

Once the new requirements have been determined, the raw material delivery schedule will be calculated using the Wagner-Whitin algorithm.

3.10.2.4 Stochastic Dynamic Programming

The final response, the use of the stochastic dynamic programming, involves the creation of the raw material delivery schedule based on the raw material requirements schedule, the probability distribution of raw material variability and the expected value of each decision.

A modification to the Wagner-Whitin algorithm is made to determine the raw material delivery schedule.

The stage is defined as the time period, the state is the raw material requirements and the decision is the order quantity.

Based on a given demand quantity, either single or multiple period demand, the optimal order quantity for that ordering period is determined by identifying the the order quantity minimizing the relevant costs identified in Equation 3.12.

Once this new order quantity for the time span in question is determined, the cost of that decision can be calculated. The expected cost for any decision is

$$f_n(Q/I) = OC + \sum_{LL}^{OQ} Cs*(D-X+I)*P_x \quad \sum_{OQ}^{UL} (Ch(X+I-D))*P_x \qquad (3.12)$$

where OQ - order quantity
CH - holding cost
OC - order cost
CS - stockout cost
D - raw material demand
I - inventory level
X - delivered quantity
UL - highest quantity delivered given OQ and probability distribution
LL - lowest quantity delivered given OQ and probability distribution

Using this cost calculation and the Wagner-Whitin algorithm, raw material requirements are determined.

3.11 Summary

This chapter presented the model of a process manufacturer to be used in this study. Additionally, experimental factors to be investigated in this research were identified and explained. Chapter 4 will provide the details of the experimental design employed in this research and will specifically state the levels of exogenous factors that will be used in the simulation model. Data collection and statistical analysis will also be covered.

CHAPTER 4

EXPERIMENTAL DESIGN

4.1 Introduction

The experimental design employed in this research focuses on two different sets of factors, endogenous and exogenous. The endogenous factors deal with planning system responses to raw material variability while exogenous factors focus on some of the elements of the environment that affect planning system performance.

In this chapter, the specific characteristics of the experimental design employed in this study are identified. These characteristics include a listing of all endogenous and exogenous factors, the levels chosen for those factors, the measures of performance collected, and statistical analysis techniques to be employed.

4.2 Endogenous Factor Levels

In Chapter 3, two types of planning system responses to raw material variability were identified, the use of finished goods safety stock, and five different raw material ordering mechanisms. The levels chosen for those factors have an effect on the performance of the planning system and the following sections discuss the levels chosen for this study.

4.2.1 Finished Goods Safety Stock

Safety stock can be used at both the finished goods level and the raw material level. Since the different raw material ordering rules order more raw material than needed, they are effectively creating safety stock at the raw material level. As a result, safety stock needs to be established at the finished goods level.

It is assumed, that demand for finished goods is normally distributed. Peterson & Silver (1985) provided an accepted method to determine quantity of safety stock to keep on hand. Safety stock is calculated based the standard deviation of product demand as follows:

$$SS = k * \sigma \qquad (4.1)$$

where

SS - safety stock

k - safety factor

σ - standard deviation of product demand

For the purpose of this study, the safety factor is either zero, providing a 50% service level, or 1.28 providing a 90% service level. Both values of k assume demand is normally distributed.

These levels were chosen to provide two extremes in finished goods safety stock. At the 50% service level, no safety stock for finished goods is provided by the system and at the 90% level safety stock is relatively high and the probability of it not performing its function is low.

4.2.2 Raw Material Ordering Mechanisms

The different planning system methods of ordering raw materials were discussed in Chapter 3. They are the economic order quantity method, the modified lot-for-lot method and the use of stochastic dynamic programming to order raw material. In the case of the first and last methods of ordering raw materials, no parameters needed to be established, but in the case of modified lot-for-lot, service levels needed to be determined.

4.2.2.1 Economic Order Quantity Ordering Rule

The logic associated with this rule has already been identified in Chapter 3, but it is important to point out the EOQ calculation is based on the exogenous factors in the study. The standard deviation and bias of the distribution of raw material quantity delivered are included in the calculation of economic order quantity and so the setting of those factors affect this raw material ordering rule.

4.2.2.2 Modified Lot-for-lot Ordering Rule

The modification to the lot-for-lot ordering rule involves adjusting raw material demand to match a variety of service levels. The choice of 50% and 90% service level match the logic used to assign service levels for finished goods safety stock. The third level, 70%, was chosen

because it provides a compromise between the other levels chosen.

Service level and adjustment to raw material requirements is based on the characteristics of the raw material variability distribution which are established as exogenous factors.

4.2.2.3 Stochastic Dynamic Programming Method

Once the mechanics of this method is determined, there are no further options require specification. As with the other raw material ordering rules, exogenous factor level settings will affect the decision making characteristics of this method, but not the method used in the decision making process.

4.3 Exogenous Factor Level Settings

The exogenous factors identified to possibly have an effect on system performance were listed and explained in Chapter 3. Of concern here, are the levels chosen for raw material variability, capacity utilization and the cost structure of the process. This section will explain how the levels were chosen and what values have been assigned to specific parameters.

4.3.1 Raw Material Variability

Parameters affecting raw material variability deal with the type of distribution employed in the study and the magnitude of that variability.

4.3.1.1 Choice of Probability Distribution

For the purpose of this study, the uniform distribution will be used to reflect raw material variability. It was chosen over other distributions, specifically the normal distribution, because it provides a higher probability of deliveries requiring corrective action by the planning system and is simpler to use than other distributions.

4.3.1.2 Levels of Raw Material Variability

The uniform distribution has two parameters that describe its characteristics. The first is bias and the second is coefficient of variation. Bias is defined as the ratio of the expected value of the delivered quantity to the quantity ordered. The coefficient of variation is the ratio of the distribution's variance to its mean.

4.3.1.2.1 Raw Material Variability Bias

The mean, or bias, of this distribution was set at 1.00, that is, over the long run, the expected value of the delivered quantity is equal to its order quantity. Although

the planning system can easily adjust to a bias that is not equal to 1.00, it was felt that by using this type of distribution another source of possible variability is eliminated and the study can focus on the question or raw material variability, not the effective yield of the raw material delivery process.

4.3.1.2.1 Raw Material Variability Coefficient of Variation

The second parameter describing raw material variability, coefficient of variation, was set at two levels, .03 and .10. These levels result in ranges of delivery of raw material that reflect relatively high and relatively low variability. The coefficient of variation determines the characteristics of the probability distribution for the raw material variability.

The range of the distribution, upper limit (a) and lower limit (b), are determined based on the formula for the standard deviation of a uniform distribution (Ross, 1976). It is:

$$\sigma = (a - b)/(\sqrt{12})$$

With a bias, or mean, of the distribution established at 1.0, the result is the coefficient of variation which is also the standard deviation. The upper and lower limits for raw material variability are shown in Table 4.1.

Coefficient of Variation	Delivered Quantity/Ordered Quantity	
	Lower Limit	Upper Limit
.03	.948	1.052
.10	.826	1.173

Range of Raw Material Quantity Variability

TABLE 4.1

4.3.2 Cost Structure

The cost structure being used in this research takes on two sets of characteristics, the nature of the costs being measured, and the way of measuring those costs.

4.3.2.1 Type of Costs

The costs important in this study are raw material and finished goods holding costs, the cost of ordering raw materials, costs incurred due to production setup and the cost of finished goods on backorder.

4.3.2.2 Cost Structure Level Settings

Ratios have been used in other studies as a way of reflecting cost. In this study, both holding cost and backorder cost will be a function of unit cost. The ratios will be set at two levels, such that the ratio of holding or backorder cost to the price of the raw material or finished good is either 1:5 or 1:10.

4.3.3 Activity Ratios

As mentioned earlier, ratios can be used to measure costs. When an order is placed with a supplier or a production order is entered for manufacture, the initiating activities of ordering and setup incur disproportionate costs. The cost of these activities is reflected by a ratio.

4.3.3.1 Raw Material Ordering Cost

The cost of ordering raw material is determined based on the unit cost of the raw material and is independent of the size of the order. The ordering cost is a multiple of the cost of one unit of that particular raw material times the activity ratio,

4.3.3.2 Setup Cost

When the production process is set up to produce a particular product, the setup time is assumed proportional to the run time for the product and dependents on unit run time, not the total run time for the order. By using this measure of setup time, different products will have different setup times.

4.3.3.3 Activity Ratio Levels

The settings of activity ratios chosen for this study reflect the large investment in ordering and setup time which occur in this type of manufacturing. The ratio of ordering cost to raw material unit cost and setup cost to run time will be either 50:1, or 250:1.

4.3.4 Capacity Utilization

Capacity utilization reflects the nature of product demand being met. During the generation of the product demand schedule, a level of capacity utilization was met and included both setup time and runtime during its generation. The level of utilization was set at either 60% or 80%.

4.4 Performance Measures

The measure of performance of the planning system will be the various costs incurred in the normal operation of the production process. Prior research has identified the need to use cost as a measure of performance. This section will identify the various cost measures employed and discuss how they will be determined.

4.4.1 Raw Material Holding Cost

Raw material inventory exists for two reasons. It is either cycle inventory to take into account lot sizing

during the ordering process, or it is buffer inventory to minimize the effect of order quantity variability. The cost of holding raw materials in inventory will be based on the average dollar value of inventory held in stock through all time periods of the simulation. Raw material holding cost will then be calculated based on unit cost of the raw material, the total number of units held in stock and the ratio of holding cost to raw material cost.

4.4.2 Finished Goods Holding Cost

Finished goods exist in inventory for the same reasons that raw material is held in inventory. Lot sizing during production creates cycle inventory and safety stock creates buffer inventory. The cost of holding finished goods in inventory will be treated the same way as raw material holding cost. It is calculated based on average finished goods in inventory, the unit price of those finished goods and the holding cost for that particular finished good. Holding cost per unit is determined based on the ratio of holding cost to the cost of that finished good.

4.4.3 Raw Material Ordering Cost

Total cost of ordering raw material is another measure of performance to be evaluated. Ordering cost is calculated as a ratio of raw material unit cost. This ratio is an exogenous variable and was discussed earlier. Cumulative

order cost is calculated by summing order cost each time a raw material is ordered and delivered.

4.4.4 Setup Cost

Each time a production run is started, time is allocated for the setup of the run. Total setup time is determined based on the run time of the product being blended and activity ratio discussed earlier. Setup cost is based on the run time for that particular product and the cost of the product being produced. It is the value of the product which could have been produced if the process was not being setup for that order.

4.4.5 Backorder Cost

Since the system allows for backorders without lost sales, it is necessary to assign a penalty cost to demand not met until a later time period. This cost is based on the total number of units on backorder during the simulation run and the cost structure ratio which provides backorder cost per unit based on the price of that product.

4.4.6 Total Cost

The last measure of performance is the total of all costs incurred. It is the sum of raw material and finished goods holding cost, raw material ordering cost, setup cost and backorder cost adjusted for time.

4.5 Data Collection

In order to calculate the cost measures used in this study, a variety of system performance data needs to be collected periodically. This data includes raw material and finished goods inventory levels, raw material ordering costs, setup costs and number of backordered products.

4.5.1 Inventory Levels

The level of raw material and finished goods inventory is recorded at the end of a day's operation. Raw material inventory is recorded after all raw materials are received and distributed to production. Finished goods inventory is measured after all products are produced shipped. At the end of the simulation run, the average daily inventory for each raw material and product is calculated. Based on these inventory averages, the cost of raw materials, the price of products and the holding cost ratio, inventory holding cost is calculated.

4.5.2 Raw Material Ordering Cost

Since raw material ordering cost is cumulative, the total order cost is incremented by the appropriate amount each time an order is placed and received for raw materials. This provides raw material ordering cost directly and no further manipulations of this data is necessary.

4.5.3 Setup Cost

Setup cost is calculated in the same way as raw material ordering costs. Prior to incrementing the total setup cost when an order is initiated, the cost of that setup is calculated and the value is added to cumulative total cost. It too, is the performance measures to be used for analysis and no further calculations to this variable are necessary at the end of the simulation.

4.5.4 Backorder Cost

Each time an order is shipped, it is analyzed to see if adequate inventory is on hand to complete the order. In those cases where the product inventory is not adequate to cover demand, the planning system must take corrective action to decide whether to issue a new order to cover the shortfall or to accept the units on backorder. During this evaluation procedure in the planning system, the magnitude of the backorder is calculated and total units on backorder is incremented by the appropriate amount. Since total backorders are cumulative, this data needs no further manipulations at the end of the simulation.

4.6 Statistical Analysis Experimental Design

The choice of the appropriate statistical analysis and experimental design is based on the combination of exogenous factors, endogenous factors and the multiple performance

measures. This type of investigation is best handled using two-way multivariate analysis of variance. A discussion of the reasons for the choice of this statistical technique and the experimental design used in this research follow.

4.6.1 Appropriateness of Statistical Technique

The appropriateness of the statistical technique is based on two factors, (1) multiple performance criteria and (2) the existence of controllable and noncontrollable factors.

Hair, Anderson, Tatham, and Grablowsky (1984) identified multivariate analysis of variance as the preferred statistical technique to study the effect of independent treatment variables on multiple dependent performance variables. In addition to allowing for identification of the effect of independent variables on all measures of performance simultaneously, multi-attribute analysis of variance does not increase the probability of a Type I error like repeated applications of univariate analysis of variance will. The probability of a Type I error in repeated applications of univariate analysis of variance is calculated using the following formula.

$$P(\text{Type I Error}) = 1.0 - (1.0 - \alpha)^k \qquad (4.2)$$

where α - probability of a Type I error for individual tests

k - number of performance measures

Based on the type of problem being investigated in this research and a standard α = .05, the probability of a Type I error for repeated applications of univariate analysis of variance is .233. This level would limit identification of significance effects of independent variables and interpretation of results. The application of multivariate analysis of variance reduces the level of the probability of a Type I error to its original value by analyzing all performance measures simultaneously.

The second concern is the identification of a way of classifying responses based on exogenous and endogenous factors. Table 4.2 provides a summary of the factors and their possible values to be used in this research.

Endogenous Factors

Finished Goods Safety Stock

- Service Level 50%
- Service Level 90%

Raw Material Ordering System

- Modified EOQ
- Modified Lot-for-Lot 50%
- Modified Lot-for-Lot 70%
- Modified Lot-for-Lot 90%
- Stochastic Dynamic Programming

Exogenous Factors

Raw Material Variability

- Coefficient of Variation .03
- Coefficient of Variation .10

Cost Structure

- 10:1 Cost Ratio
- 5:1 Cost Ratio

Activity Ratio

- 50:1 Cost Ratio
- 250:1 Cost Ratio

Capacity Utilization

- 60% Average Utilization
- 80% Average Utilization

EXOGENOUS AND ENDOGENOUS FACTOR LEVEL SETTINGS

TABLE 4.2

For the purpose of dependent variable classification, treatments will be defined as the endogenous factors under consideration and blocks are the exogenous factors identified that affect may system performance. This creates a six-factor multivariate analysis of variance problem where

each of the six dependent variables can be classified based on the value of both endogenous variables and all four exogenous variables.

In order to investigate this problem fully, a full factorial design will be employed in order to test every possible combination of exogenous and endogenous factors that may occur.

4.7 Chapter Summary

In this chapter, the specific characteristics of the experimental design employed in this study were identified. These characteristics include a listing of all endogenous and exogenous factors, the levels chosen for those factors, the measures of performance to be used, and the method of collecting system statistics were identified. Additionally, the use of multivariate analysis of variance and the characteristics of the full factorial design being employed were discussed.

CHAPTER FIVE

STATISTICAL RESULTS

5.1 Introduction

The statistical analysis performed for this research was introduced in Chapter 4. This chapter discusses the methodology in greater depth, presents the results of the analysis and discusses those results from a statistical point of view. The implications of these results as they pertain to managerial decisions faced by the material planning and control systems of process industries are discussed later in Chapter 6.

This chapter identifies the method of statistical analysis, presents the experimental design employed in the analysis, shows the results of the analyses, and identifies significant relationships shown to exist.

Although multivariate analysis of variance was previously identified as the preferred statistical analysis, univariate analysis of variance was used, as a second step in analysis, to explore the effect of all factors on differing dependent variables.

Statistical analysis was performed using the proprietary software, SPSSX. Analysis was done using their

versions of multivariate and univariate analysis of variance.

5.2 Statistical Analysis Methodology

In Chapter 4, the superiority of multivariate analysis of variance over univariate analysis of variance was established when dealing with more than one dependent variable. Univariate analysis of variance artificially inflates the probability of making a Type I error. Due to the limitations of post hoc analysis using multivariate analysis of variance, it was necessary to employ univariate analysis of variance in order to investigate the specific effect of different factors on the dependent variables.

This analysis performs a six factor multivariate analysis of variance on the six dependent variables generated by the simulation model. Both sets of endogenous factors, raw material planning method and finished goods safety stock, and all four exogenous variables, cost of capital, activity ratio, capacity utilization and coefficient of variation, were used as blocking factors. This statistical analysis design is summarized in Table 5.1.

Exogenous Factors

Capacity Utilization

Average Utilization 60%
Average Utilization 80%

Cost of Capital

Unit Cost to Holding Cost Ratio 10 : 1
Unit Cost to Holding Cost Ratio 5 : 1

Activity Ratio

Unit Cost to Setup or Order Cost 50 : 1
Unit Cost to Setup or Order Cost 250 : 1

Coefficient of Variation

Variance to Mean Ratio .03 : 1
Variance to Mean Ratio .10 : 1

Endogenous Factors

Raw Material Planning Method

Modified Economic Order Quantity
Modified Lot-for-Lot 50% Service Level
Modified Lot-for-Lot 70% Service Level
Modified Lot-for-Lot 90% Service Level
Stochastic Dynamic Programming

Finished Goods Safety Stock

50% Service Level
90% Service Level

Dependent Variables

Average Raw Material Inventory ($)
Average Finished Goods Inventory ($)
Total Order Cost ($)
Total Setup Time (Hr.)
Total Backorder Value ($)
Total Cost ($)

Multivariate Analysis of Variance
Statistical Analysis Design

TABLE 5.1

The resulting design is a six-factor, or six-dimensional, analysis. An additional element of the design this research required was the effects and interactions the statistical analysis would investigate. All main effects and interactions involving at least one of the endogenous factors, raw material planning method or finished goods safety stock, were identified and analyzed. If an effect only dealt with a single exogenous factor or interactions between exogenous factors, it was ignored because a firm would be unable to respond to those interactions and it needs the interaction with the endogenous factors to be of interest to this research. The main effects and interactions identified and investigated for this research are shown in Table 5.2.

Main Effects	Two-way Interactions
P	P by E1
S	P by E2
	P by E3
	P by E4
	S by E1
	S by E2
	S by E3
	S by E4

Three-way Interactions

P by S by E1	P by E1 by E2	S by E1 by E2
P by S by E2	P by E1 by E3	S by E1 by E3
P by S by E3	P by E1 by E4	S by E1 by E4
P by S by E4	P by E2 by E3	S by E2 by E3
	P by E2 by E4	S by E2 by E4
	P by E3 by E4	S by E3 by E4

Four-way Interactions

P by E1 by E2 by E3	P by S by E1 by E2	S by E1 by E2 by E3
P by E1 by E2 by E4	P by S by E1 by E3	S by E1 by E2 by E4
P by E2 by E3 by E4	P by S by E1 by E4	S by E2 by E3 by E4
	P by S by E2 by E3	
	P by S by E2 by E4	
	P by S by E3 by E4	

Five-way Interactions

P by S by E1 by E2 by E3
P by S by E1 by E2 by E4
P by S by E2 by E3 by E4

Six-way Interaction

P by S by E1 by E2 by E3 by E4

Where:
- P - Raw Material Planning Method Used
- S - Level of Finished Goods Safety Stock
- E1 - Capacity Utilization
- E2 - Holding Cost Ratio
- E3 - Activity Ratio
- E4 - Coefficient of Variation

Multivariate Analysis of Variance
Main Effects and Interactions Investigated

TABLE 5.2

Initially, multivariate analysis of variance tests the effect of each blocking factor to determine if the vectors created from the dependent variables are equal. Multivariate analysis of variance is used to assess group differences across all dependent variables rather than single dependent variables as done in univariate analysis of variance. This difference is illustrated in Figure 5.1.

ANOVA

$$H_0 : X_1 = X_2 = \ldots X_n$$

MANOVA

$$H_0 : \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{1n} \\ \vdots & \vdots & & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix}$$

where X_{mn} - mean of dependent variable m, group n

FIGURE 5.1

If the vectors are the same, that is, the blocking factor effects each dependent variable in the same way, then multivariate analysis of variance accepts the hypothesis of equality of the vectors. This can be interpreted as the blocking factor does not result in differing performance. If the vectors are unequal, a second set of tests compares individual performance measures. This procedure is similar to univariate analysis of variance, but by performing this analysis in conjunction with multivariate analysis of variance, the risks associated with an increased Type I error are minimized. Finally, univariate analysis of variance was performed on all significant effects and interactions. By looking only at those effects identified as significant using multivariate analysis of variance, the limitations of univariate analysis of variance are eliminated. Univariate analysis of variance will have the tendency to identify significant effects and interactions on the basis of only one dependent variable rather than all six dependent variables. These univariate analysis of variance results will be discussed in Chapter 6.

5.3 Multivariate Analysis of Variance Main Effects Results

This analysis initially looked at the main effects, raw material planning method and finished goods safety stock. By only looking at a single factor, all other factors are not used to distinguish between dependent variables. That

is, by looking at the effect of raw material planning method, no further classification of dependent variable results is made. The main effect analysis ignores the level of safety stock and the levels of all exogenous variables. As was mentioned earlier, significant relationships only dealing with exogenous variables, be they main effects or higher order interactions, have been ignored in this discussion. The SPSSX multivariate analysis of variance provides four separate ways of testing the initial hypothesis dealing with equality of the vectors created by the model. All four generate an F-Ratio that can be used to test that hypothesis.

5.3.1 Raw Material Planning Method Main Effect Results

The first statistical analysis involves comparing performance of the five raw material planning methods while ignoring the classification of results by level of safety stock and level of all four exogenous variables. The result is a single factor multivariate analysis of variance. The results of that initial test are shown in Table 5.3

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	2.17	920.71	24	.000
Hotellings	67.46	13024.15	24	.000
Wilks	.00	3102.86	24	.000

Multivariate Analysis of Variance Overall Equality Test

Main Effect--Planning Method

TABLE 5.3

The results of this analysis identify a difference between the vectors created from dependent variables when blocking is only done with the planning method. The value in Table 5.3, and subsequent tables, identified as Significance of F refers to the limit assigned to a Type I error that would allow the acceptance of the initial hypothesis of equality of vectors. Univariate F-tests were performed on the individual dependent variables. These results are shown in Table 5.4.

Dependent Variable	F Ratio	Significance of F Value Value
Raw Material Inventory	43721.44	.000
Finished Goods Inventory	301.61	.000
Order Cost	30802.60	.000
Setup Cost	543.76	.001
Backorder Units	430.40	.000
Total Cost	12672.22	.000

Multivariate Analysis of Variance Univariate F-Tests

Main Effect--Planning Method

TABLE 5.4

This table shows the equality, or this case lack of equality, in dependent variables. The multivariate analysis of variance allows one to conclude that the raw material planning method used results in different values for all dependent variables. The specific differences in performance of raw material planning methods will be explored and discussed during post hoc analysis in the next chapter.

5.3.2 Main Effect--Finished Goods Safety Stock

The next effect analyzed uses only the level of finished safety stock to partition results. It ignores raw material planning method and all exogenous factors. The initial multivariate analysis of variance shows a significant difference exists depending on the service level

of finished goods safety stock. The results are shown in Table 5.5.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.89	6105.75	6	.000
Hotellings	7.90	6105.75	6	.000
Wilks	.11	6105.75	6	.000

Multivariate Analysis of Variance Overall Equality Test

Main Effect--Finished Goods Safety Stock

TABLE 5.5

This table shows the effect of the service level of finished goods safety stock on dependent variables. The vectors created in multivariate analysis of variance are not equal thus indicating their inequality. Subsequent univariate analysis of variance based on the multivariate analysis of variance problem identified where differences occurred. This information is provided in Table 5.6.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	1122.40	.000
Finished Goods Inventory	33603.01	.000
Order Cost	619.89	.000
Setup Cost	1702.95	.000
Backorder Units	.09	.767
Total Cost	16844.78	.000

Multivariate Analysis of Variance Univariate F-Tests

Main Effect--Finished Goods Safety Stock Service Level

TABLE 5.6

It is interesting to note the inequality of all dependent variables except backorder units. This test states that the service level of finished goods safety stock has no effect on the dependent variable, backorder units.

5.4 Two-way Interactions

The next segment of statistical analysis involves investigation into all significant two-way interactions. Two-way interactions are those tests exploring differences in dependent variables when two factors are used to classify results.

The same format presenting the overall multivariate analysis of variance results followed by the univariate analysis of variance results will be employed in this discussion.

5.4.1 Raw Material Planning Method and Finished Goods Safety Stock Interaction

The first significant interaction involved classifying results based on the raw material planning method employed and the service level of finished goods safety stock. The resulting analysis classifies results using two dimensions rather than one dimension as was seen earlier with the main effect analysis. The results of the first test are shown in Table 5.7.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	1.35	393.19	24	.000
Hotellings	2.75	531.70	24	.000
Wilks	.15	475.66	24	.000

Multivariate Analysis of Variance Overall Equality Test
Raw Material Planning Method and Safety Stock Interaction

TABLE 5.7

This test identifies the existence of differences in performance measures depending on how raw material is planned and what level of finished goods safety stock is used. Further analysis identifies how these endogenous

level settings effect each performance measure. This information is presented in Table 5.8.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	558.47	.001
Finished Goods Inventory	181.39	.000
Order Cost	415.66	.000
Setup Cost	390.32	.000
Backorder Units	89.58	.000
Total Cost	779.62	.001

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method and Safety Stock Interaction

TABLE 5.8

This second test shows the type of raw material planning method and the service level of finished goods safety stock have a significant effect on all performance measures.

5.4.2 Raw Material Planning Method and Capacity Utilization Interaction

The next two way interaction that proved significant during statistical analysis was the interaction between raw material planning method and the level of capacity utilization. The first statistical results investigating significance of the factors impact on all dependent variables are presented in Table 5.9.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	1.22	342.62	24	.000
Hotellings	14.28	2756.25	24	.000
Wilks	.05	939.57	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method and Capacity Utilization
Two-way Interaction

TABLE 5.9

As is noted from Table 5.9, there is a significant difference in the vector created from performance measures depending on raw material planning method used and the level of average capacity utilization.

The results of the second statistical test identifying the effect of those two factors on individual performance measures is shown in Table 5.10.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	139.51	.000
Finished Goods Inventory	.37	.840
Order Cost	222.29	.000
Setup Cost	88.83	.000
Backorder Units	270.06	.000
Total Cost	2396.63	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method and Capacity Utilization

Two-way Interaction

TABLE 5.10

Significant differences exist in all performance measures except average finished goods inventory, that is, regardless of raw material planning method or average capacity utilization, there is not a significant difference in the level of finished goods inventory.

5.4.3 Raw Material Planning Method and Cost of Capital Interaction

The third significant two-way interaction involved the raw material planning method employed and the ratios used to establish the cost of capital for planning purposes. This analysis compared the vectors created from all dependent variables while blocking those performance measures using the two factors mentioned and ignoring the rest of the

experimental factors. The first multivariate analysis of variance results are shown in Table 5.11.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	1.28	358.50	24	.000
Hotellings	3.32	641.06	24	.000
Wilks	.14	502.38	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method and Cost of Capital
Two-way Interaction

TABLE 5.11

This table shows a significant difference in performance based on the raw material planning method employed and the cost of capital used during the planning process.

Table 5.12, which follows, shows the results of the univariate F-tests on the individual performance measures in order to identify where the significant differences exist.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	1662.74	.000
Finished Goods Inventory	59.90	.000
Order Cost	888.12	.001
Setup Cost	663.90	.001
Backorder Units	82.57	.000
Total Cost	553.40	.001

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method and Cost of Capital

Two-way Interaction

TABLE 5.12

It is easily seen, that differences in all performance measures exist when evaluating those differences based on the raw material planning method employed and the cost of capital.

5.4.4 Raw Material Planning Method and Activity Ratio Interaction

This interaction investigates the differing values of the dependent variables depending on the raw material planning method used and the activity ratio the planning system uses. The activity ratio was previously defined as the cost of starting an activity. If a purchase order is placed by the planning system, this ratio is the order cost

to the raw material unit cost. If the planning system initiates a production order, the ratio is the setup time to runtime for that product. The results of this test are shown in Table 5.13.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	1.88	687.17	24	.000
Hotellings	15.75	3040.49	24	.000
Wilks	.02	1498.14	24	.000

Multivariate Analysis of Variance Overall Equality Test
Raw Material Planning Method and Activity Ratio Interaction

TABLE 5.13

A significant difference exists in the vector created from the dependent variables based on the raw material planning method used and the activity ratio the planning system is using.

The second test, shown in Table 5.14 which follows, explores the differences in the individual performance measures.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	9224.27	.000
Finished Goods Inventory	165.62	.000
Order Cost	6433.97	.000
Setup Cost	378.77	.000
Backorder Units	294.73	.000
Total Cost	2790.57	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method and Activity Ratio Interaction

TABLE 5.14

This analysis shows significant differences in all dependent variables.

5.4.5 Raw Material Planning Method and Coefficient of Variation Interaction

The last significant interaction involving the raw material planning method is paired with the measure of raw material variability, coefficient of variation. This measure was defined previously as the ratio of standard deviation of order quantity delivered to the mean order quantity delivered. The initial multivariate analysis of variance test comparing overall equality of vectors is shown in Table 5.15.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.46	101.67	24	.000
Hotellings	.58	111.39	24	.000
Wilks	.60	107.45	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method and Coefficient of Variation

Two-way Interaction

TABLE 5.15

This table shows that significant differences exist, when all performance measures are taken into account, between raw material planning method used and the coefficient of variation of order quantity delivered.

The next analysis identifies where that difference occurs and is shown in Table 5.16.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	60.84	.000
Finished Goods Inventory	8.10	.000
Order Cost	180.01	.000
Setup Cost	133.06	.000
Backorder Units	79.21	.000
Total Cost	17.76	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method and Coefficient of Variation

Two-way Interaction

TABLE 5.16

Analysis of Table 5.16 shows that a significant difference in all measures of performance exist when investigating those differences based on raw material planning method and coefficient of variation.

5.4.6 Finished Goods Safety Stock and Average Capacity Utilization Interaction

This is the first of four significant interactions between the service level of finished goods safety stock and exogenous factors. This multivariate analysis of variance test investigated the interaction between the level of finished goods safety stock and the average capacity utilization. These results are shown in Table 5.17.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.76	2473.33	6	.000
Hotellings	3.20	2473.33	6	.000
Wilks	.24	2473.33	6	.000

Multivariate Analysis of Variance Overall Equality Test
Finished Goods Safety Stock and Average Capacity Utilization
Two-way Interaction

TABLE 5.17

A significant difference in the vector created from all performance measures exists when they are taken as a group and evaluated based on the level of finished goods safety stock and the average capacity utilization.

The next test looks at where those differences occur and the results are shown in Table 5.18.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	9.20	.002
Finished Goods Inventory	166.82	.000
Order Cost	34.39	.000
Setup Cost	3.19	.074
Backorder Units	44.69	.000
Total Cost	2255.02	.000

Multivariate Analysis of Variance Univariate F-Tests Finished Goods Safety Stock and Average Capacity Utilization Two-way Interaction

TABLE 5.18

This table provides some results worth noting. The Significance of F column in the table refers to the probability of a Type I error. In the case of the dependent variable, setup time, the level of significance is such that the significance is greater than the standard value of .05, therefore, one must conclude there is no difference in setup time based on safety stock service level and capacity utilization.

5.4.7 Finished Goods Safety Stock and Cost of Capital Interaction

The next two-way interaction to be investigated involves blocking the results based on the service level of

finished goods safety stock and the cost of capital the planning system uses. The results of the first statistical test are shown in Table 5.19.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.18	169.79	6	.000
Hotellings	.22	169.79	6	.000
Wilks	.82	169.79	6	.000

Multivariate Analysis of Variance Overall Equality Test
Finished Goods Safety Stock and Average Capacity Utilization
Two-way Interaction

TABLE 5.19

A significant difference exists in the vectors created from the dependent variables when finished goods safety stock and average capacity utilization are used to block the simulation results. The second statistical test shows the effect of those two factors on the individual performance measures. This information is presented in Table 5.20.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	417.12	.000
Finished Goods Inventory	97.09	.000
Order Cost	107.91	.000
Setup Cost	.01	.921
Backorder Units	6.03	.014
Total Cost	145.66	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock and Cost of Capital

Two-way Interaction

TABLE 5.20

No difference exists in setup cost based on the level of finished goods safety stock and the cost of capital. All other differences are not significant at the .05 level.

5.4.8 Finished Goods Safety Stock and Activity Ratio Interaction

The next interaction to be investigated, finished goods safety stock and activity ratio, exhibits results similar to those seen in other two-way interactions, an overall significance and a significant effect on each dependent variable. These results are shown in Table 5.21 and Table 5.22.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.52	838.50	6	.000
Hotellings	1.09	838.50	6	.000
Wilks	.48	838.50	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock and Activity Ratio

Two-way Interaction

TABLE 5.21

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	1032.19	.000
Finished Goods Inventory	29.23	.000
Order Cost	729.44	.000
Setup Cost	2879.38	.000
Backorder Units	146.75	.000
Total Cost	7.33	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock and Activity Ratio

Two-way Interaction

TABLE 5.22

It is clearly evident, that the service level established for finished goods safety stock and the activity ratio used

by the planning system have a significant effect on overall performance and on each dependent variable.

5.4.9 Finished Goods Safety Stock and Coefficient of Variation Interaction

The last significant two-way interaction involves blocking dependent variables based on the level of finished goods safety stock and on the variability in raw material as measured by the coefficient of variation. The first multivariate analysis of variance test showed a significant difference in overall effect. The results of this test are shown in Table 5.23.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.04	30.82	6	.000
Hotellings	.04	30.82	6	.000
Wilks	.96	30.82	6	.000

Multivariate Analysis of Variance Overall Equality Test
Finished Goods Safety Stock and Coefficient of Variation
Two-way Interaction

TABLE 5.23

The next test showed some significant effects on dependent variables, but two of the dependent variables were not significantly effected by the level of finished goods safety stock in conjunction with the coefficient of variation. These results are shown in Table 5.24.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	1.68	.195
Finished Goods Inventory	72.62	.000
Order Cost	2.67	.102
Setup Cost	34.18	.000
Backorder Units	60.38	.000
Total Cost	56.36	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock and Coefficient of Variation

Two-way Interaction

TABLE 5.24

Average raw material inventory and raw material ordering cost do not show significant differences based on the service level of finished goods safety stock and the raw material variability.

5.4.10 Other Two-way Interactions

When analyzing all possible two-way interactions for significant effects, some of the interactions between exogenous variables proved to be significant. As was discussed earlier, these significant interactions will not be discussed because a process industry would not be able to respond to interactions between those exogenous variables.

5.5 Three-way Interactions

A variety of three-way interactions were analyzed for significant effects on the six dependent variables. This involved testing the same set of hypotheses tested earlier, but dependent variables were blocked using three factors, not one or two as was previously done. All of the three-way interactions of interest were identified earlier in the chapter, this section will only report those interactions termed significant.

5.5.1 Raw Material Planning Method by Finished Goods Safety Stock by Average Capacity Utilization Interaction

This interaction involves a classification of the dependent variables based on the raw material planning method used, the level of finished goods safety stock and the average capacity utilization. All other exogenous factors are ignored. The results are shown in Table 5.25.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.81	196.84	24	.000
Hotellings	2.04	395.09	24	.000
Wilks	.29	282.61	24	.000

Multivariate Analysis of Variance Overall Equality Test
Raw Material Planning Method, Finished Goods Safety Stock
and Average Capacity Utilization Three-way Interaction

TABLE 5.25

This statistical analysis shows a significant interaction between the two endogenous factors, raw material planning method and finished goods safety stock, and one exogenous factor, average capacity utilization.

The significance of this interaction is further analyzed based on differences in the six dependent variables. This information is presented in Table 5.26.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	16.34	.000
Finished Goods Inventory	23.29	.000
Order Cost	37.73	.000
Setup Cost	89.99	.000
Backorder Units	58.49	.000
Total Cost	149.90	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock and Average Capacity Utilization Three-way Interaction

TABLE 5.26

From Table 5.26, it is evident that these three factors have a significant effect on all six performance measures.

5.5.2 Raw Material Planning Method by Finished Goods Safety Stock by Cost of Capital Interaction

This interaction involves a classification of the dependent variables based on the raw material planning method used, the level of finished goods safety stock and the cost of capital the planning system uses. As is the case in less than full factor interactions, other exogenous factors are ignored. The results are shown in Table 5.27.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.76	181.35	24	.000
Hotellings	1.51	290.85	24	.000
Wilks	.36	232.82	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock and Cost of Capital Three-way Interaction

TABLE 5.27

A significant interaction is indicated between the two endogenous factors, raw material planning method and finished goods safety stock, and one exogenous factor, cost of capital.

The significance of this interaction is further analyzed based on differences in the six performance measures. This information is presented in Table 5.28.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	140.21	.000
Finished Goods Inventory	49.53	.000
Order Cost	311.93	.000
Setup Cost	787.74	.001
Backorder Units	29.10	.000
Total Cost	77.93	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock and Cost of Capital Three-way Interaction

TABLE 5.28

It is evident that these three factors have a significant effect on all six performance measures.

5.5.3 Raw Material Planning Method by Finished Goods Safety Stock by Activity Ratio Interaction

This particular interaction requires blocking the dependent variables based on the raw material planning method used, the level of finished goods safety stock and the activity ratio the planning and productions system faces. These three factors are the only blocking factors, other exogenous factors are ignored. The results are shown in Table 5.29.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.91	227.97	24	.000
Hotellings	1.71	331.41	24	.000
Wilks	.29	282.72	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock and Activity Ratio Three-way Interaction

TABLE 5.29

A significant interaction is indicated between raw material planning method used, level of finished goods safety stock, the activity ratio.

This interaction is further analyzed based on differences in the six dependent variables. This information is presented in Table 5.30.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	507.44	.000
Finished Goods Inventory	184.11	.000
Order Cost	425.18	.000
Setup Cost	274.50	.000
Backorder Units	19.05	.000
Total Cost	640.19	.001

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock and Activity Ratio Three-way Interaction

TABLE 5.30

It is evident that these three factors have a significant effect on all six performance measures.

5.5.4 Raw Material Planning Method by Finished Goods Safety Stock by Coefficient of Variation Interaction

By blocking the dependent variables based on the raw material planning method used, the level of finished goods safety stock and the variability in raw material, the coefficient of variation, this three-way interaction can be investigated. The results are shown in Table 5.31.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.28	58.44	24	.000
Hotellings	.33	64.21	24	.000
Wilks	.74	61.60	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock and Coefficient of Variation Three-way Interaction

TABLE 5.31

All three methods of developing the F-Value indicate a significant interaction is indicated between raw material planning method used, level of finished goods safety stock, the coefficient of variation.

When investigating differences in each dependent variable, significant differences exist in all performance measures. This information is presented in Table 5.32.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	5.52	.000
Finished Goods Inventory	4.29	.002
Order Cost	146.39	.000
Setup Cost	114.27	.000
Backorder Units	21.84	.000
Total Cost	11.88	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock and Coefficient of Variation Three-way Interaction

TABLE 5.32

It is evident that these three factors have a significant effect on all six dependent variables.

5.5.5 Raw Material Planning Method, Average Capacity Utilization and Cost of Capital Interaction

Classifying dependent variables based on one endogenous factor, raw material planning method, and two exogenous factors, average capacity utilization and cost of capital, identifies another three-way interaction. The overall effect of this interaction is shown in Table 5.33.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.59	134.73	24	.000
Hotellings	.92	178.98	24	.000
Wilks	.48	157.30	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Average Capacity Utilization and Cost of Capital Three-way Interaction

TABLE 5.33

A significant overall effect is indicated when blocking the dependent variables using the three factors identified.

Further investigation into their effect on the individual performance measures shows a similar effect. These results are presented in Table 5.34.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	4.18	.002
Finished Goods Inventory	26.81	.000
Order Cost	76.16	.000
Setup Cost	108.72	.000
Backorder Units	29.32	.000
Total Cost	104.23	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Average Capacity Utilization and Cost of Capital Three-way Interaction

TABLE 5.34

5.5.6 Raw Material Planning method, Average Capacity Utilization and Activity Ratio Interaction

The next interaction proving significant was the three-way interaction created when blocking dependent variables using raw material planning method, average capacity utilization and the activity ratio faced by the planning and execution system. This relationship showed a high degree of overall significance and the results are shown in Table 5.35.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.89	222.06	24	.000
Hotellings	3.39	653.57	24	.000
Wilks	.21	385.62	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Average Capacity Utilization and Activity Ratio Three-way Interaction

TABLE 5.35

This interaction was further analyzed to identify the effect on each performance measure. These results are shown in Table 5.36.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	43.52	.000
Finished Goods Inventory	14.34	.000
Order Cost	73.21	.000
Setup Cost	60.40	.000
Backorder Units	87.37	.000
Total Cost	490.02	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Average Capacity Utilization and Activity Ratio Three-way Interaction

TABLE 5.36

When blocking dependent variables using the three factors identified, a significant difference in all measures of performance exists.

5.5.7 Raw Material Planning Method, Average Capacity Utilization and Coefficient of Variation Interaction

This interaction involves classifying dependent variables based on the level of average capacity utilization, the coefficient of variation of the raw material and the raw material planning method used. The overall multivariate analysis of variance test results are shown in Table 5.37.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.19	38.08	24	.000
Hotellings	.21	40.29	24	.000
Wilks	.82	39.31	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Average Capacity Utilization and Coefficient of Variation Three-way Interaction

TABLE 5.37

This three-way interaction shows to have a significant overall effect. When analyzing its effect on the six dependent variables, the interaction proves to have a significant on all of the performance measures. This information is presented in Table 5.38.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	19.85	.000
Finished Goods Inventory	7.15	.000
Order Cost	42.95	.000
Setup Cost	44.09	.000
Backorder Units	11.87	.000
Total Cost	37.04	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Average Capacity Utilization and Coefficient of Variation Three-way Interaction

TABLE 5.38

5.5.8 Raw Material Planning Method, Cost of Capital and Activity Ratio Interaction

When blocking dependent variables using raw material planning method, and two planning system inputs, cost of capital and activity ratio, another interaction can be investigated. The interaction proved to be significant and the results of this first multivariate analysis of variance test are shown in Table 5.39.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.83	203.03	24	.000
Hotellings	1.45	278.99	24	.000
Wilks	.34	243.08	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Cost of Capital and Activity Ratio Three-way Interaction

TABLE 5.39

A significant overall effect is identified and when evaluating the effect of these factors on the individual performance measures their effect proves to be significant again. This information is presented in Table 5.40.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	381.47	.000
Finished Goods Inventory	49.32	.000
Order Cost	336.20	.000
Setup Cost	509.72	.000
Backorder Units	74.41	.000
Total Cost	144.34	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Cost of Capital and Activity Ratio Three-way Interaction

TABLE 5.40

5.5.9 Raw Material Planning Method, Cost of Capital and Coefficient of Variation Interaction

An interaction identified as significant blocks dependent variables based on the raw material planning method used, the cost of capital used by the planning system and the raw material variability, its coefficient of variation. Table 5.41 presents the results of this analysis.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.29	60.93	24	.000
Hotellings	.33	64.38	24	.000
Wilks	.73	63.00	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Cost of Capital and Coefficient of Variation Three-way Interaction

TABLE 5.41

This effect is indicated to be significant as is the effect of these factors on all of the dependent variables, as shown in Table 5.42.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	35.87	.000
Finished Goods Inventory	11.02	.000
Order Cost	58.36	.000
Setup Cost	125.13	.000
Backorder Units	36.57	.000
Total Cost	46.79	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Cost of Capital and Coefficient of Variation Three-way Interaction

TABLE 5.42

5.5.10 Raw Material Planning Method, Activity Ratio and Coefficient of Variation Interaction

The last three-way interaction involving the type of raw material planning method used, looks at the overall effect of the endogenous factor in conjunction with two exogenous factors, activity ratio and coefficient of variation. This interaction also proves to be significant as is seen in Table 5.43.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.38	71.33	24	.000
Hotellings	.39	75.70	24	.000
Wilks	.70	73.98	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Activity Ratio and Coefficient of Variation Three-way Interaction

TABLE 5.43

Secondary analysis of the effect of the three factors on each dependent variable was performed and is shown in Table 5.44. This combination of factors proves to have a significant effect on all performance measures.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	74.76	.000
Finished Goods Inventory	9.41	.000
Order Cost	76.95	.000
Setup Cost	99.78	.000
Backorder Units	56.36	.000
Total Cost	41.95	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Activity Ratio and Coefficient of Variation Three-way Interaction

TABLE 5.44

5.5.11 Finished Goods Safety Stock, Average Capacity Utilization and Cost of Capital Interaction

The first three-way interaction involving just finished goods safety stock, and not raw material planning method, is joined with the average capacity utilization and the cost of capital to block the dependent variables. This interaction proves to be significant as indicated in Table 5.45.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.02	19.52	6	.000
Hotellings	.03	19.52	6	.000
Wilks	.98	19.52	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Average Capacity Utilization and Cost of Capital Three-way Interaction

TABLE 5.45

The next part of multivariate analysis of variance was performed to identify the effect of these factors on the dependent variables individually. This information is shown in Table 5.46.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	57.96	.000
Finished Goods Inventory	35.94	.000
Order Cost	4.96	.026
Setup Cost	.81	.367
Backorder Units	.45	.504
Total Cost	93.33	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Average Capacity Utilization and Cost of Capital Three-way Interaction

TABLE 5.46

Although a significant overall effect was identified, the interaction between the three factors does not have a significant effect on setup cost or backorder units.

5.5.12 Finished Goods Safety Stock, Average Capacity Utilization and Activity Ratio Interaction

This interaction blocks the experimental results based on the level of finished goods safety stock, the average capacity utilization and the activity ratio faced by the planning and execution system. It proves to be a significant effect both at the overall level and on the effect on individual performance measures. The results of these tests are shown in Tables 5.47 and 5.48.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.18	169.37	6	.000
Hotellings	.22	169.37	6	.000
Wilks	.82	169.37	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Average Capacity Utilization and Activity Ratio Three-way Interaction

TABLE 5.47

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	17.26	.000
Finished Goods Inventory	72.18	.000
Order Cost	15.30	.000
Setup Cost	204.34	.000
Backorder Units	22.25	.000
Total Cost	14.90	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Average Capacity Utilization and Activity Ratio Three-way Interaction

TABLE 5.48

5.5.13 Finished Goods Safety Stock, Average Capacity Utilization and Coefficient of Variation Interaction

The next interaction investigates finished goods safety stock, and two exogenous factors, average capacity utilization and the raw material variability, or coefficient of variation. This interaction proves to be significant and the results of the test are shown in Table 5.49.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.07	61.75	6	.000
Hotellings	.07	61.75	6	.000
Wilks	.93	61.75	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Average Capacity Utilization and Coefficient of Variation Three-way Interaction

TABLE 5.49

This interaction was then investigated to identify its effect on the dependent variables individually. These results are presented in Table 5.50.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	4.88	.027
Finished Goods Inventory	4.98	.026
Order Cost	161.09	.000
Setup Cost	145.02	.000
Backorder Units	37.42	.000
Total Cost	.18	.675

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Average Capacity Utilization and Coefficient of Variation Three-way Interaction

TABLE 5.50

An interesting result, to be investigated later in Chapter 6, shows no effect by this interaction on the total cost measure of performance, but differences in all others.

5.5.14 Finished Goods Safety Stock, Cost of Capital and Activity Ratio Interaction

The next interaction to be investigated involves the cost of capital and activity ratio the planning system uses and the service level of finished goods safety stock. This interaction proved to be significant at the overall level and its effect on each dependent variable when analyzed individually. Tables 5.51 and 5.52 provide the results of this analysis.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.26	277.81	6	.000
Hotellings	.36	277.81	6	.000
Wilks	.74	277.81	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Cost of Capital and Activity Ratio Three-way Interaction

TABLE 5.51

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	390.16	.000
Finished Goods Inventory	50.90	.000
Order Cost	565.69	.000
Setup Cost	171.99	.000
Backorder Units	40.49	.000
Total Cost	159.15	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Cost of Capital and Activity Ratio Three-way Interaction

TABLE 5.52

5.5.15 Finished Goods Safety Stock, Cost of Capital and Coefficient of Variation Interaction

The next interaction to be investigate involves the service level of finished goods safety stock, the cost of capital used by the planning system and the measure of raw material variability, coefficient of variation. A significant effect of this interaction was noted and reported in Table 5.53.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.03	23.75	6	.000
Hotellings	.03	23.75	6	.000
Wilks	.97	23.75	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Cost of Capital and Coefficient of Variation Three-way Interaction

TABLE 5.53

Subsequent analysis was performed on the individual performance measures with results shown in Table 5.54.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	19.14	.000
Finished Goods Inventory	59.34	.000
Order Cost	32.99	.000
Setup Cost	18.47	.000
Backorder Units	.05	.830
Total Cost	27.84	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Cost of Capital and Coefficient of Variation Three-way Interaction

TABLE 5.54

A significant effect was noted in all dependent variables except the level of backorder units.

5.5.16 Finished Goods Safety Stock, Activity Ratio and Coefficient of Variation Interaction

The final three-way interaction involving at least one endogenous factor blocks dependent variables based on raw material variability, the activity ratio used by the planning system and the service level of finished goods inventory. This interaction proved to be significant on an overall basis with the results shown in Table 5.55.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.11	99.27	6	.000
Hotellings	.13	99.27	6	.000
Wilks	.89	99.27	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Activity Ratio and Coefficient of Variation Three-way Interaction

TABLE 5.55

The second multivariate analysis of variance test exploring the effect of the three factors on the individual performance measures is shown in Table 5.56.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	1.00	.319
Finished Goods Inventory	11.01	.001
Order Cost	177.53	.000
Setup Cost	382.36	.000
Backorder Units	10.35	.001
Total Cost	7.21	.007

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Activity Ratio and Coefficient of Variation Three-way Interaction

TABLE 5.56

The final three-way interaction shows a significant effect in all performance measures except the level of raw material inventory.

5.6 Significant Four Factor Interactions

A variety of four factor interactions were initially identified, those proving to be significant will now be discussed.

5.6.1 Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Cost of Capital Interaction

The first four factor interaction to be investigated involves both endogenous factors, raw material planning method and finished goods safety stock, and two exogenous factors, average capacity utilization and the cost of capital. This interaction proved to be significant at both the overall and individual level. The results of this analysis are shown in Tables 5.57 and 5.58.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.36	76.24	24	.000
Hotellings	.46	88.84	24	.000
Wilks	.68	82.89	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Cost of Capital Four-way Interaction

TABLE 5.57

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	83.81	.000
Finished Goods Inventory	27.19	.000
Order Cost	61.73	.000
Setup Cost	90.22	.000
Backorder Units	7.73	.000
Total Cost	55.33	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Cost of Capital Four-way Interaction

TABLE 5.58

5.6.2 Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Activity Ratio Interaction

The next four factor interaction to be investigated involves both endogenous factors, raw material planning method and finished goods safety stock, and two different exogenous factors, average capacity utilization and the activity ratio affecting ordering cost and setup time. This interaction proved to be significant at both the overall and individual level. The results of this analysis are shown in Tables 5.59 and 5.60.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.68	158.19	24	.000
Hotellings	1.49	288.94	24	.000
Wilks	.38	216.65	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Activity Ratio Four-way Interaction

TABLE 5.59

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	43.89	.000
Finished Goods Inventory	15.05	.000
Order Cost	64.98	.000
Setup Cost	34.38	.000
Backorder Units	14.37	.000
Total Cost	127.56	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Activity Ratio Four-way Interaction

TABLE 5.60

5.6.3 Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Coefficient of Variation Interaction

The next four factor interaction to be investigated involves both endogenous factors, raw material planning method and finished goods safety stock, but the coefficient of variation is used instead of the activity with average capacity utilization to block the dependent variables. This interaction proved to be significant at the overall level and the results of this analysis are shown in Table 5.61.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.26	54.50	24	.000
Hotellings	.31	60.04	24	.000
Wilks	.75	57.50	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Coefficient of Variation Four-way Interaction

TABLE 5.61

The second test, shown in Table 5.62, indicated a significant effect on all performance measures, but an increased probability of a Type I error when making a prediction about raw material inventory.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	3.29	.011
Finished Goods Inventory	7.47	.000
Order Cost	132.71	.000
Setup Cost	118.42	.000
Backorder Units	16.20	.000
Total Cost	30.92	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization and Coefficient of Variation Four-way Interaction

TABLE 5.62

5.6.4 Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital and Activity Ratio Interaction

When evaluating the interaction between both endogenous factors and two different exogenous factors, cost of capital and the activity ratio the planning system uses, the interaction proved to be significant at the overall level and it was significant to each measure of performance. The results of these tests are shown in Tables 5.63 and 5.64.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.69	160.88	24	.000
Hotellings	1.30	251.19	24	.000
Wilks	.68	203.73	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital and Activity Ratio Four-way Interaction

TABLE 5.63

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	107.17	.000
Finished Goods Inventory	56.40	.000
Order Cost	255.80	.000
Setup Cost	664.47	.001
Backorder Units	22.42	.000
Total Cost	38.40	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital and Activity Ratio Four-way Interaction

TABLE 5.64

5.6.5 Raw Material Planning Method, Finished Goods Safety Stock, Cost of capital and Coefficient of Variation Interaction

Another four factor interaction involving both endogenous factors and two exogenous factors is created by combining the cost of capital and coefficient of variation with raw material planning method and finished goods safety stock. This interaction proved significant at the overall and individual levels and the results are shown in Table 5.65 and 5.66.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.20	41.08	24	.000
Hotellings	.23	43.96	24	.000
Wilks	.81	43.66	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital and Coefficient of Variation Four-way Interaction

TABLE 5.65

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	9.52	.000
Finished Goods Inventory	11.08	.000
Order Cost	72.02	.000
Setup Cost	107.60	.000
Backorder Units	23.37	.000
Total Cost	43.53	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital and Coefficient of Variation Four-way Interaction

TABLE 5.66

5.6.6 Raw Material Planning Method, Finished Goods Safety Stock, Activity Ratio and Coefficient of Variation Interaction

The final four factor interaction involving both endogenous factors involves blocking the dependent variables based on the raw material planning method used, the level of finished goods safety stock, the activity ratio used by the planning system and the measure of raw material variability, coefficient of variation. The first test, showing the overall significance is shown in Table 5.67.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.14	28.89	24	.000
Hotellings	.15	29.84	24	.000
Wilks	.86	29.44	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Activity Ratio and Coefficient of Variation Four-way Interaction

TABLE 5.67

Evaluating the effect of this interaction on the performance variables individually provides the results shown in Table 5.68.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	6.37	.000
Finished Goods Inventory	8.83	.000
Order Cost	11.98	.000
Setup Cost	40.92	.000
Backorder Units	3.37	.009
Total Cost	26.68	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Activity Ratio and Coefficient of Variation Four-way Interaction

TABLE 5.68

This interaction seems to have a significant effect on all dependent variables, although the significance of the effect on backorder units is less than other performance measures.

5.6.7 Raw Material Planning Method, Average Capacity Utilization, Cost of Capital and Activity Ratio Interaction

The first four factor interaction involving only one endogenous factor, specifically raw material planning method, and three exogenous factors, average capacity utilization, cost of capital and activity ratio, proves to be significant on an overall basis. The results of this analysis are shown in Table 5.69.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.30	63.31	24	.000
Hotellings	.36	69.45	24	.000
Wilks	.72	66.69	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Average Capacity Utilization, Cost of Capital and Activity Ratio Four-way Interaction

TABLE 5.69

Evaluation of the effect of this interaction on the individual performance measures is shown in Table 5.70.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	3.36	.009
Finished Goods Inventory	27.52	.000
Order Cost	40.01	.000
Setup Cost	46.82	.000
Backorder Units	37.49	.000
Total Cost	85.19	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Average Capacity Utilization, Cost of Capital and Activity Ratio Four-way Interaction

TABLE 5.70

A significant effect on all performance measures is indicated.

5.6.8 Raw Material Planning Method, Average Capacity Utilization, Cost of Capital and Coefficient of Variation Interaction

The next interaction to be investigated blocks dependent variables based on four factors, raw material planning method, average capacity utilization and coefficient of variation. This set of interactions proved significant at both the overall and individual performance measure level. Multivariate analysis of variance results are presented in Tables 5.71 and 5.72.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.20	41.51	24	.000
Hotellings	.22	43.33	24	.000
Wilks	.81	42.57	24	.000

Multivariate Analysis of Variance Overall Equality Test
Raw Material Planning Method, Average Capacity Utilization,
Cost of Capital and Coefficient of Variation
Four-way Interaction

TABLE 5.71

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	66.55	.000
Finished Goods Inventory	36.21	.000
Order Cost	41.64	.000
Setup Cost	67.53	.000
Backorder Units	17.04	.000
Total Cost	41.16	.000

Multivariate Analysis of Variance Univariate F-Tests
Raw Material Planning Method, Average Capacity Utilization,
Cost of Capital and Coefficient of Variation
Four-way Interaction

TABLE 5.72

5.6.9 Raw Material Planning Method, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Interaction

The next interaction investigated required the analysis to block the dependent variables based on the raw material

planning method used, the average capacity utilization, the activity ratio used by the planning system and the raw material variability measure, coefficient of variation. As was seen in the previous analysis, this interaction is significant at both the overall and individual performance measure basis. The results of this analysis are shown in Tables 5.73 and 5.74

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.28	57.11	24	.000
Hotellings	.33	64.13	24	.000
Wilks	.74	60.82	24	.000

Multivariate Analysis of Variance Overall Equality Test
Raw Material Planning Method, Average Capacity Utilization,
Activity Ratio and Coefficient of Variation
Four-way Interaction

TABLE 5.73

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	20.40	.000
Finished Goods Inventory	14.19	.000
Order Cost	145.20	.000
Setup Cost	128.60	.000
Backorder Units	10.11	.000
Total Cost	25.49	.000

Multivariate Analysis of Variance Univariate F-Tests
Raw Material Planning Method, Average Capacity Utilization,
Activity Ratio and Coefficient of Variation
Four-way Interaction

TABLE 5.74

5.6.10 Raw Material Planning Method, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction

The last significant interaction dealing with the raw material planning method and only exogenous variables blocks performance measures based on raw material planning method, cost of capital, activity ratio and the coefficient of variation of the raw material. This interaction proved significant at both levels and the results of that analysis is presented in Tables 5.75 and 5.76.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.28	57.92	24	.000
Hotellings	.31	60.29	24	.000
Wilks	.74	59.42	24	.000

Multivariate Analysis of Variance Overall Equality Test
Raw Material Planning Method, Cost of Capital, Activity Ratio and Coefficient of Variation
Four-way Interaction

TABLE 5.75

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	46.05	.000
Finished Goods Inventory	27.67	.000
Order Cost	69.03	.000
Setup Cost	57.44	.000
Backorder Units	45.70	.000
Total Cost	32.36	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Cost of Capital, Activity Ratio and Coefficient of Variation
Four-way Interaction

TABLE 5.76

5.6.11 Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Activity Ratio Interaction

This significant interaction blocks the six dependent variables using the service level of finished goods safety stock, the average capacity utilization, the cost of capital used by the planning system and the activity ratio affecting order cost and setup time. The first multivariate test for overall equality was performed, the results are shown in Table 5.77.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.09	72.74	6	.000
Hotellings	.09	72.74	6	.000
Wilks	.91	72.74	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Activity Ratio Four-way Interaction

TABLE 5.77

This interaction proves to be significant as does the effect of these four factors on the individual performance measures. Table 5.78 shows the results of the statistical tests on the dependent variables on an individual basis.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	80.58	.000
Finished Goods Inventory	33.31	.000
Order Cost	129.54	.000
Setup Cost	154.18	.000
Backorder Units	8.82	.003
Total Cost	87.14	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Activity Ratio
Four-way Interaction

TABLE 5.78

5.6.12 Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Coefficient of Variation

The next significant interaction requires classifying performance measures using the levels of finished goods safety stock, average capacity utilization, cost of capital and coefficient of variation. Table 5.79 shows the difference that exists in the vectors created from all performance measures.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.08	67.85	6	.000
Hotellings	.09	67.85	6	.000
Wilks	.92	67.85	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Coefficient of Variation Four-way Interaction

TABLE 5.79

As was the case in lesser order interactions, when safety stock is the only endogenous variable combined with exogenous variables, some dependent variables are not affected by the use of safety stock. Table 5.80 shows the results of this interaction on the individual performance measures.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	6.91	.009
Finished Goods Inventory	.44	.509
Order Cost	208.48	.000
Setup Cost	103.00	.000
Backorder Units	62.51	.000
Total Cost	48.12	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Coefficient of Variation Four-way Interaction

TABLE 5.80

This combination of endogenous and exogenous factors has a significant effect on the level of all variables except finished goods inventory.

5.6.13 Finished Goods Safety Stock, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Interaction

When the six dependent variables are categorized on the basis of the level of finished goods safety stock, average capacity utilization, activity ratio and coefficient of variation, another four factor interaction is open for analysis. This interaction proved significant at the overall level with statistical results shown in Table 5.81.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.05	36.87	6	.000
Hotellings	.05	36.87	6	.000
Wilks	.95	36.87	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Four-way Interaction

TABLE 5.81

The four factor interaction also has an varied effect on the individual performance measures, some are effected by the interaction, others are not effected. Table 5.82 presents these results.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	5.44	.020
Finished Goods Inventory	16.40	.000
Order Cost	2.07	.150
Setup Cost	1.36	.243
Backorder Units	3.23	.072
Total Cost	6.67	.010

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Four-way Interaction

TABLE 5.82

Although this interaction significantly effects raw material and finished goods inventory levels and total cost, the other dependent variables, order cost, setup time and backorder units, are not effected by this interaction.

5.6.14 Finished Goods Safety Stock, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction

The final four factor interaction proving to be significant involves finished goods safety stock, cost of capital, activity ratio and the coefficient of variation. It proved to be significant at the overall and individual performance measure levels with the results presented in Tables 5.83 and 5.84.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.07	55.21	6	.000
Hotellings	.07	55.21	6	.000
Wilks	.93	55.21	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Cost of Capital, Activity Ratio and Coefficient of Variation
Four-way Interaction

TABLE 5.83

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	18.17	.000
Finished Goods Inventory	73.82	.000
Order Cost	71.42	.000
Setup Cost	79.09	.000
Backorder Units	5.03	.025
Total Cost	46.39	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Cost of Capital, Activity Ratio and Coefficient of Variation
Four-way Interaction

TABLE 5.84

5.7 Significant Five Factor Interactions

The next area of statistical investigation involves those interactions proving to be significant when five factors are used to block the six dependent variables.

5.7.1 Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Activity Ratio Interaction

The first five factor interaction proving significant is the interaction between both endogenous factors, raw material planning method and finished goods safety stock, and three of the four exogenous factors, average capacity utilization, cost of capital and activity ratio. This

interaction proved to be significant at both the overall and individual level of statistical analysis. Results are shown in Tables 5.85 and 5.86.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.33	69.28	24	.000
Hotellings	.40	77.11	24	.000
Wilks	.70	73.56	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, and Activity Ratio Five-way Interaction

TABLE 5.85

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	75.94	.000
Finished Goods Inventory	28.04	.000
Order Cost	54.05	.000
Setup Cost	109.18	.000
Backorder Units	11.93	.000
Total Cost	39.11	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, and Activity Ratio Five-way Interaction

TABLE 5.86

5.7.2 Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital and Coefficient of Variation Interaction

The next significant interaction is a variation on the five factor interaction preceding significant interaction. Blocking is done using both endogenous variables and two of the same exogenous variables, average capacity utilization and cost of capital, but instead of using the activity ratio, the coefficient of variation is the fifth factor used in the blocking process. This interaction proved significant at the overall level as is shown in Table 5.87.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.15	29.25	24	.000
Hotellings	.16	30.19	24	.000
Wilks	.86	29.80	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, and Coefficient of Variation Five-way Interaction

TABLE 5.87

This interaction was then analyzed to identify its effect on all six performance measures individually, as shown in Table 5.88.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	2.78	.026
Finished Goods Inventory	40.08	.000
Order Cost	66.45	.000
Setup Cost	41.10	.000
Backorder Units	25.74	.000
Total Cost	38.59	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, and Coefficient of Variation Five-way Interaction

TABLE 5.88

This interaction proves significant to all dependent variables, however, if a smaller standard for a Type I Error were specified, the effect may not be significant to raw material inventory.

5.7.2 Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Activity Ratio and Coefficient of Variation Interaction

The next significant interaction is another variation on the preceding five factor significant interaction. Blocking is done using both endogenous variables and two of the same exogenous variables, average capacity utilization and coefficient of variation, but instead of using the cost of capital, the activity ratio is the fifth factor used in

the blocking process. This interaction proved significant at the overall level as is shown in Table 5.89.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.24	50.38	24	.000
Hotellings	.29	55.05	24	.000
Wilks	.77	52.91	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Activity Ratio, and Coefficient of Variation Five-way Interaction

TABLE 5.89

This interaction was then analyzed to identify its effect on all six performance measures individually, as shown in Table 5.90.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	8.74	.000
Finished Goods Inventory	13.00	.000
Order Cost	47.03	.000
Setup Cost	114.43	.000
Backorder Units	7.44	.000
Total Cost	31.31	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Activity Ratio, and Coefficient of Variation Five-way Interaction

TABLE 5.90

This interaction proves significant to all dependent variables.

5.7.4 Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction

The final interaction involving both endogenous factors and a trio of exogenous factors involves blocking the dependent variables using raw material planning method, finished goods safety stock, cost of capital, activity ratio and coefficient of variation. This interaction proved to be significant at both levels of analysis with low values specified for a Type I Error. This information presented in Tables 5.91 and 5.92.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.16	32.81	24	.000
Hotellings	.17	33.68	24	.000
Wilks	.84	33.34	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital, Activity Ratio, and Coefficient of Variation Five-way Interaction

TABLE 5.91

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	5.20	.000
Finished Goods Inventory	13.58	.000
Order Cost	38.48	.000
Setup Cost	64.63	.000
Backorder Units	22.91	.000
Total Cost	30.12	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Cost of Capital, Activity Ratio and Coefficient of Variation Five-way Interaction

TABLE 5.92

5.7.5 Raw Material Planning Method, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Interaction

Because of the magnitude of this interaction, five factors, only one combination of factors using raw material planning method without finished goods safety stock can be created for analysis. This interaction blocks the dependent variables using raw material planning method and all exogenous factors. It proved significant at the overall and individual performance measure level, as shown in Tables 5.93 and 5.94.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.38	81.86	24	.000
Hotellings	.46	88.58	24	.000
Wilks	.66	85.87	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Five-way Interaction

TABLE 5.93

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	91.09	.000
Finished Goods Inventory	24.71	.000
Order Cost	118.67	.000
Setup Cost	138.76	.000
Backorder Units	12.34	.000
Total Cost	39.26	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Five-way Interaction

TABLE 5.94

5.7.6 Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation

The final five factor interaction is formed in the same way as the preceding interaction. Finished goods safety stock, when used without raw material planning method, can only form one five factor combination with all exogenous factors being employed to block the dependent variables. This interaction proved significant at the overall level as shown in Table 5.95.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.08	70.93	6	.000
Hotellings	.09	70.93	6	.000
Wilks	.92	70.93	6	.000

Multivariate Analysis of Variance Overall Equality Test

Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Five-way Interaction

The next test, presented in Table 5.96, shows some differences in the effect of this interaction on individual measures of performance. Some performance measures are affected by the interaction, others are not.

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	4.26	.039
Finished Goods Inventory	2.64	.105
Order Cost	.00	.991
Setup Cost	8.35	.004
Backorder Units	65.79	.000
Total Cost	93.39	.000

Multivariate Analysis of Variance Univariate F-Tests

Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Five-way Interaction

TABLE 5.95

Finished goods inventory level and order cost are not effected by this interaction, all other performance measures are.

5.8 Six Factor Interaction

Because this experiment only involves six factors there is just one interaction to be investigated at this level. Blocking of the six dependent variables was done using all six factors, endogenous and exogenous. Tables 5.97 and 5.98 present the results of these tests.

Test Name	Value	Approximate F Value	Degrees of Freedom	Significance of F Value
Pillais	.19	38.72	24	.000
Hotellings	.22	41.67	24	.000
Wilks	.82	40.31	24	.000

Multivariate Analysis of Variance Overall Equality Test

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Six-way Interaction

TABLE 5.97

Dependent Variable	F Ratio	Significance of F Value
Raw Material Inventory	5.56	.000
Finished Goods Inventory	25.09	.000
Order Cost	60.75	.000
Setup Cost	112.58	.000
Backorder Units	20.50	.000
Total Cost	37.45	.000

Multivariate Analysis of Variance Univariate F-Tests

Raw Material Planning Method, Finished Goods Safety Stock, Average Capacity Utilization, Cost of Capital, Activity Ratio and Coefficient of Variation Six-way Interaction

TABLE 5.98

This interaction proved significant at both levels with a high level of significance.

5.9 Summary

This chapter detailed the statistical analysis performed on the simulation model data. Multivariate analysis of variance was performed to test the effect of all possible interactions and main effects on the overall results and then used to test the significance of those interactions and effects on individual performance measures.

Those interactions and effects tested involved all possible combinations of factors incorporating at least one

of the exogenous factors, interactions dealing only with exogenous factors were not discussed.

All interactions identified for analysis proved to be significant at the overall level, but had varying effects on the individual performance measures. Further analysis will be presented in Chapter 6.

MICHIGAN STATE UNIV. LIBRARIES
31293010907545

MICHIGAN STATE UNIVERSITY LIBRARIES
3 1293 01090 7552

LIBRARY
Michigan State
University

THE EFFECT OF A DYNAMIC BILL OF MATERIAL ON MATERIAL PLANNING AND CONTROL SYSTEMS IN PROCESS INDUSTRIES

VOLUME TWO

By

David Michael Lyth

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Management

1987

CHAPTER SIX

STATISTICAL ANALYSIS

6.1 Introduction

This chapter serves to provide the reader with the method of statistical analysis performed after the initial multivariate and univariate analysis of variance presented in Chapter 5. The results of these analyses are offered as are their managerial implications to the planning and control systems of process industries.

6.2 Statistical Analysis Overview

Koeppel (1973) discussed some of the problems encountered when dealing with analysis of variance of problems with three or more factors. His model for analysis of three-factor experiments is as follows:

> A useful way of summarizing the analysis of simple effects is to consider how the different analyses are related to the standard analysis of variance. We have already indicated that the interpretation of the standard analysis begins with the three-way interaction, moves on to the two-way interactions, if the higher-order interaction is not significant, and ends up with the main effects, if a particular factor does not enter into an interaction with another variable. . .If the interaction is significant, we will probably . . . pay little attention to analysis involving two-way matrices (i.e., two-way interactions) and main effects. With a significant triple interaction,

> the most likely subsequent analysis would be an assessment of simple two-way interactions. (Koeppel, 1973, p.292)

Because the sixth-order interaction in this problem proved significant, as seen in Chapter 5, the statistical analysis will follow Koeppel's plan and only discuss the highest order interaction present, the six-way interaction.

Koeppel (1982) presented a further discussion of the problems faced in analysis of three factor designs. His discussion of exogenous, or independent factors, provides further clarification of the analysis performed here.

> A second major way of studying interaction is . . . by isolating or combining different levels of the independent variables . . . to define one or more of the independent variables and express the three-way interaction in terms of comparisons and "intact" independent variables. (Koeppel, 1982, p. 294 - 295)

When applying Koeppel's plan to this research the result is a comparison of the effect of raw material planning method and service level of finished goods safety stock for each combination of exogenous variables. This results in ten options open to management, all possible combinations of five raw material planning methods and two levels of safety stock. By viewing the two exogenous factors in this fashion, the system design options open to management are realistically represented. A manager would be able to choose both a raw material planning method and level of finished goods safety stock, thus optimizing the system

design. These planning system design options are shown in Table 6.1.

During the discussion of planning system responses, a set of abbreviations of the planning system responses will be used. These are also identified in Table 6.1.

Planning System Design

Raw Material Planning Method	Finished Goods Safety Stock	Abbreviation
Modified EOQ	90% Service Level	EOQ-90%
Modified EOQ	50% Service Level	EOQ-50%
Modified Lot-for-Lot 50% Service Level	90% Service Level	L50-90%
Modified Lot-for-Lot 50% Service Level	50% Service Level	L50-50%
Modified Lot-for-Lot 70% Service Level	90% Service Level	L70-90%
Modified Lot-for-Lot 70% Service Level	50% Service Level	L70-50%
Modified Lot-for-Lot 90% Service Level	90% Service Level	L90-90%
Modified Lot-for-Lot 90% Service Level	50% Service Level	L90-50%
Stochastic Dynamic Programming	90% Service Level	SDP-90%
Stochastic Dynamic Programming	50% Service Level	SDP-50%

Planning System Responses to Raw Material Variability

TABLE 6.1

These options will then be evaluated at each possible combination of exogenous variable level settings. Because there are four exogenous variables with two settings, or values, for each variable, the result is sixteen different environments to compare performance of the ten different planning systems. These exogenous variable settings are shown in Table 6.2. In terms of the managerial implications of this analysis, it is assumed that a manager would have some idea of the environment a particular process industry would be operating in. As a result, the system could be designed based on a given set of exogenous factors rather than trying to design one system for all possible environments.

Exogenous Factor Setting	Average Capacity Utilization	Cost of Capital	Activity Ratio	Coefficient of Variation
1	60%	10:1	50:1	.03:1
2	60%	10:1	50:1	.10:1
3	60%	10:1	250:1	.03:1
4	60%	10:1	250:1	.10:1
5	60%	5:1	50:1	.03:1
6	60%	5:1	50:1	.10:1
7	60%	5:1	250:1	.03:1
8	60%	5:1	250:1	.10:1
9	80%	10:1	50:1	.03:1
10	80%	10:1	50:1	.10:1
11	80%	10:1	250:1	.03:1
12	80%	10:1	250:1	.10:1
13	80%	5:1	50:1	.03:1
14	80%	5:1	50:1	.10:1
15	80%	5:1	50:1	.03:1
16	80%	5:1	250:1	.10:1

All Possible Exogenous Factor Settings

TABLE 6.2

By exploring the simple effects and possible interactions between choice of raw material planning method and level of finished goods safety stock at all possible exogenous level settings, the effect of those factors can be ascertained and related to the planning and control systems of process industries.

A variety of methods are available to identify the minimum difference between cell means that would be significant. Kirk (1982) recommends one of the more widely used procedures for evaluating all pairwise comparisons among means, the HSD (honestly significant difference) test or WSD (wholly significant difference) test, developed by Tukey (1953).

Based on his formulation and the mean square error term from the six-factor interaction, the HSD for all dependent variables were calculated using equation 6.1 and a probability of a Type I error of .05. These values are presented in Table 6.3.

$$HSD = q(a,n) * (MSE/n)^{1/2} \quad (6.1)$$

Where HSD - minimum difference between means for significant difference to exist

q - critical value of the studentized range statistic

a - number of means being compared

n - number of values used to calculate cell means

MSE - mean square error for dependent variable

If the difference between cell means exceeds this critical value, it can be assumed that the difference between the cell means is significant and that a difference exists between those population means.

Performance Measure	Mean Square Error	Critical Difference
Raw Material Inventory	157451.6	116.3
Finished Goods Inventory	431931.3	578.4
Order Cost	109476.7	291.2
Setup Cost	11.0	2.9
Backorder Units	105065685.5	9020.2
Total Cost	37579090.2	5394.6

Tukey HSD Test Critical Difference Values

TABLE 6.3

These critical differences will be used to identify significant relationships between cell means while discussing the endogenous factors at all possible exogenous factor settings.

Before moving on to the analysis of endogenous factors, a clarification of one of the terms used to calculate HSD is necessary. Koeppel (1973) recommends using the MSE error term from the six factor multivariate analysis of variance presented in Chapter 5 to calculate the HSD. By using this error term to identify significant differences, the full effect of the six-way interaction is taken into account and relationships that may not be significant at a lower order interaction are not identified.

6.3 Six Factor Interaction Analysis

Because exogenous variables are beyond the control of the planning and control system, dependent variable means will be presented on the basis of a particular set of exogenous variables rather than presenting the values for a given dependent variable based on all possible combinations of endogenous and exogenous variables. The means for each combination of exogenous factor settings will be presented, the statistical analysis results provided and any consistent effects of endogenous variables will be identified.

6.3.1 First Exogenous Factor Setting Results

The first combination of exogenous factors and the means of the dependent variables based on the combination of raw material planning method and finished goods safety stock is presented in Table 6.4. To aid the analysis, these values are presented graphically in Figures 6.1 through 6.6. Through out the presentation of results, a consistent notation will be used in each of the six figures for all sixteen combinations of exogenous variables. In order to distinguish from costs generated by the two finished goods safety stock service levels, a "5" will be used to indicate a service level of 50% and a "9" to indicate a service level of 90%.

The overall rank of each planning system response was determined by ranking individual performance measure means

by row and calculating the average rank for that planning system response. If a tie occurred, the ranks for those planning methods with a tie were averaged and that number assigned as its rank, e.g. if two responses tied for second lowest mean, a rank of 2.5 was assigned as their ranks.

Exogenous Level Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10:1
Activity Ratio	50:1
Coefficient of Variation	.03:1

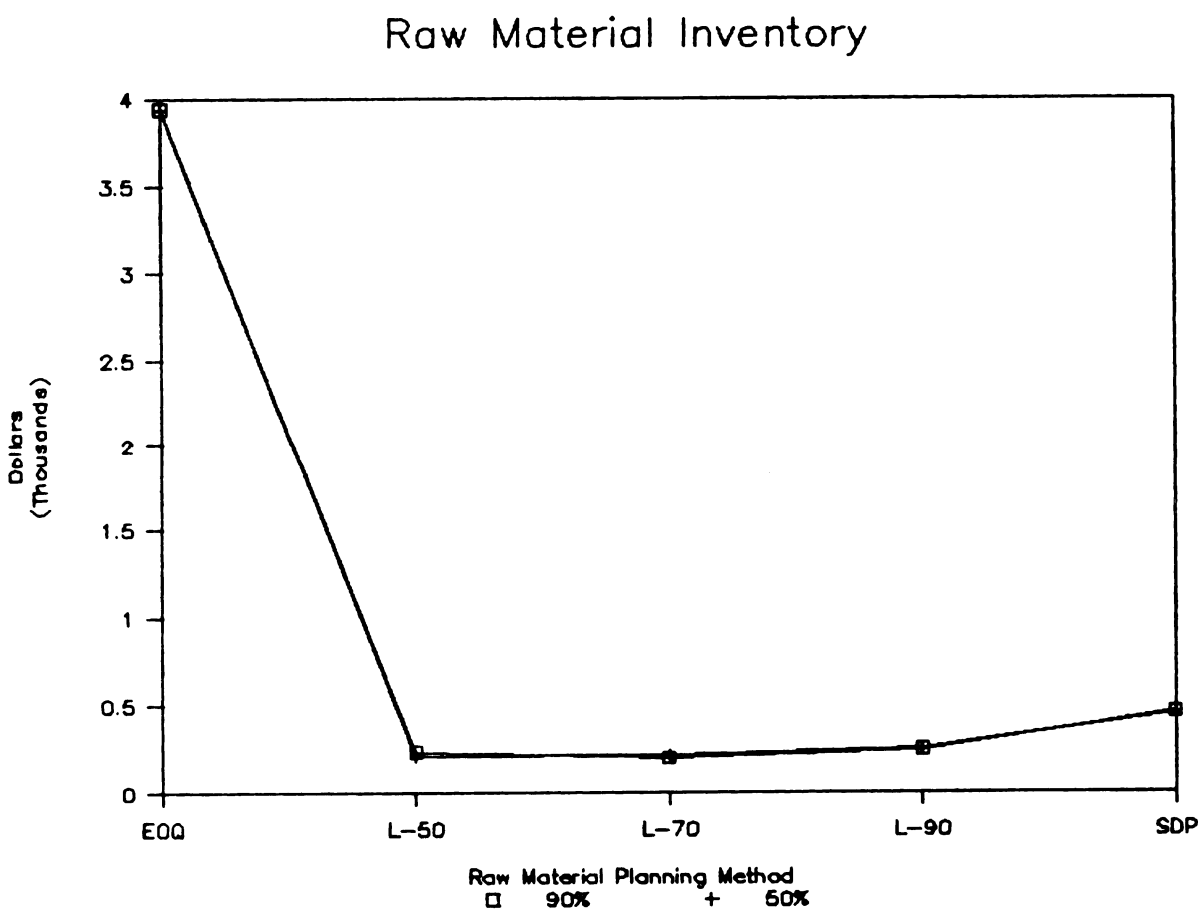
Raw Material Planning Method and Level of Finished Goods Safety Stock

Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	3942.5	3934.9	233.2	208.2	199.9	215.6	248.4	254.2	461.2	451.1
Finished Goods Inventory	3762.0	596.5	3068.3	126.0	4109.4	207.2	4008.7	457.2	3628.0	221.2
Order Cost	443.7	510.9	2396.0	2486.7	2261.6	2755.2	2183.2	2245.7	1948.1	1978.6
Setup Time	22.9	22.6	22.5	23.1	22.7	23.0	22.9	22.8	22.6	23.0
Backorder Units	5200.8	13409.0	3192.3	1560.6	1138.3	7228.4	0.0	425.7	0.0	36.8
Total Cost	44124.1	29087.1	23739.1	10831.1	28471.9	12263.9	28039.4	10402.7	26919.7	9939.2
Overall Rank	10	9	4.5	4.5	7	8	6	2	3	1
Average Rank	7.25	6.25	5.17	5.17	5.83	6.08	5.67	4.50	4.67	4.42

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS
FIRST EXOGENOUS FACTOR SETTING

TABLE 6.4

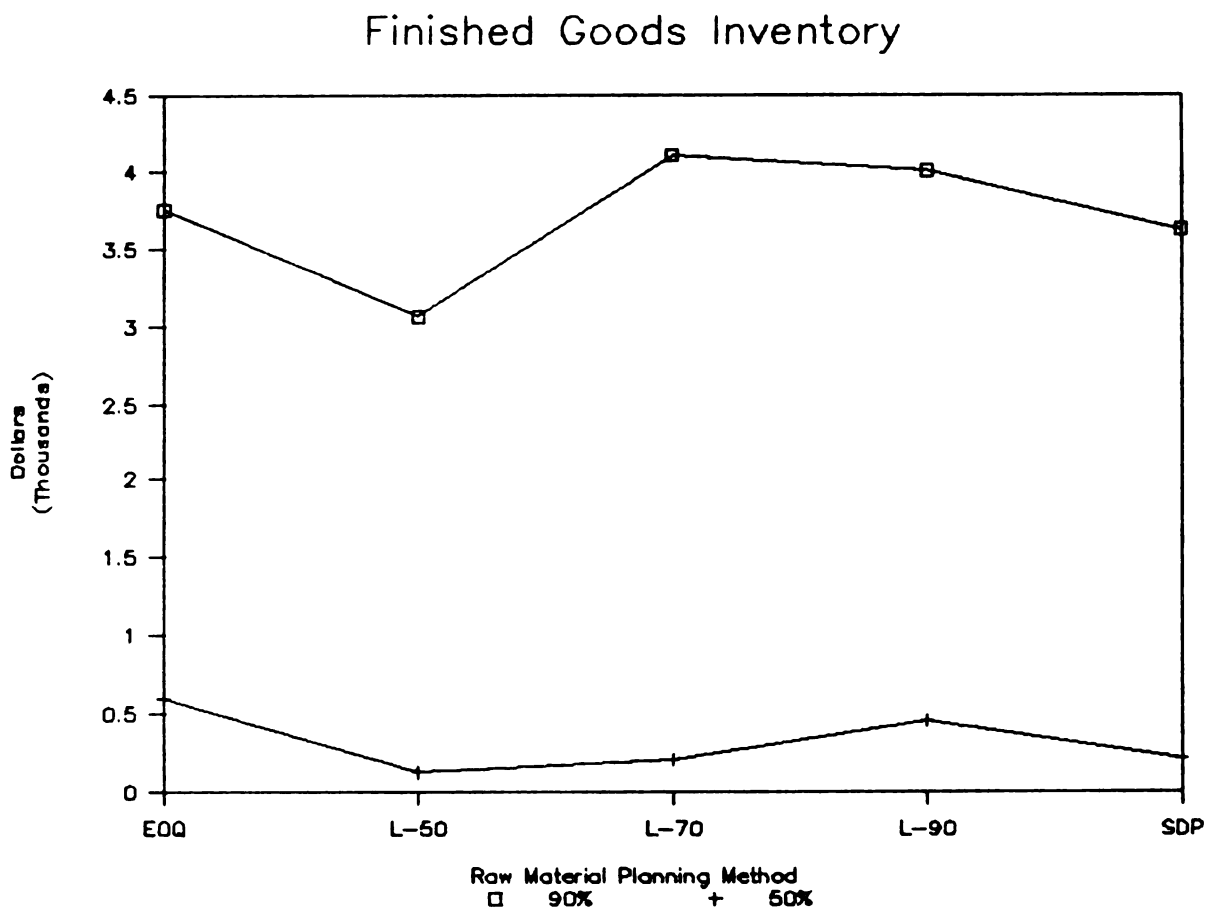


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

RAW MATERIAL INVENTORY--FIRST EXOGENOUS FACTOR SETTING

FIGURE 6.1

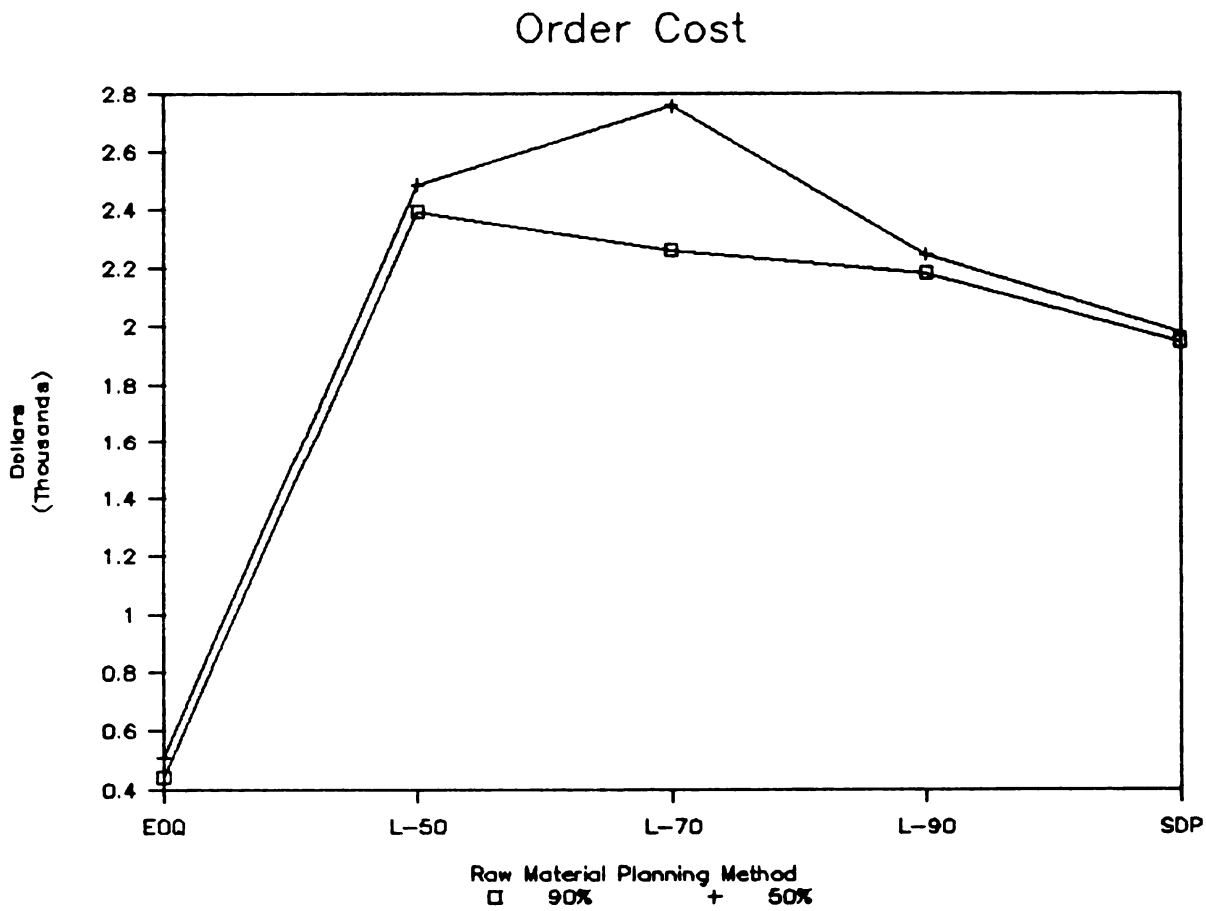


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

FINISHED GOODS--FIRST EXOGENOUS FACTOR SETTING

FIGURE 6.2

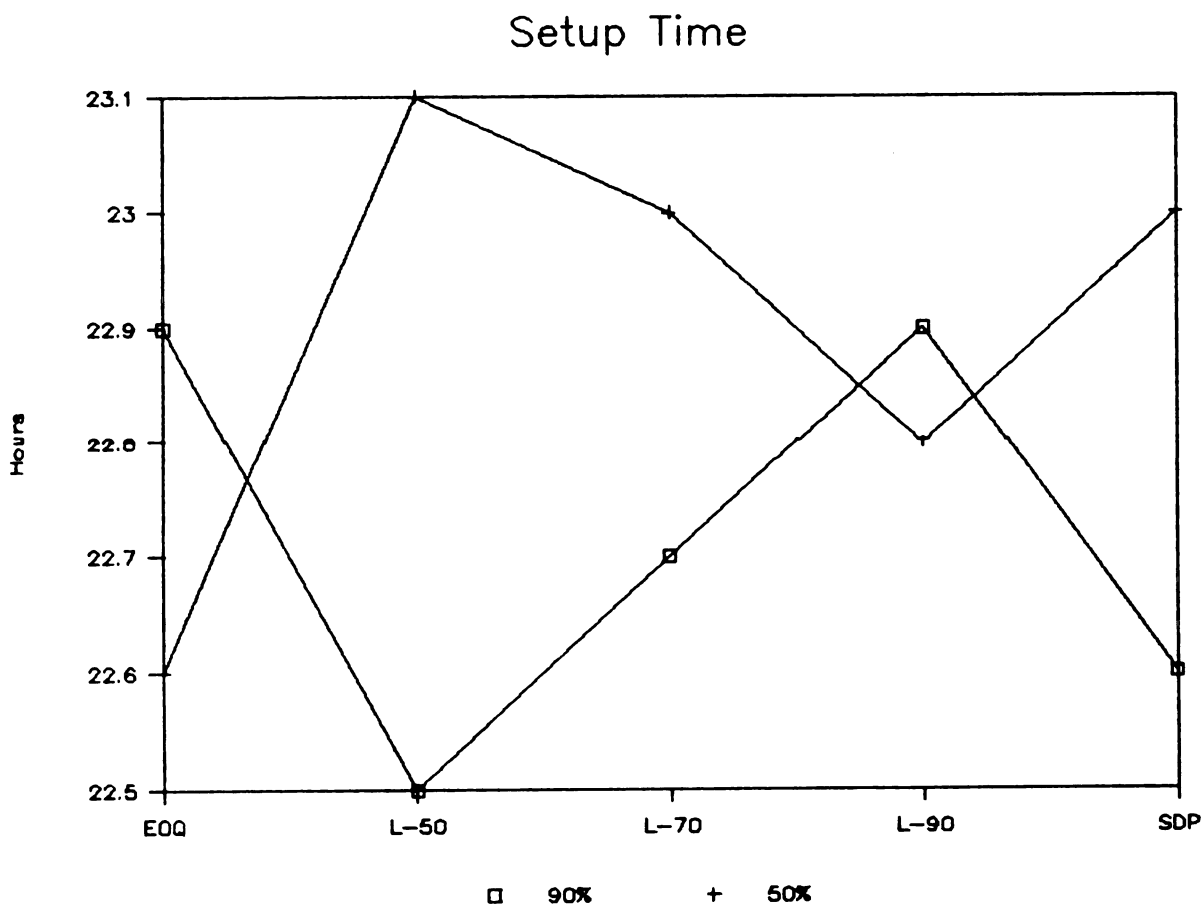


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

ORDER COST--FIRST EXOGENOUS FACTOR SETTING

FIGURE 6.3

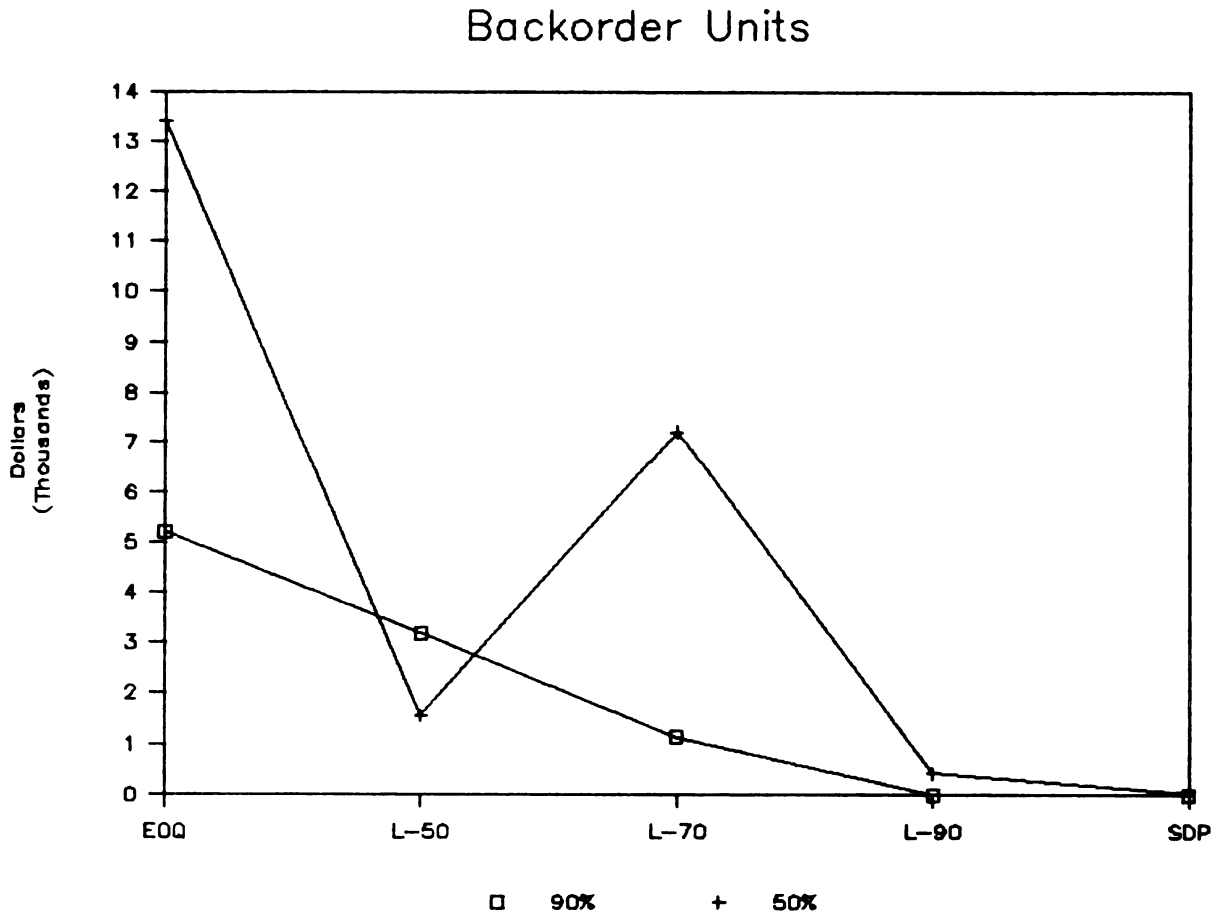


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

SETUP TIME--FIRST EXOGENOUS FACTOR SETTING

FIGURE 6.4

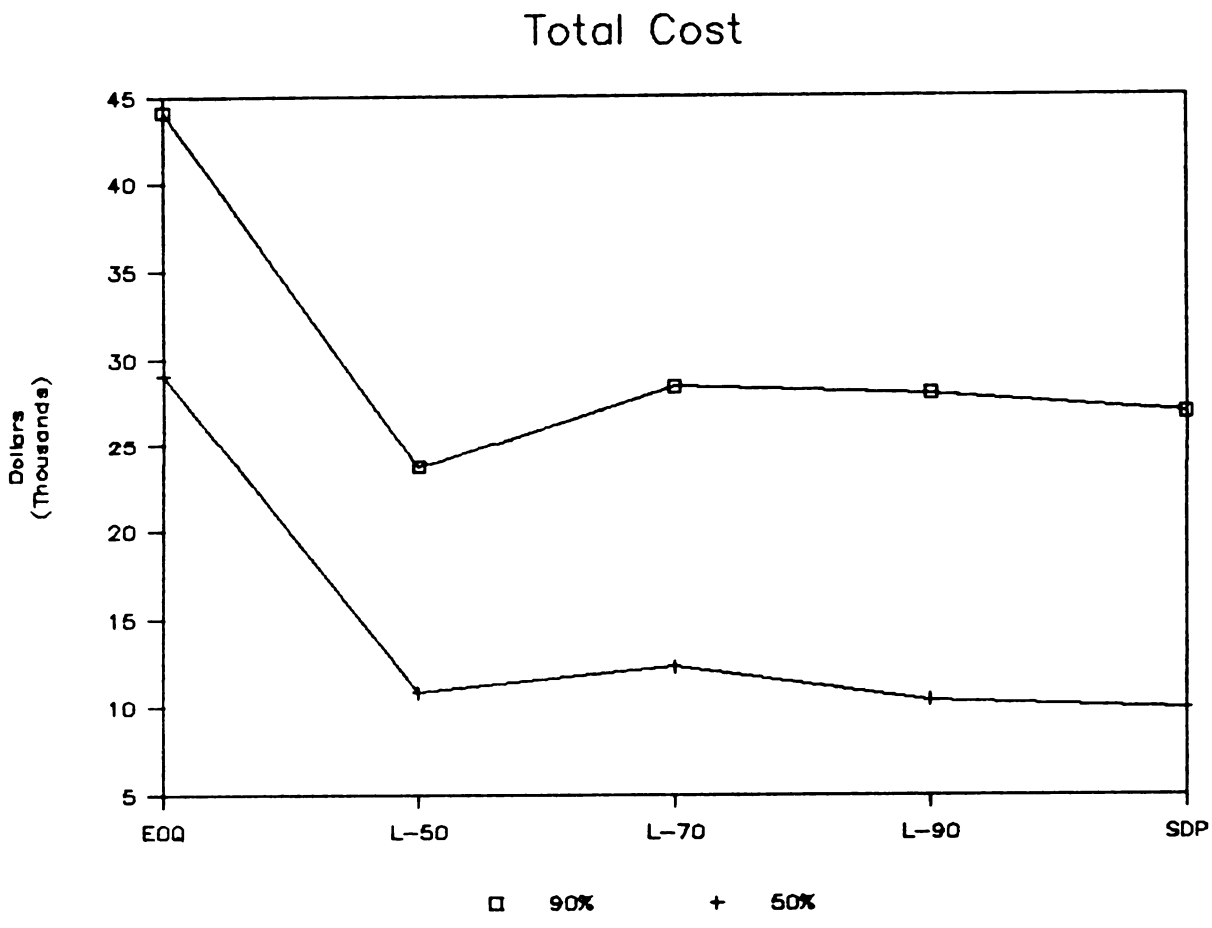


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

BACKORDER UNITS--FIRST EXOGENOUS FACTOR SETTING

FIGURE 6.5



Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

TOTAL COST--FIRST EXOGENOUS FACTOR SETTING

FIGURE 6.6

Analysis of raw material inventory for significant differences shows three distinct groups of planning responses. The groups are organized around the type of raw material planning method employed and ignores the level of finished goods safety stock. The economic order quantity method is larger than the stochastic dynamic programming method which is, in turn, larger than all of the remaining lot-for-lot planning methods. Regardless of the service level of the lot-for-lot ordering methods, 50%, 70% or 90%, they are all statistically# equal.

When evaluating finished goods inventory level, the opposite situation is noticed. Two groups of means are statistically different from one another. The groups are formed based on the finished goods safety stock level, the 90% service level has a higher average finished goods inventory than the 50% service level, no difference exists based on the raw material planning method employed.

Order cost indicates an inverse relationship to raw material inventory and the significant groups are categorized based on raw material planning method, the level of finished goods safety stock has no effect on this performance measure. As it might be expected, those raw planning material planning methods with high inventory have low order cost, those with low inventory have high order cost. All lot-for-lot groups have equal order cost but the means are significantly larger than the average order cost generated by the stochastic dynamic programming methods.

The modified economic order quantity forms the last group and it is significantly less than the other methods.

No significant difference exists in setup time for all planning responses.

In comparing the average number of backorder units generated by the system, a significant difference exists between planning methods with the lowest mean, SDP-90% and L90-90%, and the highest mean, EOQ-50%, but no other significant relationships can be identified.

Finally, total cost has three blocks of planning responses statistically equal, but significantly different from one another. The group with the lowest total cost includes SDP-50%, L90-50%, L50-50% and L70-50%. The second set of planning responses includes all remaining alternatives except EOQ-90% which is significantly larger than all other responses.

6.3.2 Second Exogenous Factor Level Setting

The next environment faced by the planning systems, the average performance and rank are shown in Table 6.5. It has an increased coefficient of variation, the measure of raw material variability. Figures 6.7 through 6.12 present this information on an individual performance measure basis.

Exogenous Level Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10:1
Activity Ratio	50:1
Coefficient of Variation	.10:1

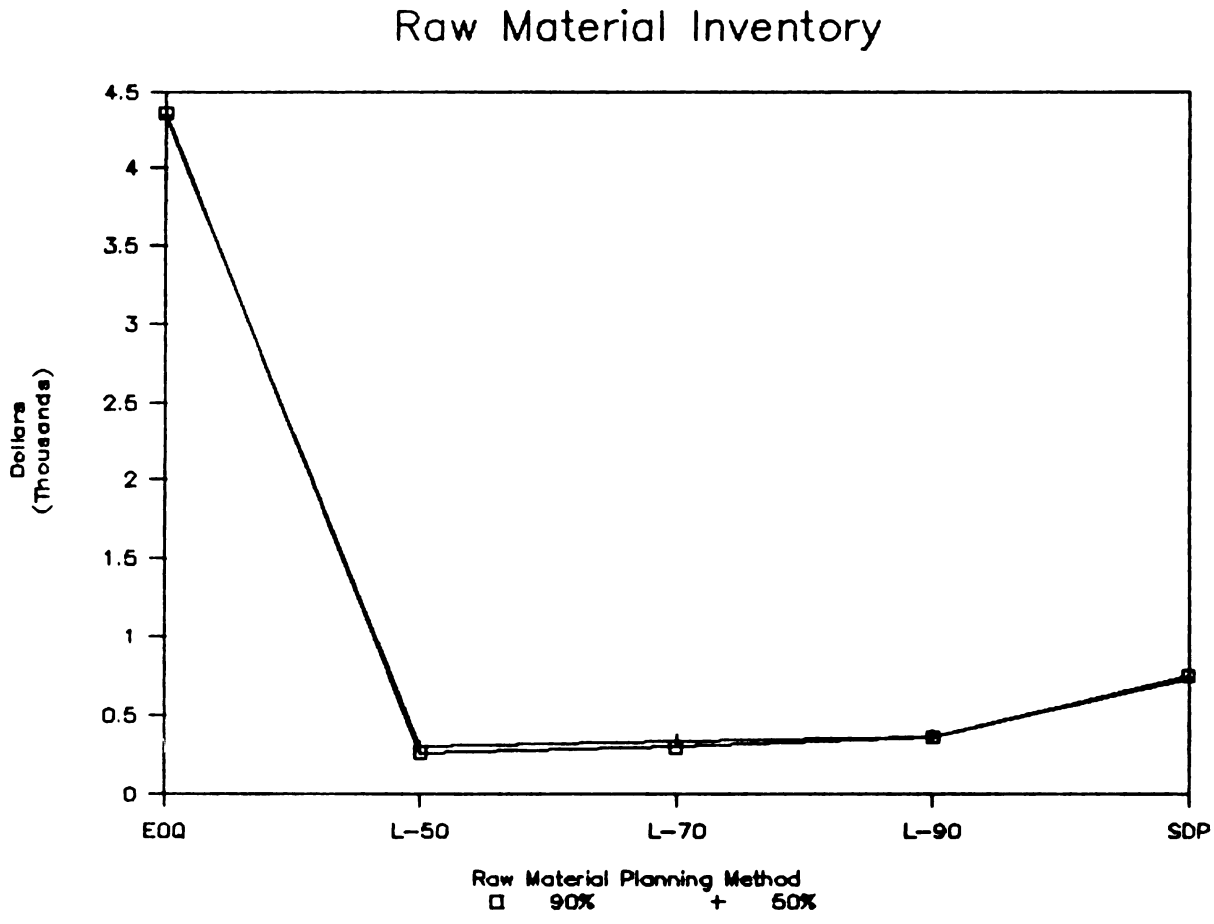
Raw Material Planning Method and Level of Finished Goods Safety Stock

Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	4359.4	4337.3	263.1	302.2	300.6	339.1	364.6	365.7	750.6	734.4
Finished Goods Inventory	3439.3	615.1	2632.2	94.8	3167.3	163.8	3079.8	242.0	3552.2	223.3
Order Cost	434.5	528.1	2502.7	2575.8	2234.8	2822.8	2253.4	2291.2	1785.6	1792.1
Setup Time	22.7	23.0	22.7	23.2	22.9	22.8	23.1	22.8	22.9	22.8
Backorder Units	21714.4	30399.2	1584.3	6673.5	10240.5	39391.9	416.6	3597.4	200.8	133.0
Total Cost	46256.4	32937.7	21605.8	12548.6	25285.1	13844.5	20136.6	10255.1	27901.3	11160.5
Overall Rank	10	9	2	5	6	4	8	3	7	1
Average Rank	6.58	8.60	4.25	5.50	5.75	5.00	7.67	4.50	5.92	3.50

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS
SECOND EXOGENOUS FACTOR SETTING

TABLE 6.5



Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

RAW MATERIAL INVENTORY--SECOND EXOGENOUS FACTOR SETTING

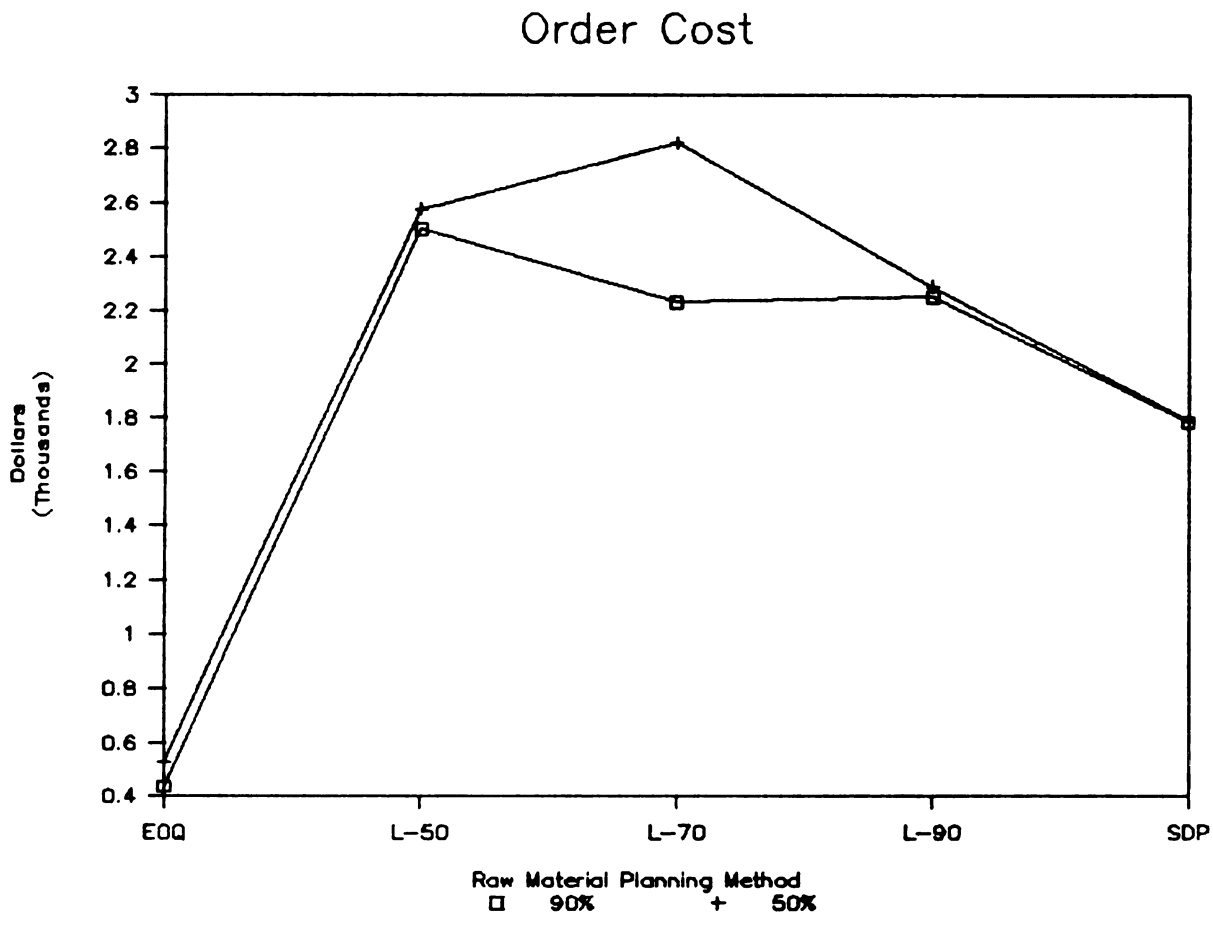
FIGURE 6.7

Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

FINISHED GOODS INVENTORY--SECOND EXOGENOUS FACTOR SETTING

FIGURE 6.8

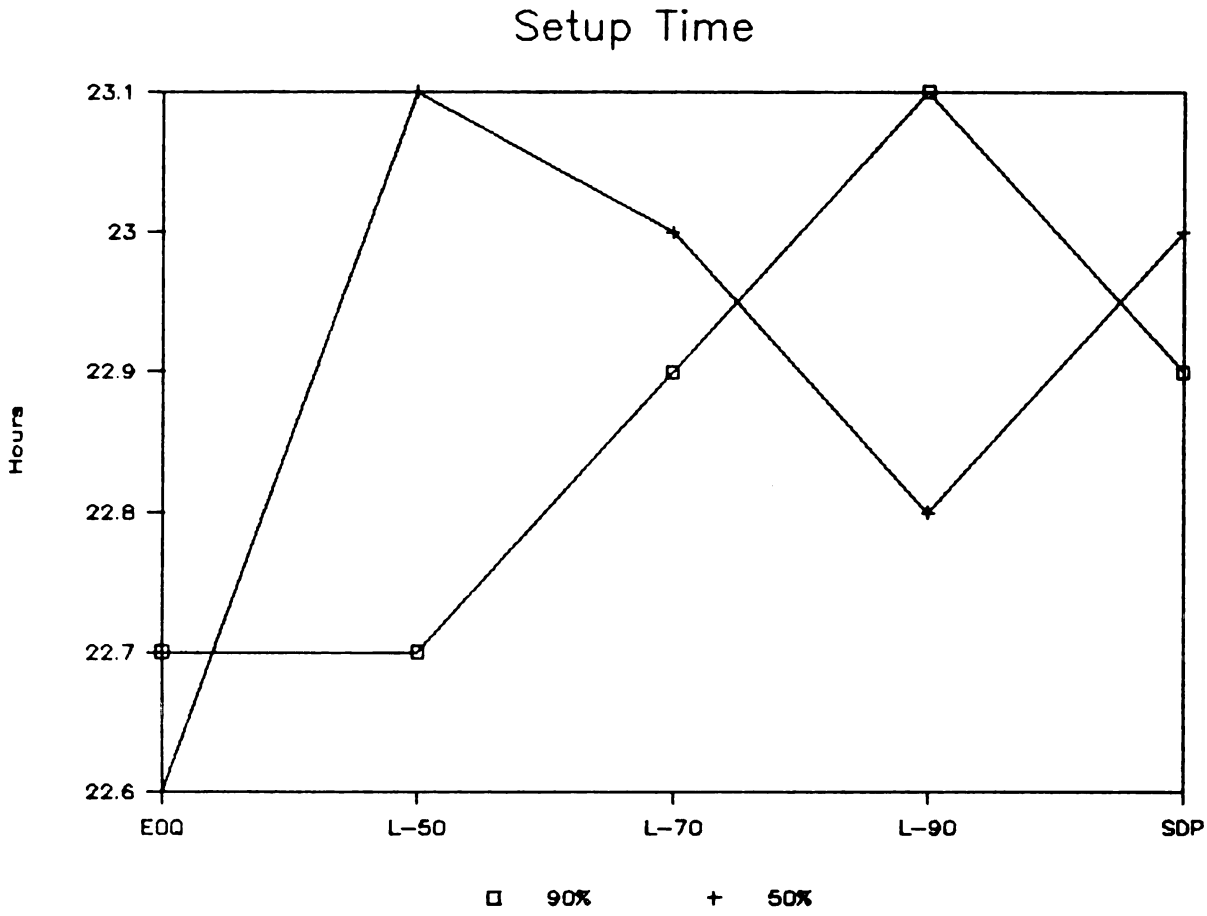


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.1 : 1

ORDER COST--SECOND EXOGENOUS FACTOR SETTING

FIGURE 6.9

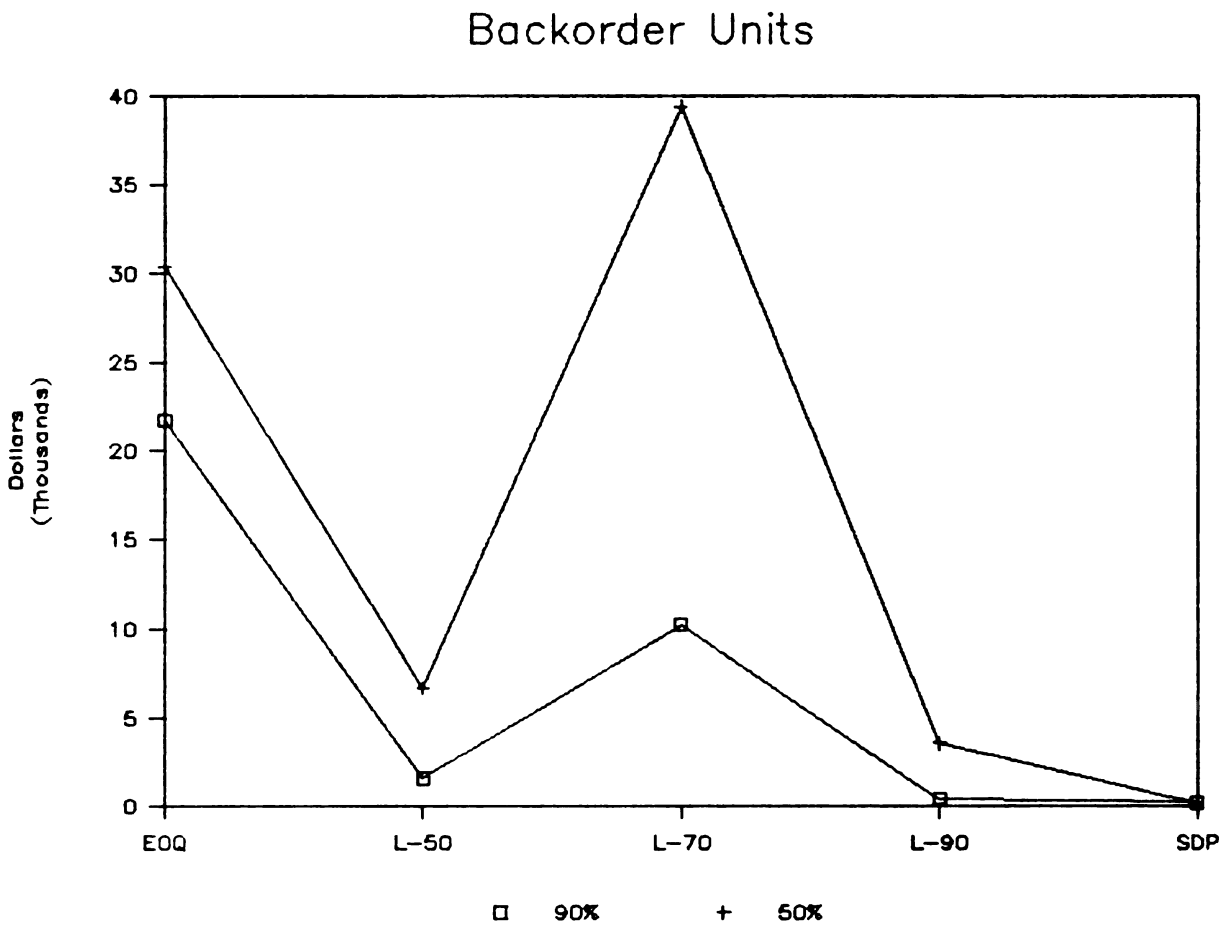


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

SETUP TIME--SECOND EXOGENOUS FACTOR SETTING

FIGURE 6.10

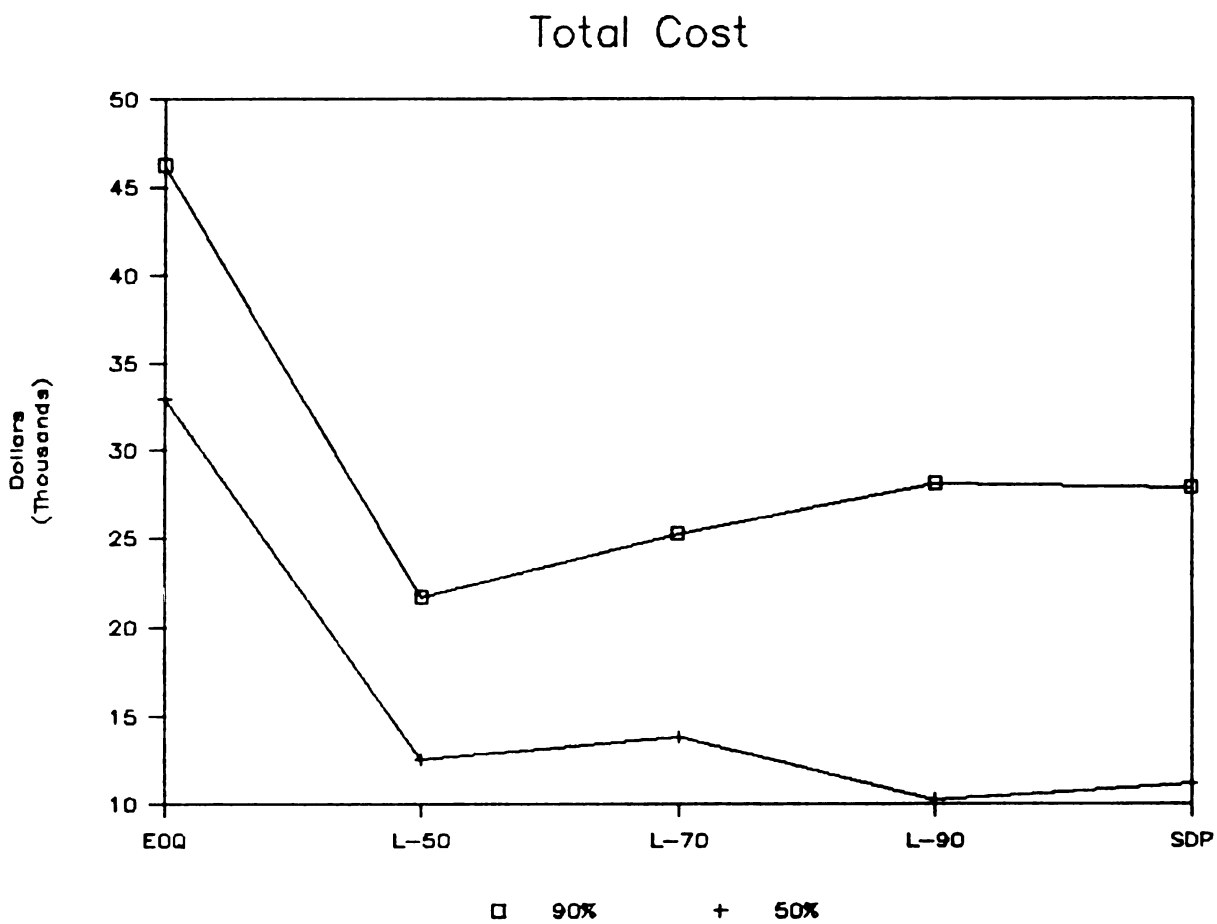


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

BACKORDER UNITS--SECOND EXOGENOUS FACTOR SETTING

FIGURE 6.11



Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

TOTAL COST--SECOND EXOGENOUS FACTOR SETTING

FIGURE 6.12

Two interesting relationships exist when comparing raw material inventory and order cost. Three statistically equal groups exist, and can be described as having low, medium and high average raw material inventory. The first group is all lot-for-lot planning responses, the second uses stochastic dynamic programming and the third, the economic order quantity methods regardless of service level of finished goods safety stock. These combinations are statistically equal within a specified group and each group is significantly different from the other groups.

When evaluating order cost, the same groups are created based on statistical differences, but as one might expect, the order cost is highest with low raw material inventory and lowest with high raw material inventory. Stochastic dynamic programming falls in the medium range of both measures. Again, the raw material planning method is significant, but not the service level of finished goods safety stock

Finished goods inventory exhibits the same relationship seen earlier. When grouping planning responses based on finished goods safety stock, the responses with a 50% service level were all equal, but significantly smaller than those with a 90% service level. Average finished goods inventory at the 90% service level, regardless of raw material planning method, were statistically equal.

As was the case in the previous combination of exogenous factors, no differences exist in the setup cost.

Backorder units had two significant groups. The EOQ-50% was equal to both EOQ-90% and L70-50% but a significant difference existed between EOQ-90% and L70-50%.These planning responses were significantly larger than all other planning methods which did not exhibit a statistically significant difference in cell means.

The final measure, total cost, showed four distinctly different groups. SDP-50%, L90-50%, L70-50% and L50-50% were all statistically equal and less than the next group which included L50-90% and L70-90%. The next group, EOQ-50%, L90-90% and SDP-90% were larger than the preceding group, but smaller than EOQ-90%.

6.3.3 Third Exogenous Factor Level Setting

Table 6.6 and Figures 6.13 through 6.18 provide information about the next environment faced by process industry planning and control systems, cost of capital is set at its high level with all other exogenous factors established at their low levels.

Exogenous Level Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10:1
Activity Ratio	250:1
Coefficient of Variation	.03:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

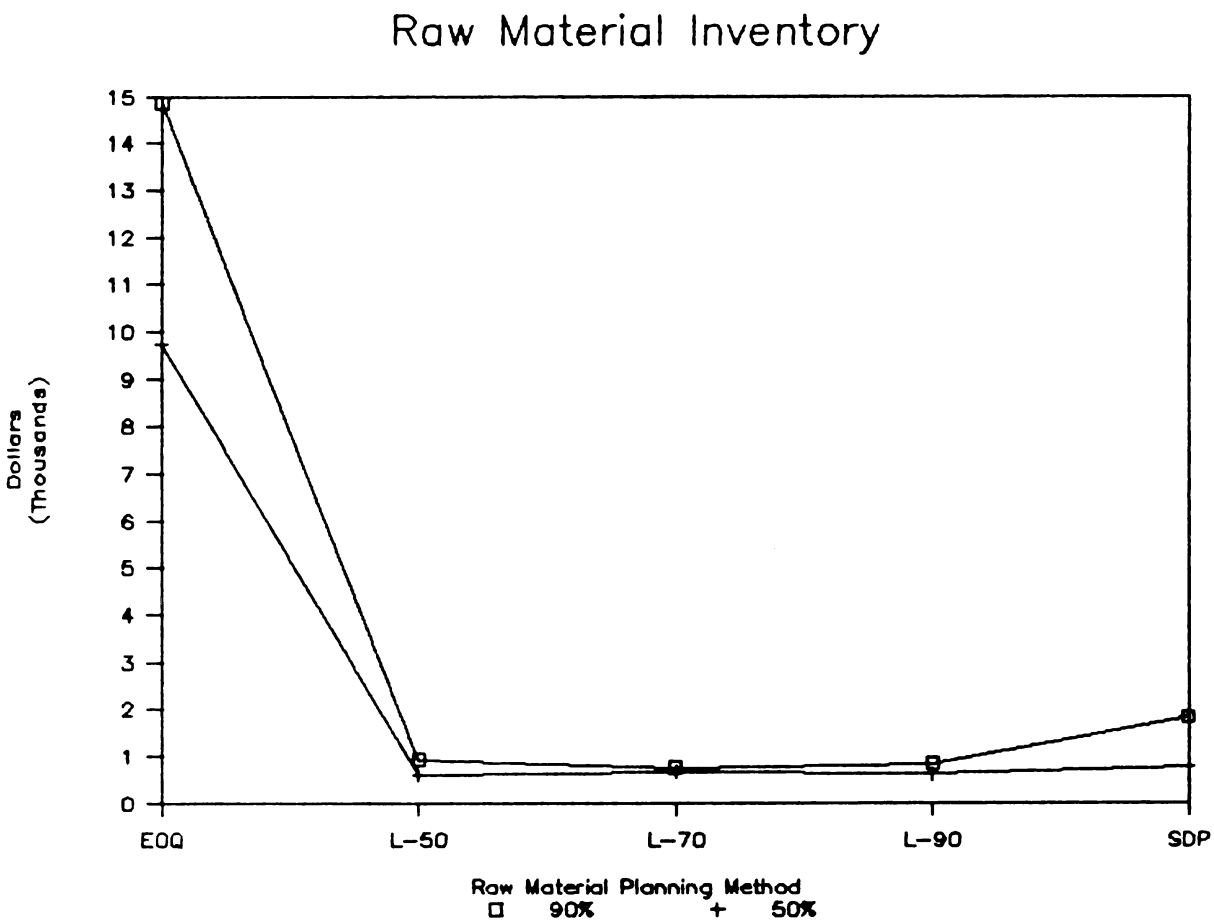
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	14864.3	9743.8	924.2	604.3	756.6	675.8	852.7	623.6	1846.4	792.4
Finished Goods Inventory	6936.9	1282.3	3273.0	938.6	3510.3	518.6	4997.8	1537.3	5349.0	969.7
Order Cost	1860.0	1598.2	7396.7	7226.8	6811.6	7364.0	6508.2	5727.0	4738.2	5133.6
Setup Time	51.1	63.6	59.6	65.7	56.9	64.6	56.2	62.3	62.2	62.7
Backorder Units	21494.5	23207.8	4418.5	2042.4	44637.2	43205.0	30437.2	25688.8	20820.1	21111.3
Total Cost	123226.3	71763.0	44934.1	31291.1	43987.3	35400.0	50037.7	31560.7	57234.6	28598.0
Overall Rank	8	6	10	2	6	4	6	3	9	1
Average Rank	6.00	5.83	7.17	4.00	5.83	5.67	5.83	4.33	6.67	3.67

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

THIRD EXOGENOUS FACTOR SETTING

TABLE 6.6

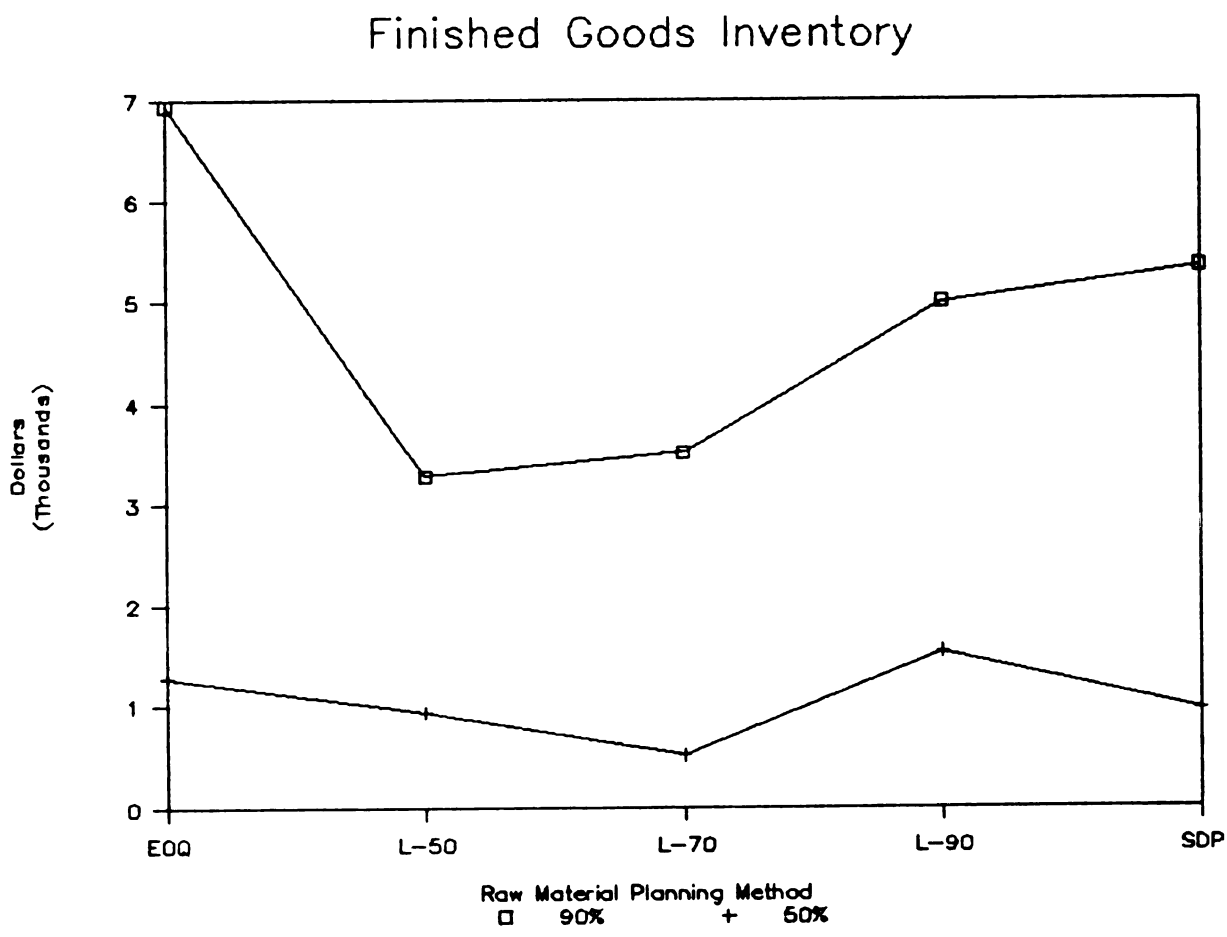


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

RAW MATERIAL INVENTORY--THIRD EXOGENOUS FACTOR SETTING

FIGURE 6.13

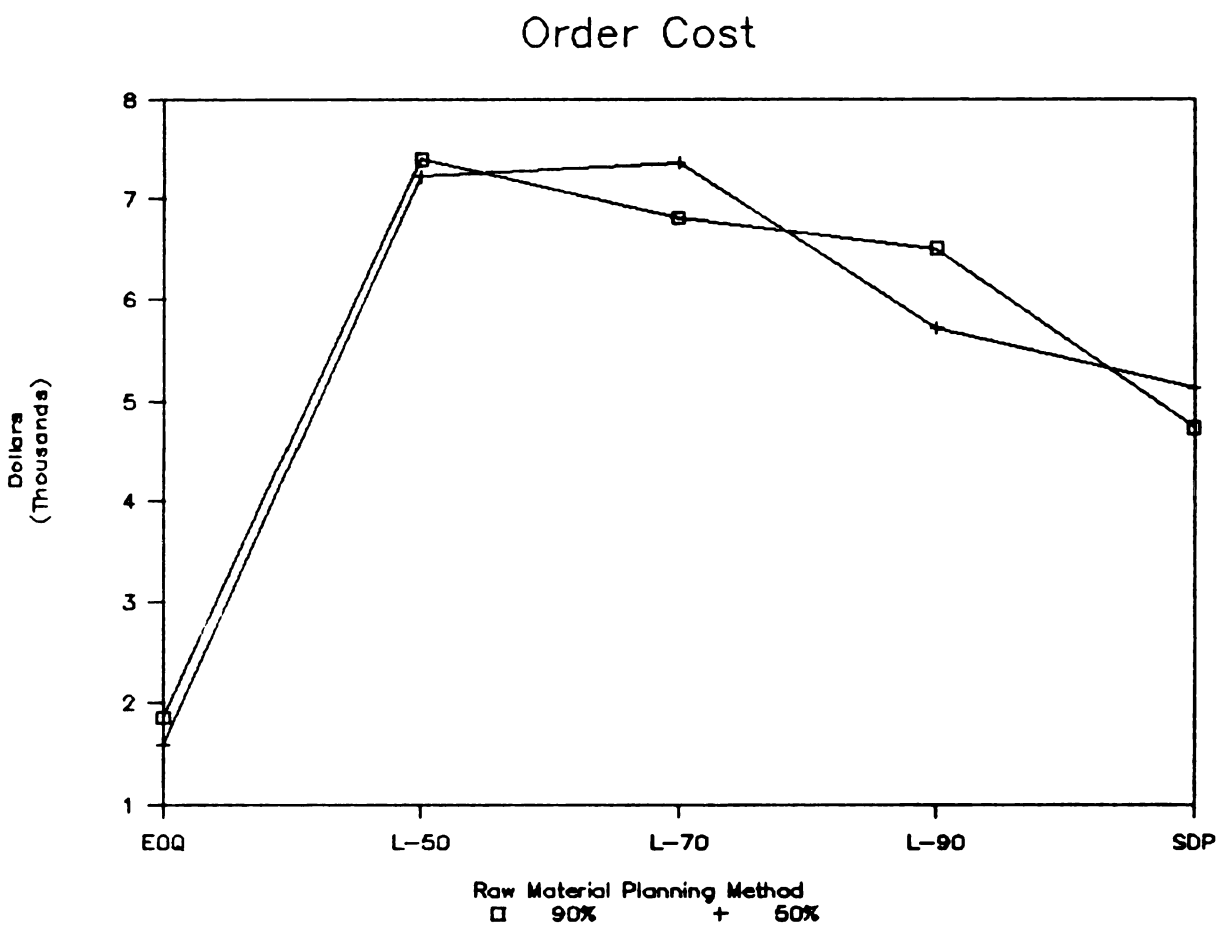


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

FINISHED GOODS--THIRD EXOGENOUS FACTOR SETTING

FIGURE 6.14

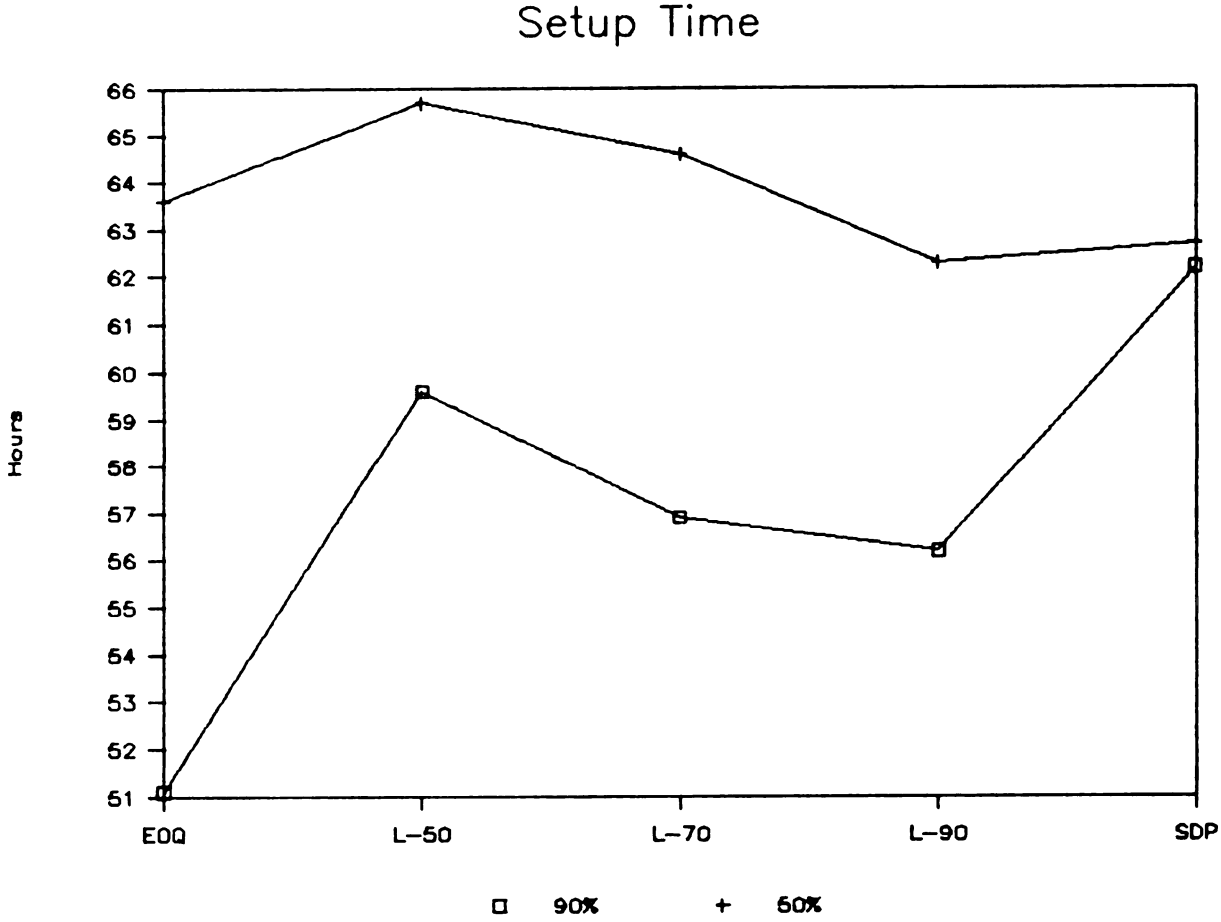


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

ORDER COST--THIRD EXOGENOUS FACTOR SETTING

FIGURE 6.15

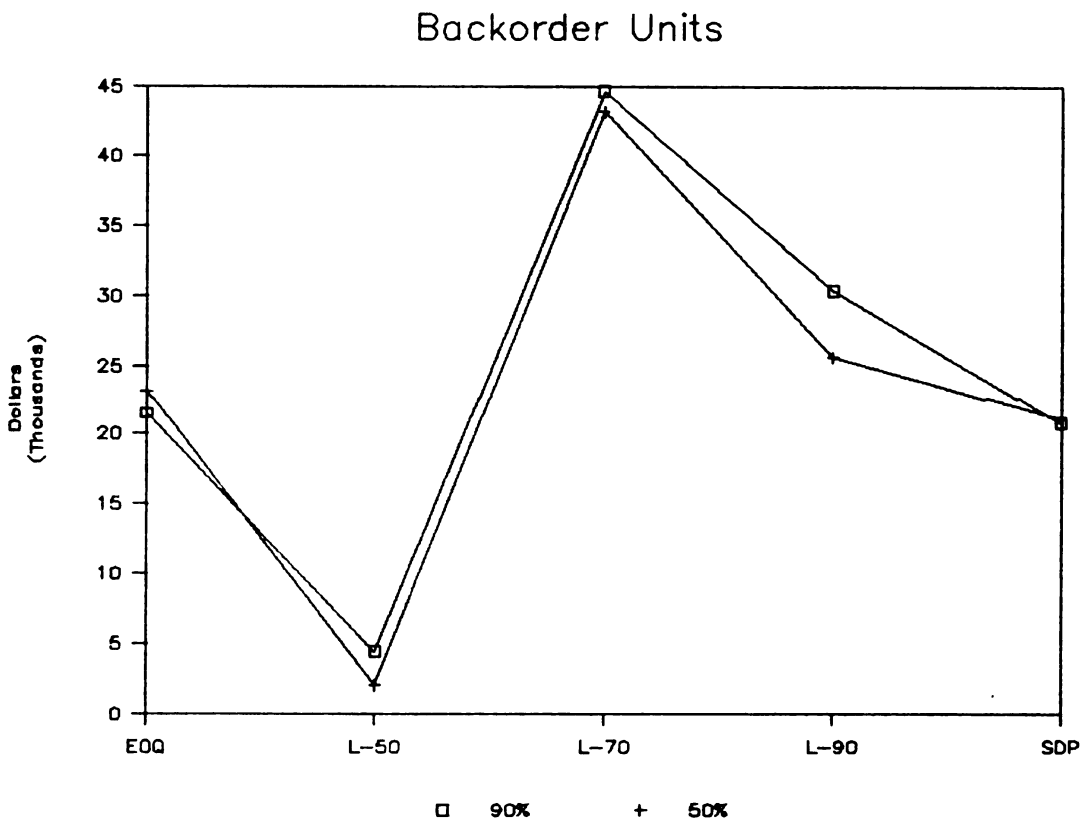


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

SETUP TIME--THIRD EXOGENOUS FACTOR SETTING

FIGURE 6.16

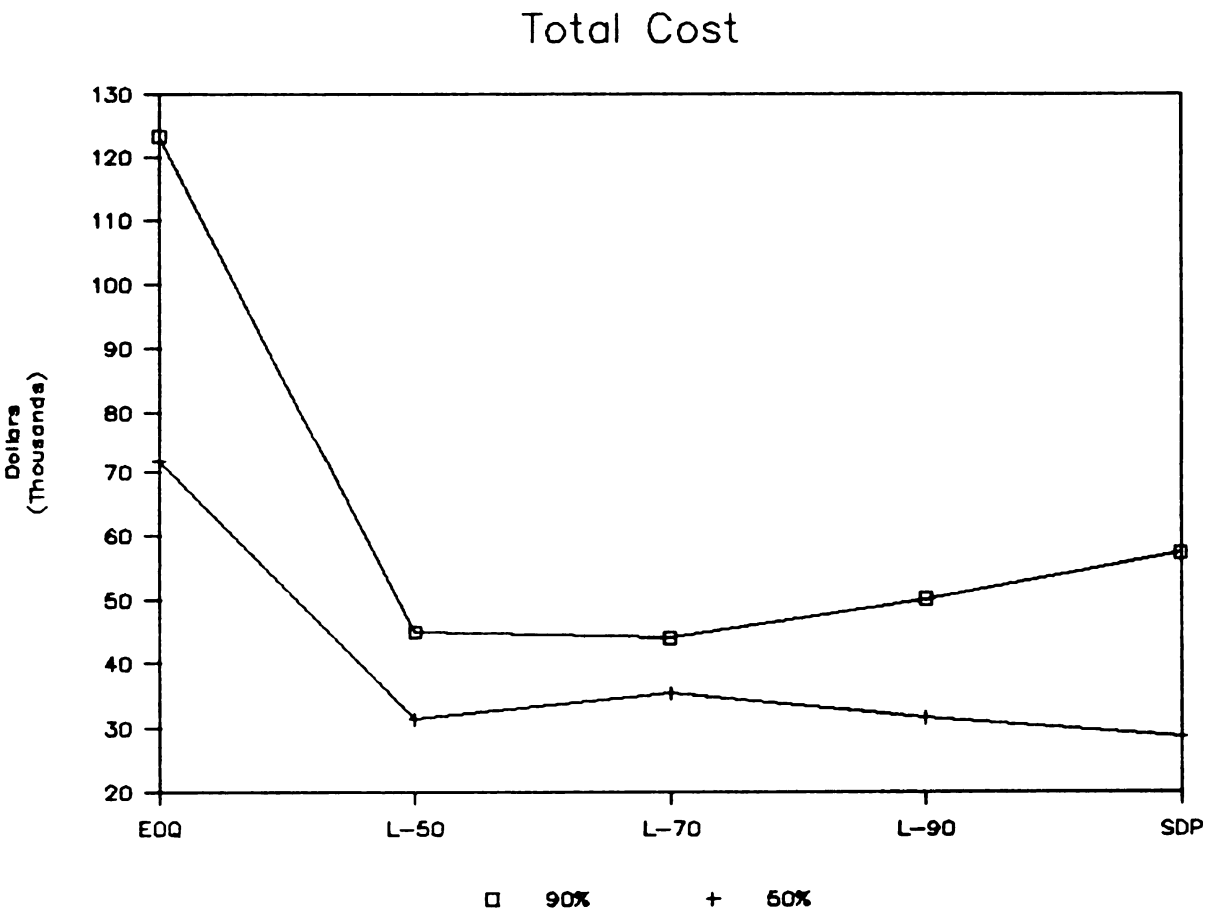


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

BACKORDER UNITS--THIRD EXOGENOUS FACTOR SETTING

FIGURE 6.17



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

TOTAL COST--THIRD EXOGENOUS FACTOR SETTING

FIGURE 6.18

Analysis of this set of performance data for significant relationships shows the same pattern in raw material inventory and order cost exhibited earlier.

The modified economic order quantity provides high levels of raw material inventory and low order cost while stochastic dynamic programming has middle values of order cost and raw material inventory. The difference in this case has lot-for-lot raw material inventory showing some overlap with stochastic dynamic programming resulting in five groups of raw material inventory. L50-50%, L70-50% and L90-50% provide equal levels of raw material significantly different from SDP-50% and L50-90% with L70-90% being statistically equal to both groups. The remaining planning responses, SDP-90%, EOQ-50% and EOQ-90%, are all statistically larger than each other respectively and larger than the groups previously identified.

Finished goods inventory exhibits statistical relationships similar to those seen earlier. Finished goods safety stock at the 90% service level has higher finished goods inventory than at the 50% service level.

Setup cost shows some significant differences, between the highest and lowest value, EOQ-90% and L50-50%, but no pattern is evident.

Backorder units indicates many different relationships, but no consistent trend. L50-50% provides the lowest mean value which is equal to L50-90%. As a group, they are

significantly different from the group of SDP-90%, SDP-50%, EOQ-90%, EOQ-50%, L90-50% and L90-90%. The next larger group includes all remaining planning options which are statistically equal to one another.

Finally, total cost shows SDP-50% to be the lowest total cost, statistically equal to L50-50% and L90-50%. Other planning responses are statistically larger as the average total cost increases.

Relationships of interest in this combination of exogenous factors is the linkage between order cost and raw material inventory, finished goods safety stock and finished goods inventory and the lack of a statistically significant relationship in either setup cost or backorder units.

6.3.4 Fourth Exogenous Factor Level Setting

The next table, Table 6.7, and figures, Figures 6.19 through 6.24, provide information regarding exogenous factor settings, individual performance measure means and planning system response rankings.

Exogenous Level Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10:1
Activity Ratio	250:1
Coefficient of Variation	.10:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

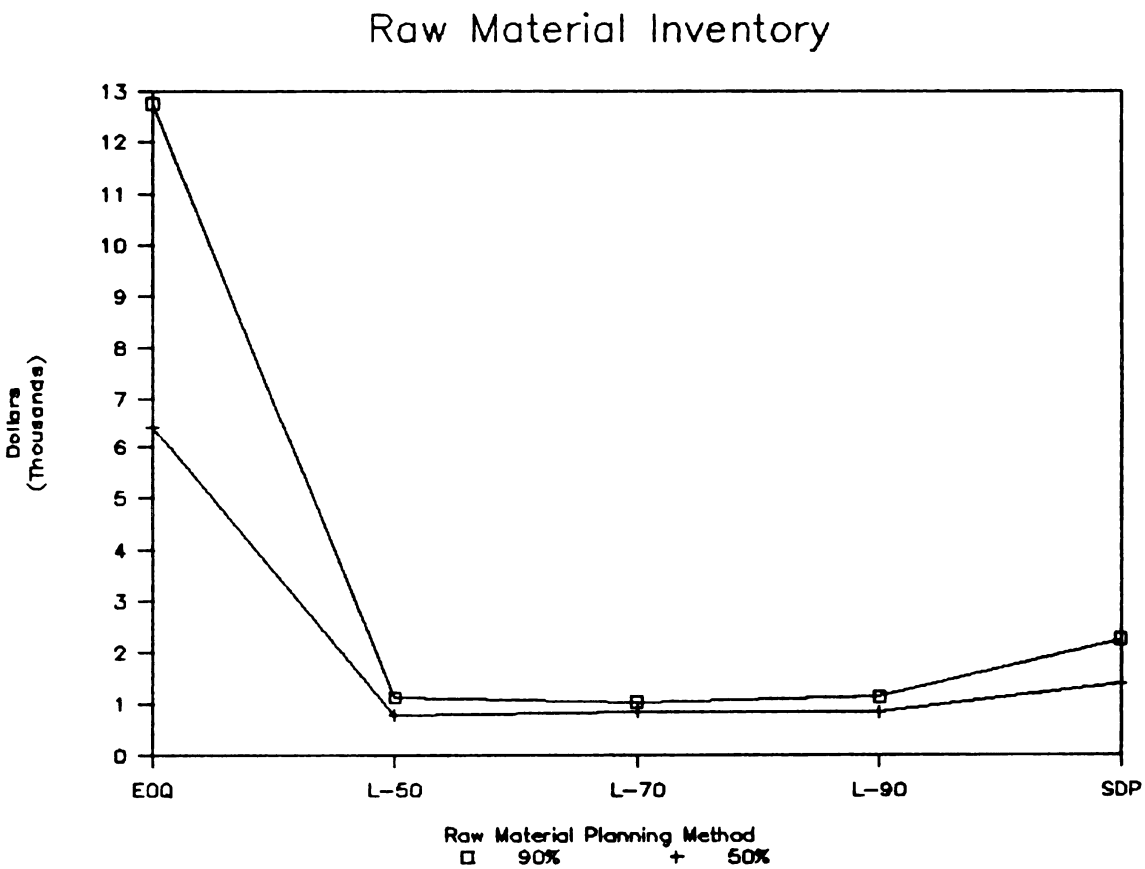
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	12759.8	6400.8	1128.2	783.1	1028.6	856.4	1146.4	842.2	2256.1	1397.4
Finished Goods Inventory	5209.3	871.1	4235.0	1080.1	4006.7	839.8	5490.3	1072.1	5421.7	950.1
Order Cost	1819.8	2123.1	7372.8	7662.5	7167.2	6976.0	5740.6	5722.5	4396.5	4910.8
Setup Time	57.0	81.9	59.2	69.2	59.7	65.0	51.8	63.2	64.6	62.7
Backorder Units	36044.8	23020.7	7324.8	4627.8	4217.9	53536.2	36157.8	32241.3	29123.6	28988.8
Total Cost	106751.4	57159.7	40719.3	34885.6	41842.6	38946.7	50406.9	35159.7	50607.1	32080.6
Overall Rank	9	7	5	2.5	4	6	8	2.5	10	1
Average Rank	6.67	5.83	5.17	4.67	5.00	5.50	6.33	4.67	7.07	4.17

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

FOURTH EXOGENOUS FACTOR SETTING

TABLE 6.7



Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

RAW MATERIAL INVENTORY--FOURTH EXOGENOUS FACTOR SETTING

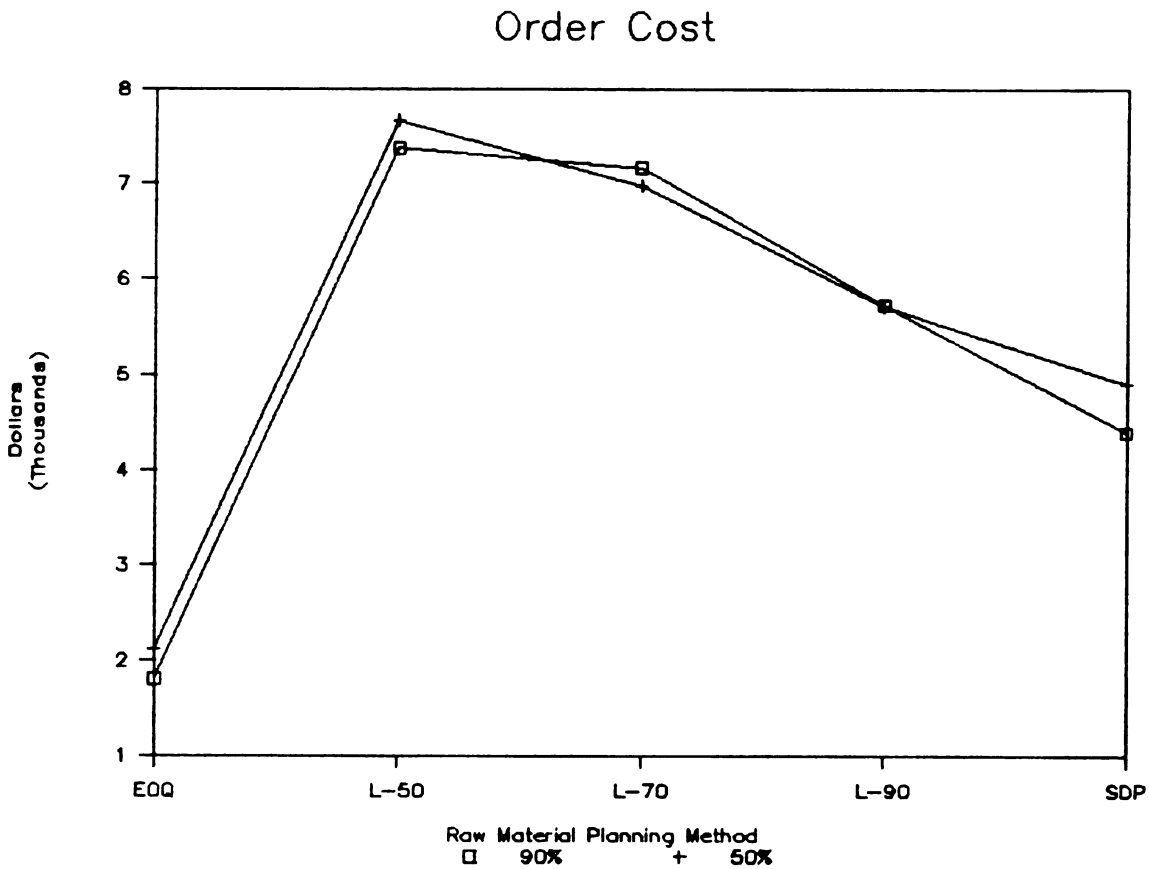
FIGURE 6.19

Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

FINISHED GOODS--FOURTH EXOGENOUS FACTOR SETTING

FIGURE 6.20

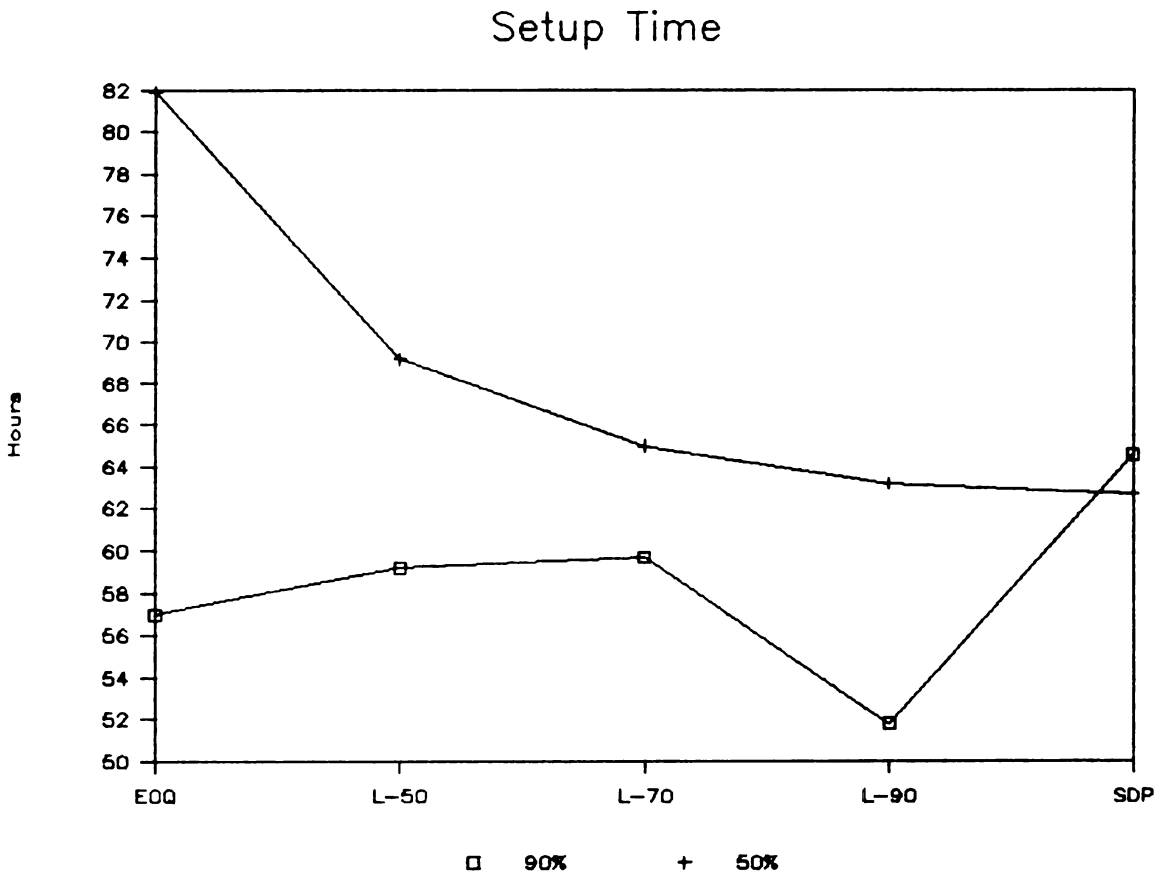


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

ORDER COST--FOURTH EXOGENOUS FACTOR SETTING

FIGURE 6.21

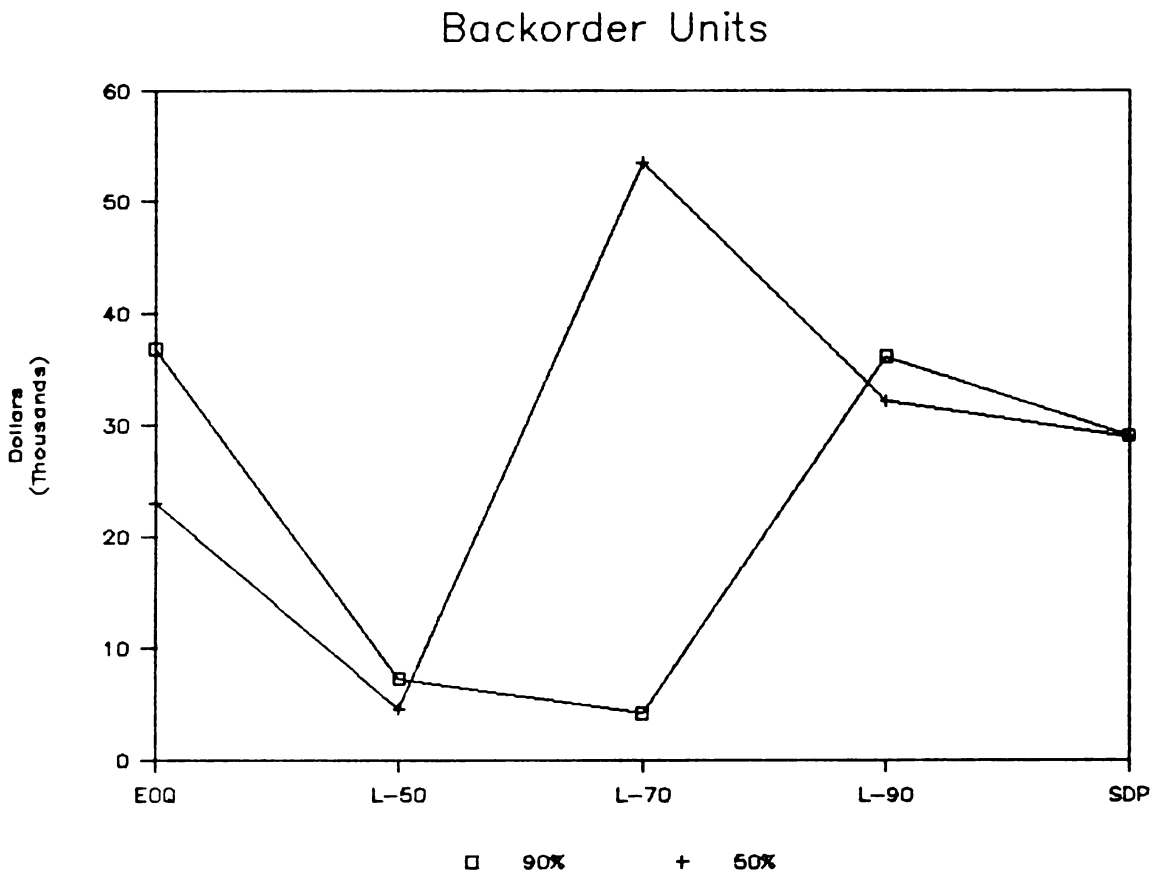


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

SETUP TIME--FOURTH EXOGENOUS FACTOR SETTING

FIGURE 6.22

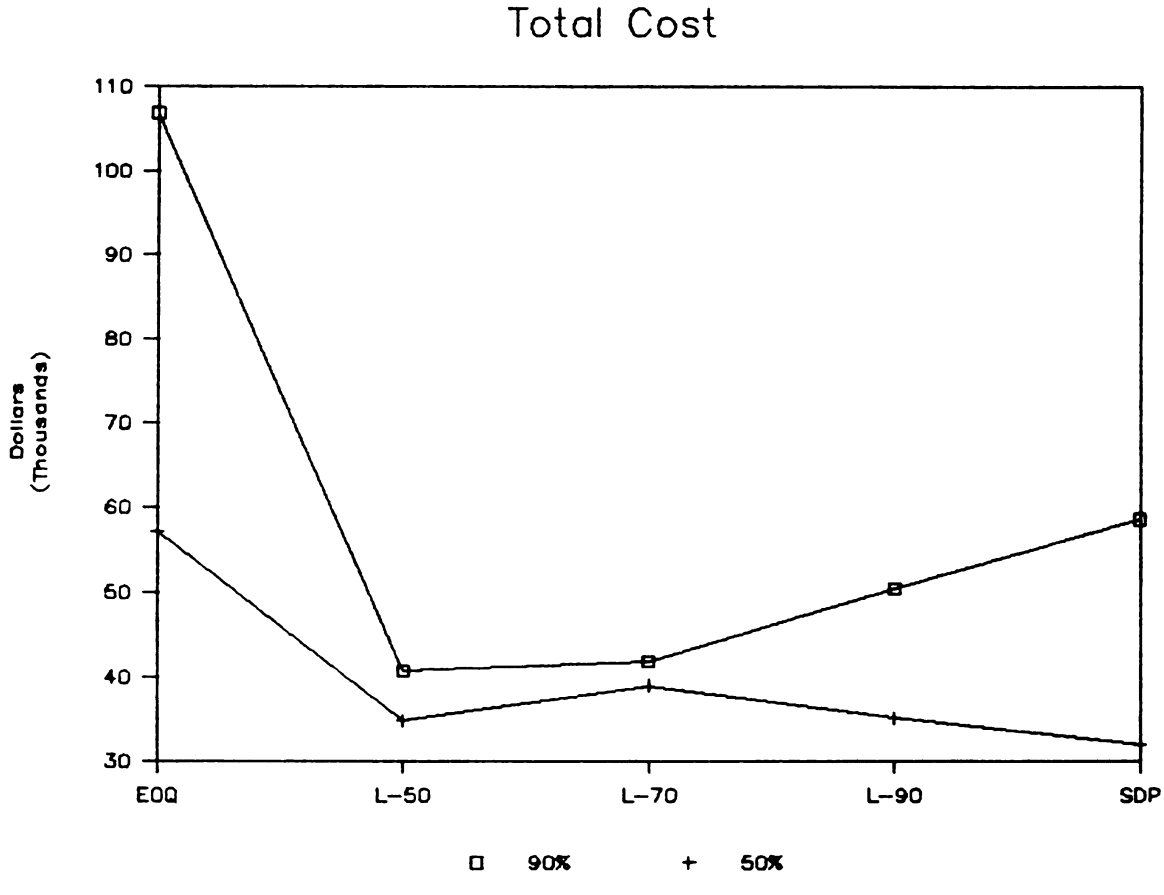


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

BACKORDER UNITS--FOURTH EXOGENOUS FACTOR SETTING

FIGURE 6.23



Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

TOTAL COST--FIRST EXOGENOUS FACTOR SETTING

FIGURE 6.24

Statistical analysis of the means presented indicates a relationship between raw material inventory and order cost with one exception. The same inverse relationship exists based on economic order quantity and lot-for-lot planning methods with stochastic dynamic programming being a separate group between the two groups mentioned. The raw material inventory levels for lot-for-lot planning methods, however, can be further broken down based on finished goods safety stock. The 50% finished goods safety stock provides a statistically equal group that is smaller than the 90% finished goods service level.

The same results found earlier in finished goods inventory, classification of means by finished goods safety stock service level, is evident in this case. Some statistical differences exist within the 90% service level group, L90-90% is larger than L50-90%, but the primary difference between the 90% service level and 50% service level is evident.

Setup time shows some significant relationships. L90-90% has the lowest mean and is significantly different from an equal group of EOQ-90%, L50-90% and L70-90%. The next significantly larger group includes L70-50%, L90-50%, SDP-90% and SDP-50%.

The significant relationships exhibited in backorder units exist, but no pattern is evident. The group of planning responses with the lowest, and equal, means includes L50-90%, L50-50%, and L70-90%. EOQ-50%, SDP-50%,

SDP-90% and L90-50% form the next larger group. The planning methods L90-90% and EOQ-90% are equal to one another and smaller than the planning system with the largest mean, L70-50%.

Total cost provides an interesting result. The planning system with the lowest average total cost is again SDP-50%. It is not significantly different from L50-50% or L90-50%. The next group includes L70-50%, L50-90% and L70-90%. This group is smaller than L90-90% and EOQ-50% which is smaller than the largest mean, EOQ-90%.

6.3.5 Fifth Exogenous Factor Level Setting

The next combination of factors sees an increased cost of capital. The performance measure means, exogenous factor settings and ranks are shown in Table 6.8 and Figures 6.25 through 6.30.

Exogenous Level Settings

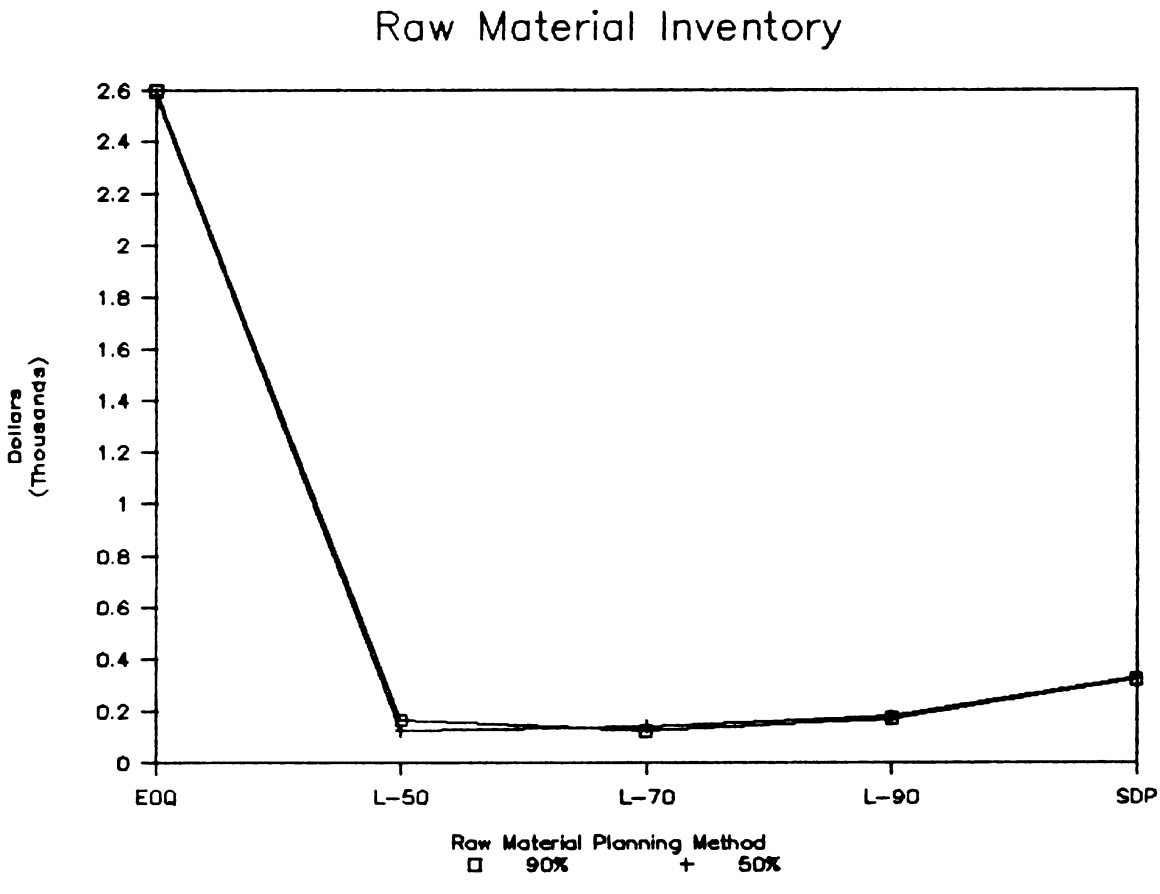
Average Capacity Utilization	60%
Cost of Capital Ratio	5:1
Activity Ratio	50:1
Coefficient of Variation	.03:1

	Raw Material Planning Method and Level of Finished Goods Safety Stock									
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	2594.5	2580.2	164.5	123.4	123.4	142.2	170.9	180.2	323.2	332.3
Finished Goods Inventory	3517.0	489.0	2949.9	79.0	4114.5	201.3	3849.7	297.6	3402.0	89.0
Order Cost	600.0	670.2	3050.2	3209.6	2947.0	3524.0	2039.1	2901.7	2547.9	2570.5
Setup Time	27.9	28.0	27.9	28.2	27.9	28.0	27.9	27.8	27.8	28.3
Backorder Units	3720.4	1544.5	3244.7	959.6	285.0	5717.3	0.0	452.6	0.0	0.0
Total Cost	37157.1	21786.7	24540.0	10985.1	29751.3	11819.4	20517.7	10903.9	27141.9	10343.5
Overall Rank	9	5	7.5	4	6	7.5	10	1	3	2
Average Rank	7.00	5.92	6.00	5.00	6.00	6.00	7.25	4.00	4.50	4.50

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS
FIFTH EXOGENOUS FACTOR SETTING

TABLE 6.8

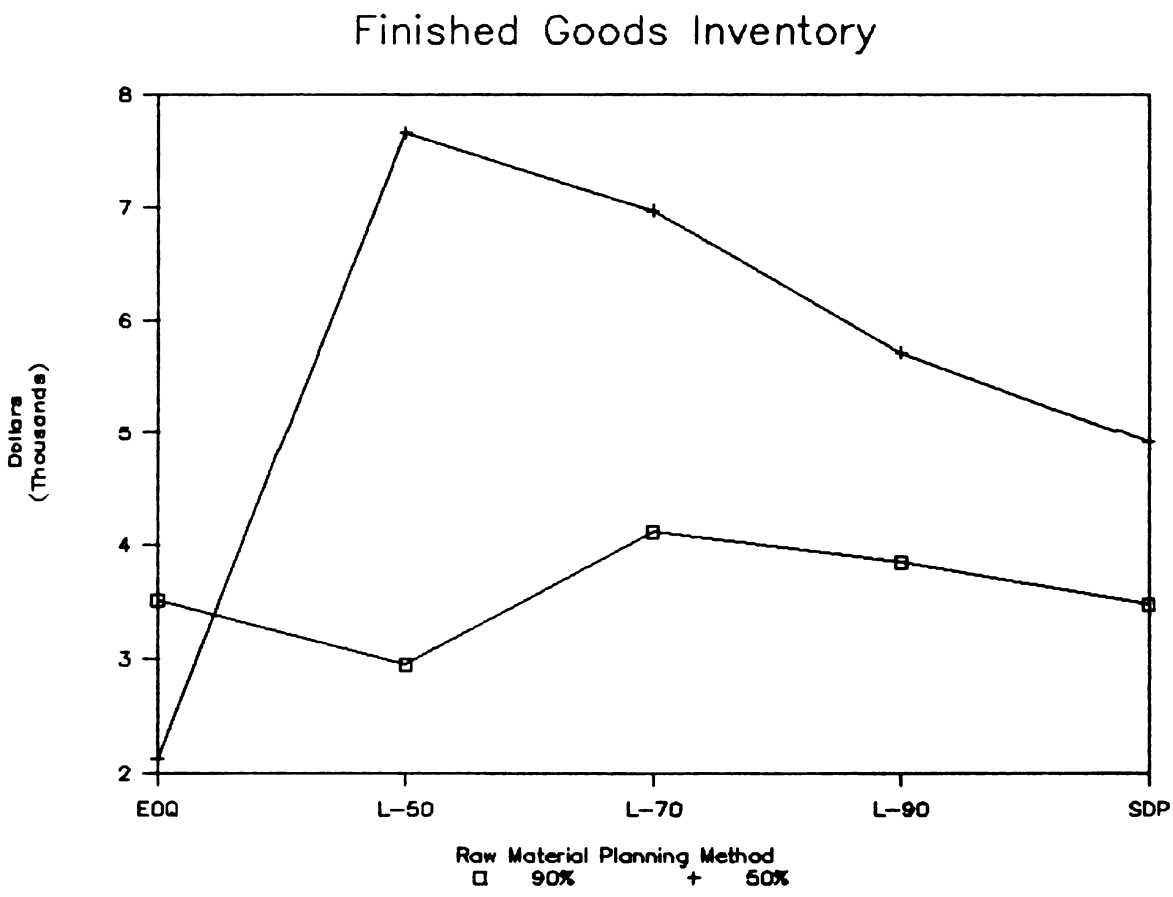


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

RAW MATERIAL INVENTORY--FIFTH EXOGENOUS FACTOR SETTING

FIGURE 6.25

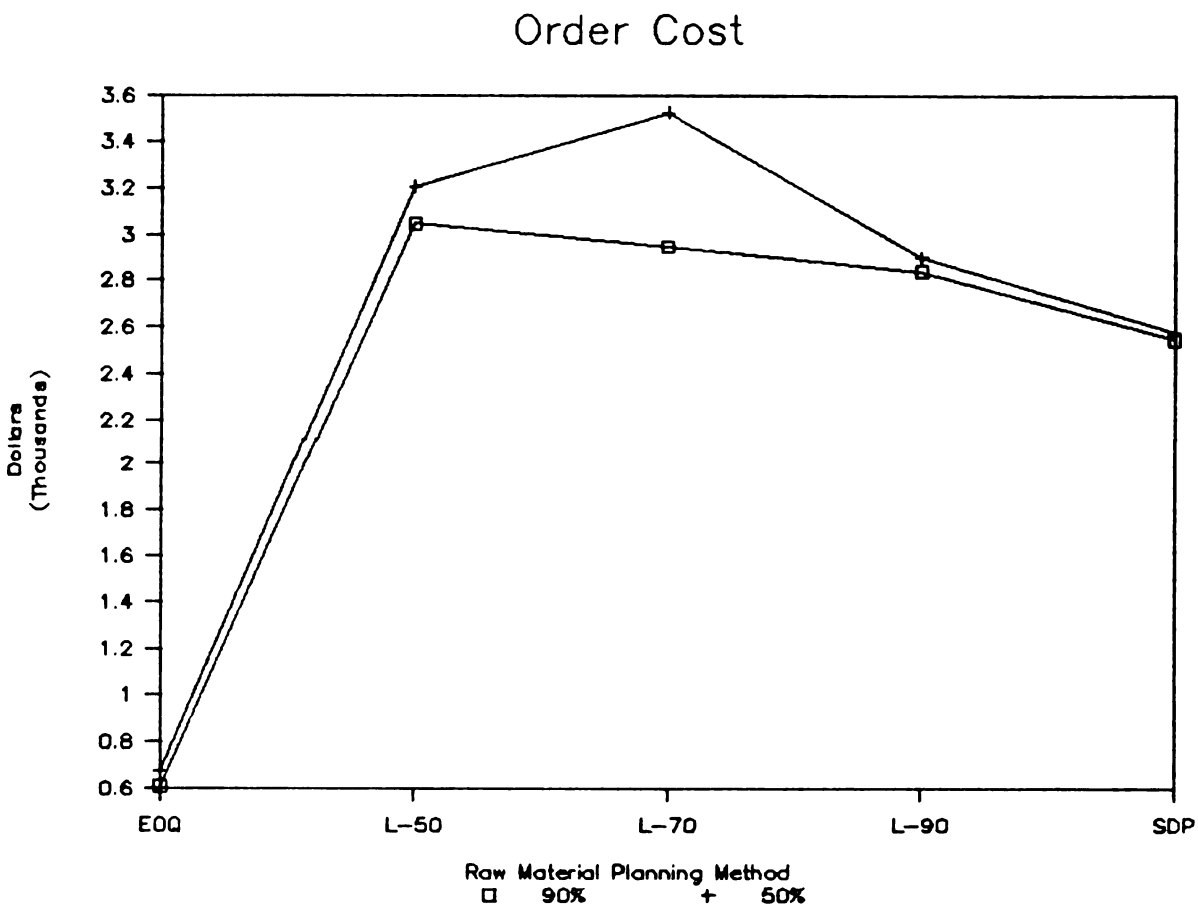


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

FINISHED GOODS--FIFTH EXOGENOUS FACTOR SETTING

FIGURE 6.26

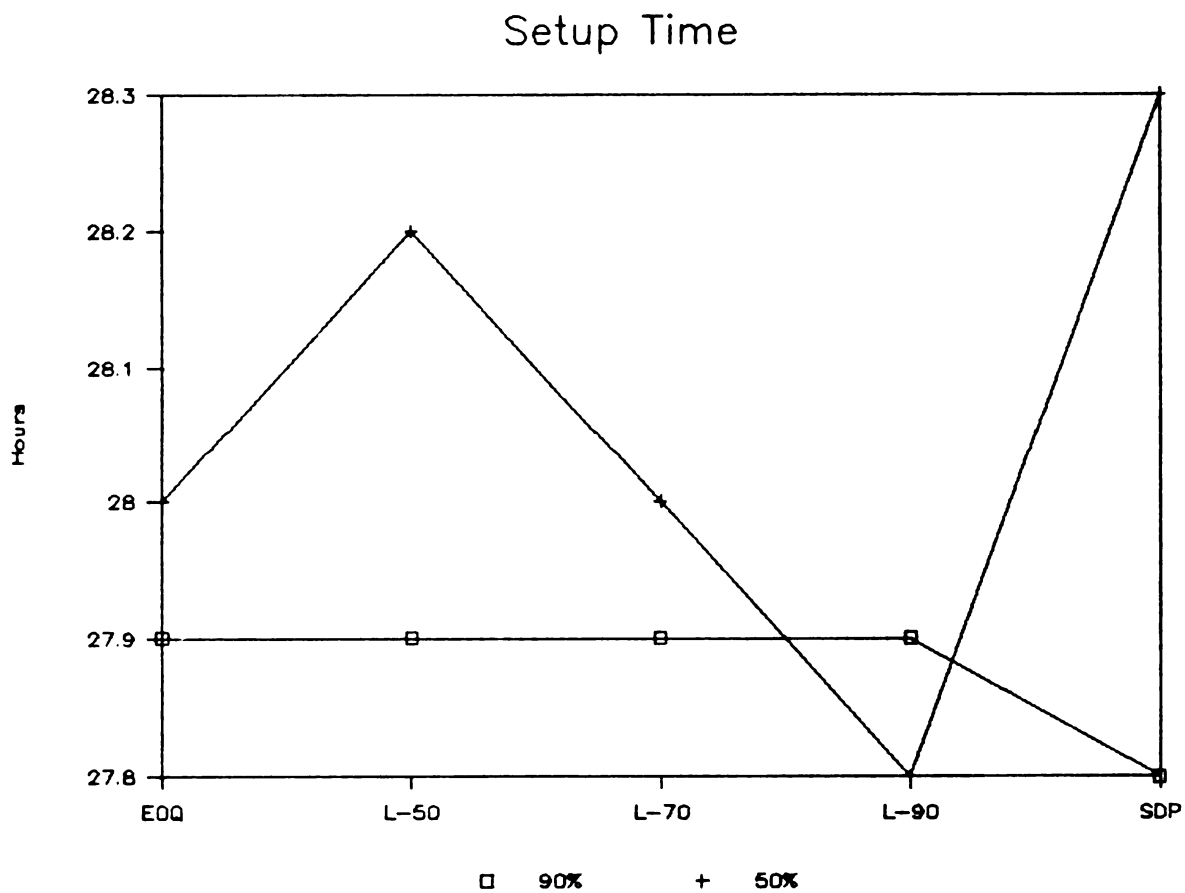


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

ORDER COST--FIFTH EXOGENOUS FACTOR SETTING

FIGURE 6.27

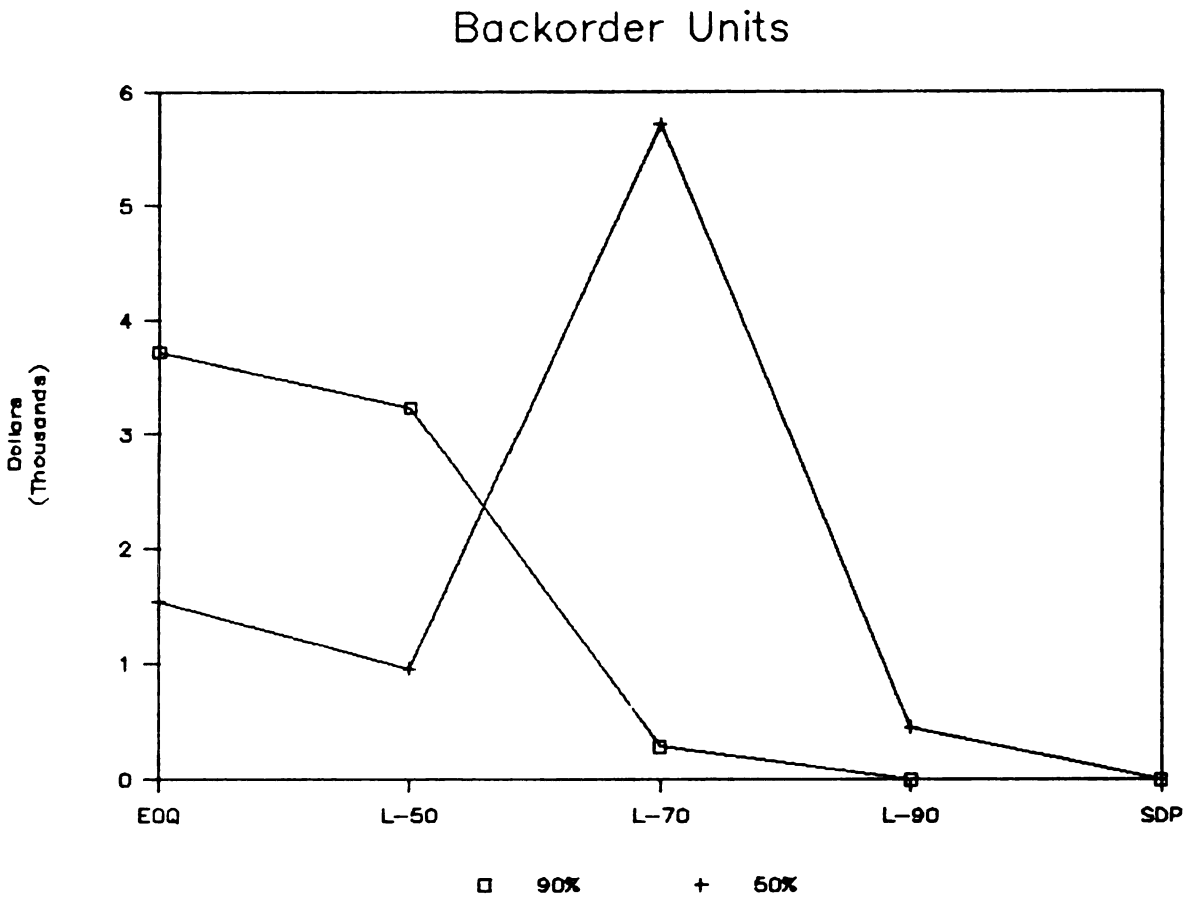


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

SETUP TIME--FIFTH EXOGENOUS FACTOR SETTING

FIGURE 6.28

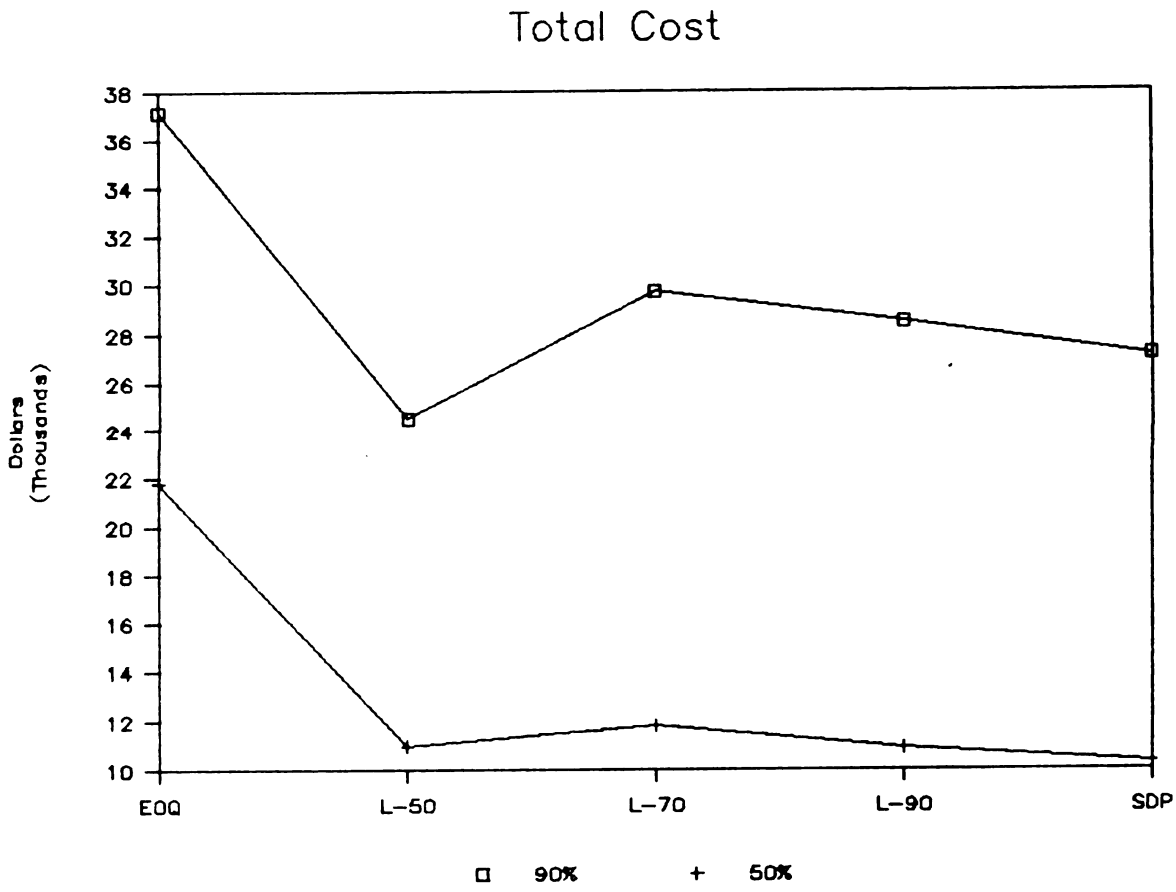


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

BACKORDER UNITS--FIFTH EXOGENOUS FACTOR SETTING

FIGURE 6.29



Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

TOTAL COST--FIFTH EXOGENOUS FACTOR SETTING

FIGURE 6.30

Significant relationships are evident in Table 6.8 and they are consistent with those relationships seen earlier. An inverse relationship between raw material inventory and order cost is evident with the same groupings seen earlier, economic order quantity, stochastic dynamic programming and lot-for-lot grouped together.

Finished goods inventory again exhibits the same relationship seen earlier when classifying means based on finished goods safety stock service level.

No significant differences exist between setup time means and backorder unit means.

Total cost allows for identification of the lowest mean, again it is SDP-50%, which is equivalent to L90-50%, L50-50% and L70-50%. The highest average total cost is generated by EOQ-90% which is larger than the remaining planning responses which are all equal to one another.

6.3.6 Sixth Exogenous Factor Level Setting

The next combination of exogenous factor level settings sees two factors increased above the base values, cost of capital and coefficient of variation. The specifications and results are presented in Table 6.9 and Figures 6.31 through 6.36.

Exogenous Level Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5:1
Activity Ratio	50:1
Coefficient of Variation	.10:1

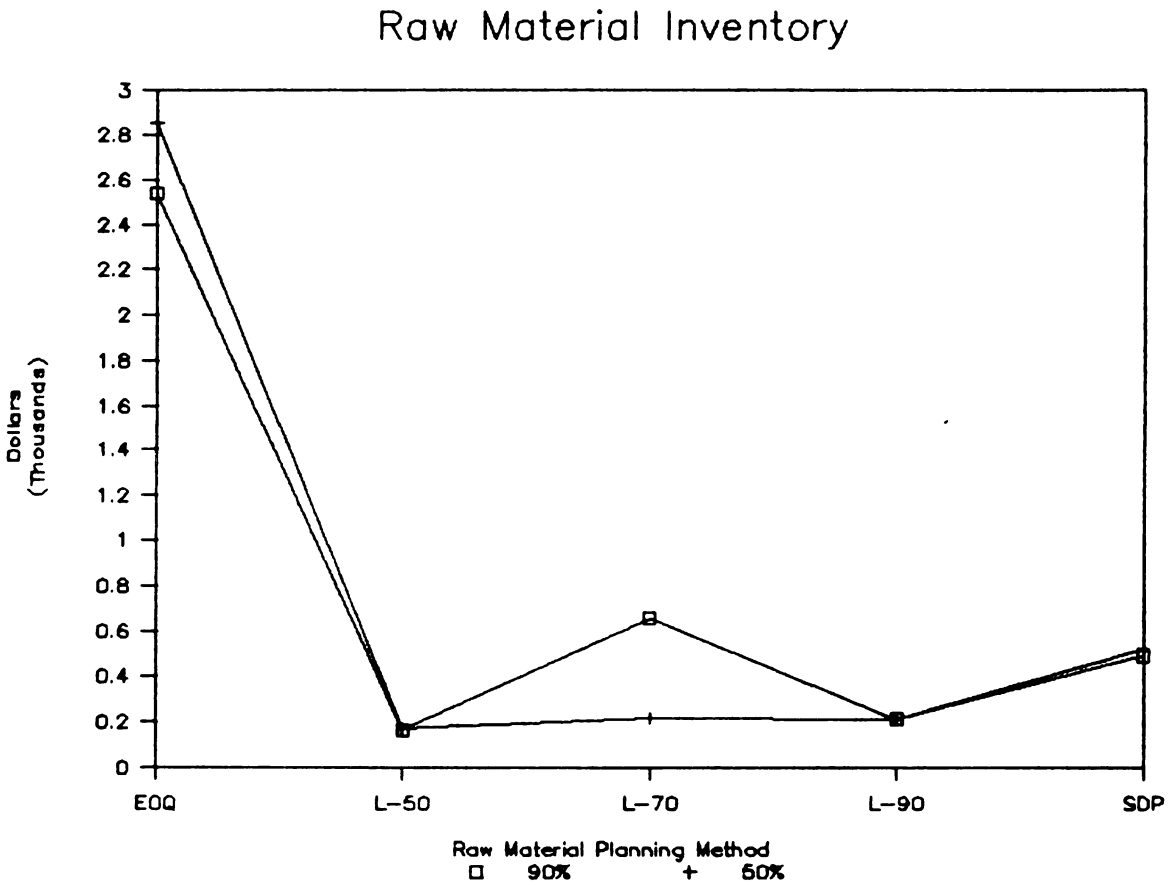
Raw Material Planning Method and Level of Finished Goods Safety Stock

Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	2540.2	2851.6	166.8	172.7	657.1	219.3	215.6	216.3	493.6	523.0
Finished Goods Inventory	2693.7	96.5	1754.9	54.5	3676.0	85.4	3745.3	474.1	3441.1	88.6
Order Cost	579.0	685.2	3137.9	3274.1	8316.8	3515.5	2906.6	2931.5	2368.8	2289.2
Setup Time	27.9	28.3	27.9	29.4	29.6	28.2	28.4	28.2	28.2	27.8
Backorder Units	20844.6	23391.4	1279.6	3294.2	2963.1	24850.8	0.0	2385.7	0.0	169.3
Total Cost	35310.8	23430.2	14303.5	12270.5	46201.2	14672.6	16877.7	12278.2	27691.9	10935.1
Overall Rank	8	7	3	2	10	9	4	5	6	1
Average Rank	5.83	5.17	3.67	3.33	7.23	6.83	4.25	4.50	4.58	2.83

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS
SIXTH EXOGENOUS FACTOR SETTING

TABLE 6.9

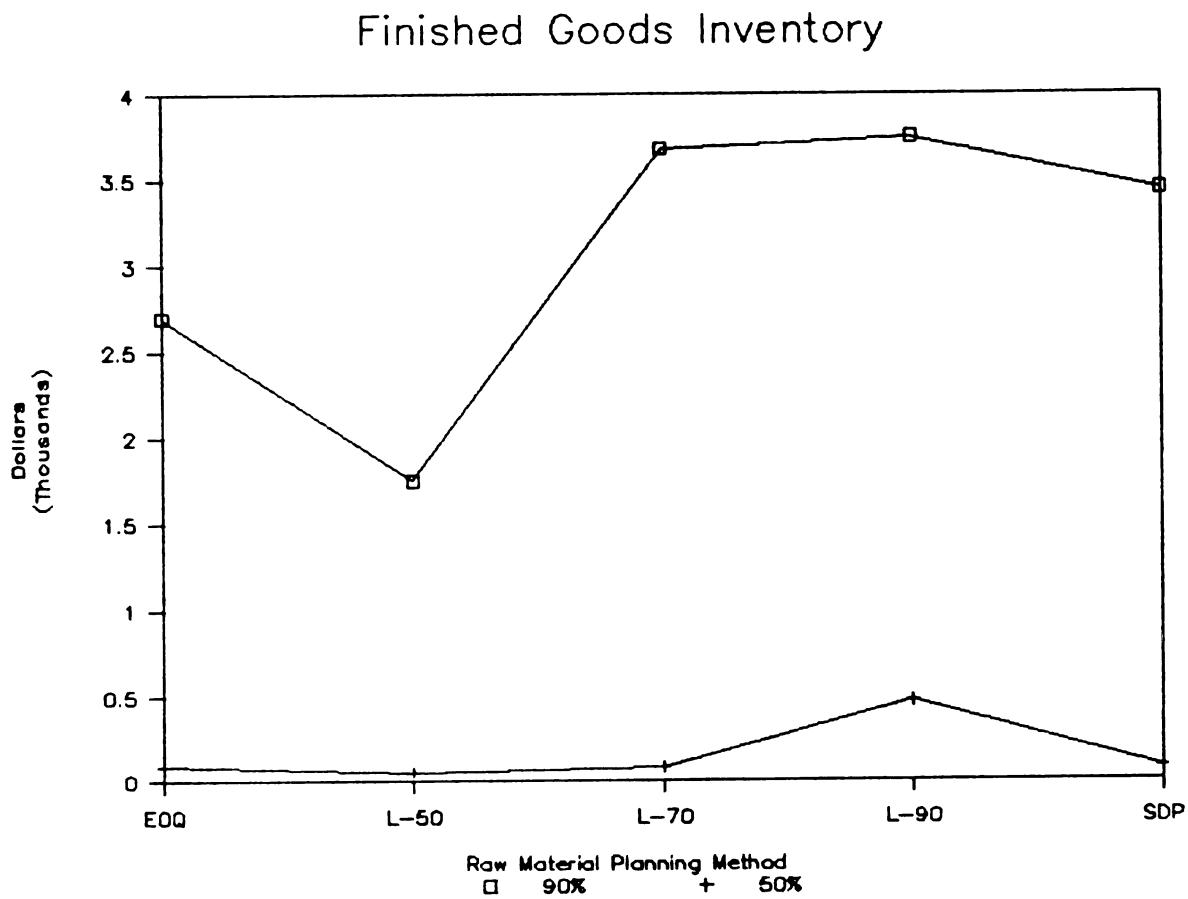


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

RAW MATERIAL INVENTORY--SIXTH EXOGENOUS FACTOR SETTING

FIGURE 6.31

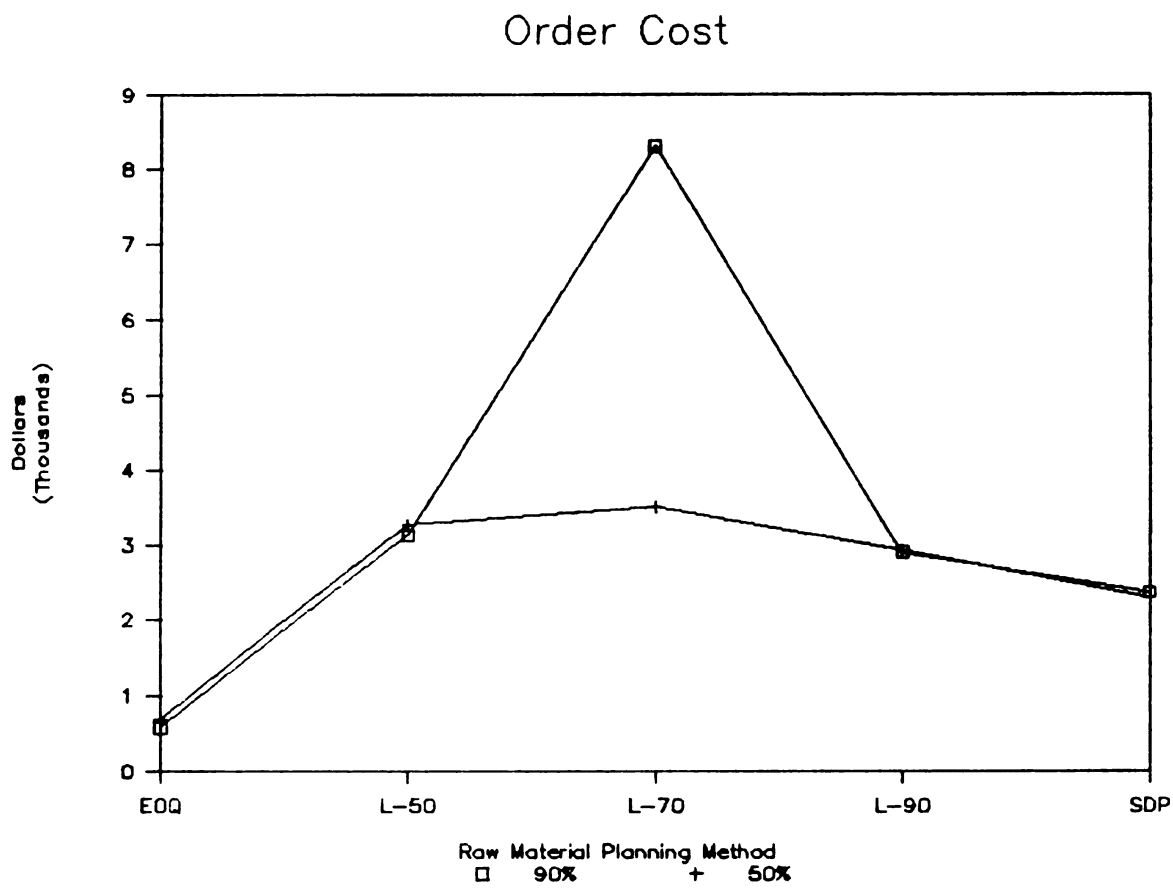


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

FINISHED GOODS--SIXTH EXOGENOUS FACTOR SETTING

FIGURE 6.32

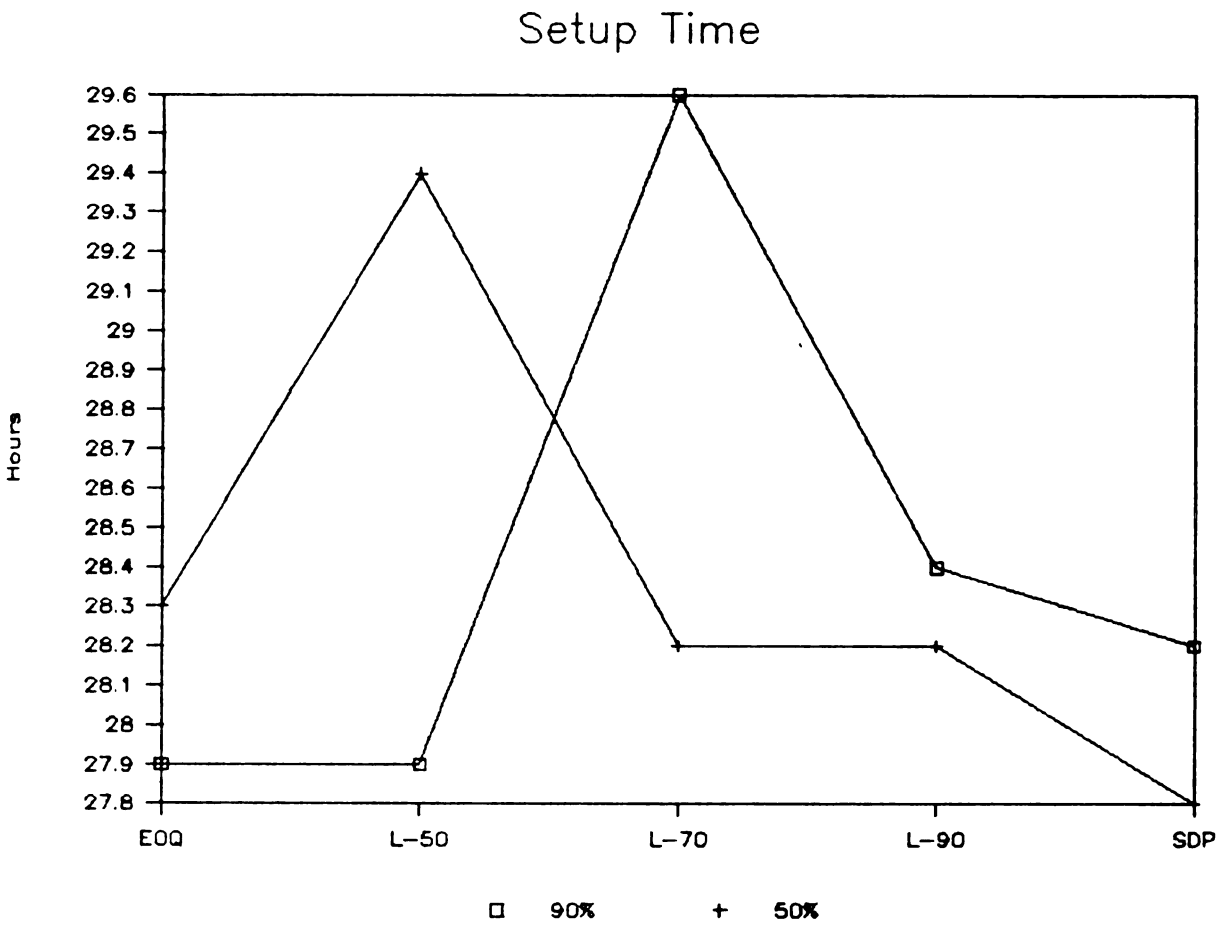


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

ORDER COST--SIXTH EXOGENOUS FACTOR SETTING

FIGURE 6.33

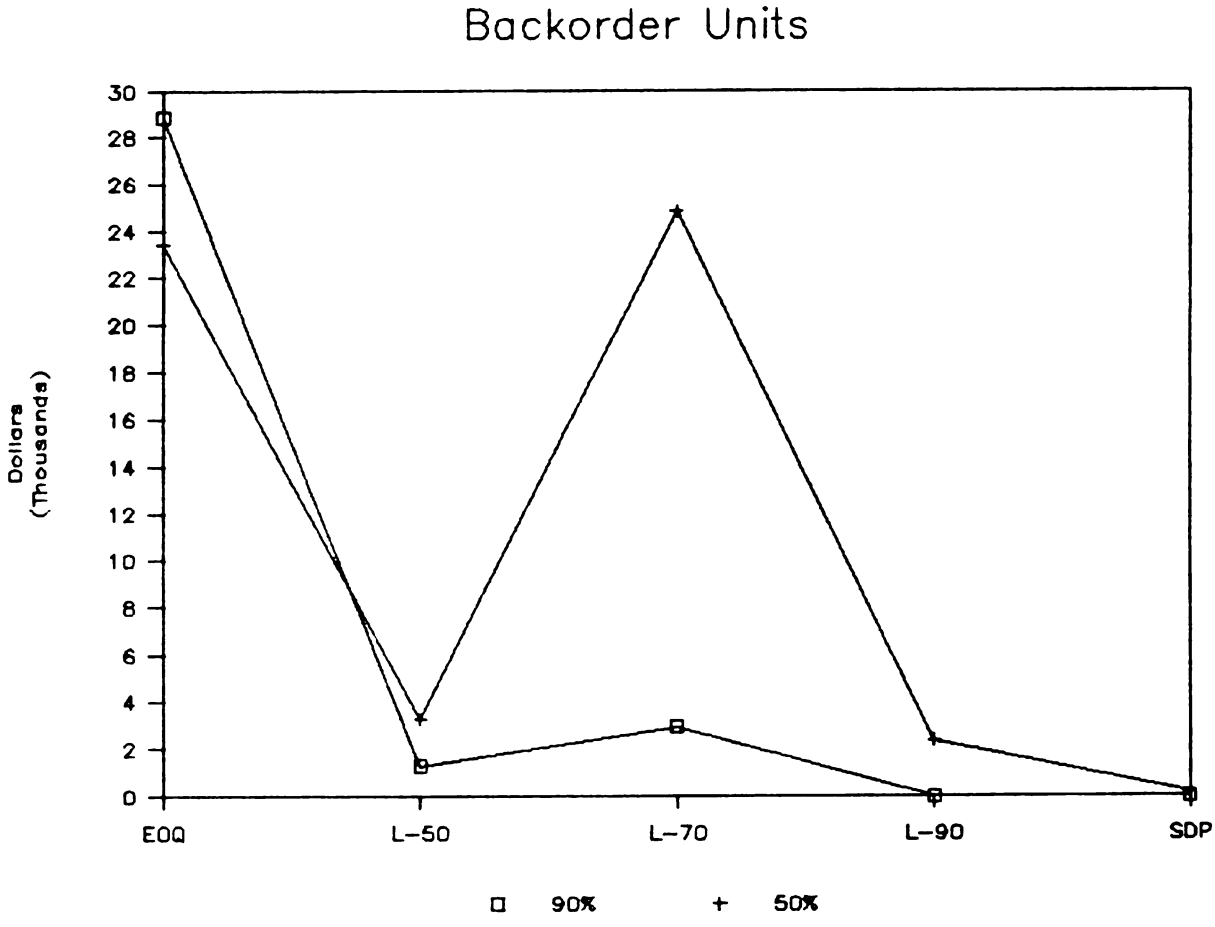


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

SETUP TIME--SIXTH EXOGENOUS FACTOR SETTING

FIGURE 6.34

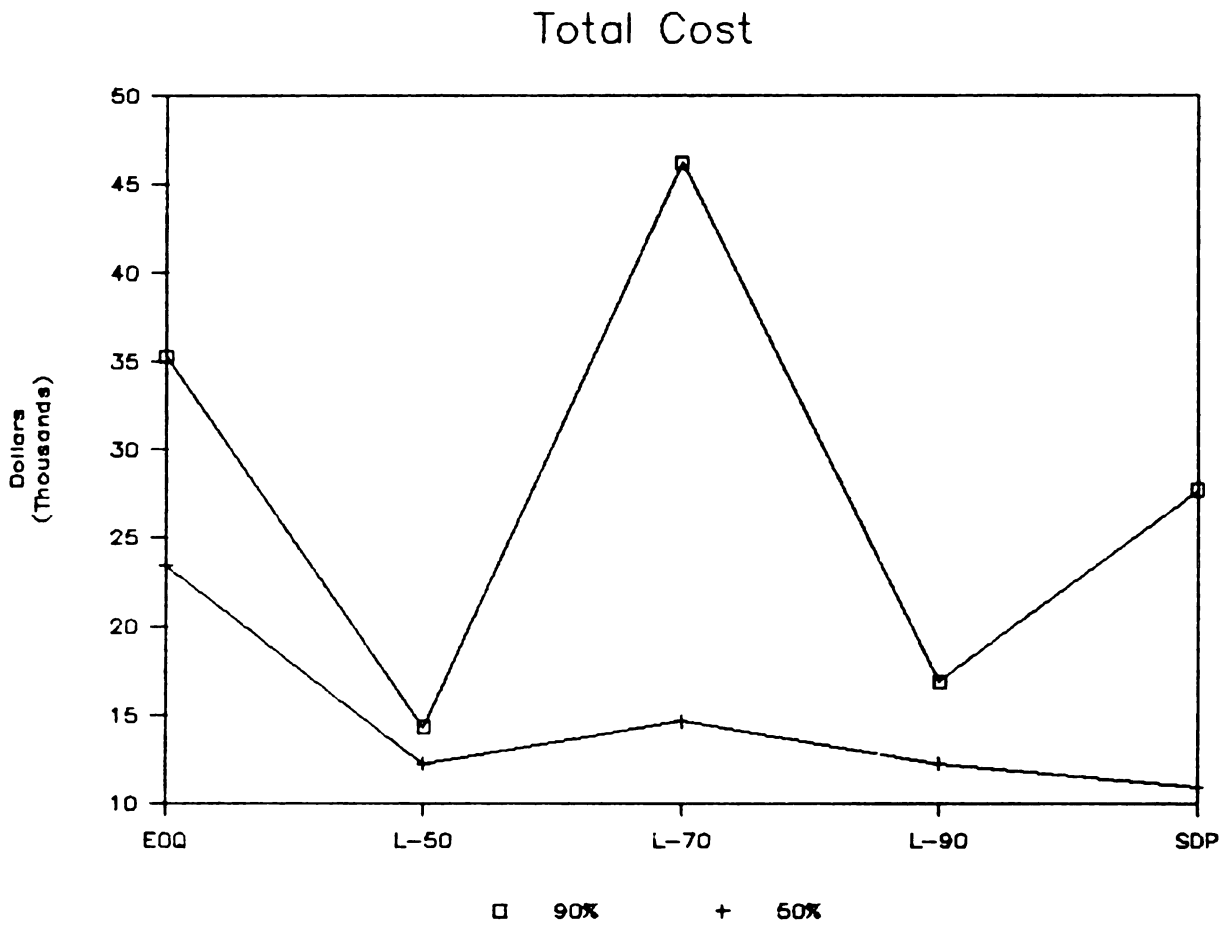


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

BACKORDER UNITS--SIXTH EXOGENOUS FACTOR SETTING

FIGURE 6.35



Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

TOTAL COST--SIXTH EXOGENOUS FACTOR SETTING

FIGURE 6.36

Again, this combination of exogenous factor level settings provides results consistent with those seen earlier. The inverse relationship between raw material inventory and order cost is consistent with one exception. The middle group of raw material inventory means normally only has the two stochastic dynamic programming responses, this time, L70-90% is a part of that group. All other results are consistent with relationships identified earlier.

Finished goods can again be broken down into two groups based on the service level of finished goods safety stock.

No corresponding relationship is indicated with setup cost as there is no significant difference in that performance measure regardless of endogenous factor settings.

Backorder units can be isolated into two groups, one being significantly larger than the other. The larger group includes both economic order quantity responses and L70-50%, the smaller contains all remaining responses.

Again, the least total cost is exhibited by SDP-50%, but it is statistically equal to four other responses, L50-90%, L50-50%, L70-50% and L90-50%. The planning methods, L90-90%, was significantly different from the lowest mean, but equal to others in the group. It was smaller than the group of EOQ-50% and SDP-90%, which was, in turn, smaller than EOQ-90%. The largest mean was exhibited by L70-90% and it was significantly larger than all other cell means.

6.3.7 Seventh Exogenous Factor Level Setting

The next combination of exogenous factors showed the same cost of capital, lower raw material variability, but a higher activity ratio. The results of this combination of factors is shown in Table 6.10 and Figures 6.37 through 6.42.

Exogenous Level Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5:1
Activity Ratio	250:1
Coefficient of Variation	.03:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

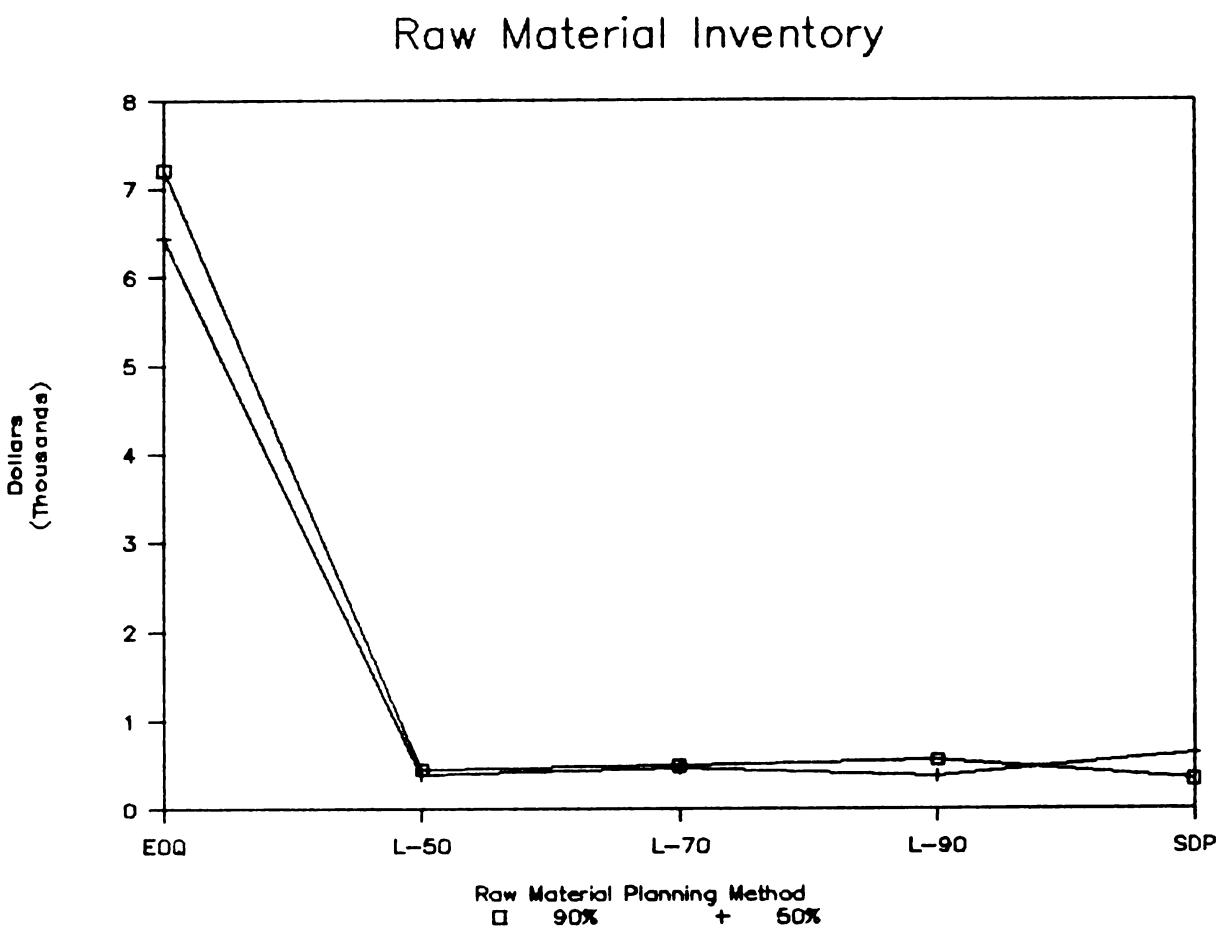
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	7202.8	6431.5	444.3	384.7	489.6	464.5	553.9	366.5	335.7	625.5
Finished Goods Inventory	4759.5	545.6	4927.7	581.8	4253.4	446.3	5058.0	925.6	482.8	620.8
Order Cost	1882.5	2042.2	9638.1	9095.5	8437.3	9805.8	8092.0	7587.1	2392.5	6906.5
Setup Time	81.2	77.9	78.5	83.2	80.6	84.8	81.2	81.9	79.6	82.4
Backorder Units	12878.1	11417.7	1911.2	2115.8	1227.2	21020.3	13121.7	7385.3	0.0	6864.3
Total Cost	79233.4	53657.3	37228.6	32712.4	48388.5	36156.6	42705.9	31162.8	11960.2	30307.2
Overall Rank	9	3	6	4.5	7	8	10	2	1	4.5
Average Rank	7.88	5.17	5.50	5.33	5.67	6.83	7.58	4.83	1.67	5.33

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

SEVENTH EXOGENOUS FACTOR SETTING

TABLE 6.10

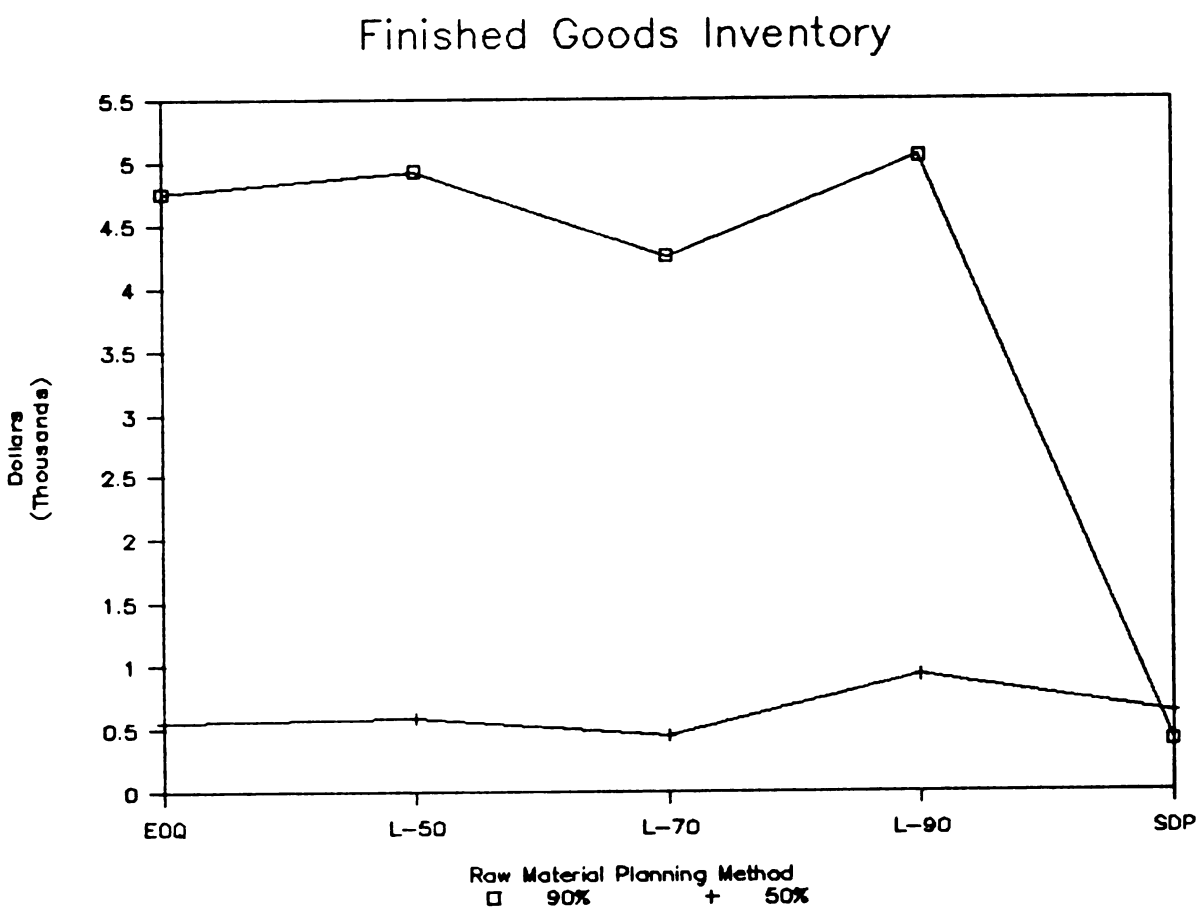


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

RAW MATERIAL INVENTORY--SEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.37

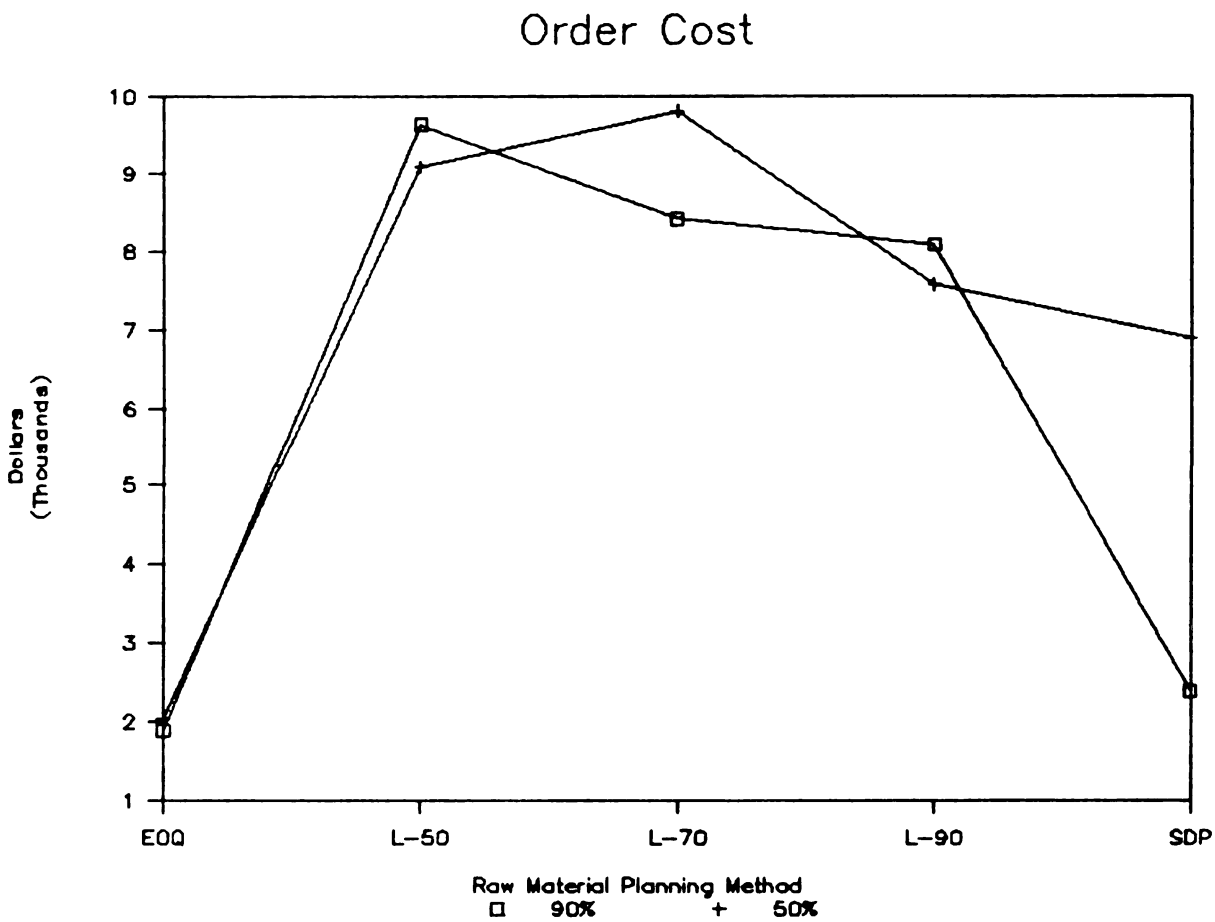


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

FINISHED GOODS--SEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.38

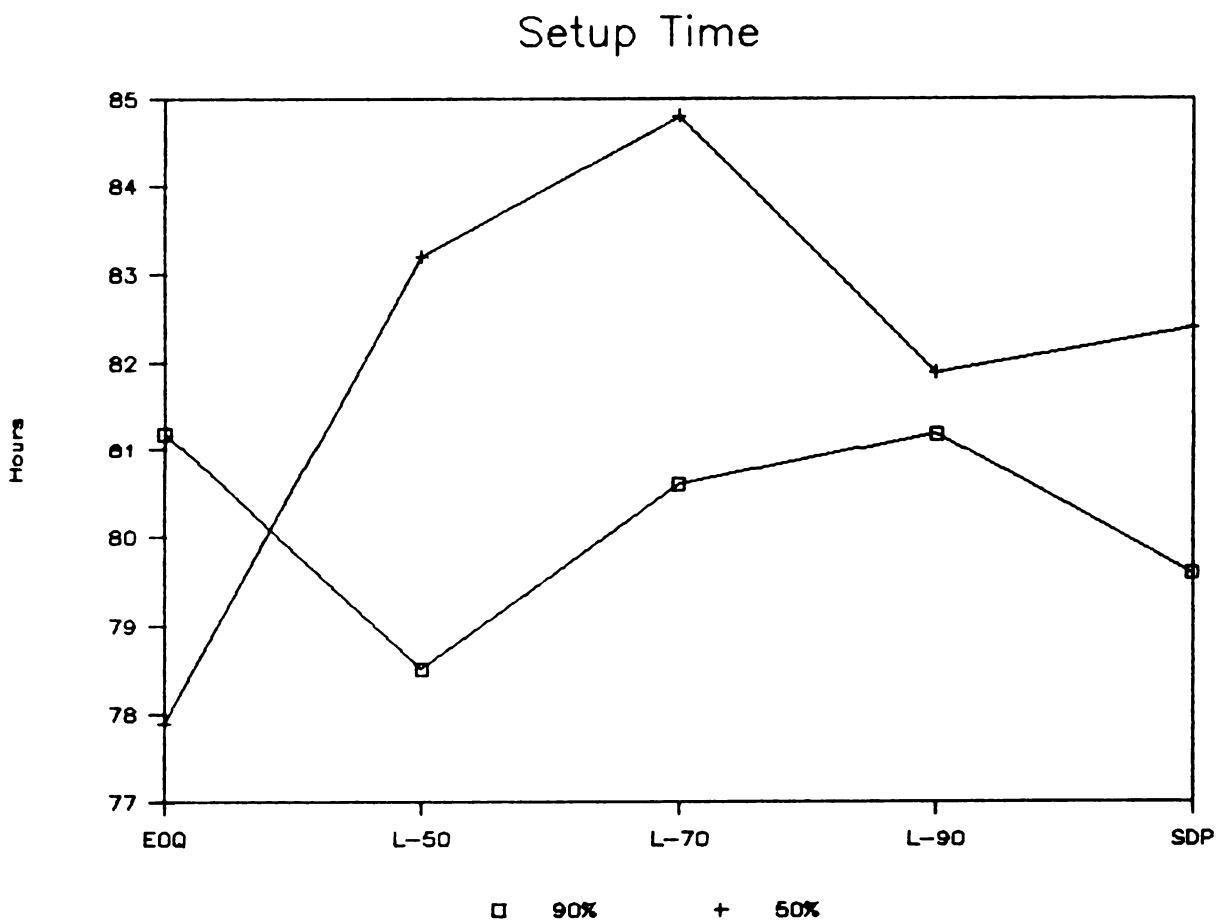


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

ORDER COST--SEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.39

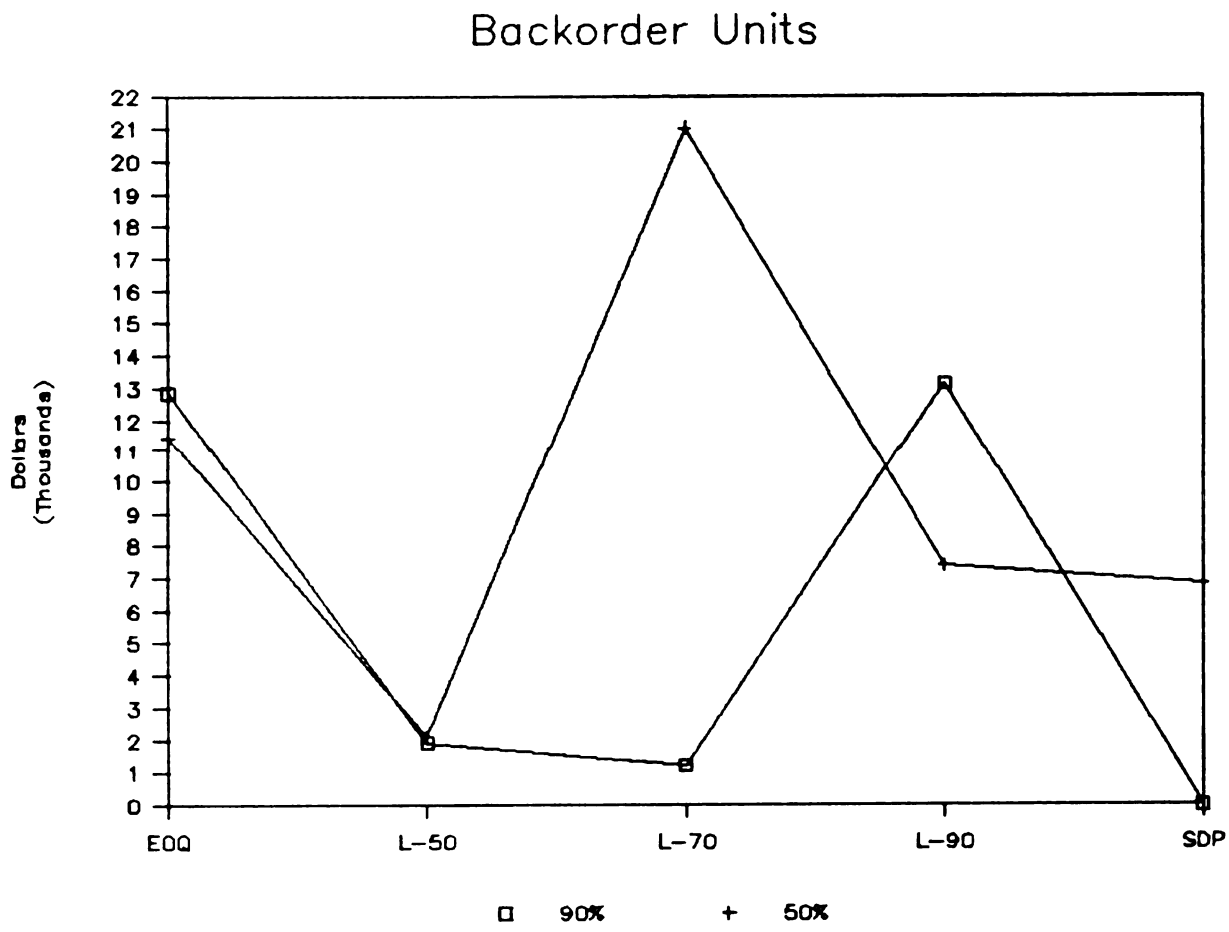


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

SETUP TIME--SEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.40

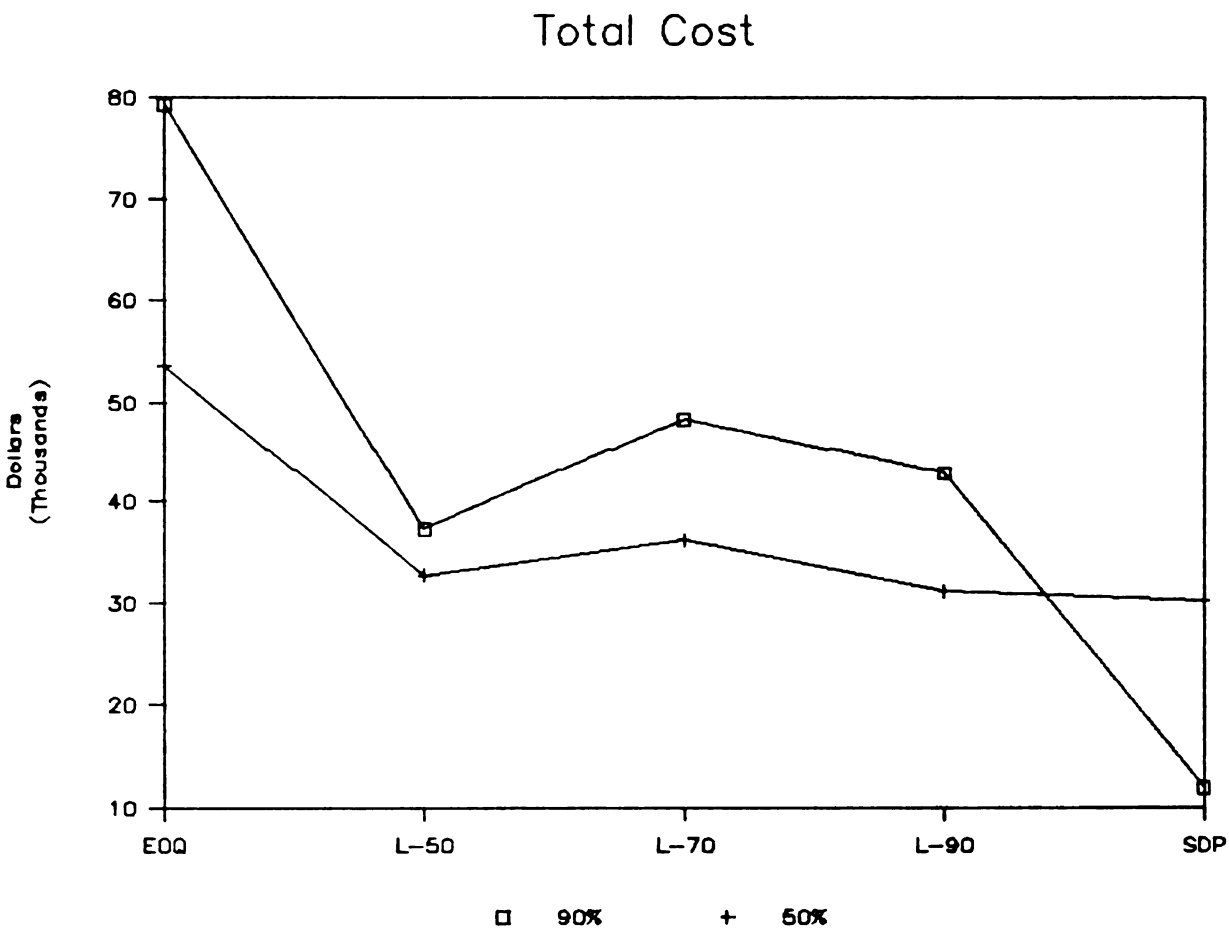


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

BACKORDER UNITS--SEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.41



Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

TOTAL COST--SEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.42

The statistical relationship between raw material inventory and order cost is evident in this combination of exogenous factor settings, but there are some variations worth noting. Both economic order quantity responses have the highest raw material inventory, but all remaining categories fall in one group which is statistically equal. The EOQ responses have the lowest order cost, but SDP-90% has a lower order cost than SDP-50%. The remaining lot-for-lot responses are all larger than the EOQ and SDP methods with some statistically significant differences in order cost. As raw material ordering service level goes up, the order cost decreases and raw material inventory increases.

Finished goods inventory can again be classified in the same manner as was noted previously with one exception, both stochastic dynamic programming methods proved equal at the lower mean group, the 50% service level for finished goods safety stock.

Setup time exhibited some statistically significant relationships, the planning systems, EOQ-50%, L50-90%, SDP-90% and L70-90% were equal and significantly smaller than all other planning responses which were also equal.

Backorder cost had one planning system with the highest mean, L70-50%. It was significantly# different from the economic order quantity methods which were equal to L90-50%. That method was equal to the remaining planning system configurations which were all significantly less than the economic order quantity methods.

The final measure, total cost, provided significant relationships worth mentioning. The two lowest average total cost values were generated by the stochastic dynamic programming responses with SDP-90% significantly lower than SDP-50%. The two highest means were generated by the economic order quantity planning methods.

6.3.8 Eighth Exogenous Factor Level Setting

The final combination of exogenous factors with low average capacity utilization was analyzed. The factor settings, average performance and ranks are shown in Table 6.11 and Figures 6.43 through 6.48.

Exogenous Level Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5:1
Activity Ratio	250:1
Coefficient of Variation	.10:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

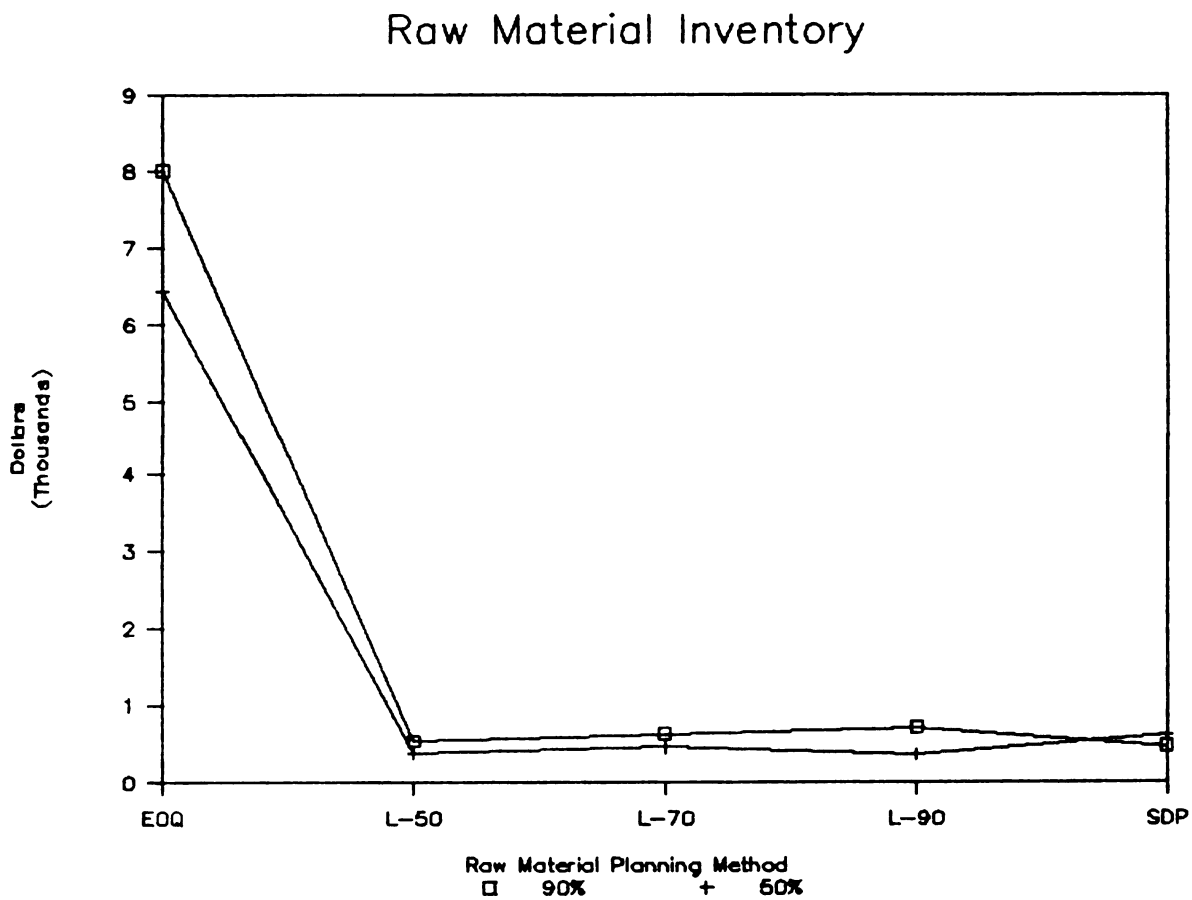
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	8017.6	6569.1	537.4	482.7	626.7	506.0	718.4	576.1	469.0	1150.3
Finished Goods Inventory	5237.3	546.1	2340.8	214.6	3713.7	560.7	2751.4	1449.6	534.6	613.7
Order Cost	1823.9	2125.2	8887.5	9318.7	8582.2	8361.3	8230.8	7828.5	2582.0	6387.2
Setup Time	76.2	81.9	81.5	87.8	79.1	83.5	80.5	82.3	79.6	82.2
Backorder Units	15246.6	22354.2	3650.7	3560.7	2822.6	35200.2	32916.7	10269.6	0.0	7447.2
Total Cost	84868.8	56311.3	37246.9	35008.8	46384.0	37038.0	44963.8	35446.6	13531.6	32405.3
Overall Rank	9	8	5.5	3	5.5	10	7	4	1	2
Average Rank	6.50	6.08	5.83	4.83	5.83	7.67	6.00	5.67	1.83	4.83

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

EIGHTH EXOGENOUS FACTOR SETTING

TABLE 6.11



Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

RAW MATERIAL INVENTORY--EIGHTH EXOGENOUS FACTOR SETTING

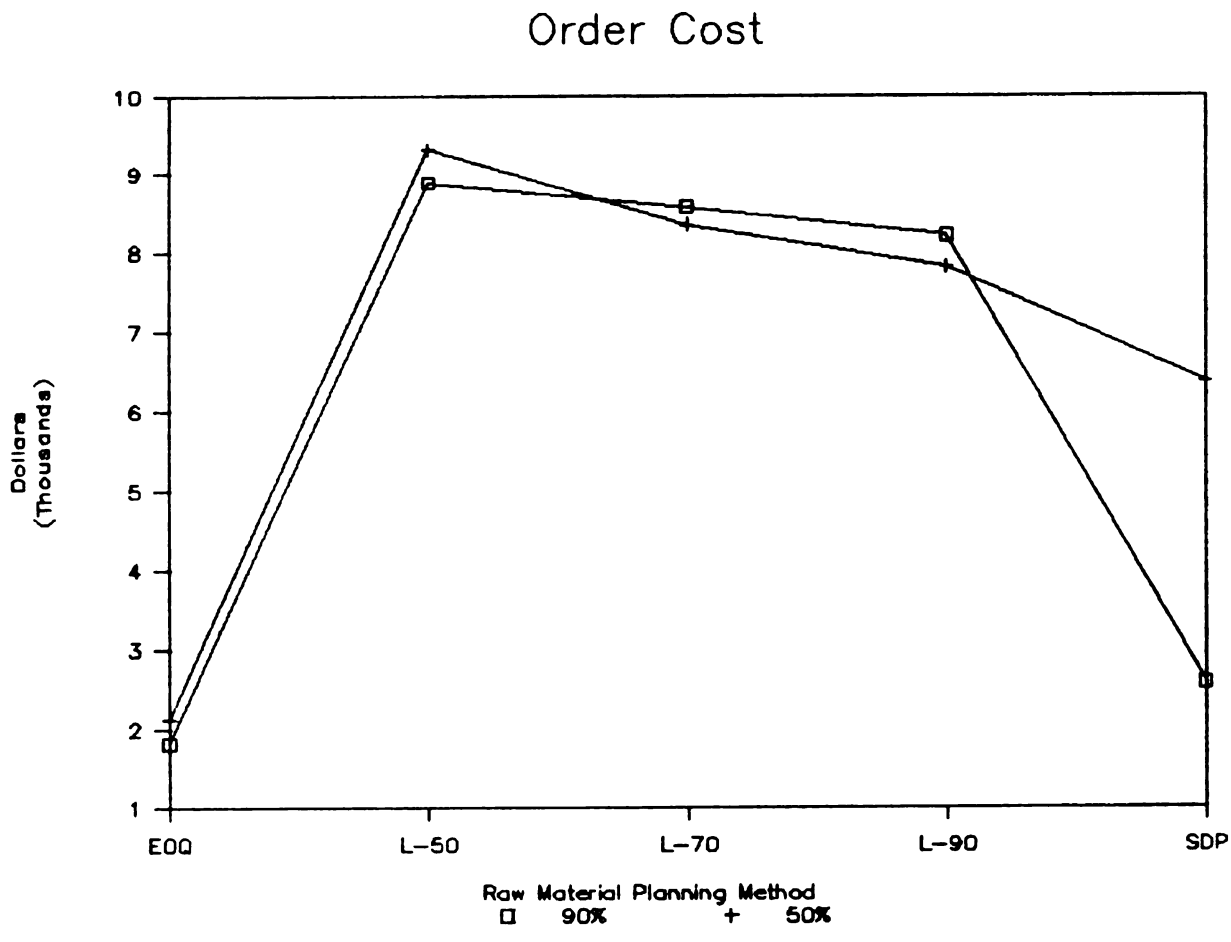
FIGURE 6.43

Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

FINISHED GOODS--EIGHTH EXOGENOUS FACTOR SETTING

FIGURE 6.44

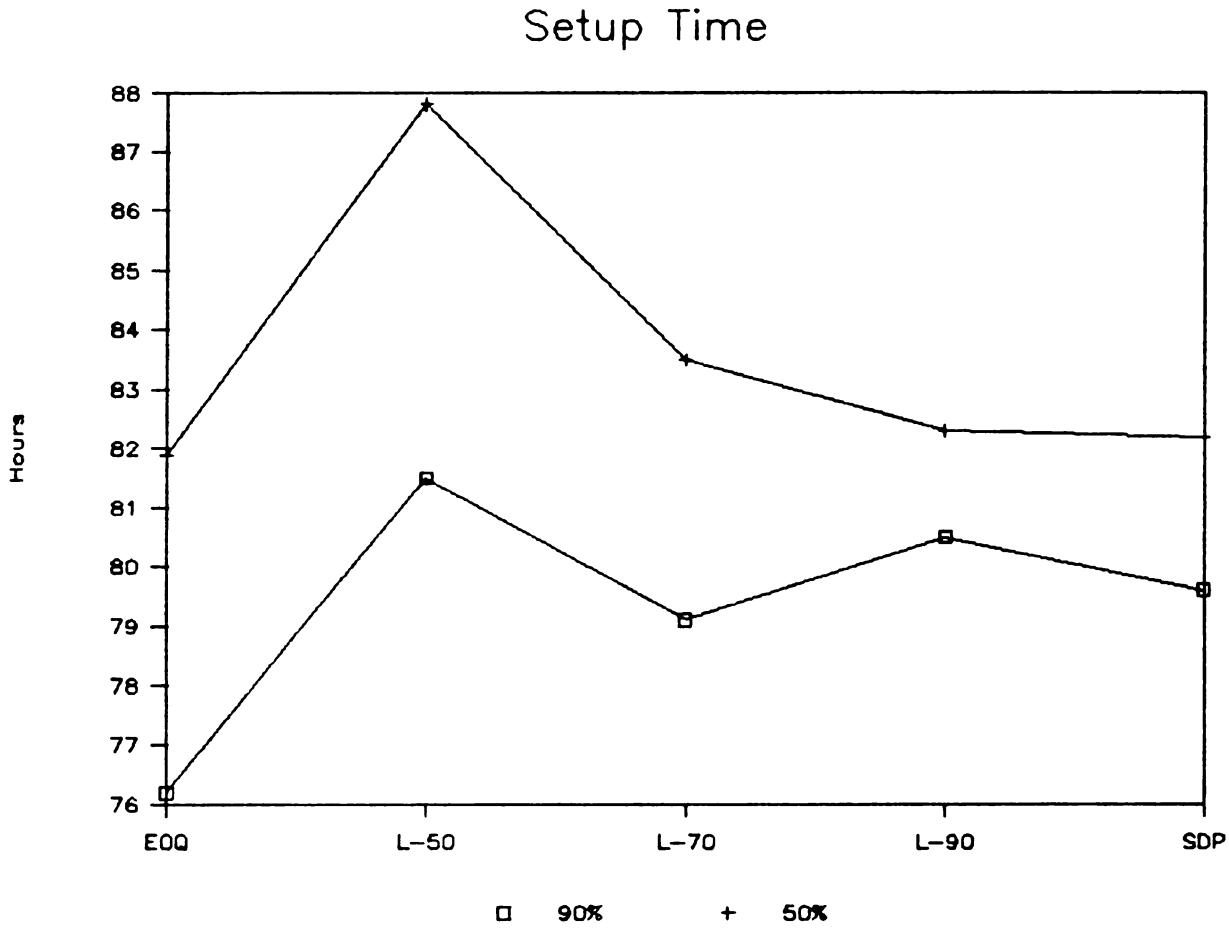


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

ORDER COST--EIGHTH EXOGENOUS FACTOR SETTING

FIGURE 6.45

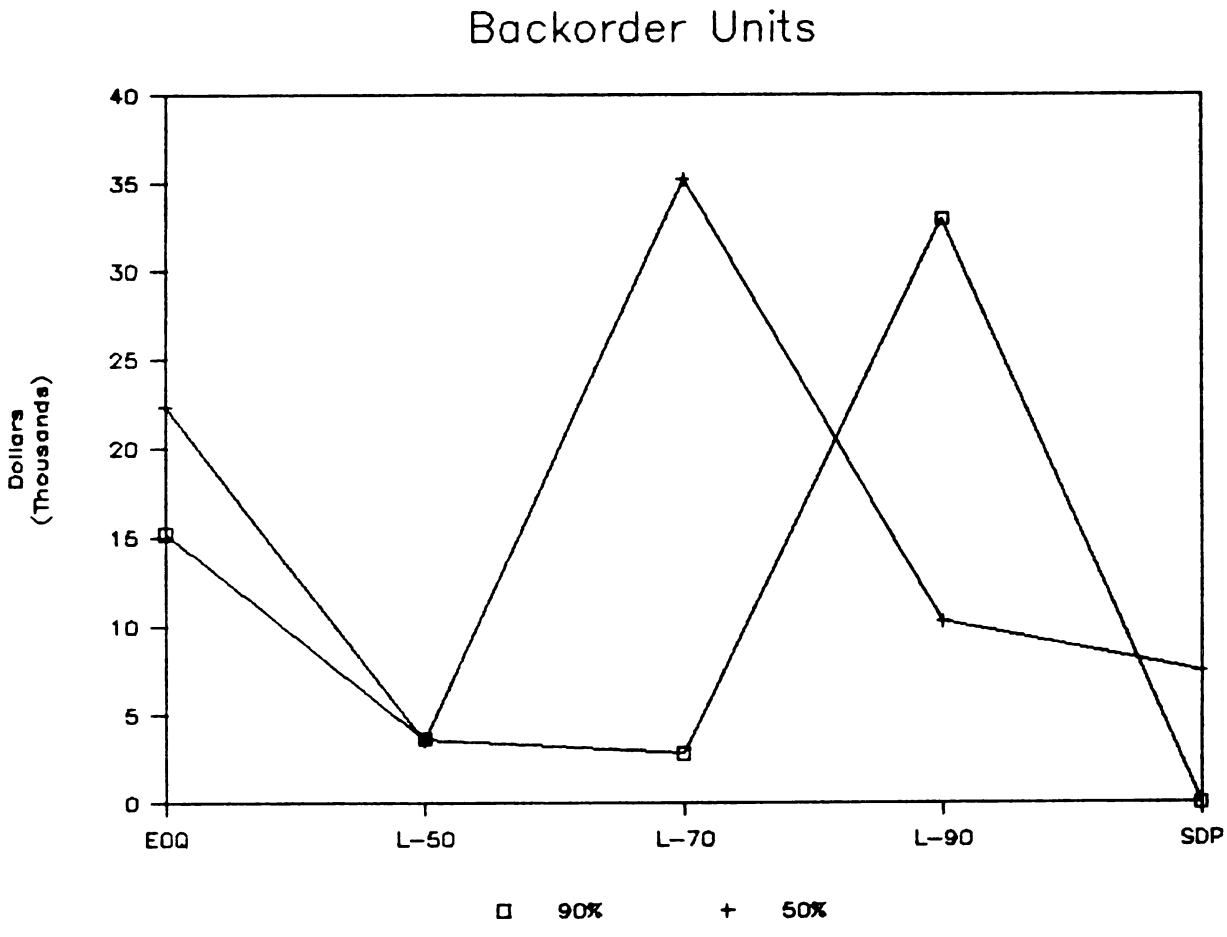


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

SETUP TIME--EIGHTH EXOGENOUS FACTOR SETTING

FIGURE 6.46

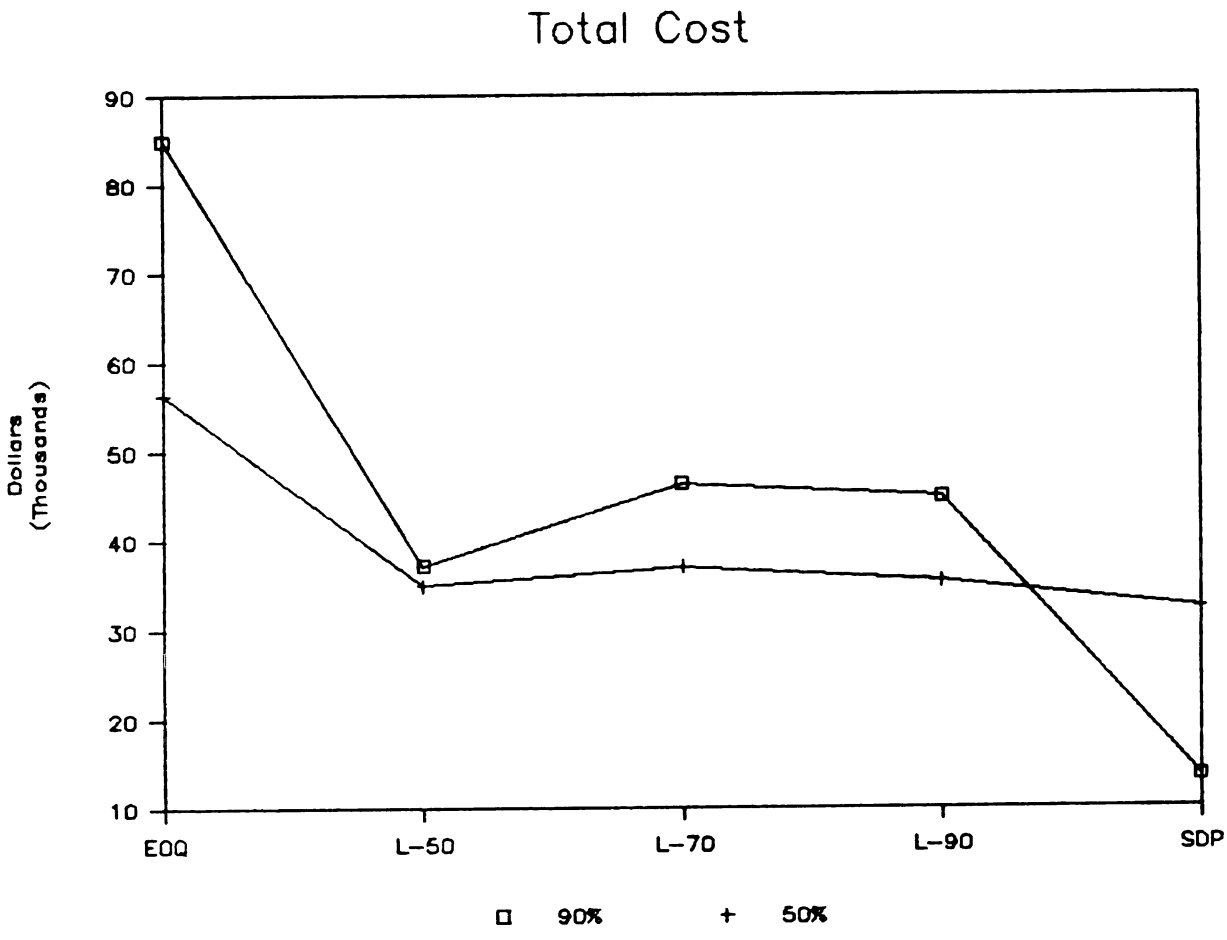


Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

BACKORDER UNITS--EIGHTH EXOGENOUS FACTOR SETTING

FIGURE 6.47



Exogenous Factor Settings

Average Capacity Utilization	60%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

TOTAL COST--EIGHTH EXOGENOUS FACTOR SETTING

FIGURE 6.48

The economic order quantity responses were consistent in their means for raw material inventory and order cost. They were significantly the highest and lowest, respectively. Some differences existed in other means from planning system responses. Lowest raw material inventory was exhibited by SDP-90%, L50-50%, L70-50%, L50-90% and L90-50%. A second larger equal group included L70-90%, L90-90%, and SDP-50%. Order cost saw SDP-90% equal to the two economic order quantity methods, SDP-50% significantly larger and the remaining responses, using lot-for-lot raw material planning, a group with equal larger means.

Finished goods inventory means were consistent with past exogenous factor level settings with one exception. Both stochastic dynamic programming methods were in the group with smaller means.

Setup time showed EOQ-90% equal to L70-90%, but smaller than all other planning methods. A group composed of all remaining methods except L50-50% was equal to one another.

Low average backorder units was exhibited by both stochastic dynamic programming methods, L70-90%, L50-50% and L50-90%. High values were shown in the remaining planning systems.

Total cost showed two different patterns. The two stochastic dynamic programming methods provided the lowest means, SDP-90% and SDP-50%, and the economic order quantity responses provided the highest means.

6.3.9 Ninth Exogenous Factor Level Settings

The next combination of factors sees one major difference, an increase in average capacity utilization to 80% from 60%. The specific settings, averages and ranks are shown in Table 6.12 and Figures 6.49 through 6.54.

Exogenous Level Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10:1
Activity Ratio	50:1
Coefficient of Variation	.03:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

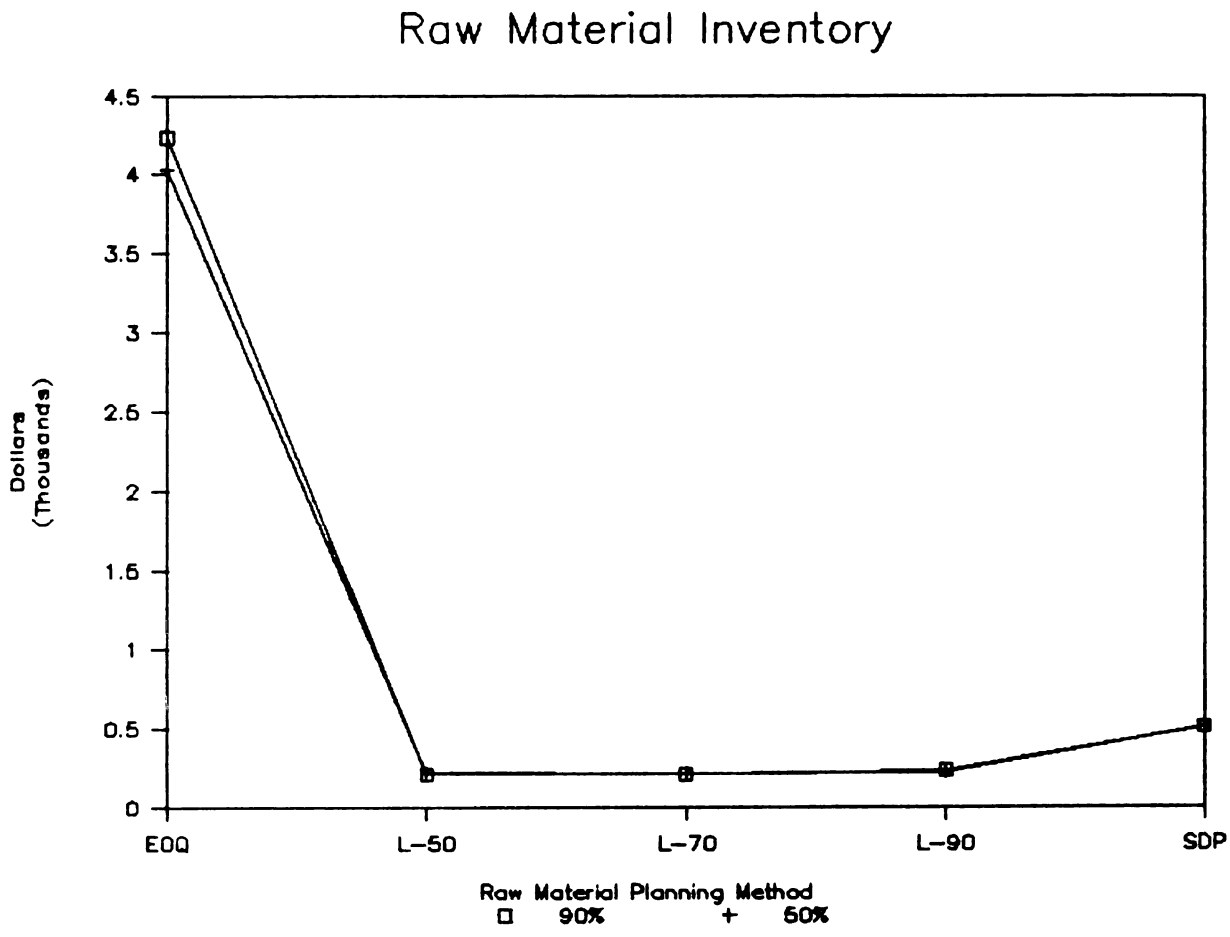
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	4233.9	4028.9	212.3	226.2	215.6	220.2	235.6	226.1	509.9	509.2
Finished Goods Inventory	4572.8	219.0	4185.8	260.2	4351.2	195.1	5101.5	213.0	4669.2	226.5
Order Cost	519.3	550.5	2642.9	2782.3	2525.0	2698.2	2487.9	2534.2	2211.3	2227.8
Setup Time	25.1	25.0	25.1	25.3	24.9	25.0	25.2	25.2	25.2	25.1
Backorder Units	4505.2	13409.3	445.7	2628.7	70.1	1468.7	0.0	18.4	352.6	514.1
Total Cost	94599.1	50713.3	25981.0	15827.4	53194.0	12147.0	32070.1	15159.5	59122.6	14723.5
Overall Rank	10	6	5	7	2.5	1	8	4	9	2.5
Average Rank	7.33	5.25	5.00	5.33	4.50	4.25	6.00	4.33	6.83	4.52

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

NINTH EXOGENOUS FACTOR SETTING

TABLE 6.12



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

RAW MATERIAL INVENTORY--NINTH EXOGENOUS FACTOR SETTING

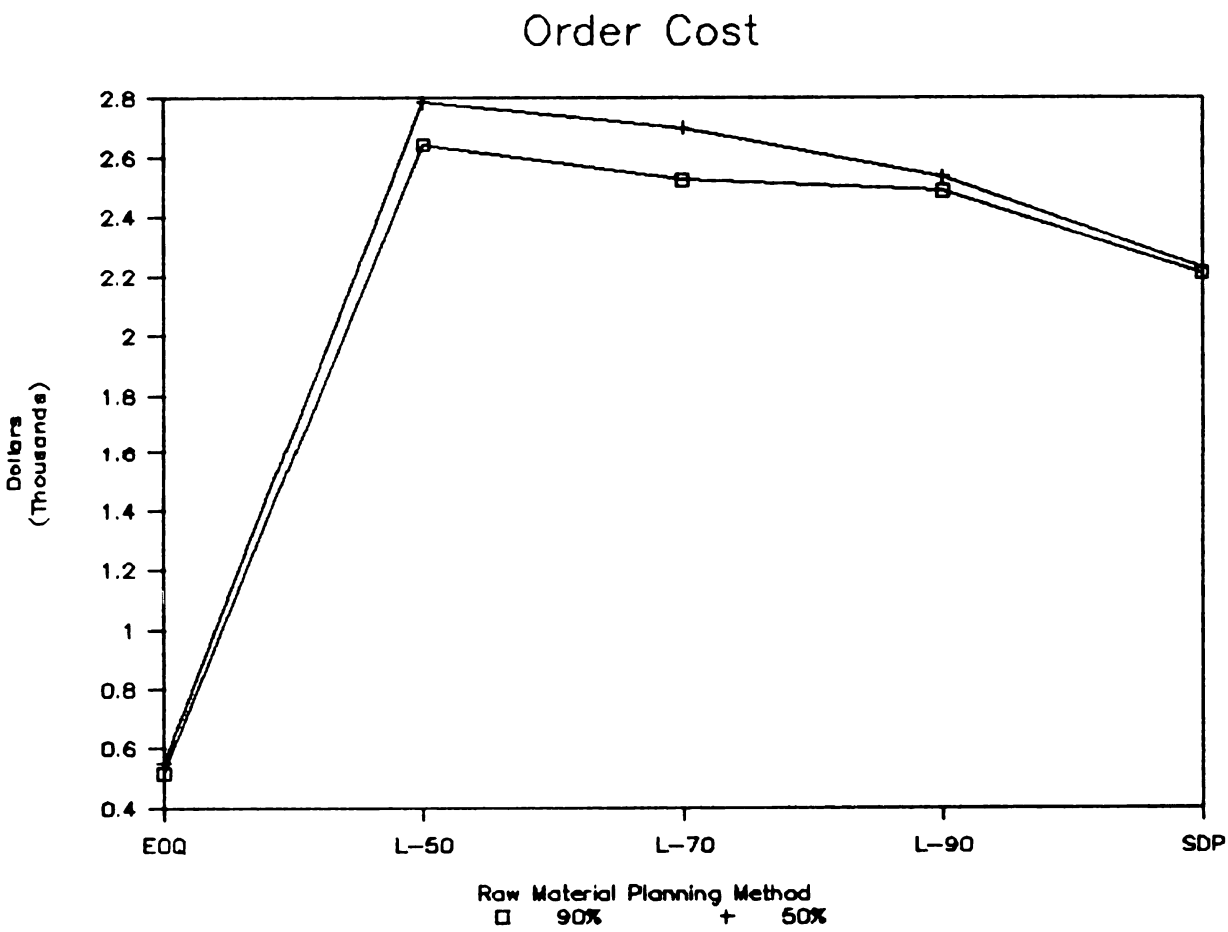
FIGURE 6.49

Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

FINISHED GOODS--NINTH EXOGENOUS FACTOR SETTING

FIGURE 6.50

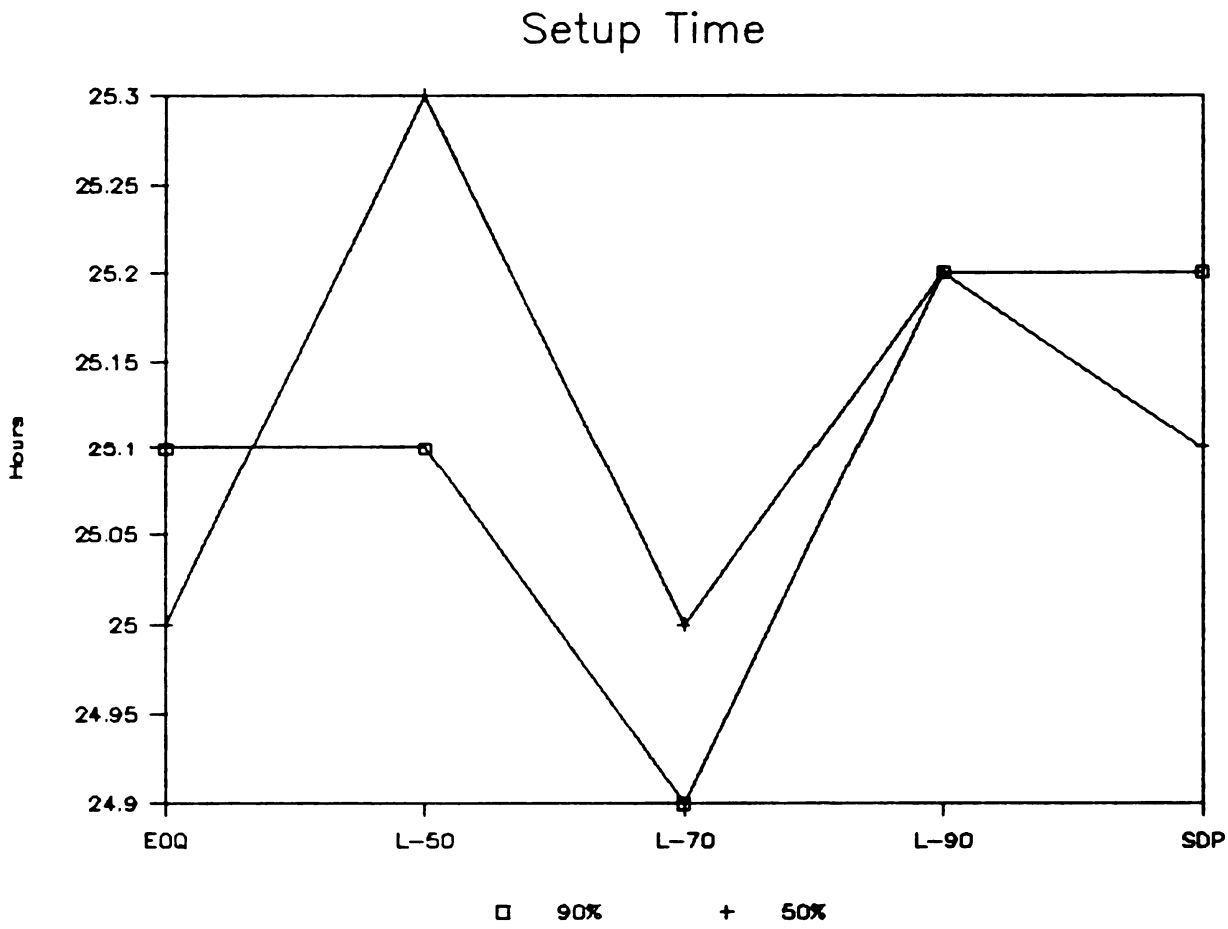


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

ORDER COST--NINTH EXOGENOUS FACTOR SETTING

FIGURE 6.51

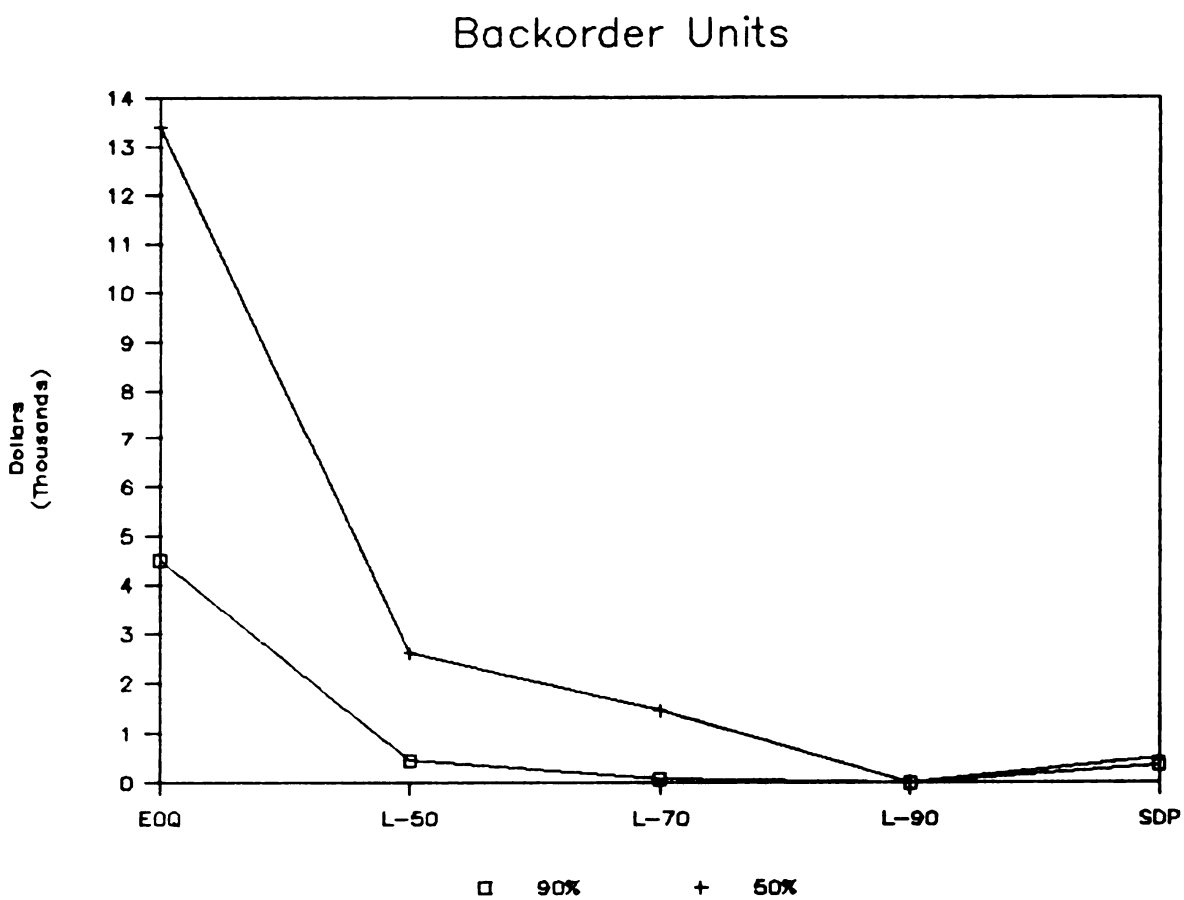


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

SETUP TIME--NINTH EXOGENOUS FACTOR SETTING

FIGURE 6.52

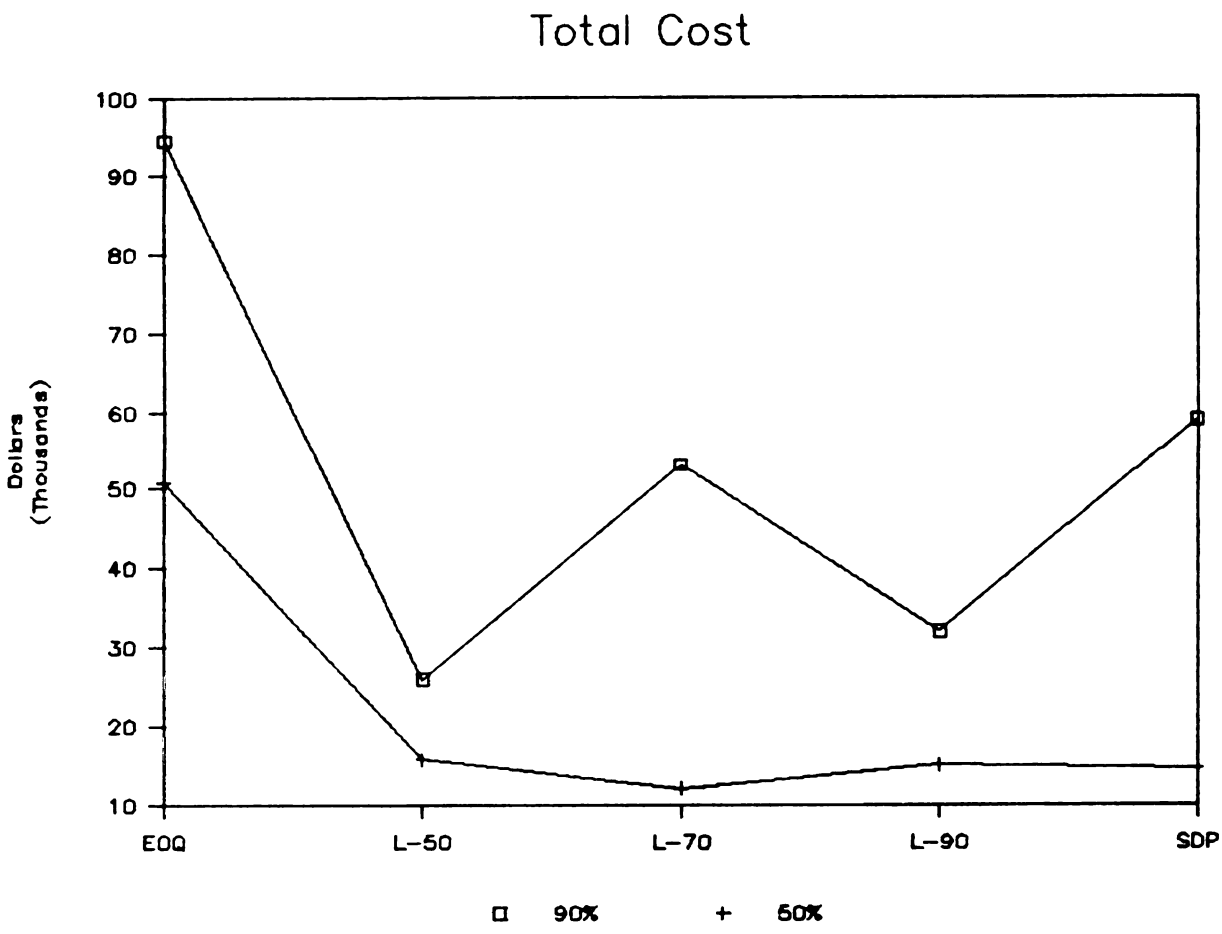


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

BACKORDER UNITS--NINTH EXOGENOUS FACTOR SETTING

FIGURE 6.53



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

TOTAL COST--NINTH EXOGENOUS FACTOR SETTING

FIGURE 6.54

Statistically significant relationships are consistent with relationships seen earlier for the first four performance measures. Raw material inventory means are grouped based on raw material planning method, lot-for-lot, stochastic dynamic programming and economic order quantity.

Order cost is grouped in the same way, with order cost means inversely related to raw material inventory means.

Finished goods inventory is classified into two groups based on service level of finished goods safety stock, 90% service level having a larger mean than 50% service level.

No significant difference is evident in setup cost.

The means of backorder units is consistent with previous results. The two highest means are the economic order quantity responses with EOQ-50% having the highest mean and all other planning response means are equal.

Total cost has a variety of significant relationships, but none providing a pattern consistent with other results. The group with the lowest equal means includes L70-50%, SDP-50%, L90-50% and L50-50%. The remaining planning responses are all significantly larger in the following order; L50-90%, L90-90%, EOQ-50%, L70-90%, SDP-90% and EOQ-90%.

6.3.10 Tenth Exogenous Factor Level Setting

The next combination of exogenous factor level settings sees an increase in raw material variability. Specific levels, dependent variable means and rankings are shown in Table 6.13 and Figures 6.55 through 6.60.

Exogenous Level Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10:1
Activity Ratio	50:1
Coefficient of Variation	.10:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

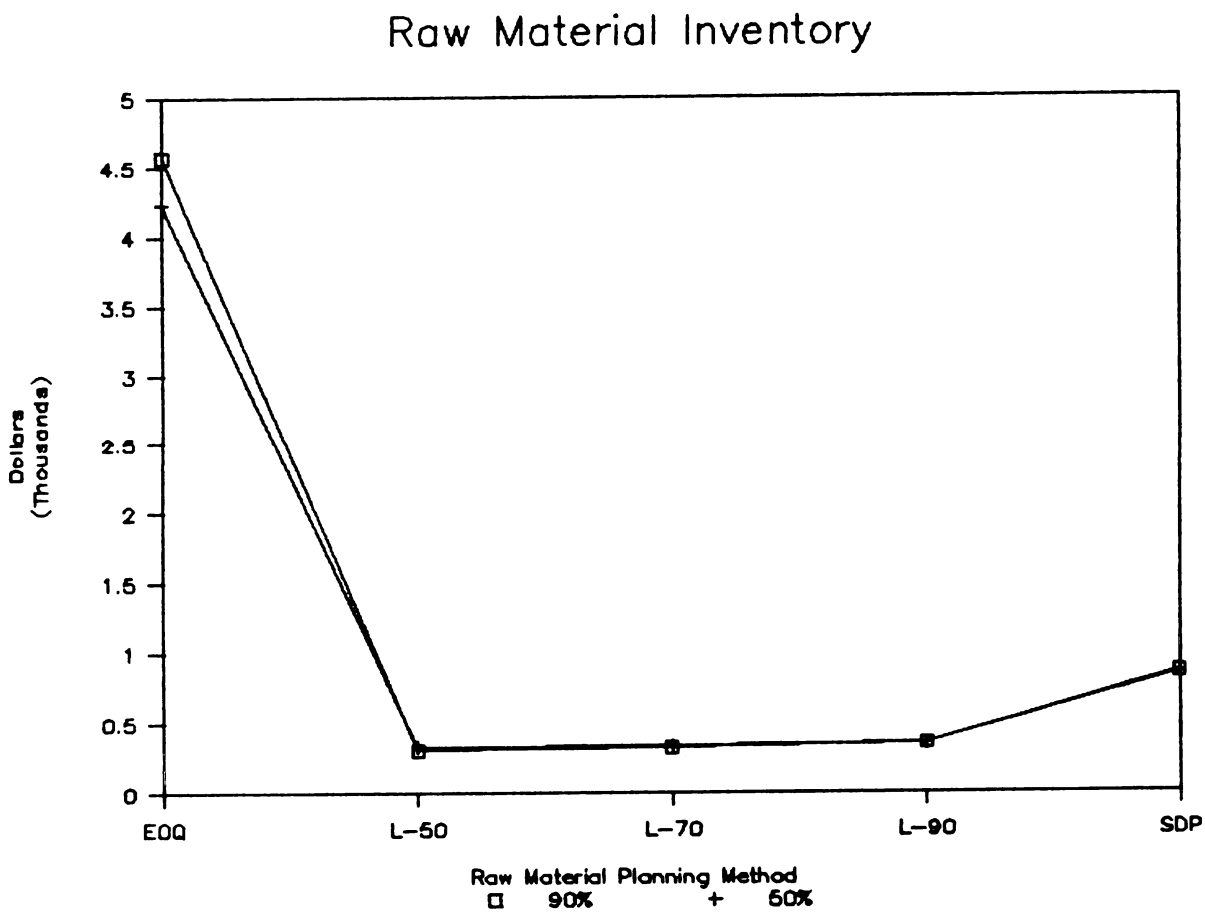
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	4569.3	4226.3	302.7	328.7	324.2	333.8	356.2	351.1	861.8	851.6
Finished Goods Inventory	4105.6	214.1	2736.8	100.8	3733.2	157.4	4245.5	212.9	4666.6	229.0
Order Cost	509.5	693.1	2750.4	2767.6	2631.8	2695.0	2510.1	2547.0	2015.5	2019.8
Setup Time	25.1	25.1	25.1	24.9	25.0	24.9	25.2	25.2	25.2	25.1
Backorder Units	21540.2	30471.8	2366.2	9152.1	777.7	5575.6	67.6	217.2	213.1	702.7
Total Cost	96651.8	56224.4	24954.0	13878.3	48359.3	13702.3	32352.0	18739.2	62387.2	18012.8
Overall Rank	10	8	6	2	5	1	7	3	9	4
Average Rank	7.92	6.58	5.42	4.25	5.17	3.92	6.00	5.00	6.83	5.08

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

TENTH EXOGENOUS FACTOR SETTING

TABLE 6.13



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

RAW MATERIAL INVENTORY--TENTH EXOGENOUS FACTOR SETTING

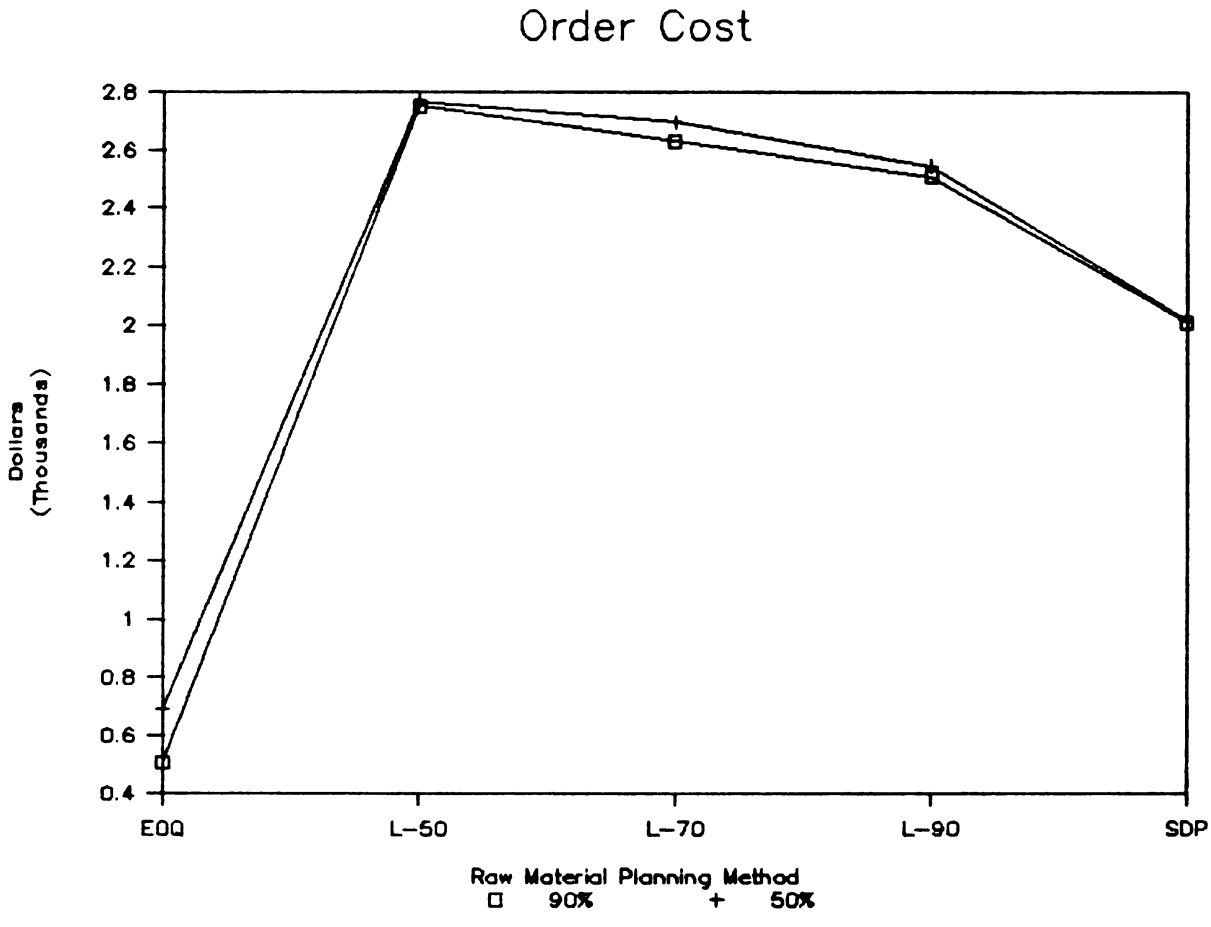
FIGURE 6.55

Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

FINISHED GOODS--TENTH EXOGENOUS FACTOR SETTING

FIGURE 6.56

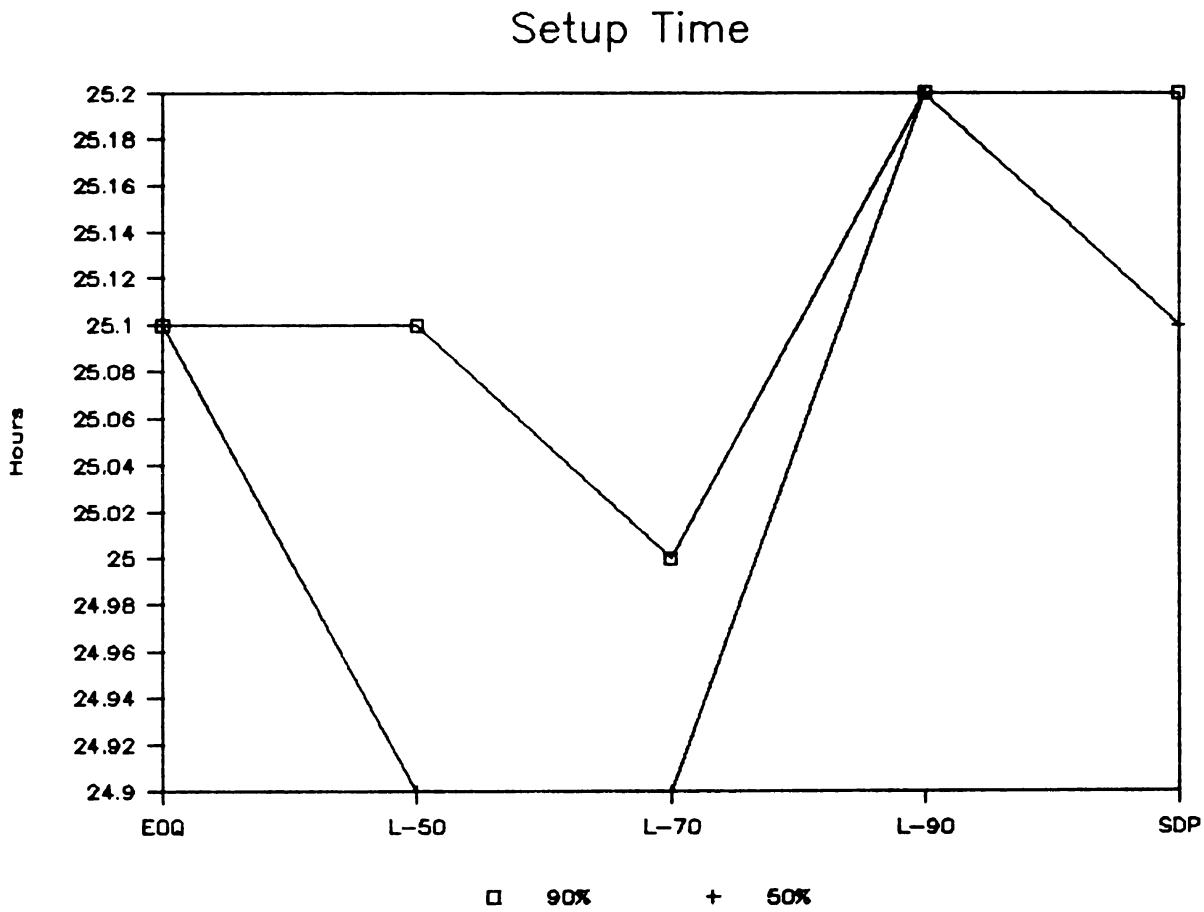


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

ORDER COST--TENTH EXOGENOUS FACTOR SETTING

FIGURE 6.57

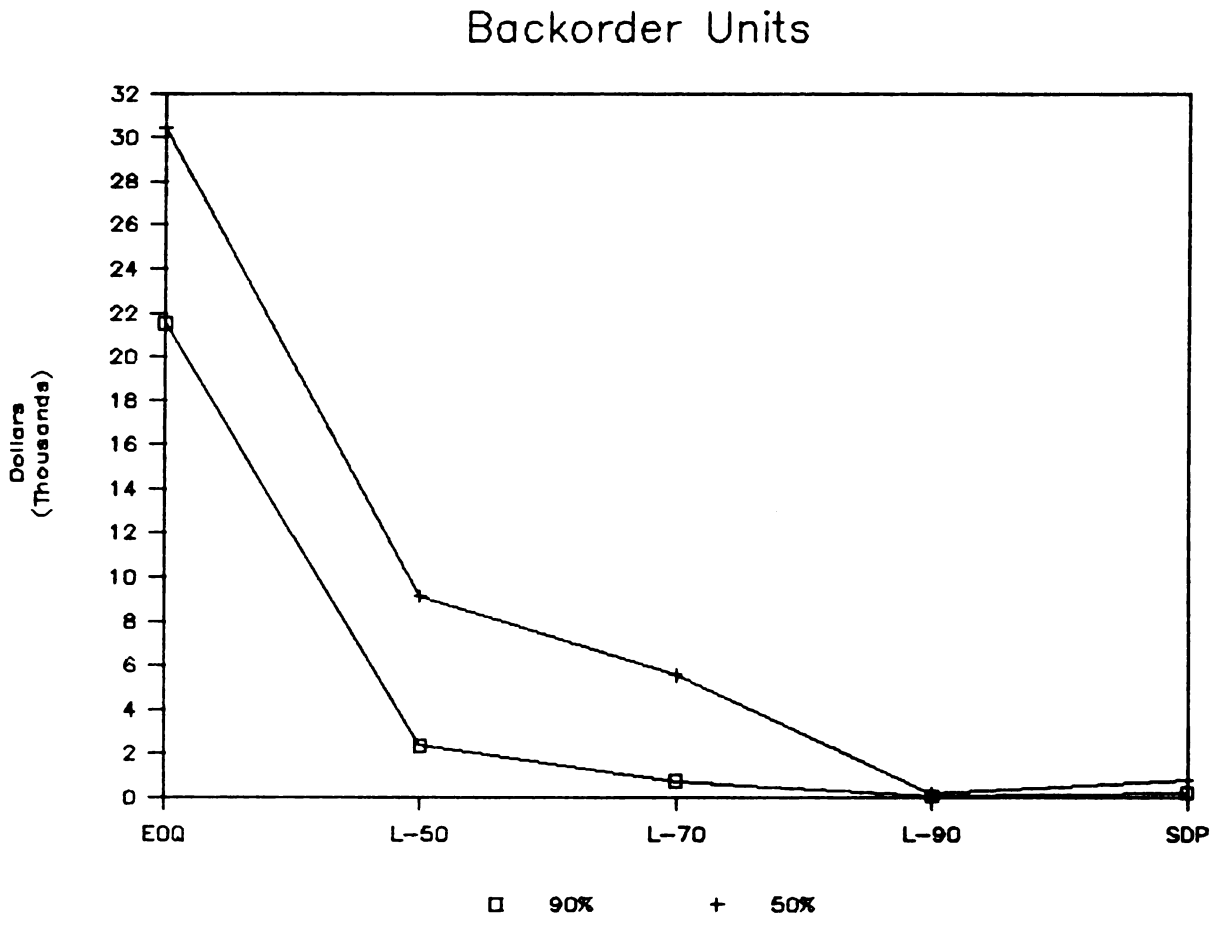


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

SETUP TIME--TENTH EXOGENOUS FACTOR SETTING

FIGURE 6.58

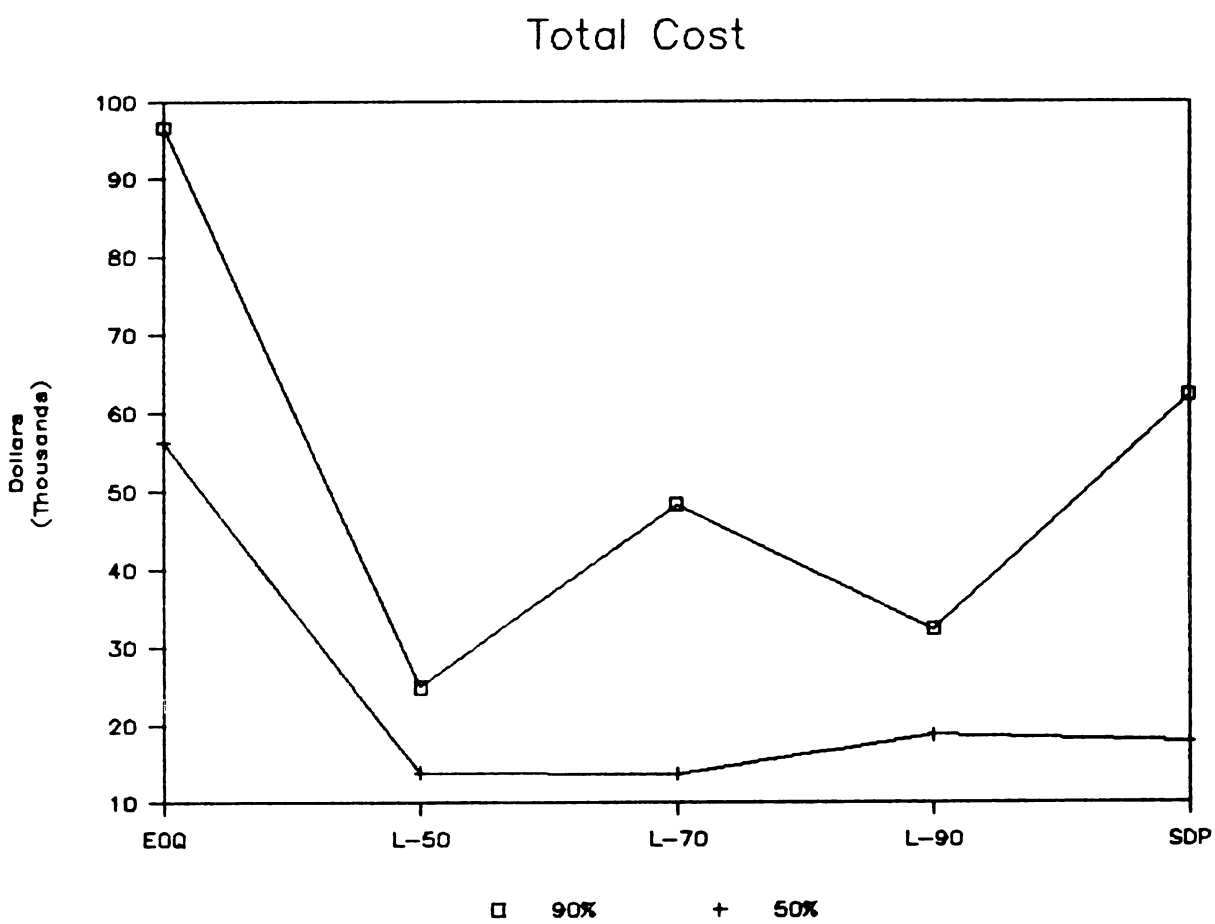


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

BACKORDER UNITS--TENTH EXOGENOUS FACTOR SETTING

FIGURE 6.59



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

TOTAL COST--TENTH EXOGENOUS FACTOR SETTING

FIGURE 6.60

The first four dependent variables indicate the same significant relationships exhibited earlier. Raw material inventory and order cost sees significant differences between economic order quantity, stochastic dynamic programming and lot-for-lot methods with ranks of the three groups inversely related.

Classification of finished goods inventory by service level of finished goods safety stock sees the 50% service level means all equal and less than all 90% means which are also equal. Although the differences are not statistically significant, as the service level of raw material ordering goes down, average inventory goes up.

The corresponding measure, setup time, shows no significant differences between means.

Backorder units shows two groups of means exhibiting statistically significant differences. Both economic order quantity methods and SDP-90% are equal and higher than all remaining planning system responses which are equal.

Total cost shows a variety of responses. The two highest means are, again, the economic order quantity methods with SDP-90% being equal to those means. The group of planning system responses with the lowest means are L70-50%, L50-50%, L90-50% and SDP-50%. The remaining planning systems are significantly different from one another in the following increasing order; L50-90%, L90-90%, L70-90%, EOQ-50%, SDP-90% and EOQ-90%. The interesting common element in the group with the lowest means is the 50% service level of

finished goods safety stock.

6.3.11 Eleventh Exogenous Factor Level Setting

An increase in the activity ratio and reduction in raw material variability is evident in this combination of exogenous factor level settings. Specific settings, performance measure averages and rankings of those averages is presented in Table 6.14 and Figures 6.61 through 6.66.

Exogenous Level Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10:1
Activity Ratio	250:1
Coefficient of Variation	.03:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

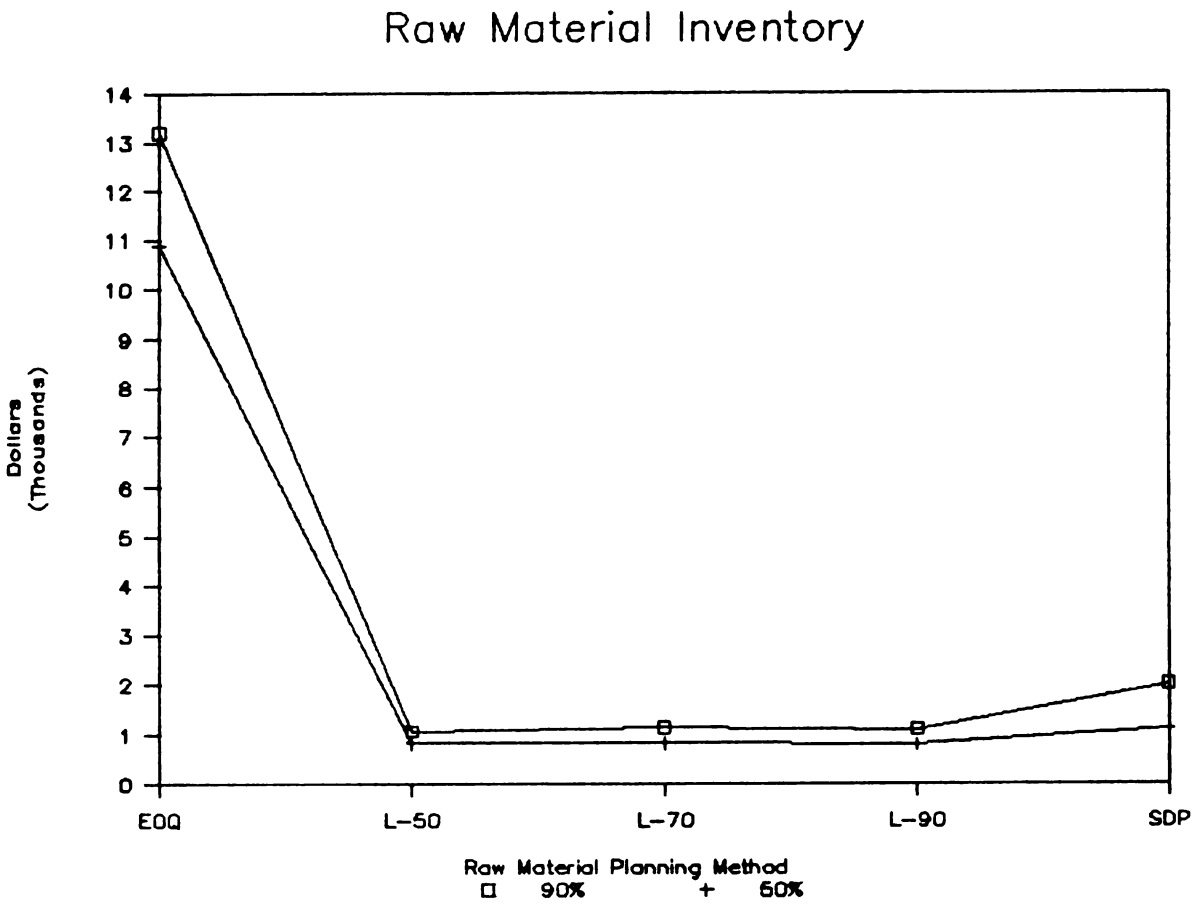
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	13202.6	10910.7	1074.8	822.4	1148.9	827.8	1110.8	809.6	2031.0	1134.3
Finished Goods Inventory	6261.5	1209.7	3042.4	1033.3	4617.4	1138.1	5457.6	1312.8	2538.8	1172.0
Order Cost	1529.5	1638.2	7458.0	8007.7	7149.2	7282.6	6600.8	6623.5	5496.3	5782.9
Setup Time	62.1	70.0	64.3	73.8	66.4	72.8	66.6	69.3	70.9	69.9
Backorder Units	38065.1	33653.3	5010.8	3221.8	4056.6	2555.6	5652.8	822.2	40020.1	33412.7
Total Cost	216211.7	143566.9	65874.7	41960.6	79066.8	42004.1	73189.9	49926.8	46605.8	49499.7
Overall Rank	10	9	5	3	7	2	6	1	8	4
Average Rank	6.83	6.50	5.50	4.50	6.17	4.33	6.00	3.83	6.33	5.00

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

ELEVENTH EXOGENOUS FACTOR SETTING

TABLE 6.14



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

RAW MATERIAL INVENTORY--ELEVENTH EXOGENOUS FACTOR SETTING

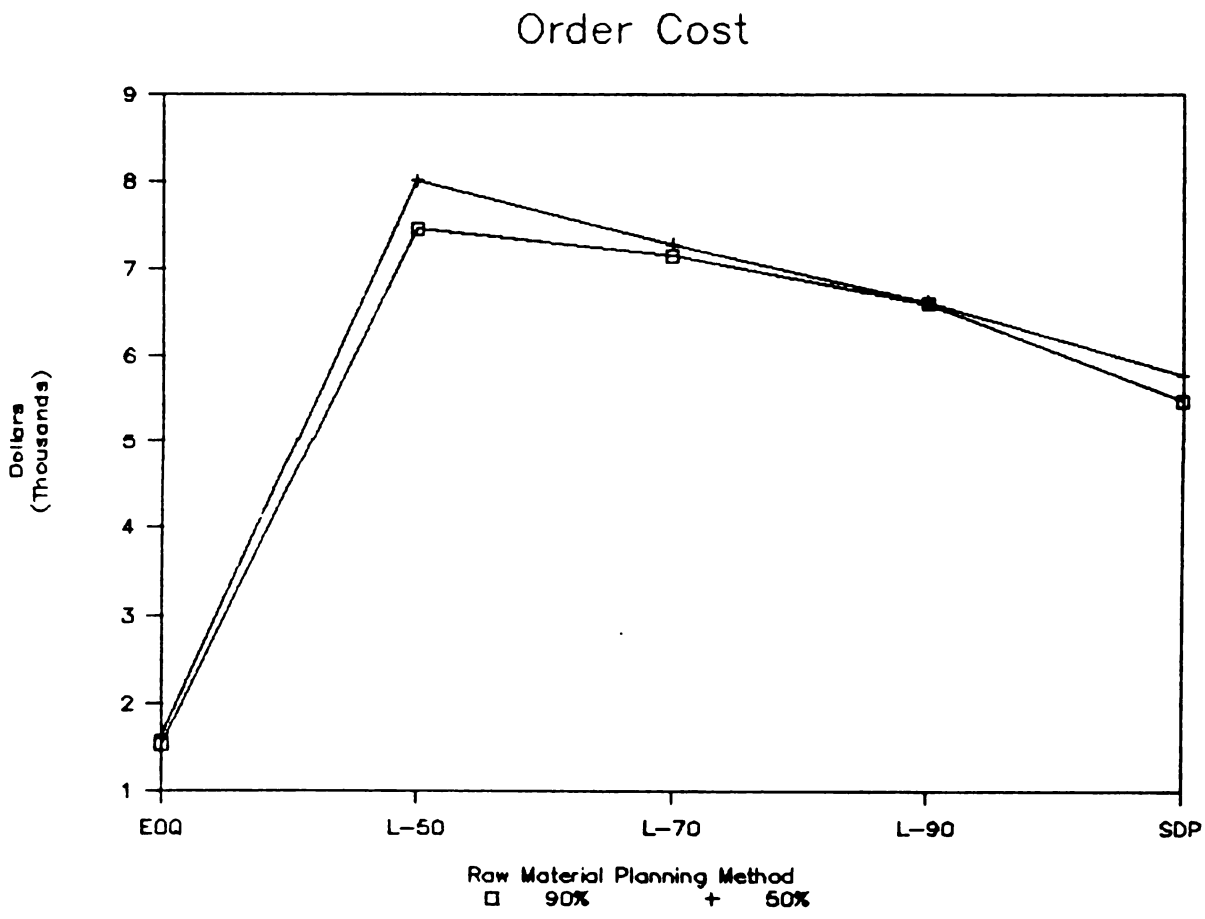
FIGURE 6.61

Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

FINISHED GOODS--ELEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.62

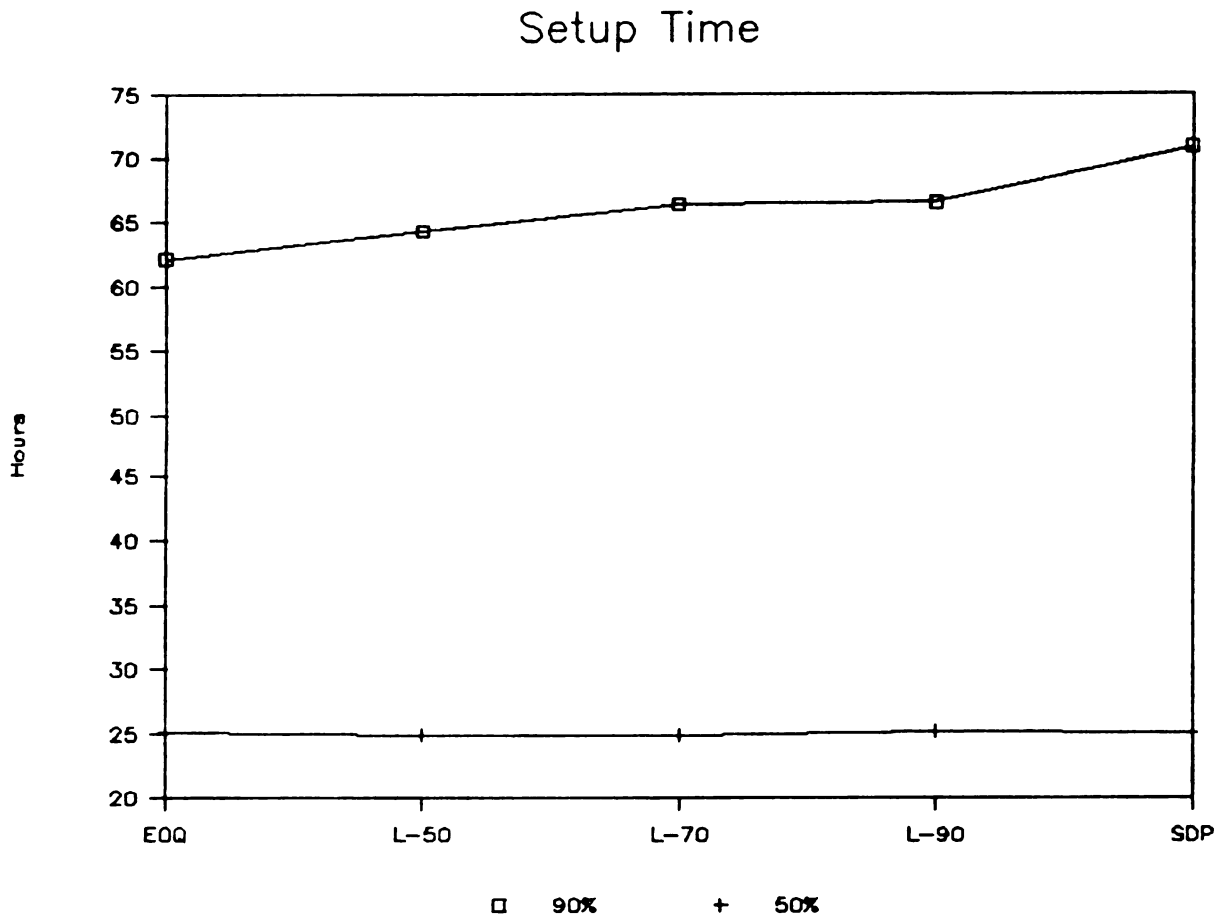


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

ORDER COST--ELEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.63

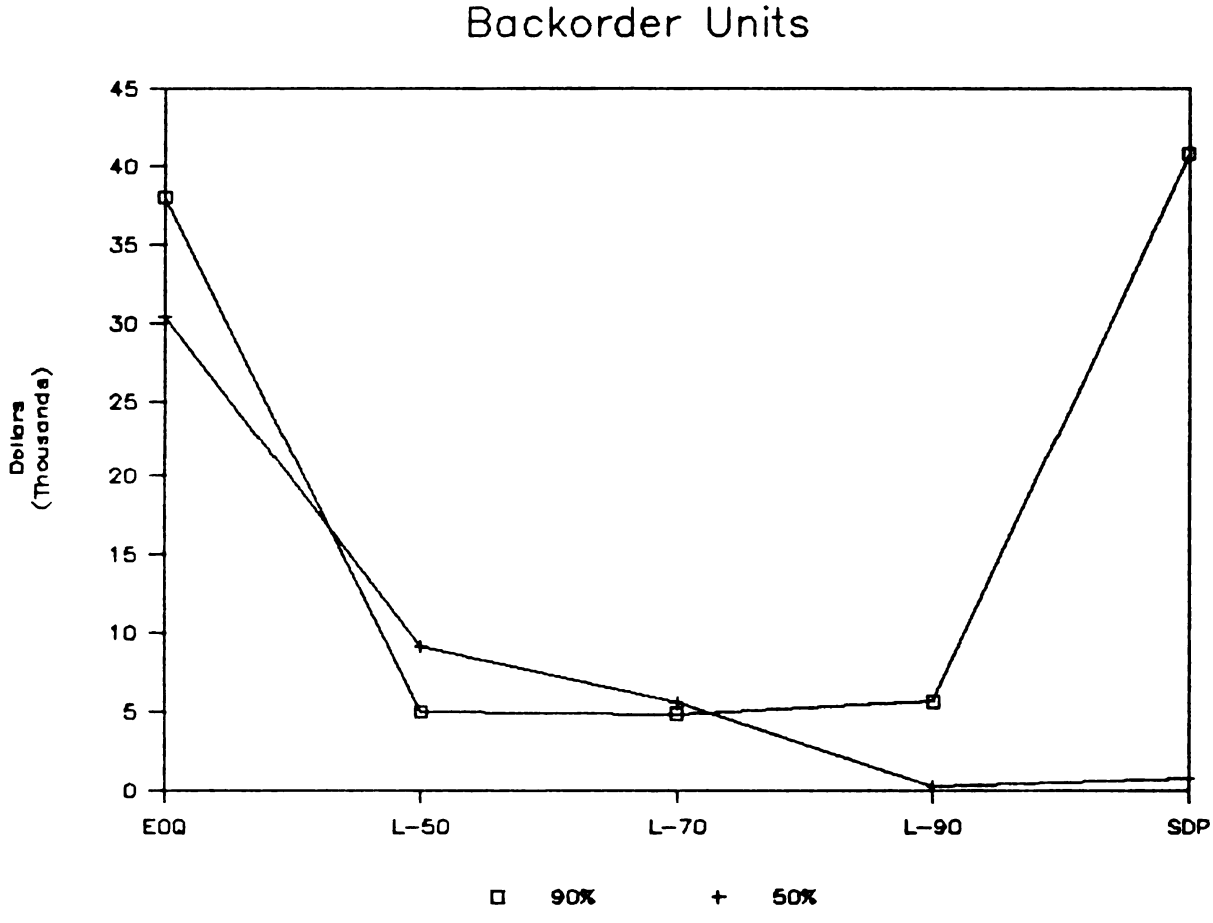


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

SETUP TIME--ELEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.64

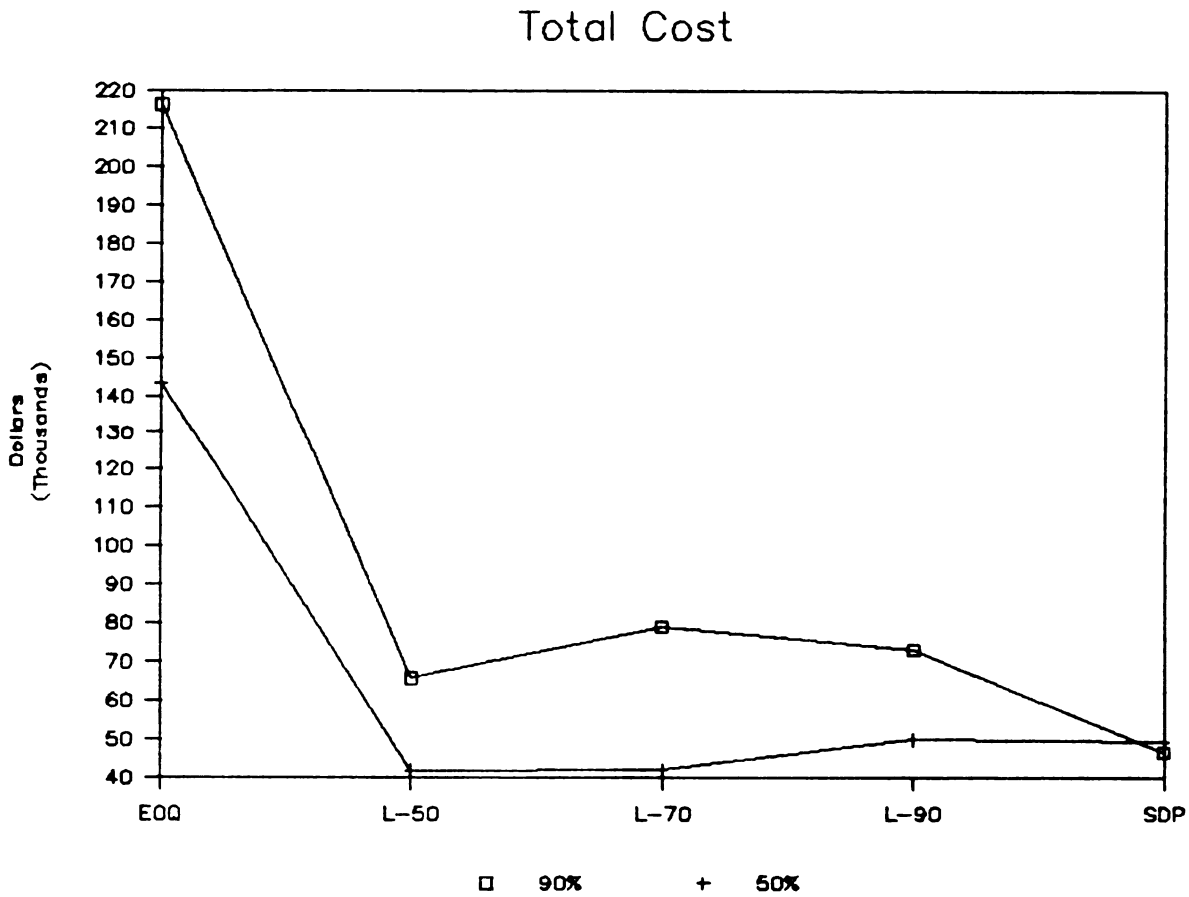


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

BACKORDER UNITS--ELEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.65



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

TOTAL COST--ELEVENTH EXOGENOUS FACTOR SETTING

FIGURE 6.66

Analysis of raw material inventory levels shows four equal groups of means. The economic order quantity planning responses show the highest means, L50-50%, L70-50% and L90-50% for the group with the smallest means with the remaining planning responses forming another group equal, but significantly different from the two groups with highest and lowest means.

The corresponding measure, order cost, is consistent with previous results. The economic order quantity methods have the lowest averages, all lot-for-lot methods have the highest averages and stochastic dynamic programming methods provide averages between the two groups.

Finished goods inventory has two significant groups which are, again, classified based on finished goods safety stock service level. The corresponding measure, setup time, shows a variety of significant effects, a pattern starting to develop indicates EOQ-90% and EOQ-50% with the lowest average setup times. Another interesting relationship is the group of highest means, L50-50% and L70-50% have equal means significantly# larger than all others
exists in those relationships.

The lot-for-lot planning responses provided a group of means with the lowest backorder units and the economic order quantity methods has significantly higher means of backorder units. The highest mean was produced by SDP-50%.

Total cost provided a consistent result, the significantly higher means from the economic order quantity

methods. The lowest means came from a group including L50-50%, L70-50% and SDP-90%.

6.3.12 Twelfth Exogenous Factor Level Setting

With only one exogenous factor set at the lower level, a different combination of exogenous factors has been specified. All factors are at their high levels except cost of capital which is low. The specific level settings, performance measure means and rankings are shown in Table 6.15 and Figures 6.67 through 6.72.

Exogenous Level Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10:1
Activity Ratio	250:1
Coefficient of Variation	.10:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

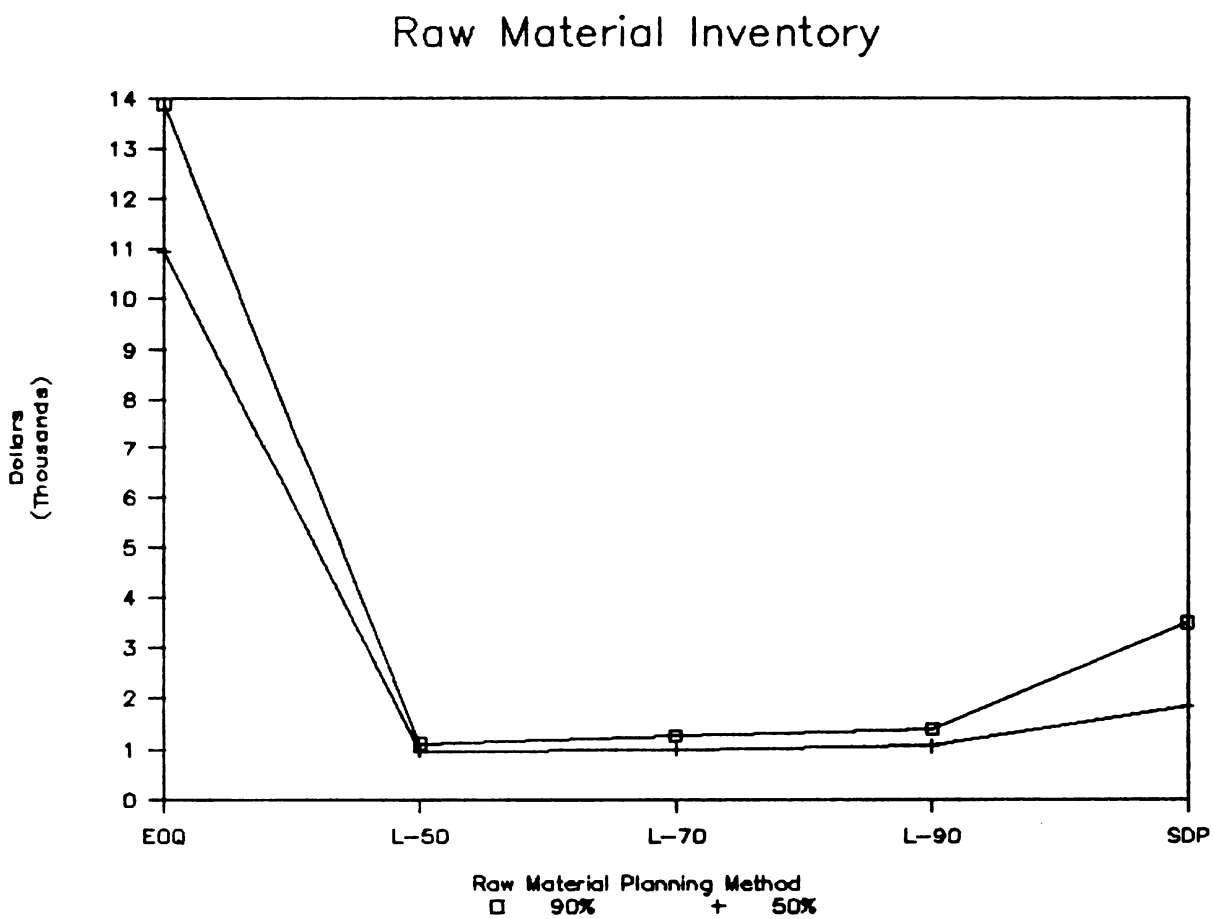
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	13883.6	10955.3	1110.5	971.3	1265.1	1002.4	1403.4	1069.3	3519.5	1850.7
Finished Goods Inventory	6920.2	1159.2	3565.7	1356.2	4712.9	1200.0	6569.9	1565.9	4223.4	1180.9
Order Cost	1747.4	1936.1	7504.4	8077.0	7246.1	7383.0	6397.1	6379.1	4704.3	5476.7
Setup Time	61.4	65.3	70.6	73.3	60.3	73.3	56.7	70.5	64.6	70.0
Backorder Units	39809.1	41555.7	6695.5	5425.3	4466.6	3593.3	26765.2	36201.6	37370.7	33287.7
Total Cost	230024.5	145334.8	68661.9	47101.9	79973.8	44795.5	95888.7	64508.7	65065.3	56455.3
Overall Rank	10	7	9	2	7	1	4	3	8	2
Average Rank	7.00	5.83	6.50	5.25	5.50	4.25	5.00	4.67	6.17	4.83

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

TWELFTH EXOGENOUS FACTOR SETTING

TABLE 6.15



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

RAW MATERIAL INVENTORY--TWELFTH EXOGENOUS FACTOR SETTING

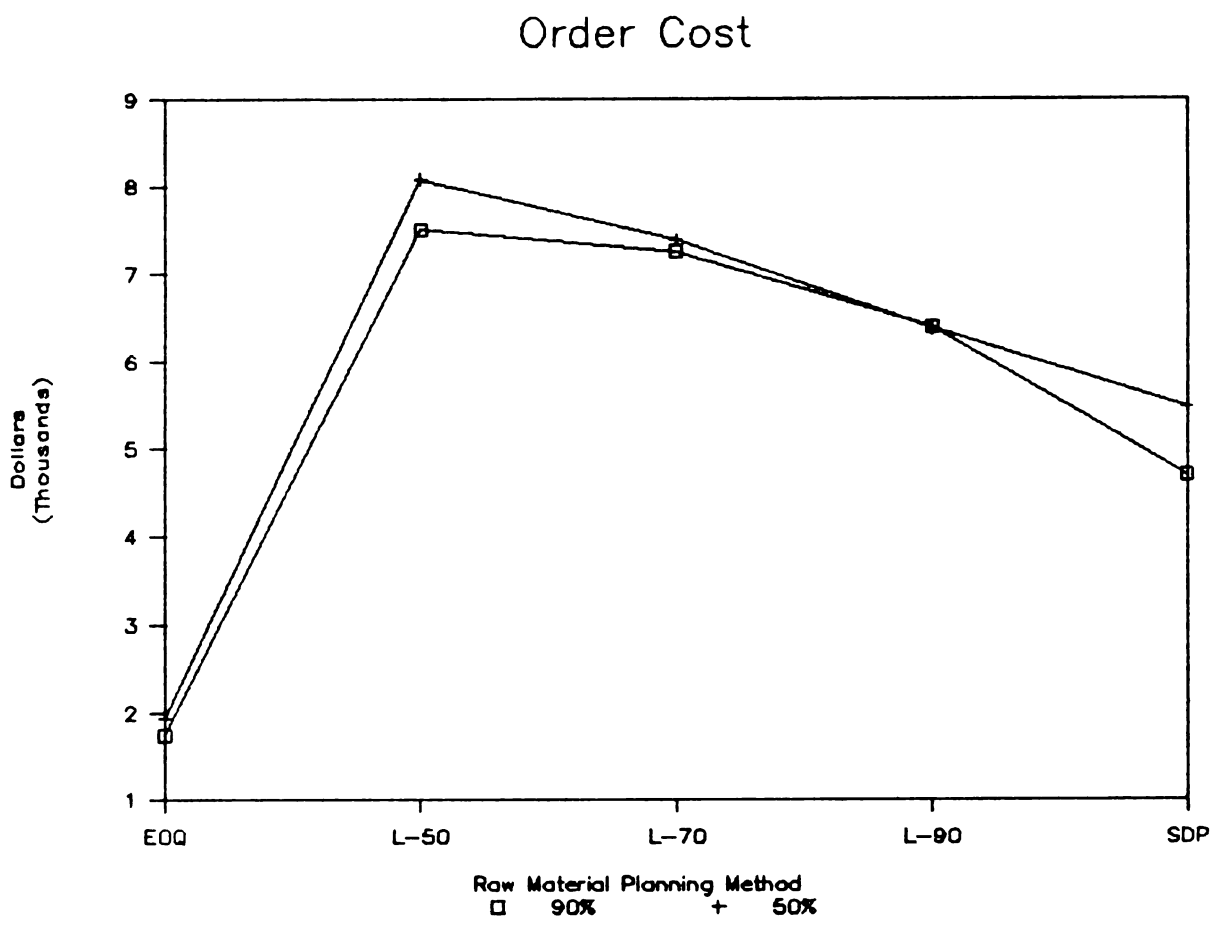
FIGURE 6.67

Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

FINISHED GOODS--TWELFTH EXOGENOUS FACTOR SETTING

FIGURE 6.68

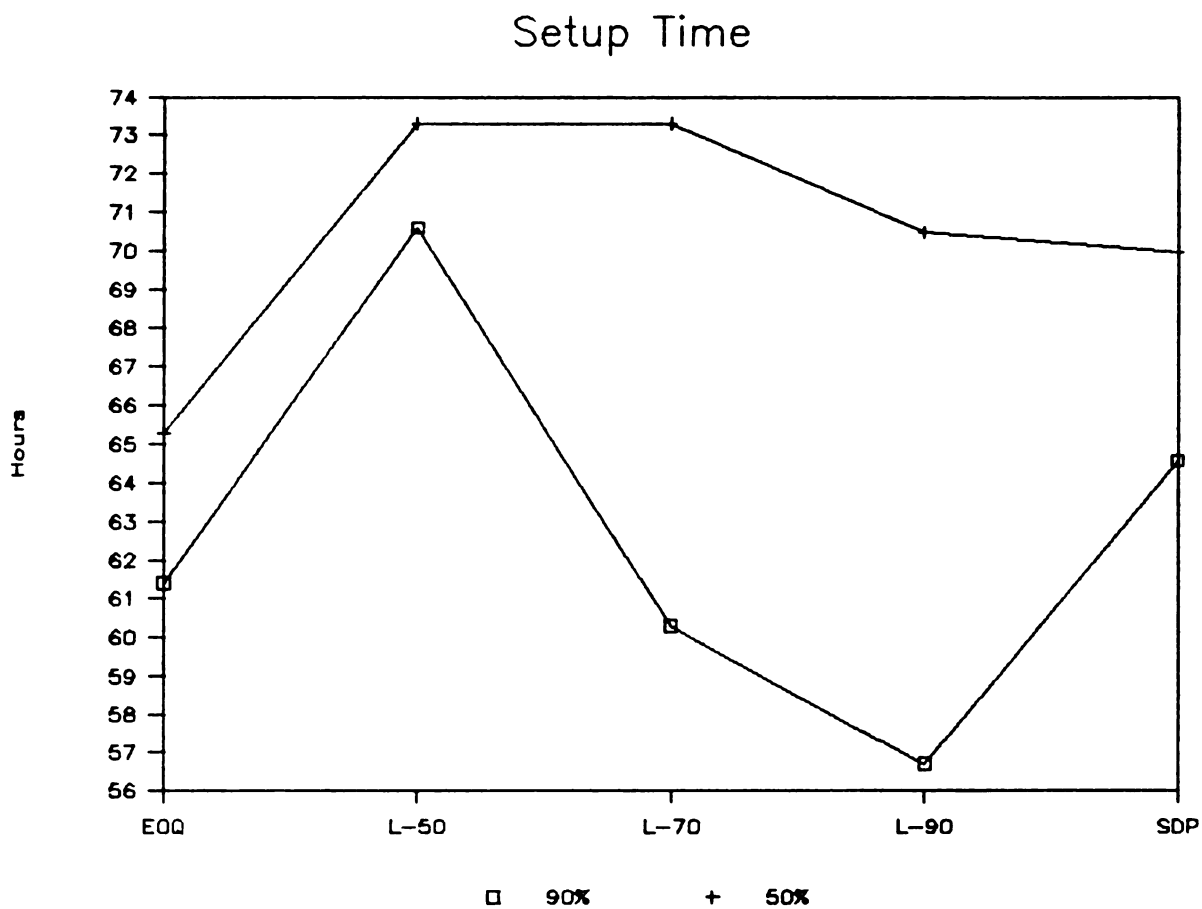


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

ORDER COST--TWELFTH EXOGENOUS FACTOR SETTING

FIGURE 6.69

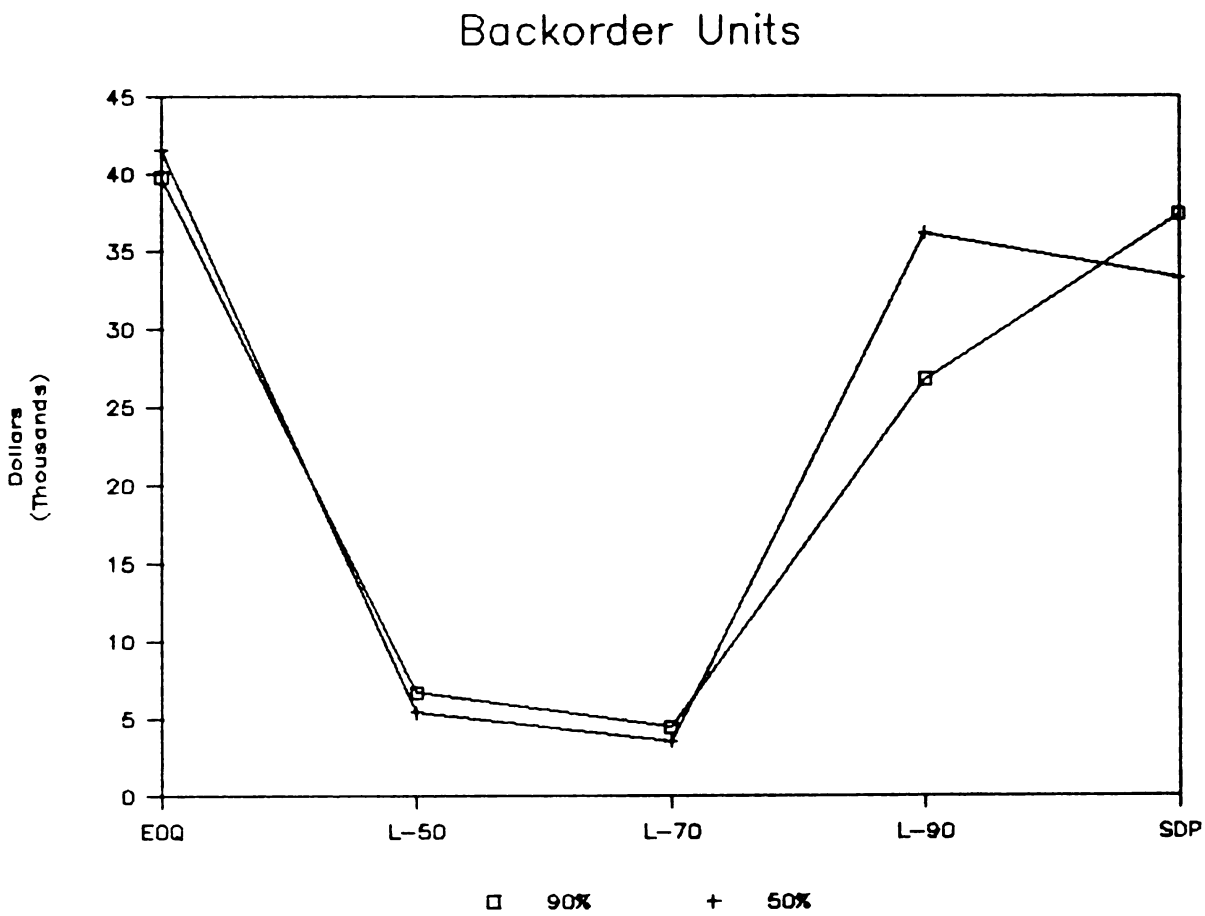


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

SETUP TIME--TWELFTH EXOGENOUS FACTOR SETTING

FIGURE 6.70

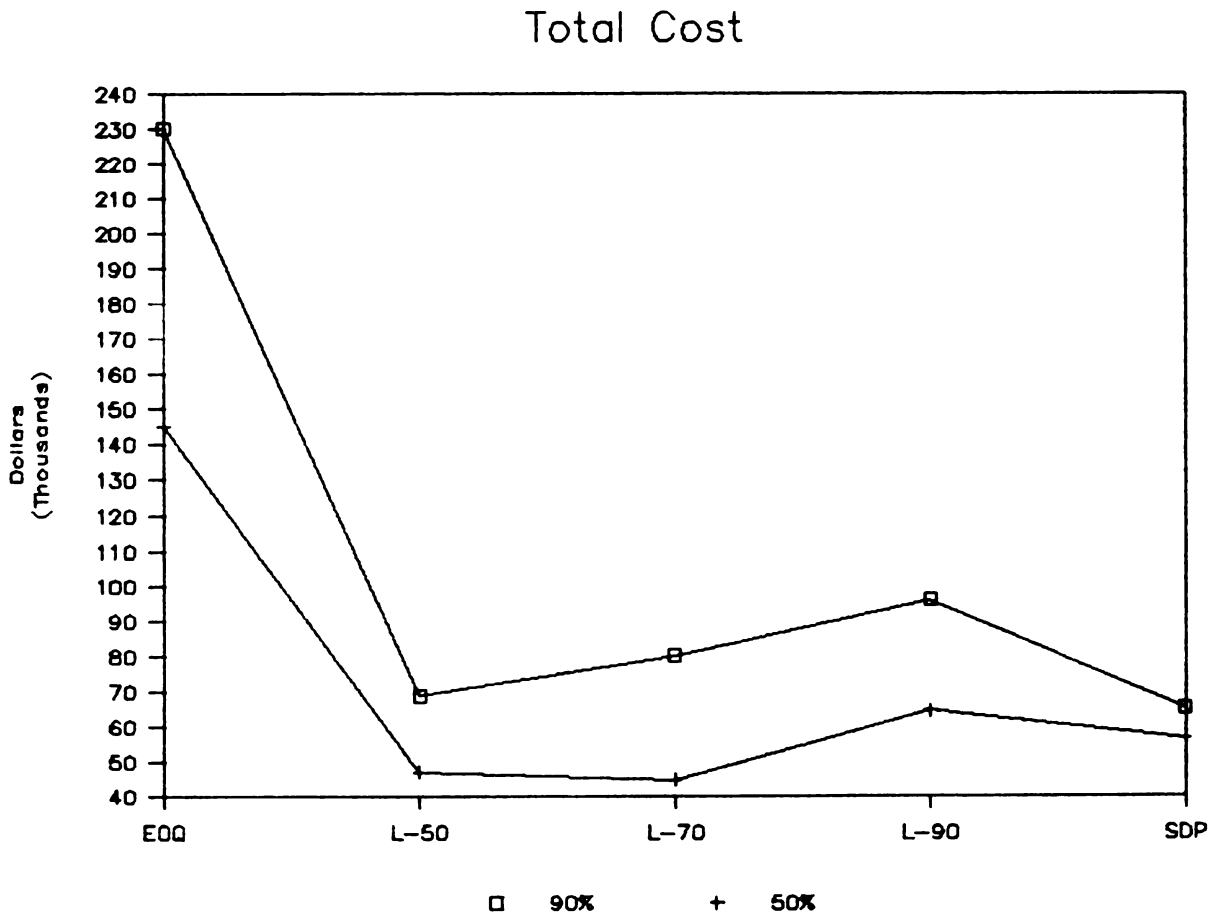


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

BACKORDER UNITS--TWELFTH EXOGENOUS FACTOR SETTING

FIGURE 6.71



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	10 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

TOTAL COST--TWELFTH EXOGENOUS FACTOR SETTING

FIGURE 6.72

The first three performance measure means exhibit relationships similar to those seen earlier in this discussion. Raw material inventory means are grouped based on raw material planning method. The differences in setup time are consistently ordered but significant differences exist within raw material planning methods. Both economic order quantity methods are equal and have the lowest means, they are significantly smaller than the stochastic dynamic programming methods with SDP-50% being larger than SDP-90%. The lot-for-lot methods are significantly different from one another with order cost means increasing as raw material ordering service level decreases, but no differences existed within that service level between finished goods safety stock service level.

Finished goods inventory levels are easily grouped based on safely stock level, the 90% service level is larger than the 50% service level.

Setup time does indicate a variety of significant differences between means, LFL-90% had the lowest mean. The next larger group included EOQ-90% and L70-90% which was significantly smaller than SDP-90% and EOQ-50%. The next group, SDP-50%, L90-50% and L50-90% were equal and smaller than the largest group, L50-50% and L70-50%. Again, EOQ-90% had a mean that was smaller than most and L50-50% and L70-50% had high means.

The means of backorder units again show the highest means in the economic order quantity methods and SDP-90%,

all of the lot-for-lot methods had the lowest means with the exception of L90-50% which was relatively high.

Total cost means are all unequal with the lowest average total cost produced by L70-50% and the economic order quantity methods producing the two highest total cost with EOQ-90% having a higher mean than EOQ-50%.

6.3.13 Thirteenth Exogenous Factor Level Setting

High average capacity utilization and cost of capital are paired with a low activity ratio and raw material variability to create the next combination of exogenous factor level settings. The specific values of those factors, dependent variable means and rankings are shown in Table 6.16 and Figures 6.73 through 6.78.

Exogenous Level Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5:1
Activity Ratio	50:1
Coefficient of Variation	.03:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

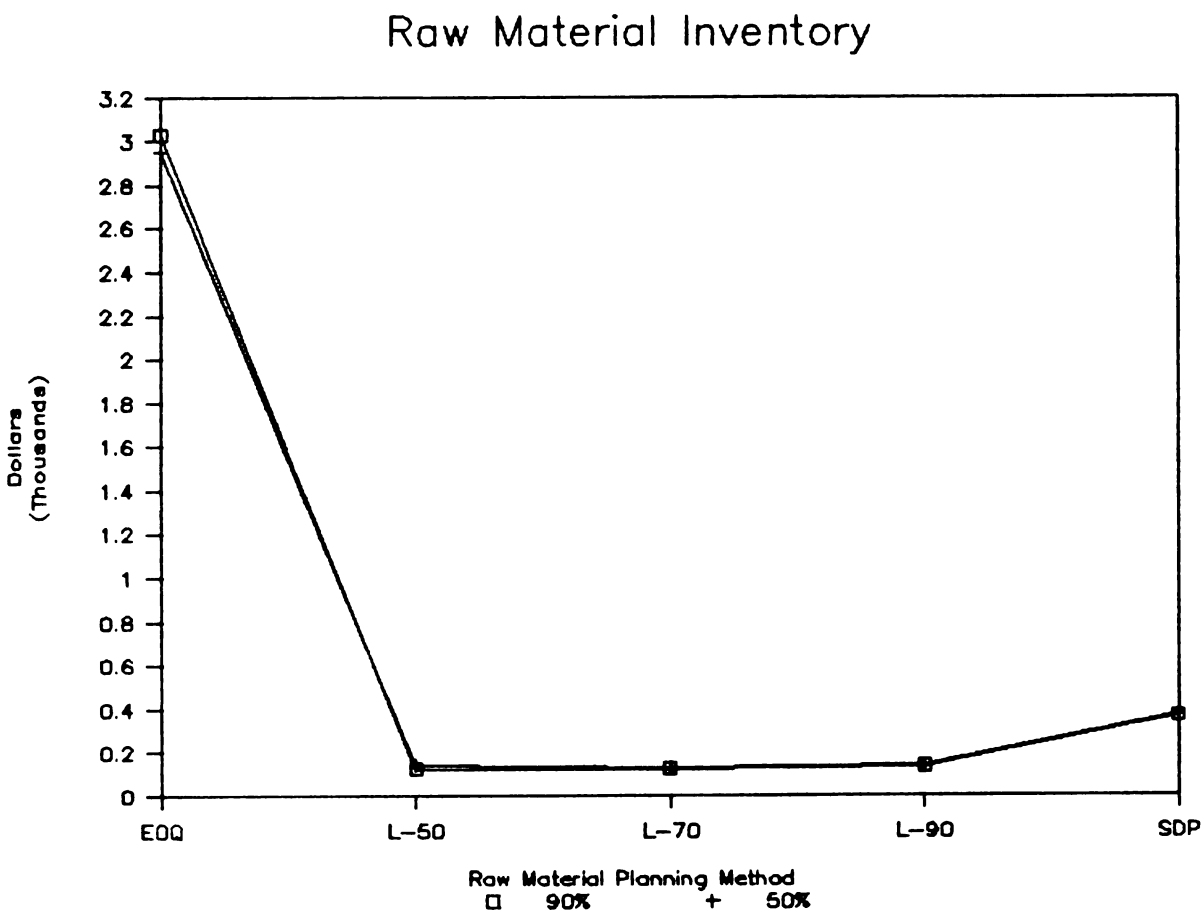
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	3031.2	2949.7	123.5	144.4	124.7	131.9	136.3	139.9	369.4	378.3
Finished Goods Inventory	4342.3	87.9	3564.8	118.0	4193.6	80.7	4596.4	72.4	4428.7	75.3
Order Cost	680.9	792.2	3383.4	3529.8	3343.3	3435.0	3212.2	3283.6	2874.5	2859.4
Setup Time	30.5	30.9	30.6	30.7	30.5	30.6	30.4	31.2	31.0	30.5
Backorder Units	6308.1	18624.1	118.1	2371.8	35.0	1195.3	0.0	29.6	0.0	25.0
Total Cost	82003.4	41059.1	24477.6	12783.0	52641.7	11912.3	27428.0	13940.8	57051.9	13508.2
Overall Rank	10	4.5	6	8	7	3	2	4.5	9	1
Average Rank	6.83	5.00	5.25	6.33	5.33	4.75	4.58	5.00	6.58	3.67

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

THIRTEENTH EXOGENOUS FACTOR SETTING

TABLE 6.16

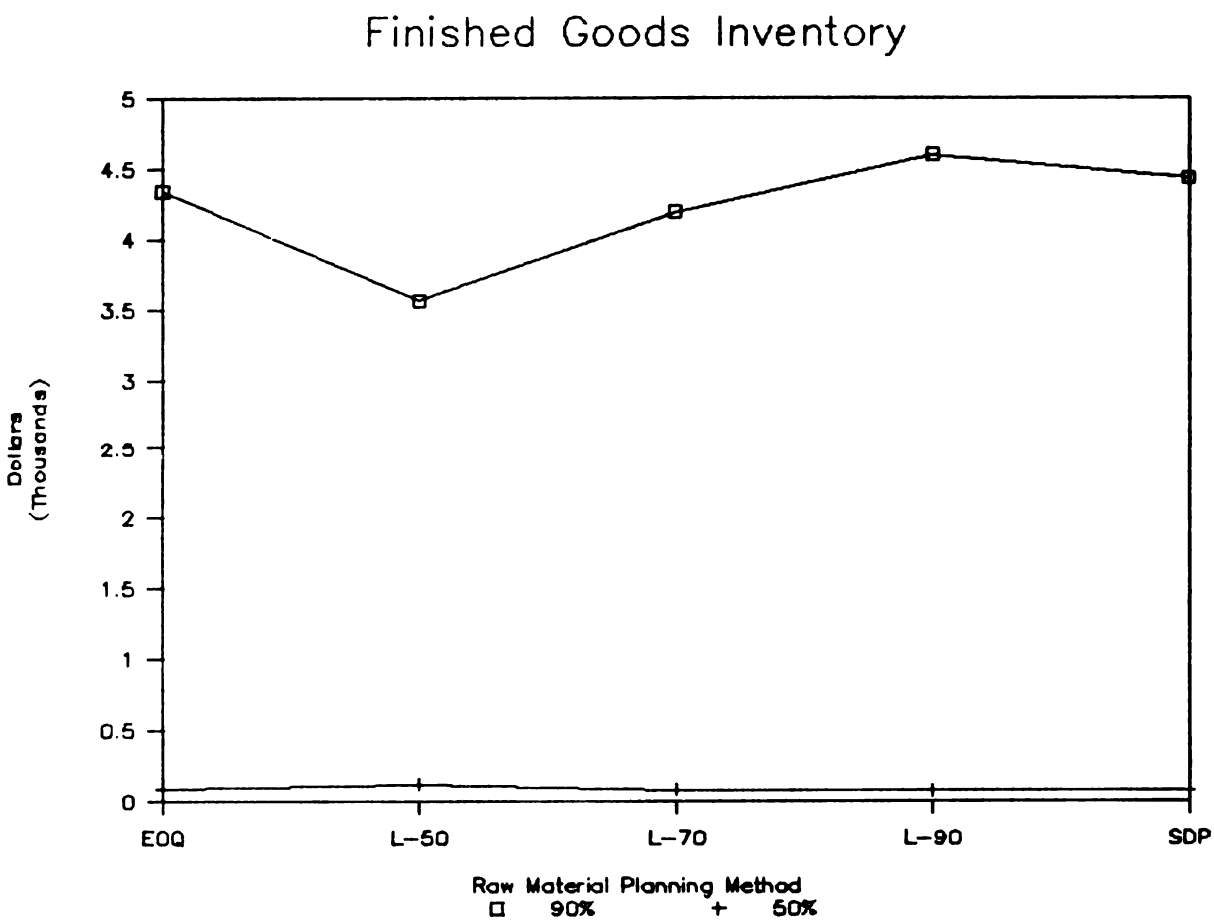


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

RAW MATERIAL INVENTORY--THIRTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.73

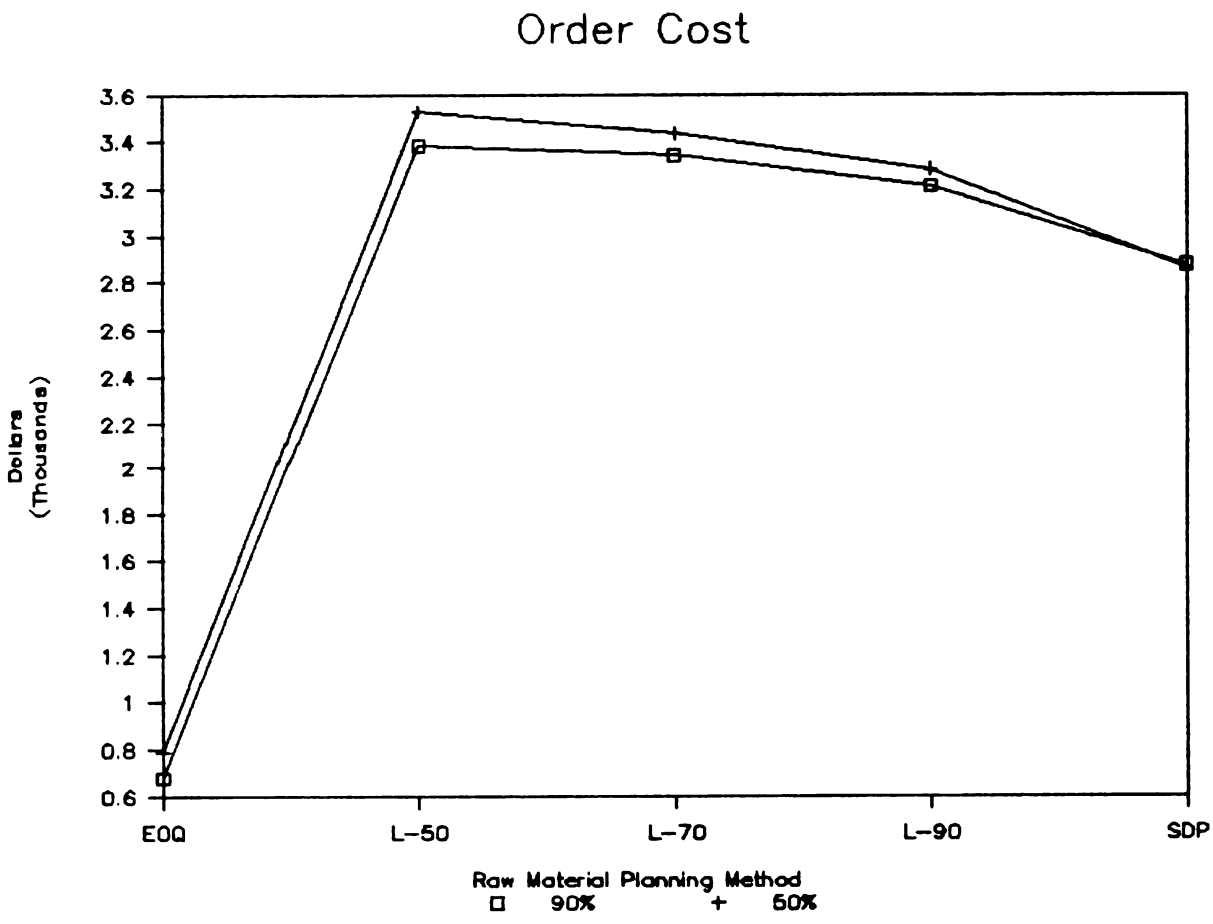


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

FINISHED GOODS--THIRTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.74

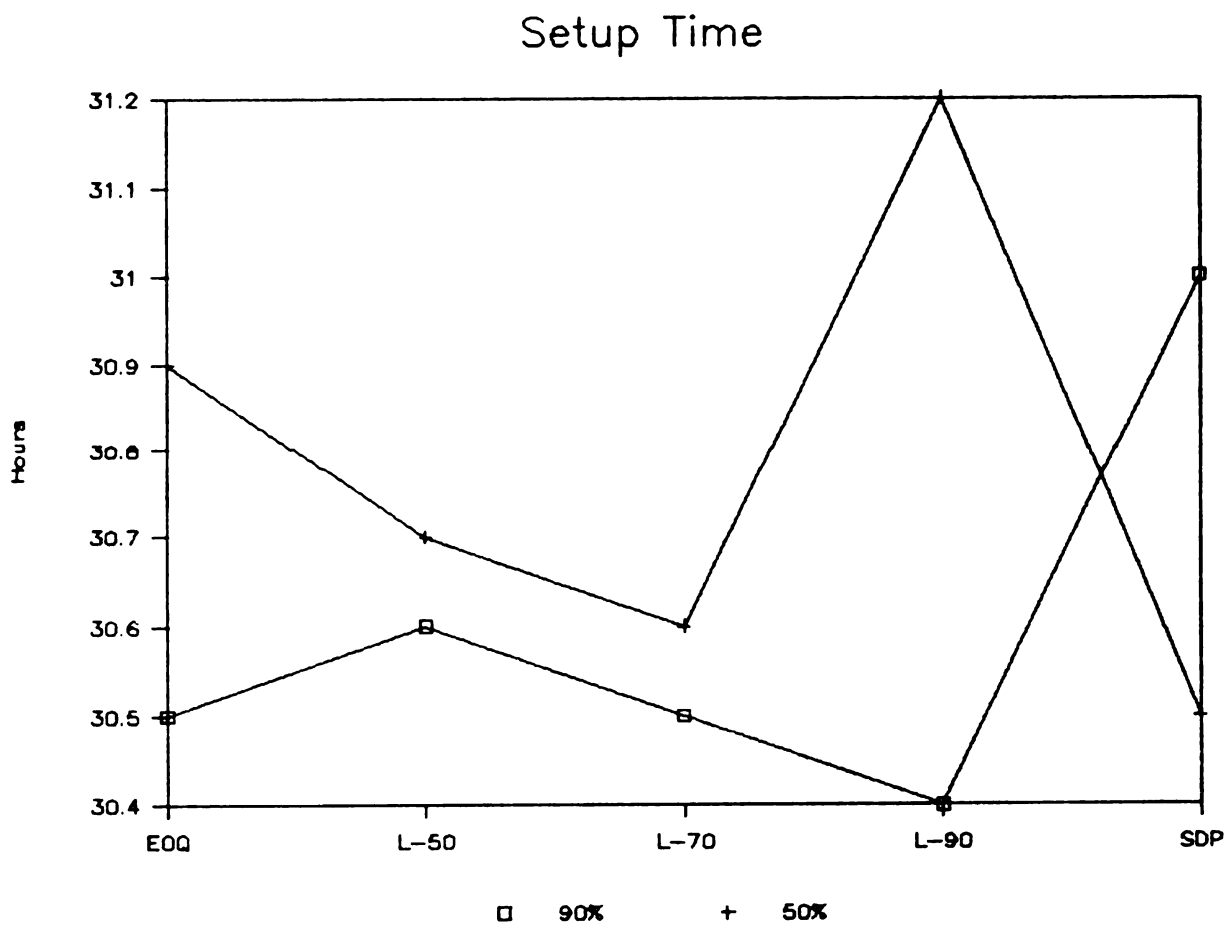


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

ORDER COST--THIRTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.75

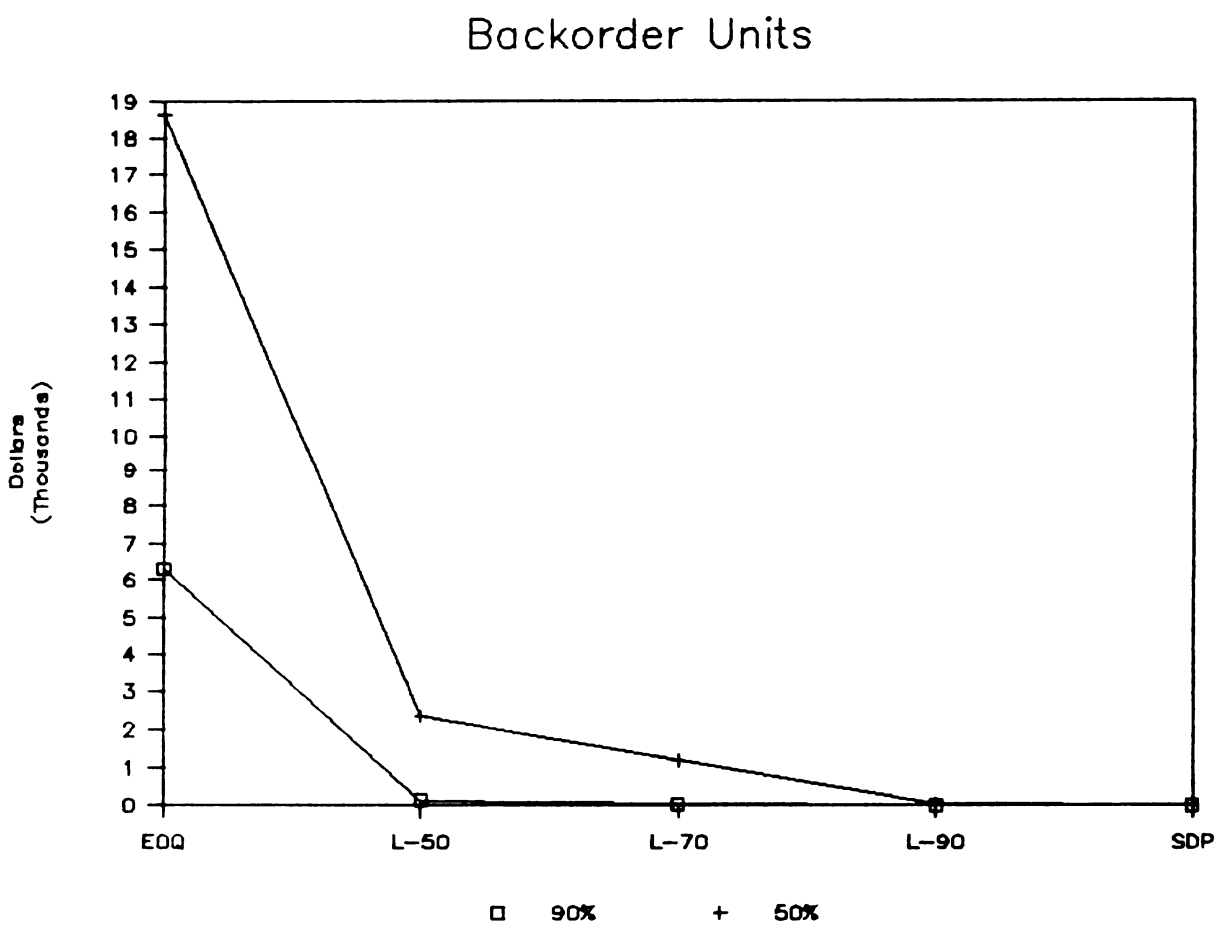


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

SETUP TIME--THIRTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.76

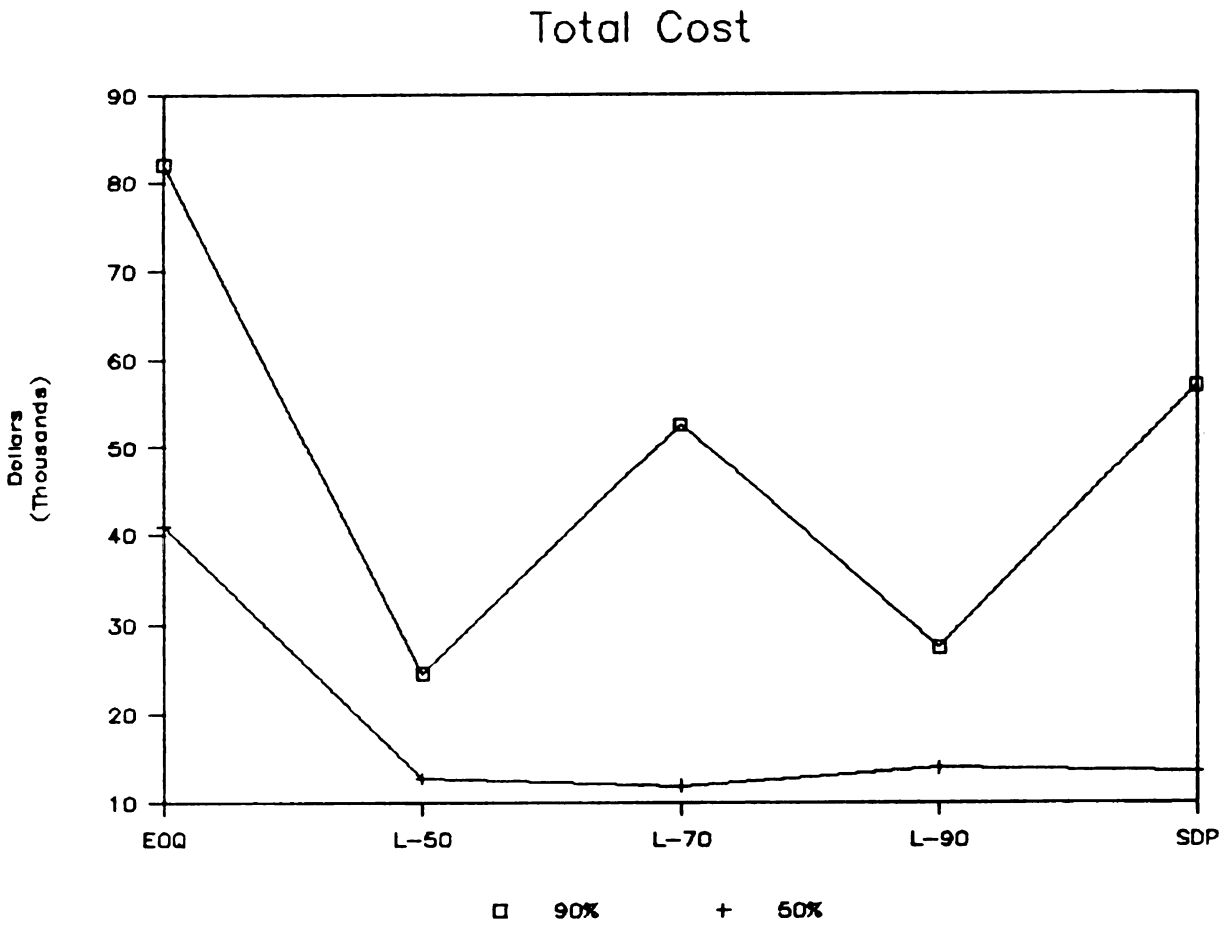


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

BACKORDER UNITS--THIRTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.77



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.03 : 1

TOTAL COST--THIRTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.78

As has been seen throughout this analysis, the relationships evident in the first four performance measures are easily noted here. Raw material inventory, finished goods inventory and order cost all exhibit the same relationships identified in earlier analyses. No significant difference exists in setup time.

All planning system responses had equal backorder unit means except that generated by EOQ-50% which was significantly larger than all other methods.

Total cost has some consistent relationships with past investigations. The highest total cost was generated by the EOQ-90% planning method, but the lowest means were created by a group including L70-50%, L50-50%, SDP-50% and L90-50%. It is interesting to note the group with the lowest total cost consistently has a 50% service level on finished goods safety stock.

6.3.14 Fourteenth Exogenous Factor Level Setting

This combination of exogenous factors sees high levels of capacity utilization, cost of capital and raw material variability with a low activity ratio. Table 6.17 and Figures 6.79 through 6.84 provide the specific exogenous factor values, dependent variable means and planning system response rankings.

Exogenous Level Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5:1
Activity Ratio	50:1
Coefficient of Variation	.10:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

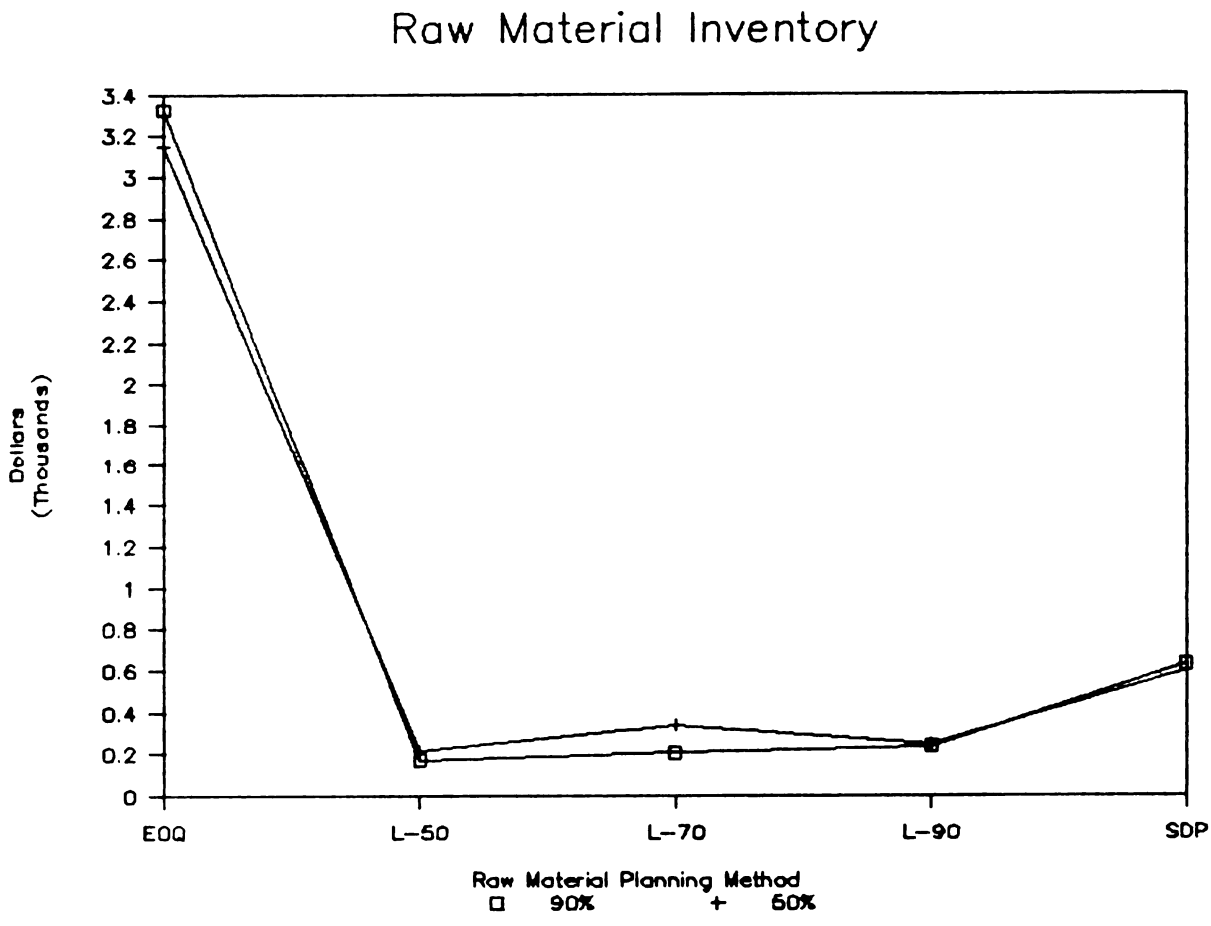
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	3324.7	3150.8	172.0	213.4	206.3	340.6	236.3	248.9	629.4	603.2
Finished Goods Inventory	3418.1	84.8	2967.9	66.1	3701.4	121.8	4504.0	70.6	4449.8	76.0
Order Cost	636.1	775.4	3418.2	3440.5	3311.8	3350.6	3186.8	3295.8	2533.3	2571.7
Setup Time	30.5	30.7	30.7	30.9	30.6	30.6	30.1	30.4	30.5	30.4
Backorder Units	43247.2	39406.9	1457.5	7123.5	395.6	3679.7	0.0	3321.3	0.0	175.2
Total Cost	82814.3	47052.9	41259.6	13826.6	40591.5	14025.7	29910.0	17570.0	59423.8	15481.3
Overall Rank	10	9	7.5	4	7.5	5.5	3	2	5.5	1
Average Rank	7.08	6.58	5.92	5.50	5.92	5.75	4.42	4.25	5.75	3.75

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

FOURTEENTH EXOGENOUS FACTOR SETTING

TABLE 6.17



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

RAW MATERIAL INVENTORY--FOURTEENTH EXOGENOUS FACTOR SETTING

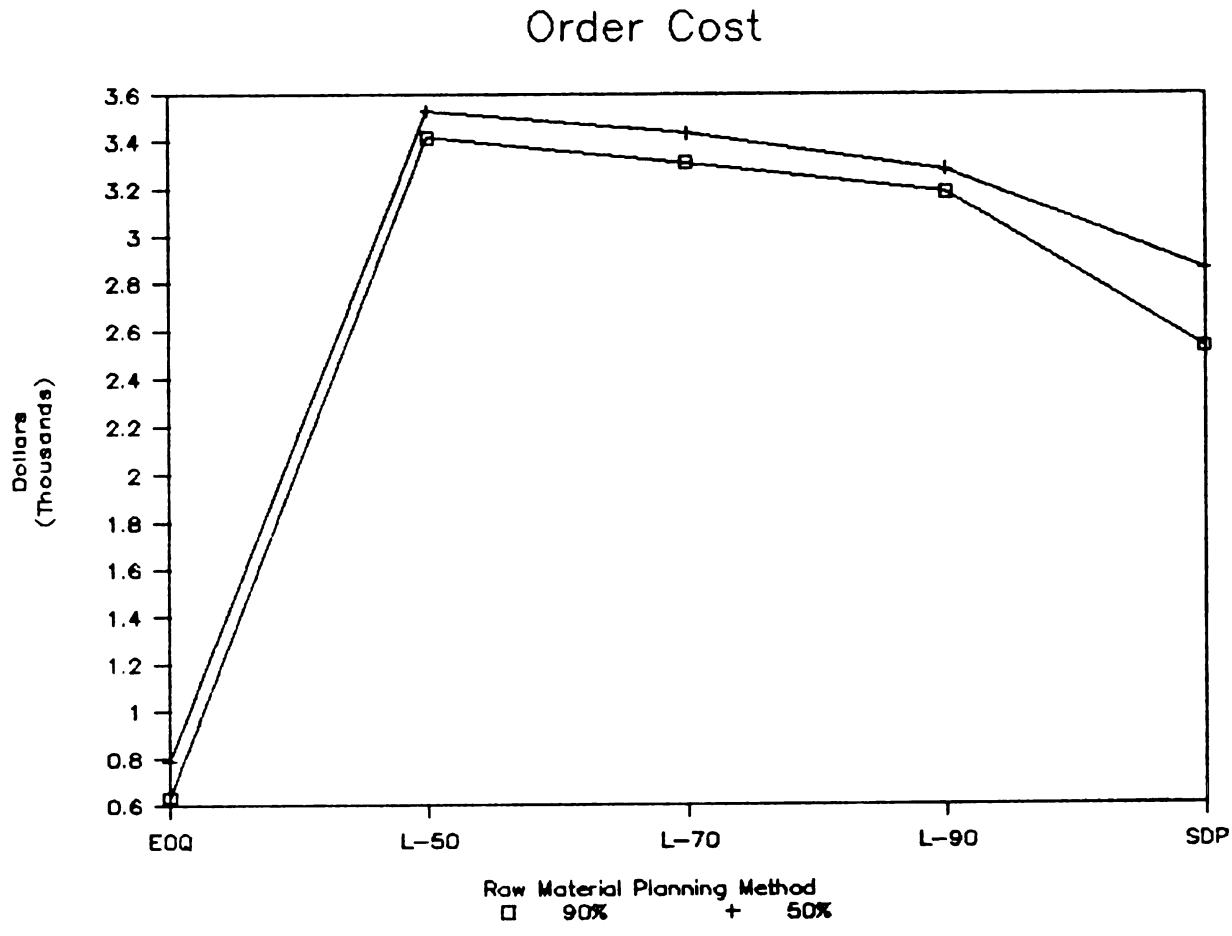
FIGURE 6.79

Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

FINISHED GOODS--FOURTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.80

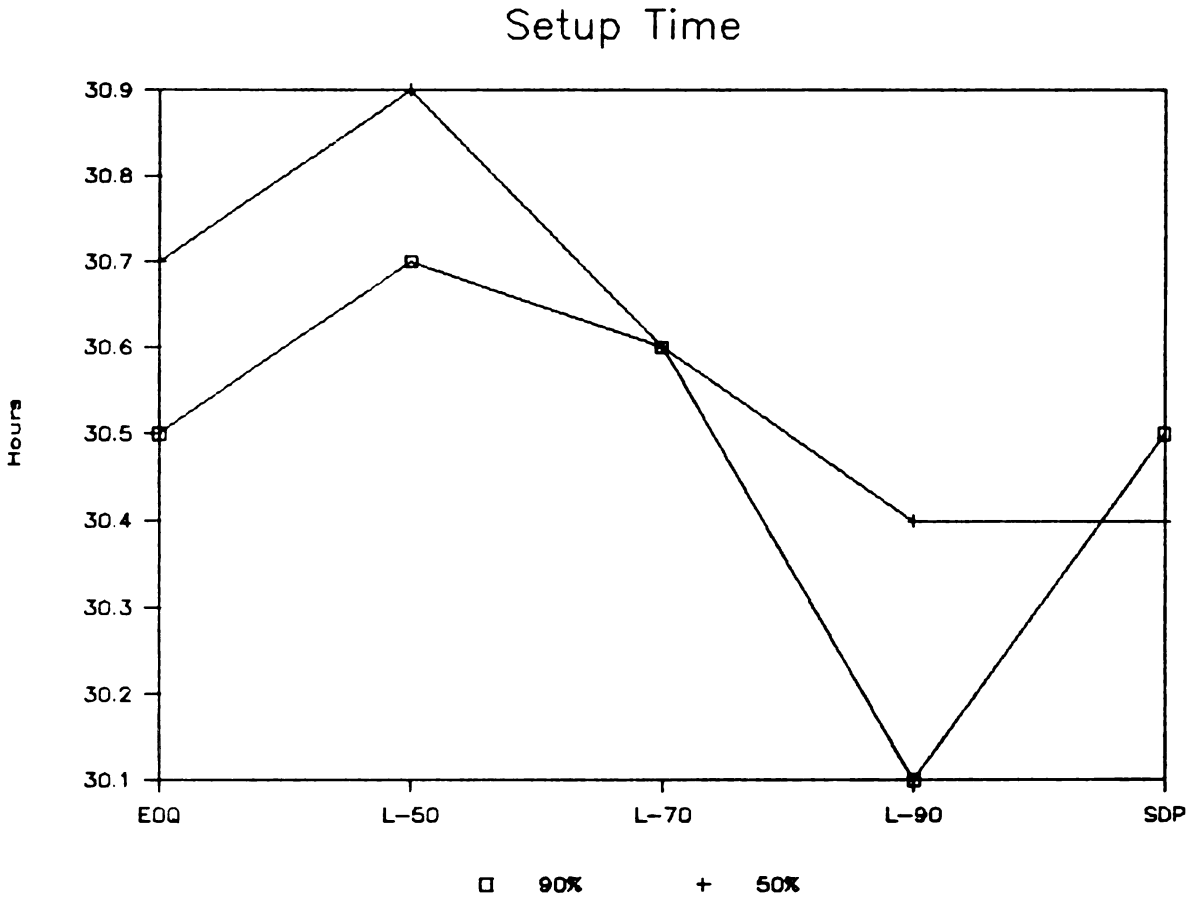


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

ORDER COST--FOURTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.81

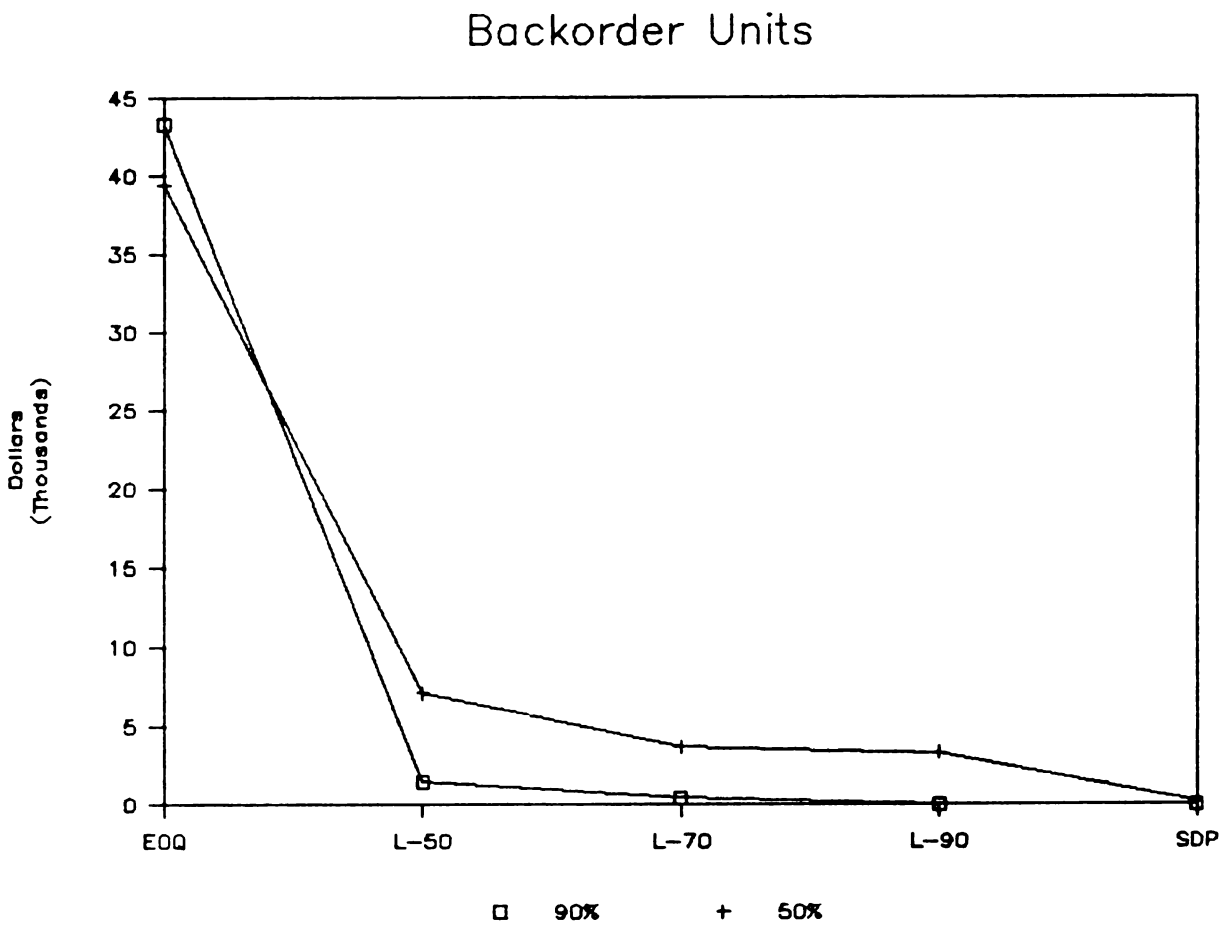


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

SETUP TIME--FOURTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.82

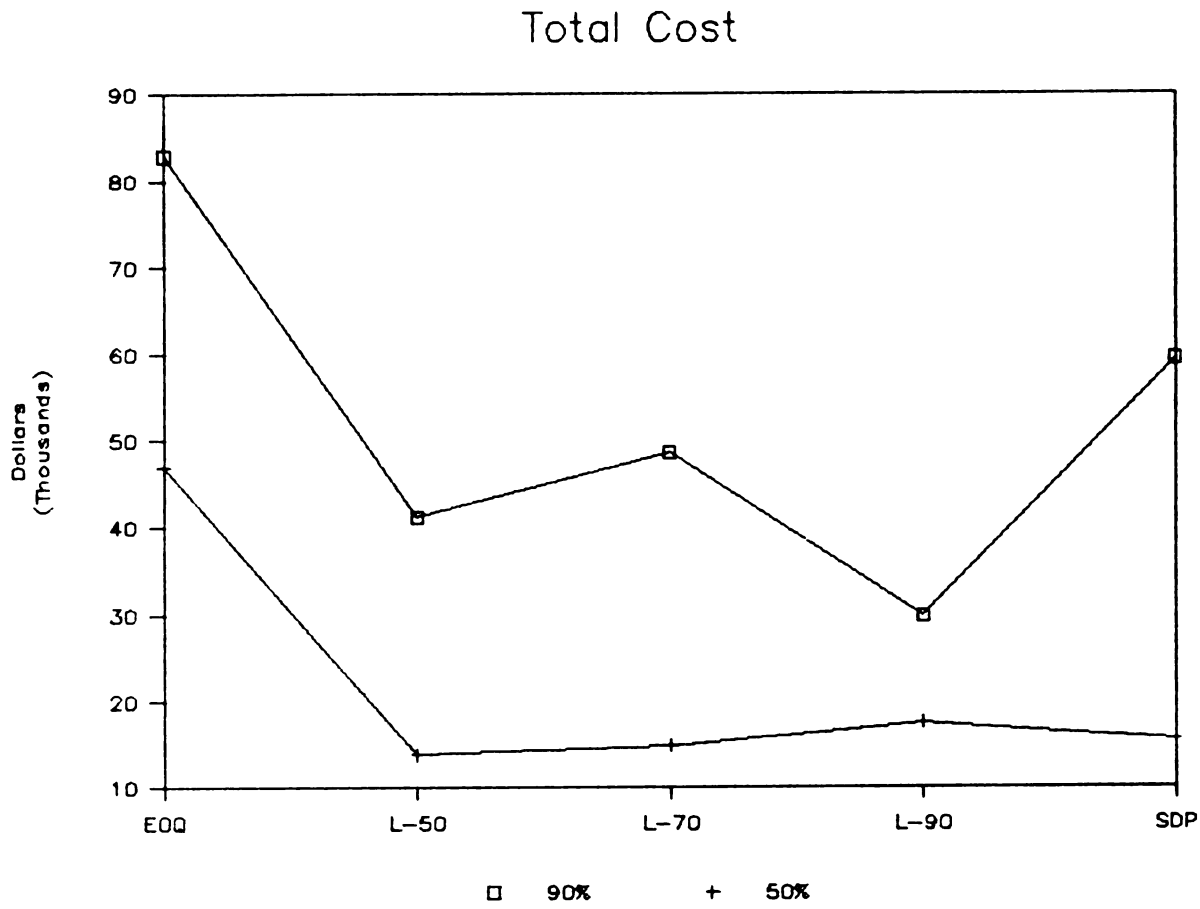


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

BACKORDER UNITS--FOURTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.83



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	50 : 1
Coefficient of Variation	.10 : 1

TOTAL COST--FOURTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.84

The relationships evident in Table 6.17 are consistent with those identified earlier. Raw material inventory and order cost can be grouped based on raw material planning method and the two measures are inversely related. Average order cost again shows an inverse relationship to service level of raw material ordering method in the lot-for-lot methods.

No differences in finished goods inventory means are noted based on raw material planning method, only on level of finished goods safety stock. The corresponding measure, setup time, shows no significant differences.

The two planning system responses relying on economic order quantity had the highest backorder unit means with all other means statistically equal and smaller than the economic order quantity methods.

Total cost showed a familiar group with low means, L50-50%, L70-50%, SDP-50% and L90-50%, and all specified finished goods safety stock at the 50% service level. The next lowest cost system was L90-90% followed by L50-90% and the group of EOQ-50% and L70-90%. The next highest mean was SDP-90% and the highest total cost was produced by EOQ-90%.

6.3.15 Fifteenth Exogenous Factor Level Setting

The last combination of exogenous factors with only one factor at its lower setting has a low coefficient of variation coupled with high average capacity utilization, high cost of capital and a high activity ratio. Table 6.18

presents the results of this combination of exogenous factors. Figure 6.85 through 6.90 present the same information graphically.

Exogenous Level Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5:1
Activity Ratio	50:1
Coefficient of Variation	.03:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

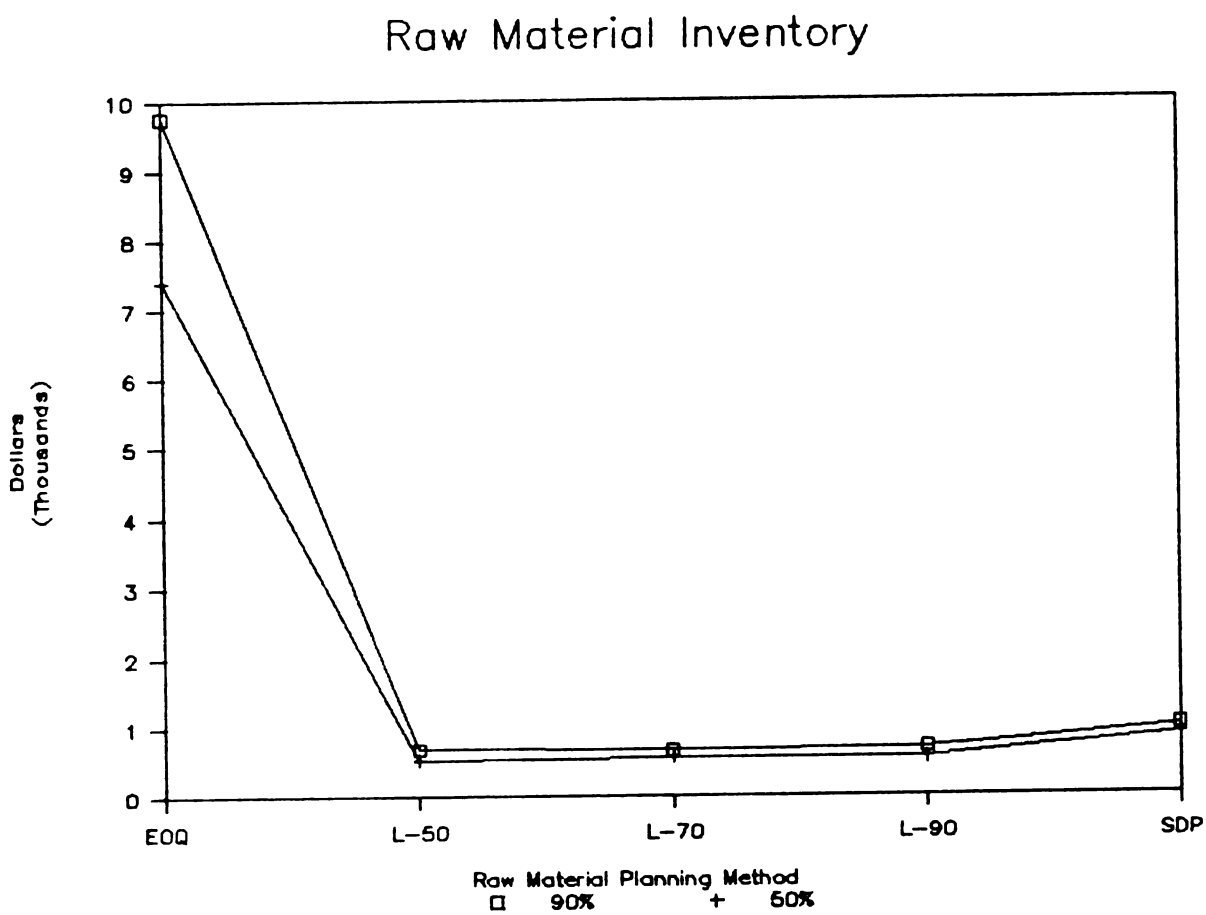
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	9758.4	7398.9	684.9	527.6	667.4	557.6	698.5	552.3	1085.3	889.7
Finished Goods Inventory	5586.2	913.5	4014.0	940.4	4421.2	1314.1	4942.1	871.4	4363.3	952.3
Order Cost	2087.0	2344.9	9415.5	9630.6	8971.2	9096.1	8965.5	8860.7	6190.7	7549.6
Setup Time	88.3	91.1	92.3	91.4	88.4	90.5	89.9	91.5	82.0	92.1
Backorder Units	39841.4	21605.6	4852.4	4149.4	4013.8	3934.5	45537.6	42467.2	27265.6	20550.3
Total Cost	101171.1	108008.8	75834.5	43413.4	78338.0	46696.5	75932.6	55691.8	85727.4	48504.1
Overall Rank	9	6	9	2	4	1	9	3	7	5
Average Rank	6.67	5.67	6.67	4.12	5.17	4.00	6.67	4.67	6.00	5.33

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

FIFTEENTH EXOGENOUS FACTOR SETTING

TABLE 6.18

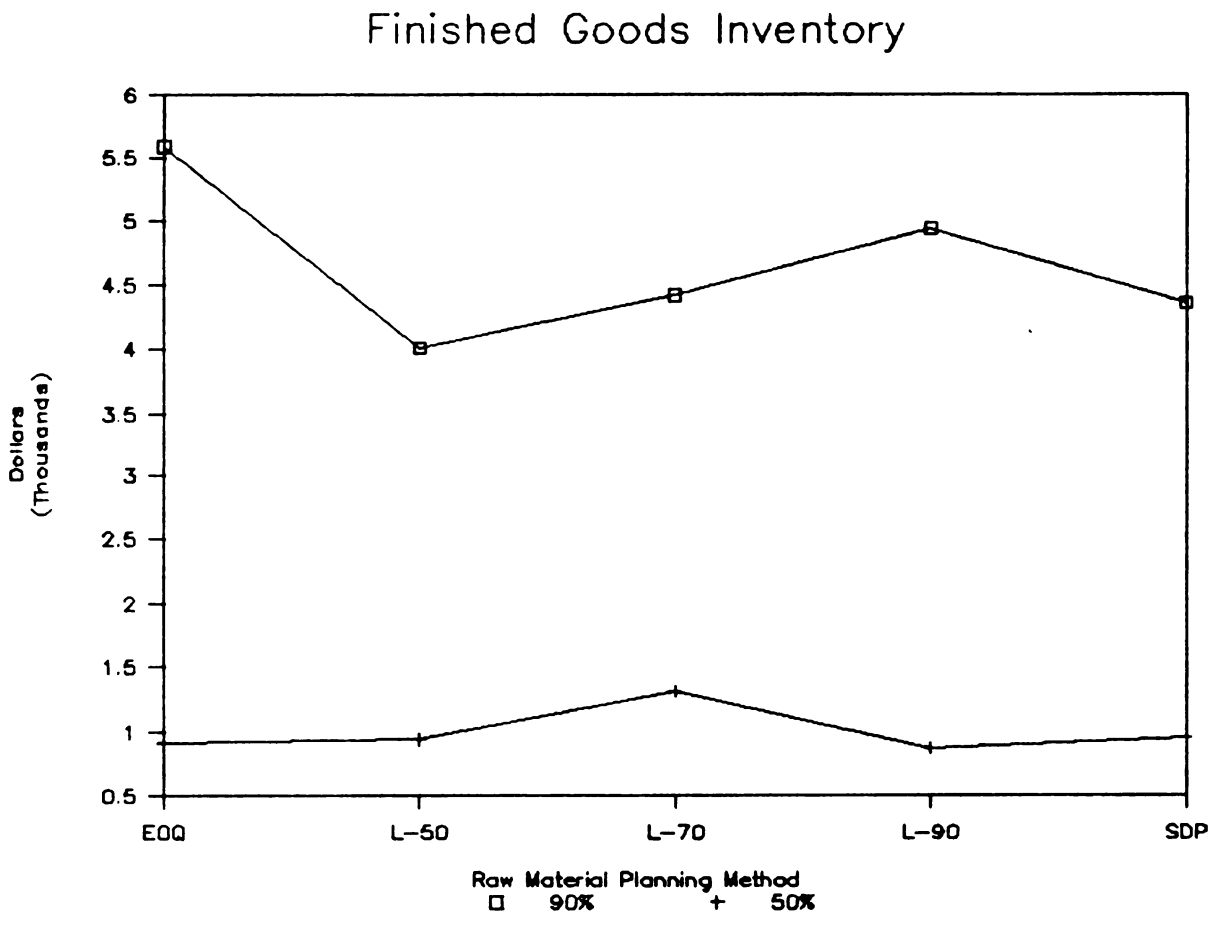


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

RAW MATERIAL INVENTORY--FIFTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.85

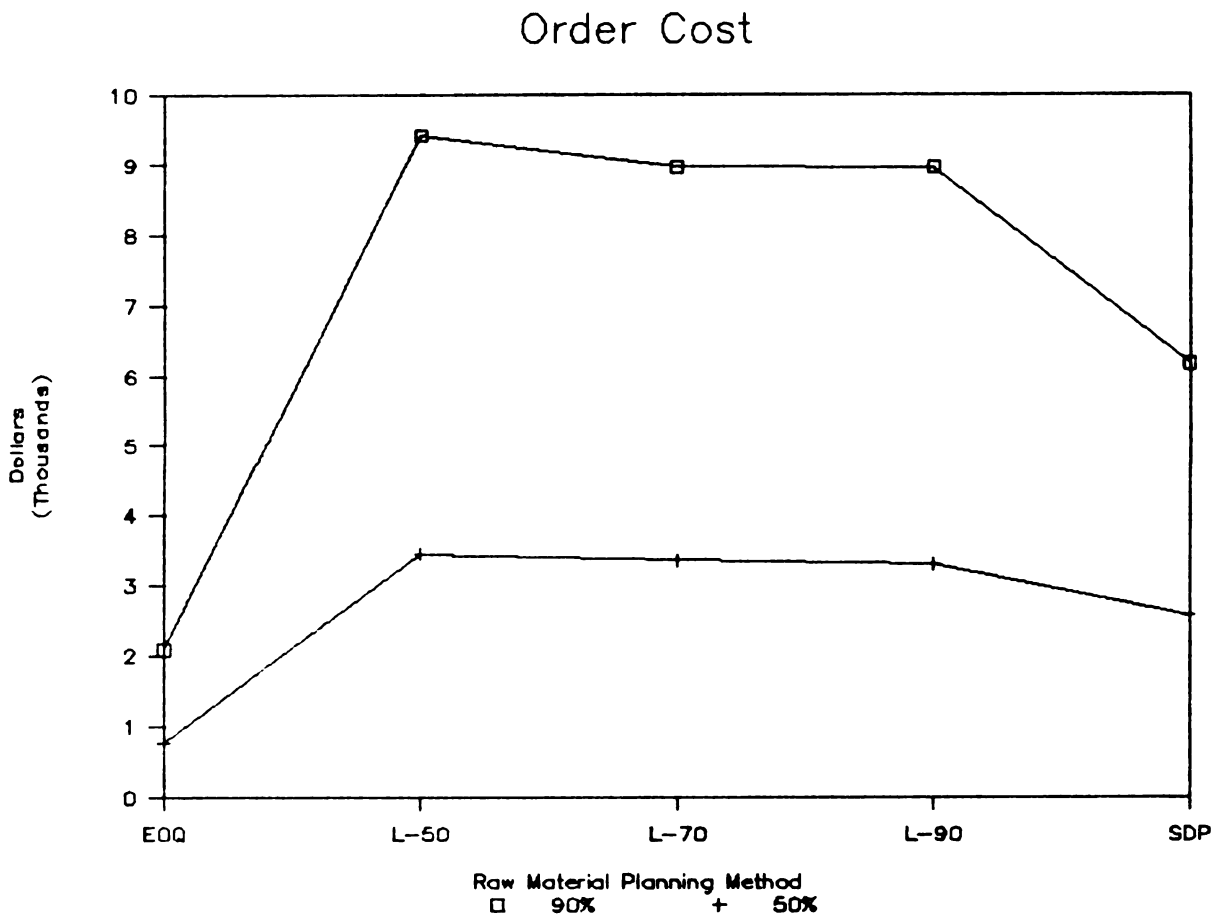


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

FINISHED GOODS--FIFTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.86

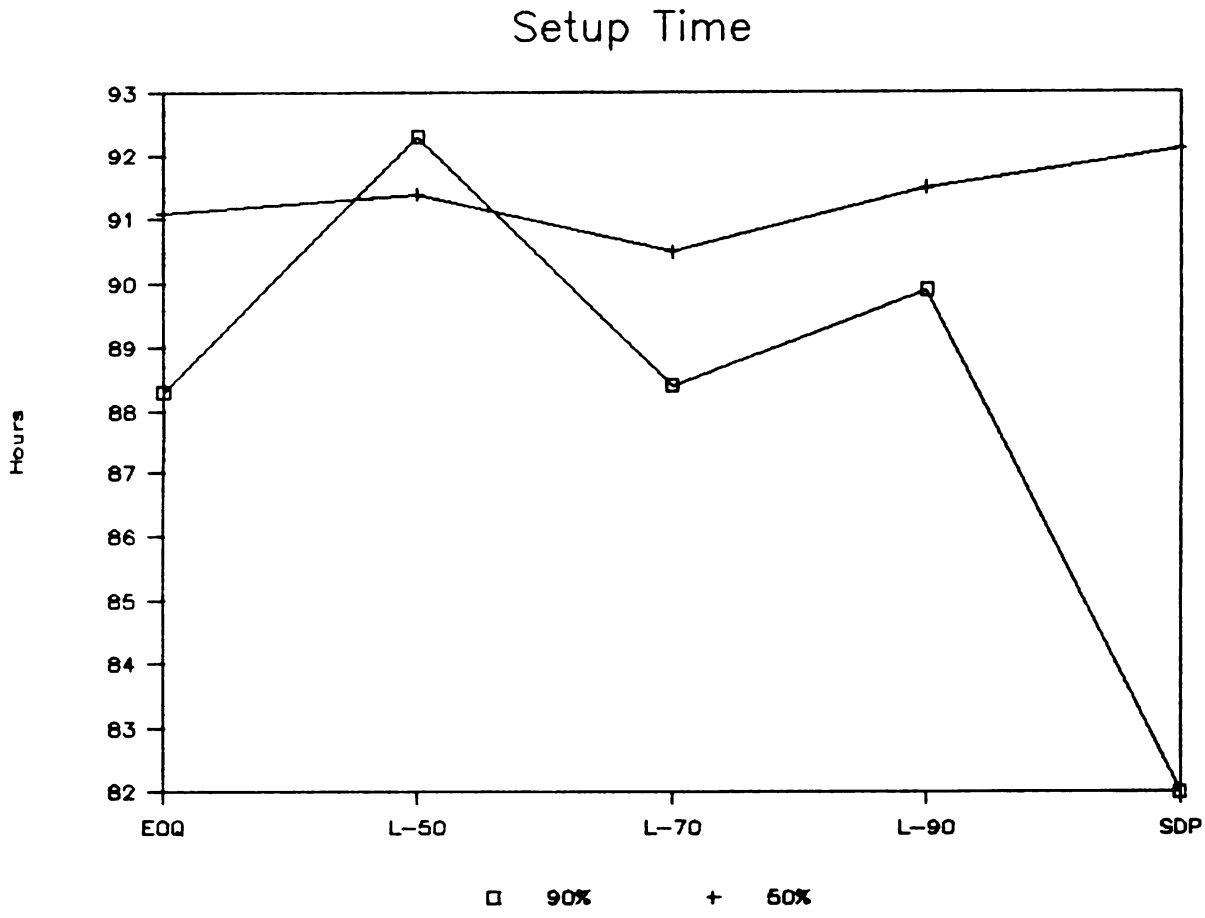


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

ORDER COST--FIFTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.87

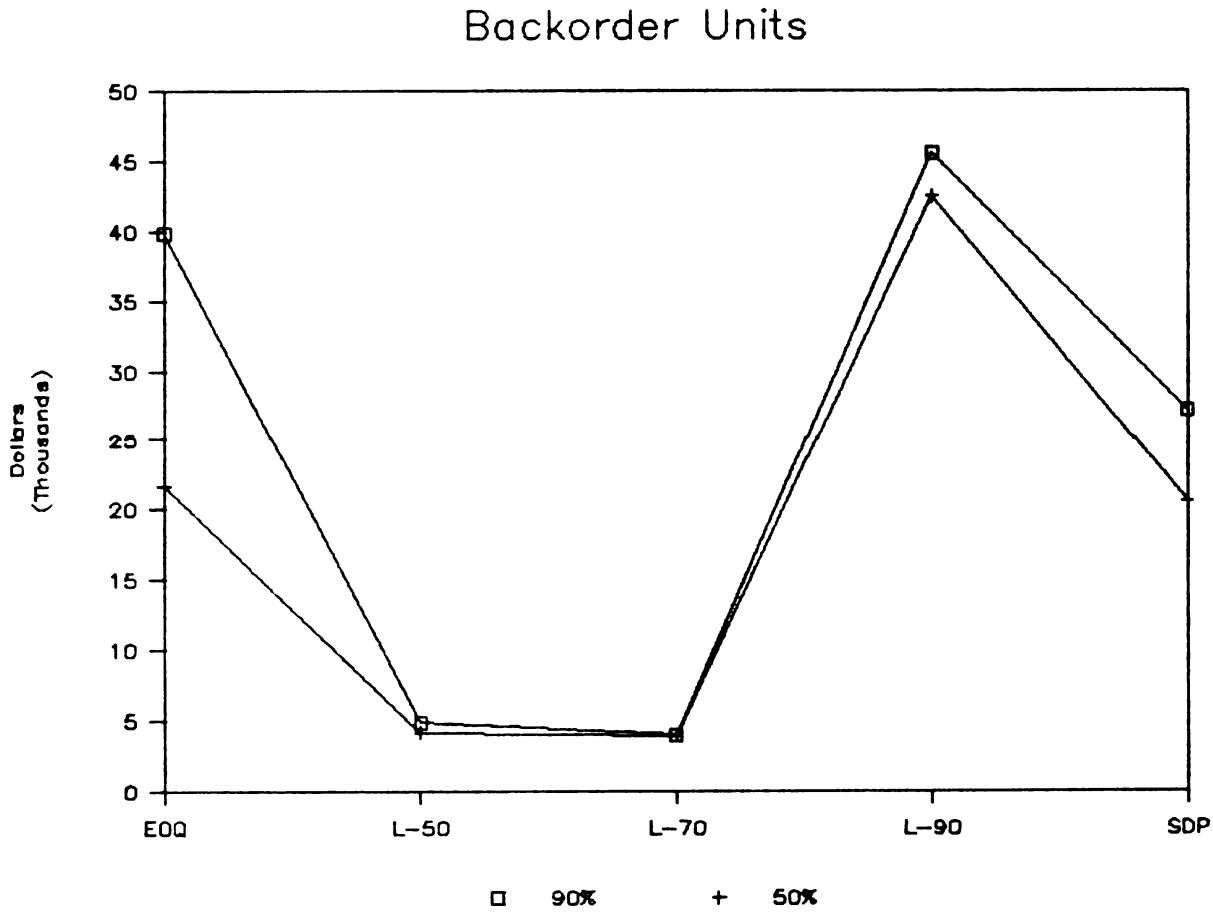


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

SETUP TIME--FIFTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.88

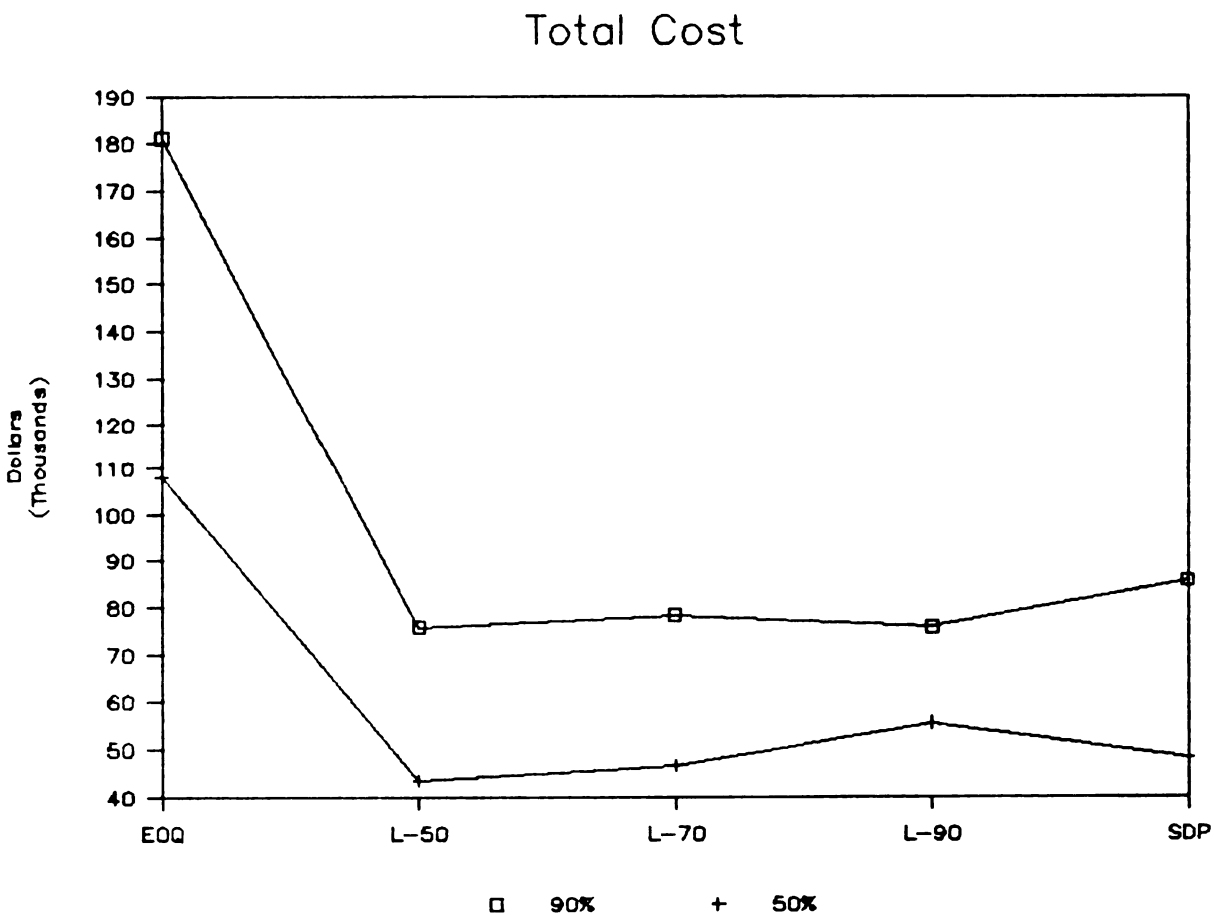


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

BACKORDER UNITS--FIFTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.89



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.03 : 1

TOTAL COST--FIFTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.90

Again, this combination of exogenous factors provides a set of significant relationships consistent with those rankings identified earlier. Raw material inventory and order cost means can be classified by raw material planning method ignoring finished goods safety stock with the three sets of means inversely related. Service level of lot-for-lot raw material ordering methods are inversely related to average order cost. Finally, finished goods inventory can be classified based on the service level of finished goods safety stock.

Setup time shows some significant differences, the lowest setup time was from SDP-90%, significantly different from all other methods, but EOQ-90% had the second lowest average setup time.

The average backorder units produced by the planning system responses finds a group of means equivalent and less than all other means. This group requires planning using the lot-for-lot raw material ordering method at the 50% or 70% service level. All other means are significantly larger.

Total cost shows some significant differences, but the important one is the high group, both economic order quantity methods. A second important condition is the equivalence of the group with the lowest total cost, L50-50%, L70-50% and SDP-50%.

6.3.16 Sixteenth Exogenous Factor Level Settings

The final combination of exogenous factors finds all of the factors set at their highest level. These values, performance measure means and rankings are shown in Table 6.19 and presented graphically in Figures 6.91 through 6.96.

Exogenous Level Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5:1
Activity Ratio	250:1
Coefficient of Variation	.10:1

Raw Material Planning Method and Level of Finished Goods Safety Stock

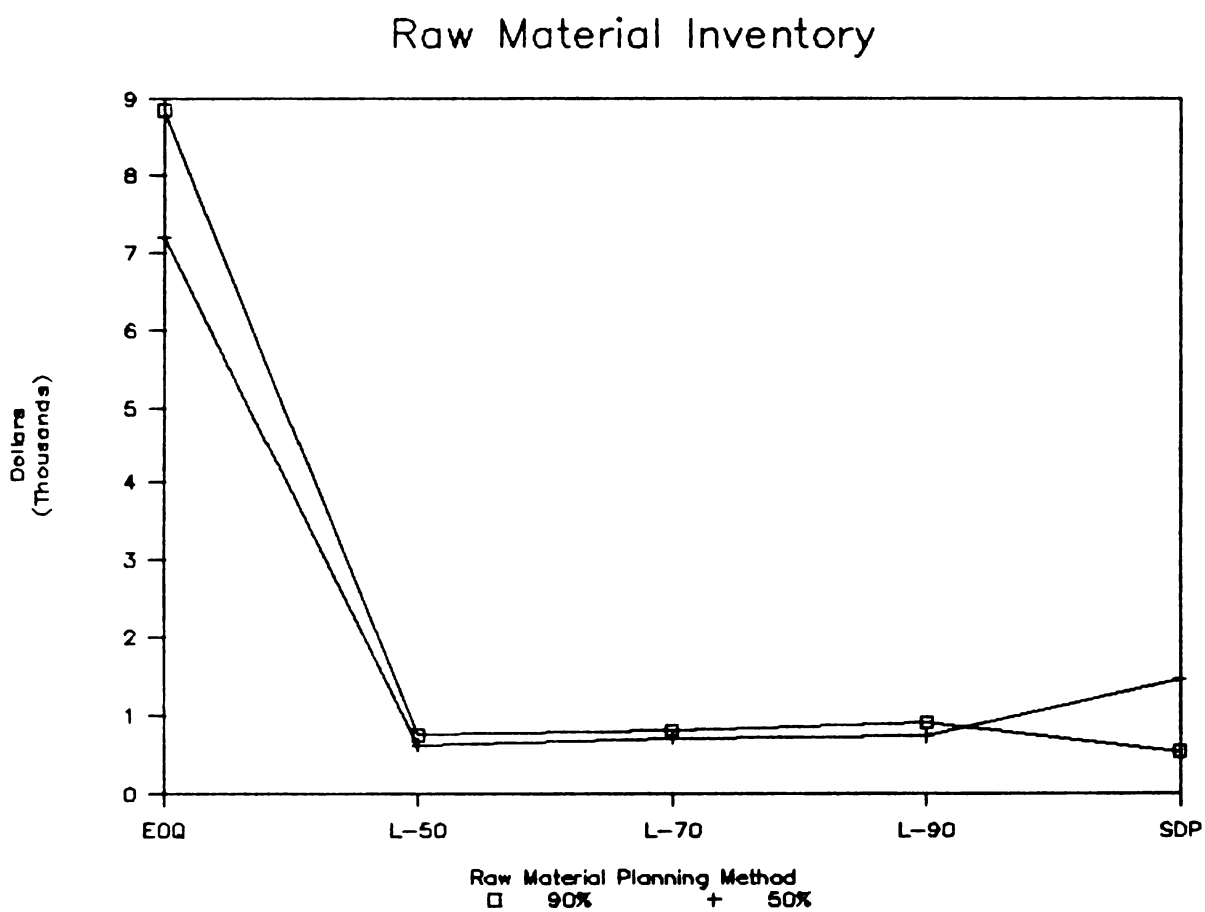
Performance Measure	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
Raw Material Inventory	8845.2	7221.9	754.7	625.6	813.4	706.0	913.1	737.1	541.2	1473.1
Finished Goods Inventory	5084.2	904.8	3775.8	874.8	4732.7	746.6	5059.5	674.1	703.60	890.2
Order Cost	1886.0	2393.3	9694.0	10267.3	9036.3	9480.5	8817.2	8796.6	2888.0	7066.6
Setup Time	89.0	92.1	90.4	89.7	91.8	91.7	89.1	91.8	88.8	90.9
Backorder Units	41489.1	32959.6	5552.6	7029.8	4073.2	3028.4	30837.8	30618.7	0.0	23985.7
Total Cost	167269.0	108666.6	74194.5	44614.7	83665.8	42952.3	83408.3	60219.7	22167.3	53675.4
Overall Rank	8.5	10	6	3	7	2	8.5	5	1	4
Average Rank	7.00	7.17	6.00	4.83	6.75	4.33	7.00	5.25	1.57	5.17

Note: EOQ - Modified Economic Order Quantity
L50 - Modified Lot-for-Lot at 50% Service Level
L70 - Modified Lot-for-Lot at 50% Service Level
L90 - Modified Lot-for-Lot at 50% Service Level
SDP - Stochastic Dynamic Programming

DEPENDENT VARIABLE MEANS

SIXTEENTH EXOGENOUS FACTOR SETTING

TABLE 6.19

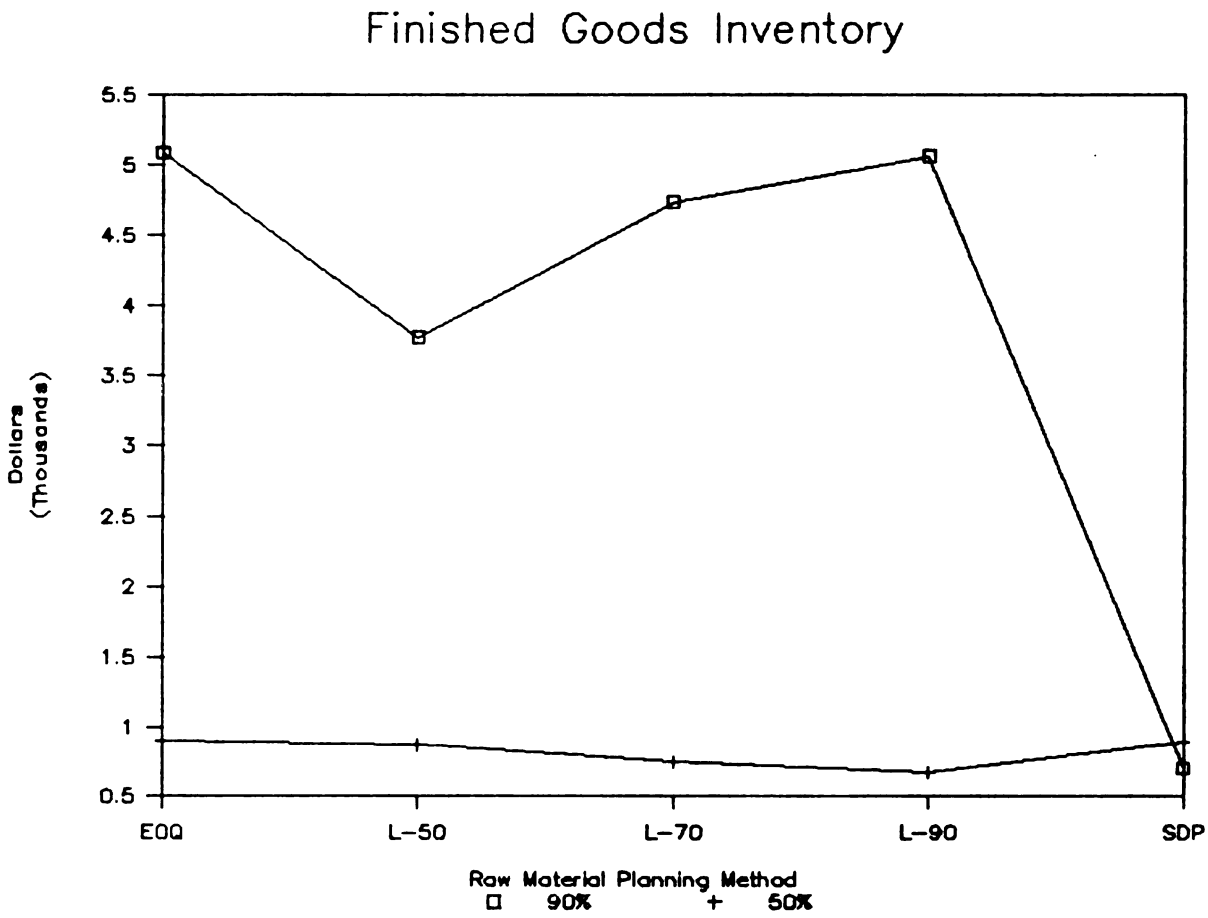


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

RAW MATERIAL INVENTORY--SIXTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.91

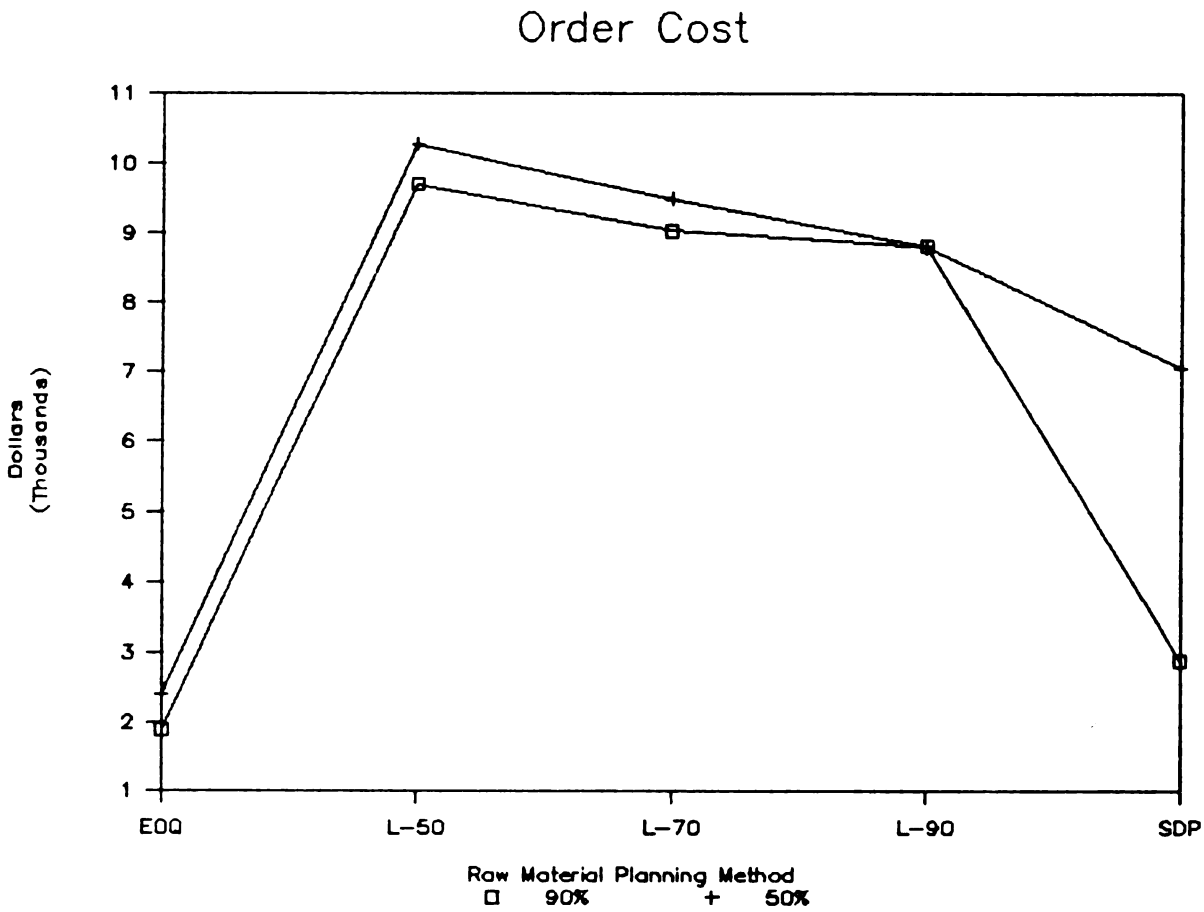


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

FINISHED GOODS--SIXTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.92

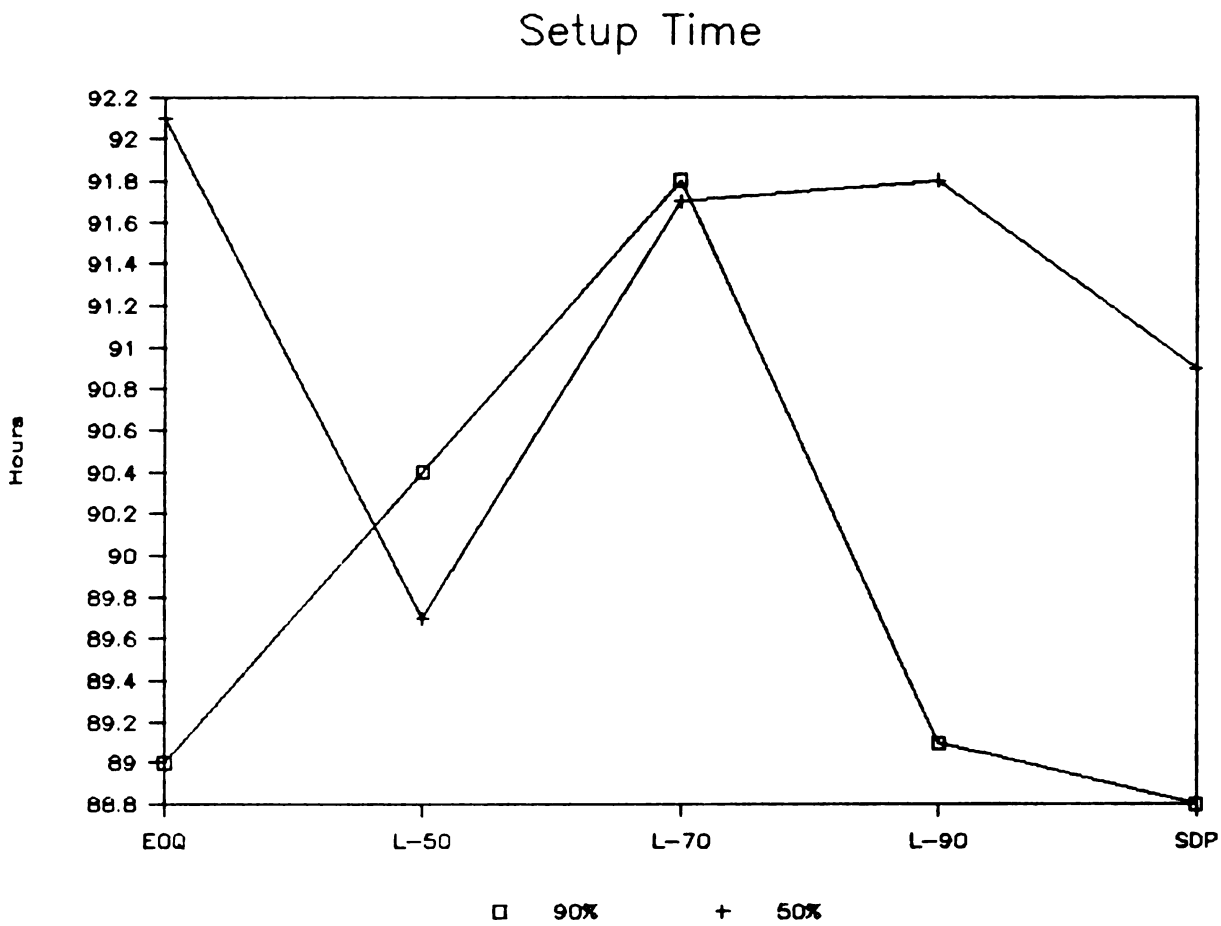


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

ORDER COST--SIXTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.93

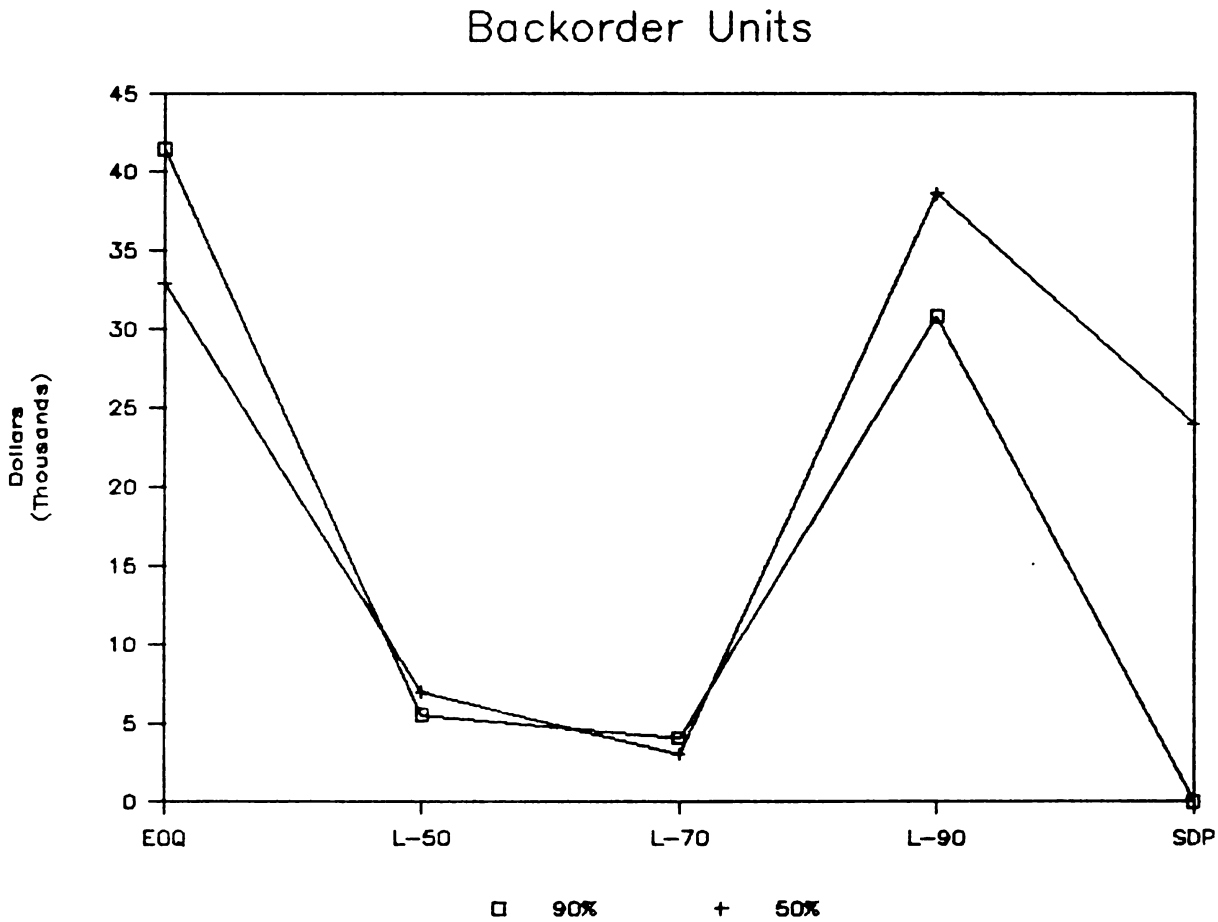


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

SETUP TIME--SIXTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.94

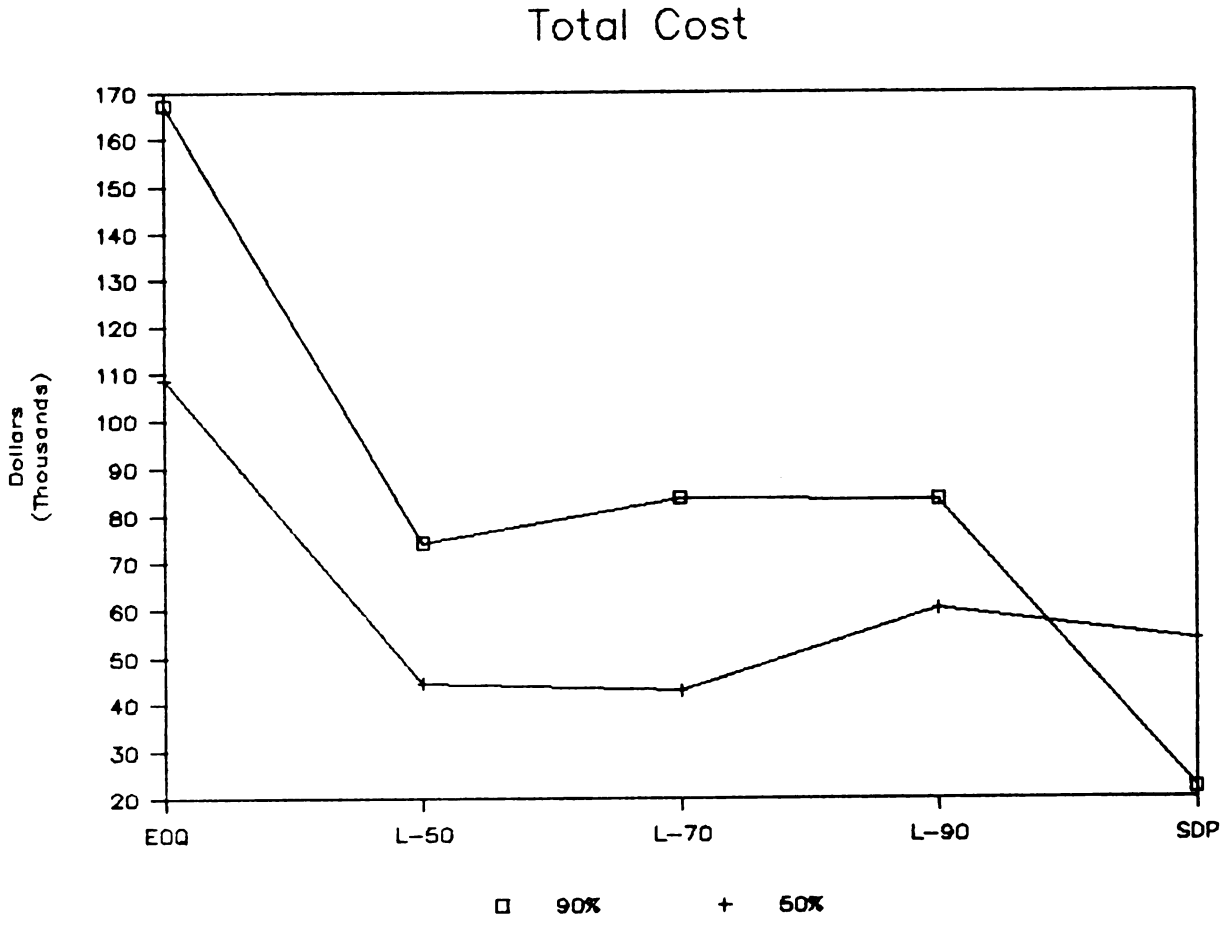


Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

BACKORDER UNITS--SIXTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.95



Exogenous Factor Settings

Average Capacity Utilization	80%
Cost of Capital Ratio	5 : 1
Activity Ratio	250 : 1
Coefficient of Variation	.10 : 1

TOTAL COST--SIXTEENTH EXOGENOUS FACTOR SETTING

FIGURE 6.96

The last combination of exogenous factors is less consistent with past analyses. The economic order quantity methods have the highest raw material inventory, with EOQ-90% significantly larger than EOQ-50%. In decreasing order, SDP-50% is larger than L90-90% followed by all other methods except SDP-90% which has the lowest raw material inventory.

Finished goods inventory shows some similar patterns, but one difference. Classification by finished goods safety stock service level is modified by both stochastic dynamic programming methods being included in the group with lesser means.

When evaluating order cost, both economic order quantity methods and SDP-90% have equally low means with SDP-50% significantly larger. A trend noted earlier, increasing cost as raw material ordering service level decreases, is again noted here.

Order cost exhibits the same pattern identified earlier, with one exception. The planning method SDP-90%, is included in the group of lowest means with the economic order quantity methods.

Setup time shows a significant difference between the tow lowest means, SDP-90% and EOQ-90%, and the two highest, L70-90% and L90-50%.

The group of planning system responses with low backorder unit means includes lot-for-lot planning at the 50% and 90% level and SDP-90% while the economic order

quantity methods , both L90 responses and SDP-50% indicated higher averages.

Economic order quantity methods provided the highest total cost with SDP-90% providing the lowest. Other significant relationships are evident, but no trends are evident.

6.4 Dependent Variable Trends

Throughout the analysis of dependent variable means, statistically significant relationships were monitored in an attempt to identify those endogenous and exogenous variables affecting dependent variable means. These relationships were identified by summarizing statistically significant relationships across all combinations of exogenous variables. There were significant relationships dealing with dependent variables. The details of those interactions and their managerial# implications follow.

6.4.1 Raw Material Inventory and Order Cost

Throughout all combinations of exogenous variables, with some exceptions, raw material inventory and order cost could be grouped based on the general class of raw material planning method employed, economic order quantity, stochastic dynamic programming or lot-for-lot methods, and not the service level of finished goods safety stock. Raw material inventory and order cost are presented in Tables 6.20 and 6.21.

Exogenous Factor Level Setting				Raw Material Planning Method and Level of Finished Goods Safety Stock							
E1	E2	E3	E4	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
-	-	-	-	3942.5	3934.9	233.2	208.2	199.9	215.6	248.4	254.2	461.2	451.1
-	-	-	+	4359.4	4337.3	263.1	302.2	300.6	339.1	364.6	365.7	750.6	734.4
-	-	+	-	14864.3	9743.8	924.2	604.3	756.6	675.8	852.7	623.6	1846.4	792.4
-	-	+	+	12759.8	6400.8	1128.2	703.1	1028.6	856.4	1146.4	842.2	2256.1	1397.4
-	+	-	-	2594.5	2580.2	164.5	123.4	123.4	142.2	170.9	180.2	323.2	332.3
-	+	-	+	2540.2	2851.6	166.8	172.7	657.1	219.3	215.6	216.3	493.6	523.8
-	+	+	-	7202.8	6431.5	444.3	384.7	489.6	464.5	553.9	366.5	335.7	625.5
-	+	+	+	8017.6	6569.1	537.4	482.7	626.7	506.0	718.4	576.1	469.8	1150.3
+	-	-	-	4233.9	4028.9	212.3	226.2	215.6	220.2	235.6	226.1	509.9	509.2
+	-	-	+	4569.3	4226.3	302.7	328.7	324.2	333.8	356.2	351.1	861.8	851.6
+	-	+	-	13202.6	10910.7	1074.8	822.4	1148.9	827.8	1110.8	809.6	2031.8	1134.3
+	-	+	+	13883.6	10955.3	1110.5	971.3	1265.1	1002.4	1403.4	1069.3	3519.5	1850.7
+	+	-	-	3031.2	2949.7	123.5	144.4	124.7	131.9	136.3	139.9	369.4	378.3
+	+	-	+	3324.7	3150.8	172.8	213.4	206.3	340.6	236.3	248.9	629.4	603.2
+	+	+	-	9758.4	7398.9	604.9	527.6	667.4	557.6	698.5	552.3	1885.3	889.7
+	+	+	+	8845.2	7221.9	754.7	625.6	813.4	706.8	913.1	737.1	541.2	1473.1
Average				7320.1	5170.4	518.2	432.1	558.8	470.7	584.6	422.1	1024.8	855.7

RAW MATERIAL INVENTORY MEANS

TABLE 6.20

Exogenous Factor Level Setting				Raw Material Planning Method and Level of Finished Goods Safety Stock							
				EOQ	EOQ	L50	L50	L70	L70	L90	L90	SDP	SDP
E1	E2	E3	E4	90%	50%	90%	50%	90%	50%	90%	50%	90%	50%
-	-	-	-	443.7	510.9	2396.0	2406.7	2261.6	2755.2	2183.2	2245.7	1948.1	1978.6
-	-	-	+	434.5	520.1	2502.7	2575.8	2234.0	2822.8	2253.4	2291.2	1785.6	1792.1
-	-	+	-	1060.0	1598.2	7396.7	7226.8	6811.6	7364.0	6508.2	5727.0	4738.2	5133.6
-	-	+	+	1019.8	2123.1	7372.8	7662.5	7167.2	6976.0	5748.6	5722.5	4396.5	4910.8
-	+	-	-	608.8	678.2	3050.2	3209.6	2947.8	3524.8	2839.1	2901.7	2547.9	2578.5
-	+	-	+	579.0	685.2	3137.9	3274.1	8316.8	3515.5	2906.6	2931.5	2368.8	2289.2
-	+	+	-	1882.5	2842.2	9638.1	9095.5	8437.3	9805.8	8092.0	7587.1	2392.5	6906.5
-	+	+	+	1823.9	2125.2	8887.5	9318.7	8582.2	8361.3	8238.8	7828.5	2582.0	6387.2
+	-	-	-	519.3	550.5	2642.9	2782.3	2525.0	2698.2	2487.9	2534.2	2211.3	2227.8
+	-	-	+	509.5	693.1	2750.4	2767.6	2631.8	2695.0	2518.1	2547.0	2015.5	2019.8
+	-	+	-	1529.5	1638.2	7458.0	8007.7	7149.2	7282.6	6600.8	6623.5	5496.3	5782.9
+	-	+	+	1747.4	1936.1	7504.4	8077.8	7246.1	7383.8	6397.1	6379.1	4784.3	5476.7
+	+	-	-	688.9	792.2	3383.4	3529.8	3343.3	3435.0	3212.2	3283.6	2874.5	2859.4
+	+	-	+	636.1	775.4	3418.2	3440.5	3311.8	3358.6	3186.8	3295.8	2533.3	2571.7
+	+	+	-	2087.0	2344.9	9415.5	9630.6	8971.2	9896.1	8965.5	8860.7	6198.7	7549.6
+	+	+	+	1886.0	2393.3	9694.8	10267.3	9036.3	9488.5	8817.2	8796.6	2888.8	7866.6
Average Cost				1198.8	1338.1	5227.7	5834.8	5685.4	5248.8	4182.8	4596.8	3896.1	4188.8

ORDER COST MEANS

TABLE 6.21

Examination of the tables finds overall averages consistent with trends identified earlier. The economic order quantity methods have the highest average inventory levels followed by the stochastic dynamic programming

methods with all lot-for-lot methods having approximately the same values. No difference is evident in raw material levels based on the service level of finished goods safety stock.

The inverse relationship between raw material inventory and order cost was consistently noted. It is logical for order cost to go down as raw material inventory increases, since the planning system is ordering more raw material when it orders. Because order cost was not affected by the size of the order, but by the unit cost of raw material, this inverse relationship is consistent with logical inventory flow.

Once the relative magnitude of average raw material inventory had been determined, based on raw material planning method, it was also consistent for the order cost to be similarly grouped and inversely related.

The implications of this relationship for the design of the material planning and control system are not to identify the best method of raw material planning, but to note the tradeoffs that exist between raw material inventory and order cost. The second implication involves the level of finished goods safety stock. This endogenous variable had no consistent effect on these dependent variables so it need not be an input into the design of the material planning system when one is only concerned with raw material inventory and order cost.

A third effect noted in some of the analyses was the increase in order cost of the lot-for-lot planning methods as the service level of the ordering process increased. As more inventory is ordered to respond to raw material variability it is not surprising that the 50% service level has to order more often than the 70% or 90% methods to respond to raw material variability by ordering raw material again.

6.4.2 Finished Goods Inventory and Backorder Units

An unsurprising, but important, result was the dependence of finished goods inventory on the service level for finished goods. For the most part, finished goods safety stock maintained at the 90% service level had fewer backorders than when maintained at the 50% service level, regardless# of raw material planning method employed. In all environments, the average number of backorder units at the 90% service level was less than or equal to the average at the 50% service level.

This result is important when viewed in terms of the average number of backorder units experienced by the different planning system combinations. Initially, finished goods safety stock was established as a way of responding to reduced production order quantities due to raw material variability. It is evident that finished goods safety stock shows limited effectiveness in dealing with uncertainty in raw materials. It also points out the ineffectiveness of

the economic order quantity methods when performance is based on minimizing the number of units placed on backorder.

Tables 6.22 and 6.23 summarize the finished goods inventory and backorder unit performance of each planning system. There is a consistent relationship in finished goods inventory where a difference exists based on service level, but no consistent difference is noted between raw material planning method.

The backorder results are consistent with trends identified earlier, but an interesting condition worth noting is the superiority of a 90% finished goods safety stock service level over the 50% service level. In all cases, backorder units at the 50% service level were greater than or equal to the 90% service level with two exceptions. When using stochastic dynamic programming, the 50% service level had a lower backorder unit mean than the 90% service level when the coefficient of variation was low and activity ratio was high. Of the four combinations of cost of capital and average capacity utilization, three showed the 50% to be better than the 90% and the fourth, low capacity and a high cost of capital, the difference between backorder units was 6864, close to the required difference of 9020. The second set of exceptions involved the lot-for-lot 90% raw material service level method. The 50% finished good safety stock service level was lower than 90% when three exogenous variables, cost of capital, activity ratio and coefficient

of variation, were high, average capacity utilization could be either high or low.

An interesting, yet unsurprising, result is the relationship between the activity ratio and the level of backorder units. Analysis of the table with average number of backorder units shows that as the activity ratio goes from low to high, the number of backorder units increases. The logic associated with replanning required a comparison of penalty cost with the cost of starting a new order. As the cost of initiating a new order, order cost and setup time, goes up, more backorder units would be expected.

Exogenous Factor Level Setting R1 R2 R3 R4				Raw Material Planning Method and Level of Finished Goods Safety Stock EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
-	-	-	-	3762.0	596.5	3068.3	126.0	4109.4	207.2	4008.7	457.2	3628.0	221.2
-	-	-	+	3439.3	615.1	2632.2	94.8	3167.3	163.8	3879.8	242.0	3552.2	223.3
-	-	+	-	6936.9	1282.3	3273.0	938.6	3510.3	518.6	4997.8	1537.3	5349.0	969.7
-	-	+	+	5209.3	871.1	4235.0	1080.1	4006.7	839.8	5490.3	1872.1	5421.7	950.1
-	+	-	-	3517.0	489.8	2949.9	79.8	4114.5	281.3	3849.7	297.6	3482.0	89.8
-	+	-	+	2693.7	96.5	1754.9	54.5	3676.0	85.4	3745.3	474.1	3441.1	88.6
-	+	+	-	4759.5	545.6	4927.7	581.8	4253.4	446.3	5050.0	925.6	402.8	620.8
-	+	+	+	5237.3	546.1	2340.8	214.6	3713.7	568.7	2751.4	1449.6	534.6	613.7
+	-	-	-	4572.8	219.0	4185.8	260.2	4351.2	195.1	5101.5	213.0	4669.2	226.5
+	-	-	+	4105.6	214.1	2736.8	100.8	3733.2	157.4	4245.5	212.9	4666.6	229.0
+	-	+	-	6261.5	1209.7	3042.4	1033.3	4617.4	1138.1	5457.6	1312.8	2538.8	1172.0
+	-	+	+	6920.2	1159.2	3565.7	1356.2	4712.9	1200.0	6569.9	1565.9	4223.4	1180.9
+	+	-	-	4342.3	87.9	3564.8	118.0	4193.6	80.7	4596.4	72.4	4428.7	75.3
+	+	-	+	3418.1	84.8	2967.9	66.1	3701.4	121.8	4584.0	70.6	4449.8	76.0
+	+	+	-	5586.2	913.5	4014.0	940.4	4421.2	1314.1	4942.1	871.4	4363.3	952.3
+	+	+	+	5084.2	904.8	3775.8	874.8	4732.7	746.6	5059.5	674.1	703.60	890.2
Average Cost				4740.0	614.3	3312.9	494.6	4113.0	503.6	4645.1	765.1	3490.5	535.6

FINISHED GOODS INVENTORY MEANS

TABLE 6.22

Exogenous Factor Level Setting				Raw Material Planning Method and Level of Finished Goods Safety Stock							
				EOQ	EOQ	L50	L50	L70	L70	L90	L90	SDP	SDP
R1	R2	R3	R4	90%	50%	90%	50%	90%	50%	90%	50%	90%	50%
-	-	-	-	5200.8	13409.0	3192.3	1560.6	1138.3	7228.4	0.0	425.7	0.0	36.8
-	-	-	+	21714.4	30399.2	1584.3	6673.5	10240.5	39391.9	416.6	3597.4	200.0	133.0
-	-	+	-	21494.5	23207.8	4418.5	2042.4	44637.2	43205.0	30437.2	25688.8	20820.1	21111.3
-	-	+	+	36844.8	23020.7	7324.8	4627.8	4217.9	53536.2	36157.8	32241.3	29123.6	28988.8
-	+	-	-	3728.4	1544.5	3244.7	959.6	285.8	5717.3	0.0	452.6	0.0	0.0
-	+	-	+	28844.6	23391.4	1279.6	3294.2	2963.1	24050.8	0.0	2385.7	0.0	169.3
-	+	+	-	12870.1	11417.7	1911.2	2115.8	1227.2	21020.3	13121.7	7385.3	0.0	6864.3
-	+	+	+	15246.6	22354.2	3650.7	3568.7	2822.6	35200.2	32916.7	10269.6	0.0	7447.2
+	-	-	-	4505.2	13409.3	445.7	2628.7	70.1	1468.7	0.0	18.4	352.6	514.1
+	-	-	+	21540.2	30471.8	2366.2	9152.1	777.7	5575.6	67.6	217.2	213.1	782.7
+	-	+	-	38065.1	33653.3	5018.8	3221.8	4856.6	2555.6	5652.8	822.2	40820.1	33412.7
+	-	+	+	39809.1	41555.7	6695.5	5425.3	4466.6	3593.3	26765.2	36201.6	37370.7	33287.7
+	+	-	-	6308.1	18624.1	118.1	2371.8	35.8	1195.3	0.0	29.6	0.0	25.0
+	+	-	+	43247.2	39406.9	1457.5	7123.5	395.6	3679.7	0.0	3321.3	0.0	175.2
+	+	+	-	39841.4	21605.6	4852.4	4149.4	4013.8	3934.5	45537.6	42467.2	27265.6	20550.3
+	+	+	+	41489.1	32959.6	5552.6	7029.8	4073.2	3028.4	30837.8	38618.7	0.0	23985.7
Average				23796.5	20570.2	5433.7	4121.0	5091.6	12602.4	11833.8	10897.8	15385.3	9207.4

AVERAGE BACKORDER UNITS

TABLE 6.23

When viewing system performance based on minimizing the level of units placed on backorder, the results have some implications on system design. When evaluating raw material planning methods, the economic order quantity methods do not perform well based on this measure, and lot-for-lot at the

50% raw material service level performs surprisingly well.

Finished goods safety stock service level is more complicated situation. Usually, a 90% service level performs better than a 50% service level, but conditions were identified for both stochastic dynamic programming and lot-for-lot at the 90% raw material service level where the opposite was true.

6.4.3 Setup Time

The performance measure, setup time, was analyzed to identify consistent trends throughout all combinations of exogenous variables. The only trend noted dealt with the equality, or inequality, of setup time based the third exogenous variable, activity ratio. In all eight cases, when the activity ratio was high, there was a significant difference in setup times. When the activity ratio was low, no difference was significant.

Setup times across all combinations of exogenous variables are presented in Table 6.24.

Exogenous Factor Level Setting R1 R2 R3 R4	Raw Material Planning Method and Level of Finished Goods Safety Stock									
	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
- - - -	22.9	22.6	22.5	23.1	22.7	23.0	22.9	22.8	22.6	23.0
- - - +	22.7	23.0	22.7	23.2	22.9	22.8	23.1	22.8	22.9	22.8
- - + -	51.1	63.6	59.6	65.7	56.9	64.6	56.2	62.3	62.2	62.7
- - + +	57.0	81.9	59.2	69.2	59.7	65.0	51.8	63.2	64.6	62.7
- + - -	27.9	28.0	27.9	28.2	27.9	28.0	27.9	27.8	27.8	28.3
- + - +	27.9	28.3	27.9	29.4	29.6	28.2	28.4	28.2	28.2	27.8
- + + -	81.2	77.9	78.5	83.2	80.6	84.8	81.2	81.9	79.6	82.4
- + + +	76.2	81.9	81.5	87.8	79.1	83.5	80.5	82.3	79.6	82.2
+ - - -	25.1	25.0	25.1	25.3	24.9	25.0	25.2	25.2	25.2	25.1
+ - - +	25.1	25.1	25.1	24.9	25.0	24.9	25.2	25.2	25.2	25.1
+ - + -	62.1	70.0	64.3	73.8	66.4	72.8	66.6	69.3	70.9	69.9
+ - + +	61.4	65.3	70.6	73.3	60.3	73.3	56.7	70.5	64.6	70.0
+ + - -	30.5	30.9	30.6	30.7	30.5	30.6	30.4	31.2	31.0	30.5
+ + - +	30.5	30.7	30.7	30.9	30.6	30.6	30.1	30.4	30.5	30.4
+ + + -	88.3	91.1	92.3	91.4	88.4	90.5	89.9	91.5	82.0	92.1
+ + + +	89.0	92.1	90.4	89.7	91.8	91.7	89.1	91.8	88.8	90.9
Average Time	43.7	44.8	50.6	49.3	49.8	52.5	50.6	51.6	50.4	51.6

SETUP TIME

TABLE 6.24

Analyzing the setup times presented in Table 6.24 shows a result worth noting. The average setup time in both economic order quantity methods is lower than all other methods and with the exception of the L50-90% and L50-50% methods, the 50% service level for finished goods safety

stock has a higher setup time than the 90% service level. No other trends were noted.

6.4.4 Total Cost

Differing total cost performance will be discussed in more depth later in this chapter, the significant result was the high means generated by the economic order quantity methods. Based on the magnitude of raw material inventory levels and backorder units it was obvious that these methods did not provide performance consistent with the other planning methods. Total cost averages are presented in Table 6.25.

Exogenous Factor Level Setting				Raw Material Planning Method and Level of Finished Goods Safety Stock							
				EOQ	EOQ	L50	L50	L70	L70	L90	L90	SDP	SDP
E1	E2	E3	E4	90%	50%	90%	50%	90%	50%	90%	50%	90%	50%
-	-	-	-	44124.1	29007.1	23739.1	10031.1	28471.9	12263.9	28039.4	10402.7	26919.7	9939.2
-	-	-	+	46256.4	32937.7	21685.8	12548.6	25285.1	13844.5	28136.6	10255.1	27901.3	11160.5
-	-	+	-	123226.3	71763.0	44934.1	31291.1	43987.3	35400.0	50037.7	31560.7	57234.6	28598.0
-	-	+	+	106751.4	57159.7	40719.3	34005.6	41842.6	38946.7	50406.9	35159.7	50607.1	32080.6
-	+	-	-	37157.1	21706.7	24540.0	10905.1	29751.3	11019.4	28517.7	10903.9	27141.9	10343.5
-	+	-	+	35310.8	23430.2	14303.5	12270.5	46201.2	14672.6	16877.7	12278.2	27691.9	10935.1
-	+	+	-	79233.4	53657.3	37220.6	32712.4	40388.5	36156.6	42705.9	31162.0	11960.2	30307.2
-	+	+	+	84868.8	56311.3	37246.9	35008.8	46384.0	37038.0	44963.8	35446.6	13531.6	32405.3
+	-	-	-	94599.1	50713.3	25981.0	15827.4	53194.0	12147.0	32070.1	15159.5	59122.6	14723.5
+	-	-	+	96651.8	56224.4	24954.0	13878.3	48359.3	13702.3	32352.0	18739.2	62387.2	18012.8
+	-	+	-	216211.7	143566.9	65874.7	41960.6	79066.8	42004.1	73189.9	49926.8	46605.8	49499.7
+	-	+	+	230024.5	145334.8	68661.9	47101.9	79973.8	44795.5	95880.7	64508.7	65065.3	56455.3
+	+	-	-	82003.4	41059.1	24477.6	12783.0	52641.7	11912.3	27428.0	13940.8	57051.9	13508.2
+	+	-	+	82814.3	47052.9	41259.6	13826.6	48591.5	14825.7	29910.0	17570.0	59423.8	15481.3
+	+	+	-	181171.1	108008.8	75834.5	43413.4	78338.0	46696.5	75932.6	55691.8	85727.4	48504.1
+	+	+	+	167269.0	108666.6	74194.5	44614.7	83665.8	42952.3	83408.3	60219.7	22167.3	53675.4
Average Cost				106729.2	65422.0	40351.8	25870.8	52133.5	26823.1	46240.6	29957.3	42600.7	27226.5

TOTAL COST

TABLE 6.25

Another interesting situation noted in the total cost performance is the higher total cost of all planning systems with a 90% service level for finished goods safety stock over the planning systems with a 50% service level. The only exceptions involve stochastic dynamic programming in

three environments. With a high cost of capital and high activity ratio, all four other exogenous variable combinations except high capacity utilization and a low coefficient of variation show the 50% service level with a higher cost than the 90%.

Analysis of average total cost shows the relative equivalence of all lot-for-lot planning methods regardless of raw material ordering service level and stochastic dynamic programming when finished goods safety stock is at the 50% service level. If a planning system is designed using total cost as its criteria, finished goods safety stock should not be employed and the raw material planning method could be either lot-for-lot or stochastic dynamic programming.

6.5 Overall Rank of Planning System Methodologies

In a situation with multiple performance measures, it is difficult to identify one best method of raw material ordering and finished goods safety stock to maintain. In order to put the performance of the ten responses in perspective, the data just presented was ranked using two methods. The first ranking procedure calculated the number of standard errors a cell mean was above or below the overall average for that performance measure. Using this procedure, equal weights are assigned to all performance measures, not the weights used when total cost was

calculated from the other five performance measures. This was done using Equation 6.2.

$$T = (\bar{\bar{X}} - \bar{X})/(MSE/n) \qquad (6.2)$$

Where T - measure of deviation

$\bar{X}$ - cell mean

$\bar{\bar{X}}$ - overall mean

MSE - mean square error

n - number of samples used to calculate cell mean

The values of T for each dependent variable were then summed over all dependent variables to provide relative measure of performance of that combination of raw material planning method and level of finished goods safety stock. These results are shown in Table 6.27. For each combination of exogenous variables, the sum of the T values are shown and the within row rank is identified. The overall rank is based on the average rank, which is the average rank across all combinations of exogenous variables. It is calculated by calculating the average rank of a column of values.

Exogenous Factor Level Setting				Raw Material Planning Method and Level of Finished Goods Safety Stock							
				EOQ	EOQ	L50	L50	L70	L70	L90	L90	SDP	SDP
R1	R2	R3	R4	90%	50%	90%	50%	90%	50%	90%	50%	90%	50%
-	-	-	-	10	9	4	2	8	3	7	6	5	1
				-54.0	-108.5	-110.4	-153.0	-108.8	-143.6	-111.0	-112.1	-116.6	-159.0
-	-	-	+	10	9	5	4	7	3	8	1	6	2
				-60.4	-89.3	-121.9	-146.1	-113.4	-150.4	-108.7	-158.5	-114.4	-157.5
-	-	+	-	10	9	8	3	5	4	6	2	7	1
				252.5	105.9	81.3	25.9	62.4	49.6	67.8	13.9	76.9	-3.0
-	-	+	+	10	8	6	4	2	9	5	3	7	1
				369.7	81.9	63.7	47.3	24.3	82.4	59.4	27.7	76.3	8.9
-	+	-	-	9	4	7	3	10	5	8	2	1	6
				-90.4	-129.4	-99.8	-134.4	-89.2	-124.5	-93.9	138.0	-143.0	-102.0
-	+	-	+	9	5	4	3	10	6	7	2	8	1
				-98.7	-115.2	-118.4	-128.6	22.3	-112.0	-102.5	-132.4	-101.0	-145.2
-	+	+	-	10	4	9	5	7	6	8	3	1	2
				134.6	62.2	123.1	81.1	111.4	108.6	120.8	57.8	14.8	47.4
-	+	+	+	10	4	7	6	8	5	9	3	1	2
				146.9	80.4	101.8	93.1	107.6	92.5	112.3	78.8	-50.3	47.9
+	-	-	-	10	8	6	4	9	2	7	3	5	1
				24.6	-86.5	-100.4	-137.7	-77.2	-145.6	-89.7	-144.9	-131.5	-146.3
+	-	-	+	10	9	5	4	6	2	7	3	8	1
				-2.7	-67.3	-109.2	-137.3	-94.5	-140.0	-94.4	-139.2	-79.4	-141.6
+	-	+	-	10	9	4	8	7	2	6	1	3	5
				328.6	202.4	84.1	114.9	108.2	53.1	101.1	43.9	73.2	89.1
+	-	+	+	10	9	6	3	5	2	7	4	8	1
				359.2	205.5	110.8	77.1	102.8	61.6	112.2	79.5	125.7	61.2
+	+	-	-	10	4	5	3	8	2	6	7	9	1
				-30.6	-94.6	-86.9	-122.1	-57.5	-125.7	-78.8	-67.6	-55.1	-131.2
+	+	-	+	10	6	7	4	9	3	5	2	8	1
				-14.5	-76.8	-74.9	-95.6	-31.9	-120.8	-76.3	-120.7	-55.8	-131.3
+	+	+	-	10	4	8	2	6	1	9	5	3	7
				221.9	125.2	157.4	120.7	147.4	114.7	101.8	132.2	120.5	151.0
+	+	+	+	10	9	6	4	7	3	8	5	1	2
				259.1	249.8	173.2	129.9	101.8	116.9	201.9	144.5	-20.8	107.9
Average Rank Within Column				9.875	6.875	6.063	3.875	7.125	3.625	7.063	3.250	5.063	2.188
Overall Rank				10	9	6	4	8	3	7	2	5	1

AVERAGE RANK USING MSE

TABLE 6.26

Before moving on to the next type of analysis, the performance of stochastic dynamic programming at the 50% service level merits explanation. In those three environments where its rank is 5, 6 or 7, SDP-50% had a total cost statistically equal to the planning system with the least total cost for that environment.

The next method used to identify overall performance calculated a within row rank for each combination of exogenous variables, averaged those ranks by column and provided an overall rank based on that average rank. This information is presented in Table 6.27.

Exogenous Factor Level Setting R1 R2 R3 R4	Raw Material Planning Method and Level of Finished Goods Safety Stock									
	EOQ 90%	EOQ 50%	L50 90%	L50 50%	L70 90%	L70 50%	L90 90%	L90 50%	SDP 90%	SDP 50%
- - - -	10	9	4.5	4.5	7	8	6	2	3	1
- - - +	10	9	2	5	6	4	8	3	7	1
- - + -	8	6	10	2	6	4	6	3	9	1
- - + +	9	7	5	2.5	4	6	8	2.5	10	1
- + - -	9	5	7.5	4	6	7.5	10	1	3	2
- + - +	8	7	3	2	10	9	4	5	6	1
- + + -	9	3	6	4.5	7	8	10	2	1	4.5
- + + +	9	8	5.5	3	5.5	10	7	4	1	2
+ - - -	10	6	5	7	2.5	1	8	4	9	2.5
+ - - +	10	8	6	2	5	1	7	3	9	4
+ - + -	10	9	5	3	7	2	6	1	8	4
+ - + +	10	7	9	2	7	1	4	3	8	2
+ + - -	10	4.5	6	8	7	3	2	4.5	9	1
+ + - +	10	9	7.5	4	7.5	5.5	3	2	5.5	1
+ + + -	9	6	9	2	4	1	9	3	7	5
+ + + -	8.5	10	6	3	7	2	8.5	5	1	4
Average Rank	9.34	7.09	6.06	3.66	6.16	4.56	6.66	3.00	6.03	2.31
Overall Rank	10	9	6	3	7	4	8	2	5	1

Overall and Average Rank of Planning Systems

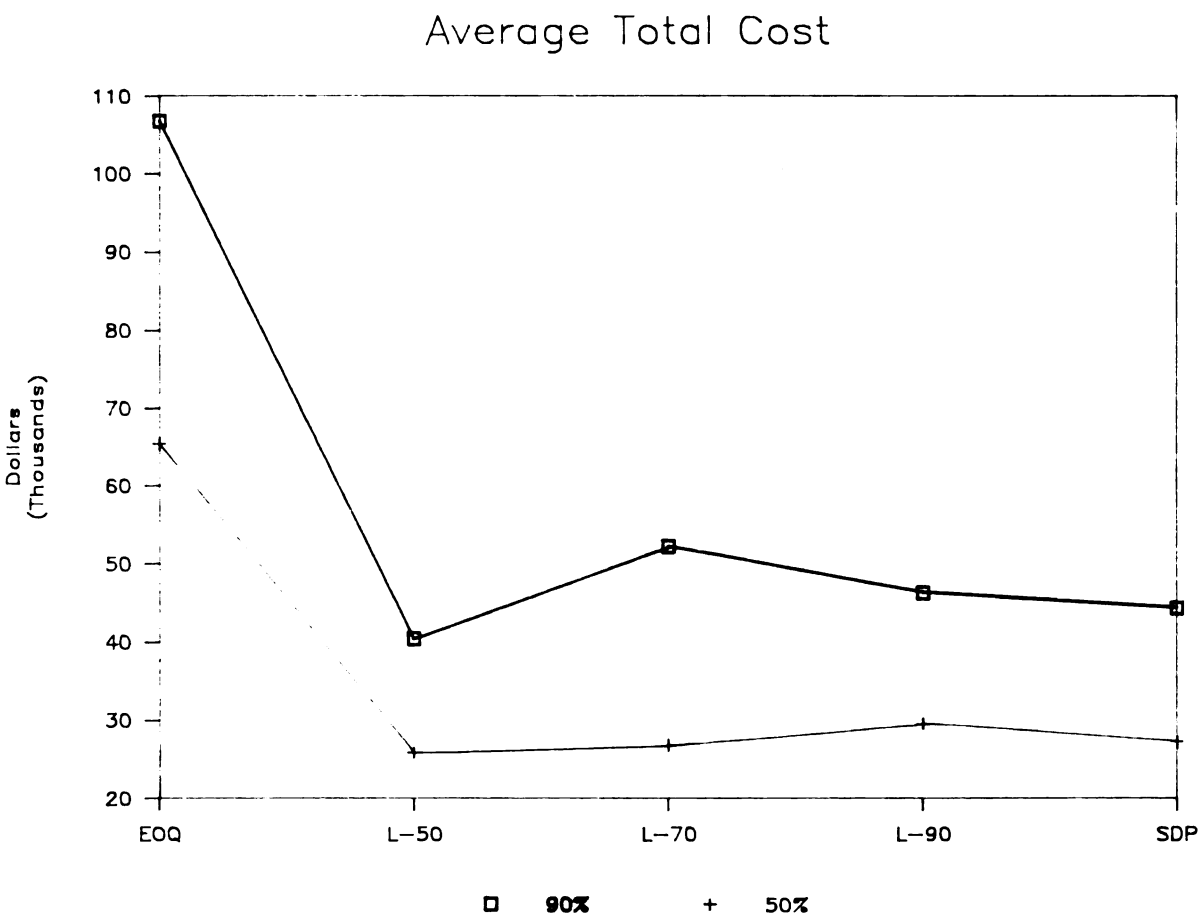
TABLE 6.27

A different procedure was used to analysis of performance, the total cost values for each planning method were analyzed across all exogenous factor settings. This information is presented in Table 6.28 and Figure 6.97. The equality of the lot-for-lot procedures and stochastic dynamic programming when the finished goods safety stock has a 50% service level is evident as is the inferior performance of the economic order quantity methods.

Exogenous Factor Level Setting				Raw Material Planning Method and Level of Finished Goods Safety Stock							
				EOQ	EOQ	L50	L50	L70	L70	L90	L90	SDP	SDP
E1	E2	E3	E4	90%	50%	90%	50%	90%	50%	90%	50%	90%	50%
-	-	-	-	44124.1	29087.1	23739.1	10831.1	28471.9	12263.9	28039.4	10402.7	26919.7	9939.2
-	-	-	+	46256.4	32937.7	21685.8	12548.6	25285.1	13044.5	28136.6	10255.1	27901.3	11160.5
-	-	+	-	123226.3	71763.0	44934.1	31291.1	43987.3	35400.0	50037.7	31560.7	57234.6	20598.0
-	-	+	+	106751.4	57159.7	40719.3	34805.6	41842.6	30946.7	50406.9	35159.7	58607.1	32080.6
-	+	-	-	37157.1	21786.7	24540.0	10985.1	29751.3	11019.4	28517.7	10903.9	27141.9	10343.5
-	+	-	+	35310.8	23430.2	14303.5	12270.5	46201.2	14672.6	16877.7	12278.2	27691.9	10935.1
-	+	+	-	79233.4	53657.3	37228.6	32712.4	40388.5	36156.6	42705.9	31162.0	11960.2	30307.2
-	+	+	+	84868.8	56311.3	37246.9	35008.8	46384.0	37038.0	44963.8	35446.6	13531.6	32405.3
+	-	-	-	94599.1	50713.3	25981.0	15827.4	53194.0	12147.0	32070.1	15159.5	59122.6	14723.5
+	-	-	+	96651.8	56224.4	24954.0	13878.3	48359.3	13702.3	32352.0	18739.2	62387.2	18012.8
+	-	+	-	216211.7	143566.9	65874.7	41960.6	79066.8	42004.1	73189.9	49926.8	46605.8	49499.7
+	-	+	+	230024.5	145334.8	68661.9	47101.9	79973.8	44795.5	95888.7	64508.7	65065.3	56455.3
+	+	-	-	82803.4	41859.1	24477.6	12783.8	52641.7	11912.3	27428.8	13940.8	57051.9	13508.2
+	+	-	+	82814.3	47052.9	41259.6	13826.6	48591.5	14825.7	29918.8	17570.8	59423.8	15481.3
+	+	+	-	181171.1	108008.8	75834.5	43413.4	78338.8	46696.5	75932.6	55691.8	85727.4	48504.1
+	+	+	+	167269.8	108666.6	74194.5	44614.7	83665.8	42952.3	83488.3	60219.7	22167.3	53675.4
Average Cost				106729.2	65422.8	40351.8	25878.8	52133.5	26823.1	46240.6	29957.3	42688.7	27226.5

INDIVIDUAL AND AVERAGE TOTAL COST FOR ALL EXOGENOUS FACTOR SETTINGS

TABLE 6.28



AVERAGE TOTAL COST

FIGURE 6.97

Using the critical values identified earlier, a difference between means of at least $5,394.60 must be present in order for that difference to be significant. Using this value and analyzing the average total cost information, no significant difference exists between any of the lot-for-lot planning methods and the stochastic dynamic programming methods at the 50% finished goods safety stock level. The poor performance of the economic order quantity methods is evident as is the superior performance of planning systems using finished goods safety stock at the 50% service level.

When comparing planning system responses based on average rank, similar conclusions can be drawn. Based on their average ranks, stochastic dynamic programming and lot-for-lot at the 90% raw material service level with 50% finished goods safety stock have comparable performance. Based on average rank, they both have significantly lower ranks than all other methods.

6.6 Backorder Units and Replanning

One of the unexpected results of this research was the surprisingly low total cost and backorder units with the L50-50% planning system. Investigation into this result was aided by analyzing the number of times a planning system needed to replan production and raw material ordering schedules. Although these measures were not primary measures of performance, the replanning frequency was

collected during the simulation runs and is presented in Table 6.29. When evaluating the replanning frequencies,it is important to remember the different logic used in the 90% service level when compared with the 50% service level. Comparisons between those two types of planning systems would not be meaningful because of the tendency for the 90% service level system to replan due to the need to initiate production orders to cover safety stock levels.

Exogenous Factor Level Setting				Raw Material Planning Method and Level of Finished Goods Safety Stock							
				EOQ	EOQ	L50	L50	L70	L70	L90	L90	SDP	SDP
E1	E2	E3	E4	90%	50%	90%	50%	90%	50%	90%	50%	90%	50%
-	-	-	-	16.5	3.8	44.9	6.2	44.7	3.9	42.8	0.1	42.5	0.0
-	-	-	+	29.4	5.1	45.7	15.1	44.7	8.2	44.2	1.3	42.5	0.0
-	-	+	-	45.3	0.1	45.7	2.8	45.8	2.0	45.7	0.1	46.0	0.0
-	-	+	+	45.8	0.8	45.3	6.3	46.0	2.6	46.0	0.3	46.0	0.0
-	+	-	-	21.5	2.2	45.5	7.5	44.4	3.9	45.1	0.1	42.9	0.0
-	+	-	+	30.5	6.2	45.5	17.3	46.0	7.1	44.7	1.4	44.1	0.0
-	+	+	-	32.9	0.9	44.8	4.3	45.1	2.3	45.1	0.0	44.0	0.0
-	+	+	+	41.0	3.3	45.3	7.6	44.1	3.2	44.0	0.3	43.9	0.0
+	-	-	-	15.1	2.3	45.6	8.1	44.6	3.7	43.5	0.1	35.7	0.0
+	-	-	+	27.5	4.7	45.7	15.8	45.7	9.7	43.3	0.9	42.9	0.0
+	-	+	-	44.7	0.1	45.3	4.1	45.9	2.9	39.1	0.9	46.0	0.0
+	-	+	+	44.9	0.5	45.7	6.4	45.5	3.3	45.7	0.4	46.1	0.0
+	+	-	-	24.3	3.0	45.6	11.9	45.1	4.1	44.2	0.3	40.3	0.0
+	+	-	+	32.6	6.1	45.8	20.9	45.4	10.1	45.1	1.4	43.1	0.0
+	+	+	-	41.6	0.4	45.1	5.1	45.2	3.9	44.5	2.5	46.0	0.0
+	+	+	+	40.3	1.8	45.3	9.7	45.1	5.1	45.1	1.9	43.2	0.0

Average Number of Replans

TABLE 6.29

Analysis of the replanning frequency shows three very interesting results. A high frequency of replanning at the 90% service level, regardless of raw material planning method, is noted. This can be explained in part by the logic used when safety stock existed. If finished goods inventory levels fell below their desired service level, the

planning system initiated a production order and raw material delivery for that shortage and scheduled that order for the next day's production. This resulted in a high level of replanning, or system nervousness, when safety stock was held at the 90% service level.

When evaluating the remaining planning system responses, a 50% service level of finished goods safety stock, the frequency of replanning increases as the service level of raw material planning decreases. This could account for L50-50%'s surprising good performance. Since raw material orders cover more than one period, a shortage in raw material delivery does not affect that period's production, but the difference is large enough for the planning system to replan raw material and production schedules. The true performance of this method is masked by its tendency to replan frequently.

The final condition meriting discussion also deals with system nervousness. When compiling the replanning averages, the stochastic# dynamic programming method at the 50% finished goods safety stock level did not need to replan the raw material and production schedules once they were initially established. This characteristic is valuable in a planning system, replanning has two detrimental effects, the cost of the replanning and system nervousness. Stochastic dynamic programming at the 50% service level exhibited no replanning.

6.7 Chapter Summary

This chapter has presented the statistical analysis results, managerial implications and conclusions to be drawn from the simulation model results.

The effect of exogenous and endogenous variables on dependent variables and interrelationships between dependent variables were identified as were the performance characteristics of each of the combinations of raw material planning method and service level for finished goods safety stock. These performance characteristics were analyzed across all combinations of exogenous variable levels.

Ranking of the various planning system configurations was done in an attempt to identify the planning system with the best overall performance.

In most environments, the modified lot-for-lot procedure at the 50% raw material service level performed the best and when the activity ratio was low, stochastic dynamic programming performed equally well. In some environments, stochastic dynamic programming was recommended with a 90% service level for finished goods safety stock.

CHAPTER 7

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

7.1 Introduction

This chapter serves a variety of purposes in order to bring this research to a close. A look is taken at the original research question asked, and the answers provided are detailed and summarized. The results are categorized based on the choice of raw material planning method and service level of finished goods safety stock to be employed. The next section of the chapter discusses some of the questions generated by this investigation while answering the original research question.

Finally, research questions generated by this research are discussed, both in terms of the issues they address and possible research methodologies.

7.2 Summary

The research question posed initially in Chapter 1 was as follows:

> For a given set of responses to raw material variability available to the planning and control system of a process industry manufacturer, what are the performance characteristics of each response and which response has the best performance?

The following summary of the results of this research will respond to that question.

7.2.1 Summary of Findings

The choice of planning system methods to compare in this study was based on existing methodologies and the development of a new response to raw material variability.

7.2.2 Choice of Endogenous Factor Levels

This investigation showed the choice of raw material planning method and the effect of the service level of finished goods safety stock can have an effect on system performance measures. It further showed the ineffectiveness of both the economic order quantity methods and finished goods safety stock as a way of dealing with raw material variability.

Based on overall rankings of raw material planning methods, stochastic dynamic programming and lot-for-lot raw

material ordering at the 90% service level provided better performance. Stochastic dynamic programming is superior to lot-for-lot at the 90% service level if performance also includes that method's ability to order raw materials and avoid system nervousness.

7.3 Environmental Factors

Through multivariate analysis of variance, the effect of all environmental factors proved to be significant when analyzed in conjunction with at least one of the endogenous factors. Although significant interactions existed between exogenous factors without endogenous factors being included, these interactions were not investigated because a planning and control system would not be able to act on those interactions.

7.4 Contribution of Research

As part of the summary of this research, its contribution to the field of production/operations management needs to be identified.

Initially, this research identified a different way to view raw material variability, as variation in order quantity delivered. Further investigation through a literature review provided four responses to the variability, the modified economic order quantity method and the three lot-for-lot methods. A fifth method was developed in this research, the use of stochastic dynamic programming.

These five responses were tested in combination with varying service levels of finished goods safety stock to see what performance characteristics each possessed.

This research is valuable in it identified a new way of viewing raw material variability and developed a new application of stochastic dynamic programming as a way to plan for variability.

7.5 Further Investigation into Current Research Question

Future research into the question posed in this research can focus around four primary areas. Initially, research could investigate some of the researcher's cognitive dissonance generated by the results of this research. A priori, one would think the modified lot-for-lot procedure at the 50% service level would have provided poor performance and the economic order quantity method would provide acceptable performance. Both methods exhibited unexpected results. The reasons for these performances should be investigated by focusing on a smaller part of the planning and control process, the corrective action mechanism.

A second unexpected result was the relative ineffectiveness of safety stock as a way of dealing with raw material variability. This result may also be investigated in two ways, first, by focusing on the corrective action mechanism of the planning and control system, and second, by

evaluating the option of holding safety stock at the raw material level.

The second area of investigation may involve the concept of information economics. The higher level of replanning in the modified lot-for-lot at the 50% service level was noted. Information economics recognizes the cost of computing resources and would assign a cost to replanning. By incorporating this performance measure into the model, different results may be noted.

System nervousness has long been investigated in material requirements planning systems. This system is also affected by system nervousness. In some cases, production and raw materials were replanned in each period. This resulted in a high degree of system nervousness. Although it is difficult to quantify, system nervousness may be an important measure of performance to measure the effectiveness of the different responses to raw material variability.

Finally, the sensitivity of performance to the parameters used in this research can be investigated. Exogenous factor settings were established in a logical fashion, but were discrete rather than continuous variables. Establishing parameters at different levels may, quite likely, affect the performance of the individual planning system responses to raw material variability.

7.7 Suggestions for Future Research

The problem investigated in this research, raw material variability, is analogous to a variety of other problems faced by manufacturing planning and control systems. The concept of variation in order quantity received was developed for this research as a way of responding to raw material variability, but the solution developed in this research, stochastic dynamic programming, has only been applied to the process manufacturing environment, specifically the blending process. Future research will be able to investigate the performance of the various planning methods in different environments.

Operation yield has also been a problem faced by manufacturing management. The problem of operation yield is similar to the raw material variability problem with one exception. The variability here allowed the possibility of a delivery that exceeded the original order quantity. In an operation yield environment, there would be an upper limit to operation yield and the response to variability would face a different type of probability distribution.

APPENDIX A

CENSUS OF MANUFACTURERS DATA

SIC Code	Industry	Raw Material Cost	Shipping Value	Purchases Ratio
3211	Flat Glass	827.0	1665.6	.497
3221	Glass Containers	2521.8	5216.8	.483
3011	Tires & Tubes	4594.6	9340.1	.492
3041	Rubber Hose	893.3	1963.6	.455
2873	Nitrogen Fertilizer	2395.3	3391.1	.706
2874	Potassium Fertilizer	3055.8	3921.9	.779
2875	Fertilizer Mixing	1445.4	1903.4	.759
2879	Agricultural Chemicals	2449.2	5436.1	.451
2861	Wood Chemicals	409.2	624.2	.655
2865	Cyclic Crudes	5007.8	7138.2	.658
2851	Paint	5167.6	9162.1	.564
2869	Industrial Organic Chemicals	19989.0	30394.0	.658
2831	Biological Products	884.4	2300.0	.384
2833	Medicinals & Botanicals	1335.2	3397.9	.393
2834	Pharmaceutical Preparations	5529.8	18997.6	.290
2821	Plastic & Resin	10812.0	15813.0	.684
2822	Synthetic Rubber	2217.6	3138.5	.707
2823	Cellulose Fiber	806.8	1239.9	.651
2824	Organic Fiber	4973.4	8287.5	.600

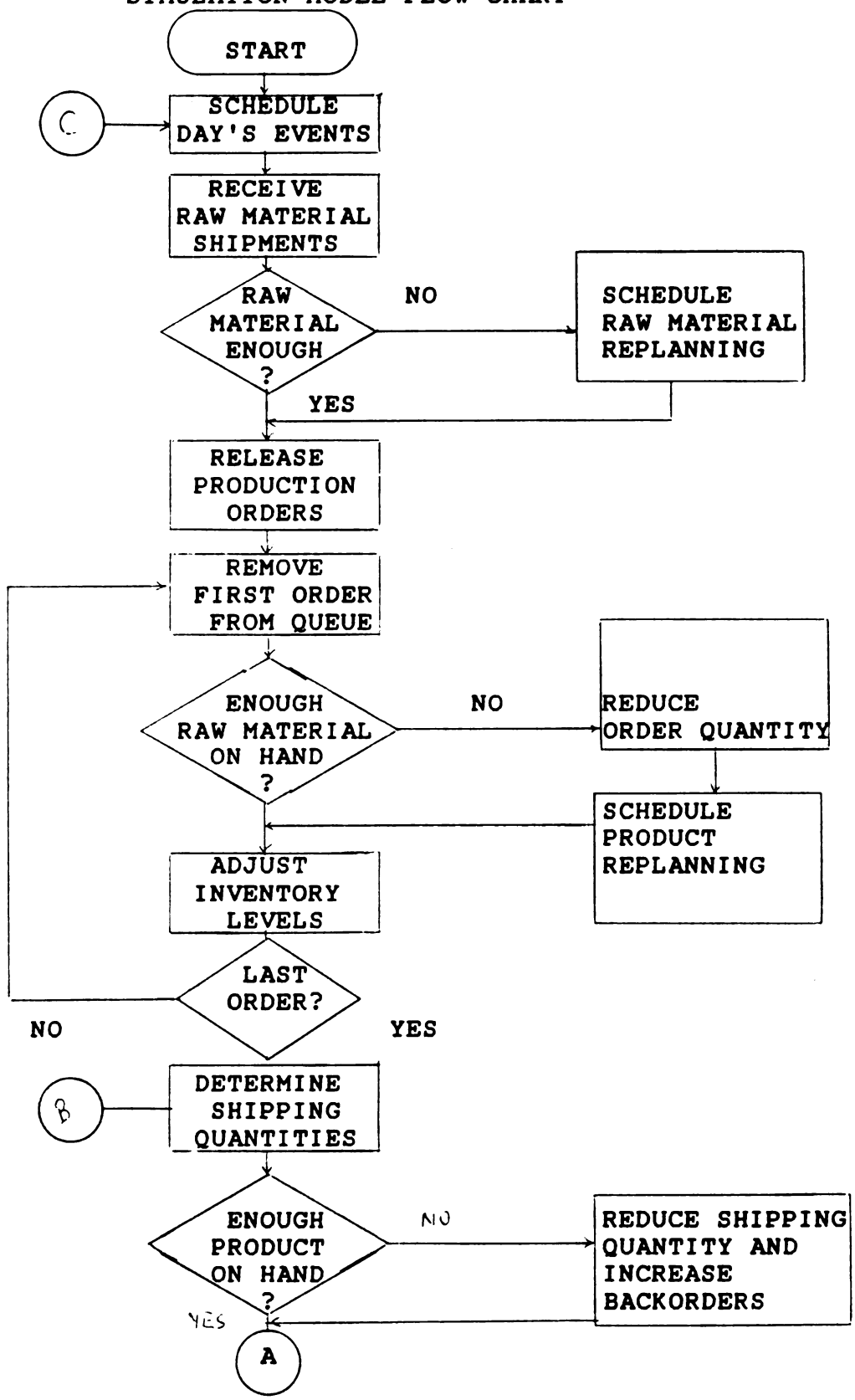
2611	Pulp Mill	1986.5	3110.4	.639
2621	Paper Mill	12136.7	20994.6	.578
2631	Paperboard Mill	5842.3	9531.1	.613
2661	Building Paper and Board	204.4	366.1	.557
2091	Canned and Cured Seafood	1235.3	1840.1	.668
2092	Fresh & Frozen Fish	3030.3	4009.1	.754
2095	Coffeee	3749.0	5826.9	.640
2098	Spaghetti	514.6	1065.0	.483
2099	Food Preparation	5344.8	10979.0	.487
2082	Malt Beverages	6669.7	11183.2	.596
2083	Malt	480.8	661.5	.726
2084	Wine & Brandy	1762.9	2785.7	.633
2085	Liquor	1700.5	3126.1	.544
2086	Soft Drinks	9981.0	16807.5	.594
2087	Flavorings	1569.3	4236.8	.370

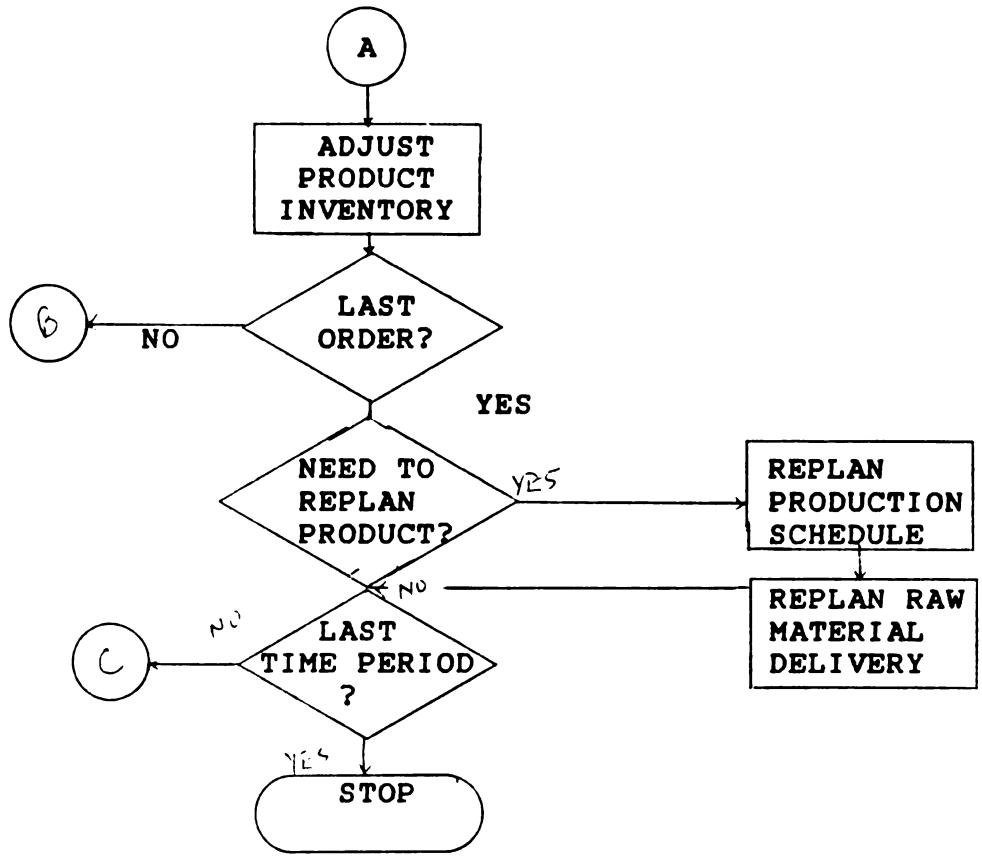
Note: All dollar values expressed in millions

Source: Census of Manufacturers, United States Census Bureau, 1982.

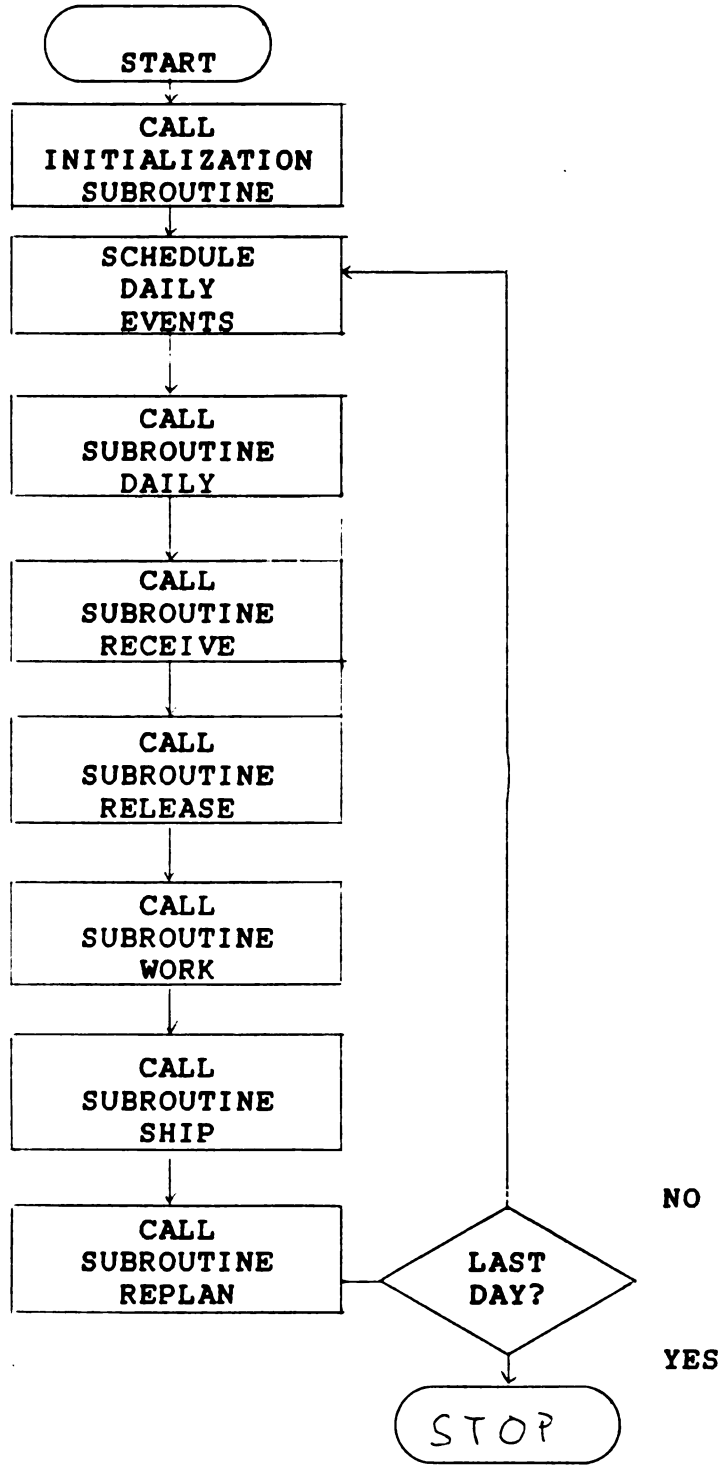
APPENDIX B

SIMULATION MODEL FLOW CHART

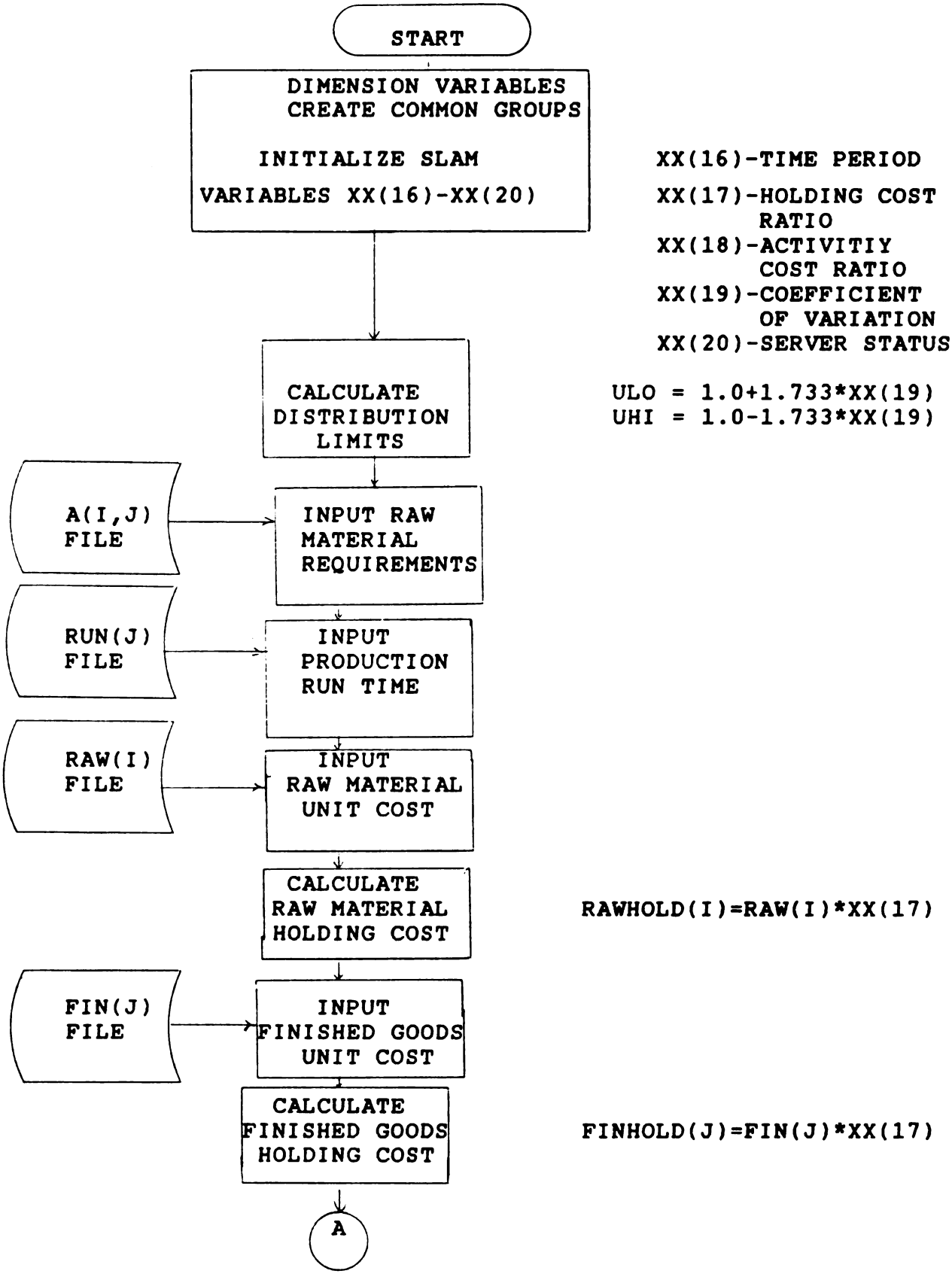


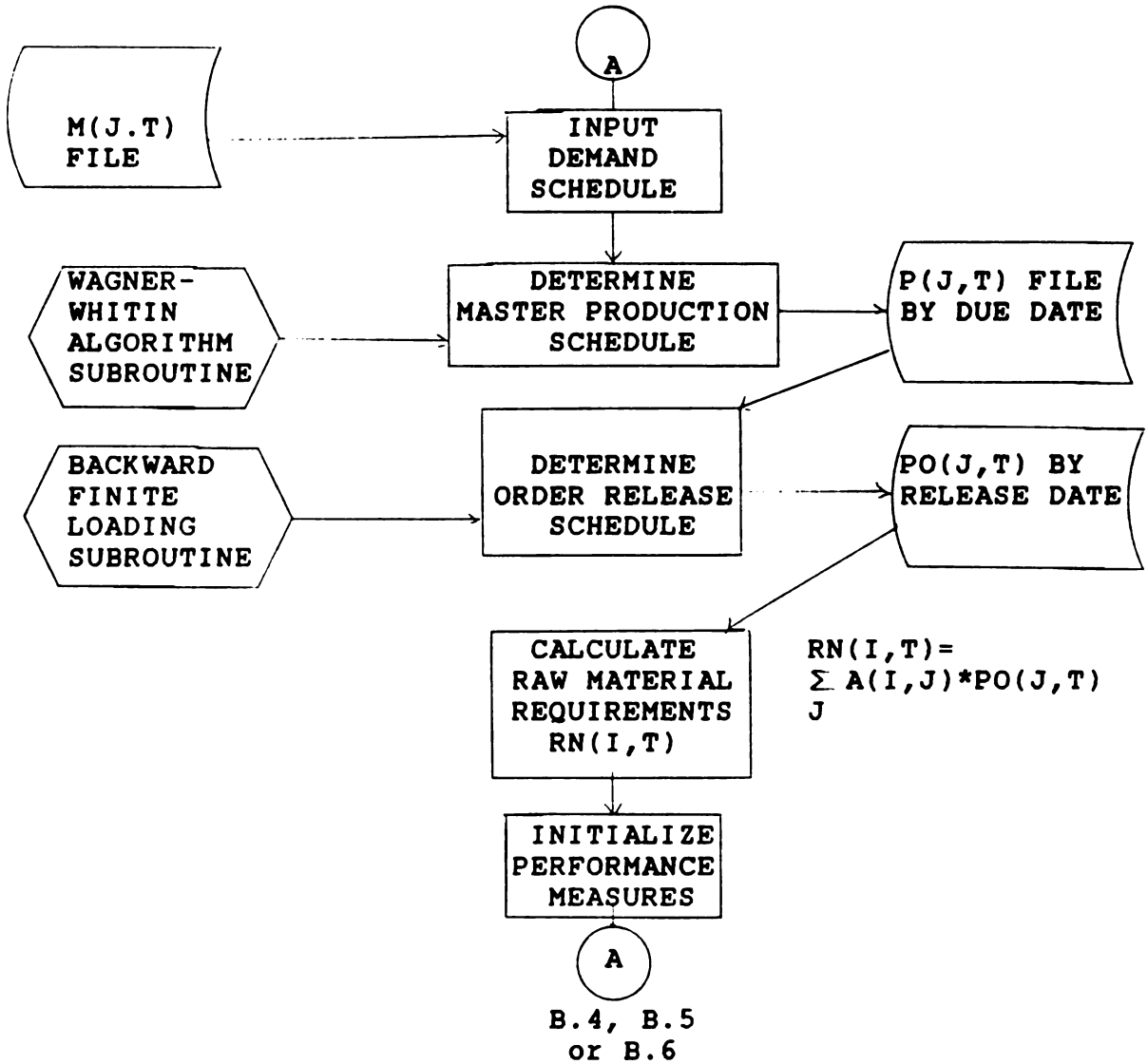

A
ADJUST PRODUCT INVENTORY
LAST ORDER?
NO
B
YES
NEED TO REPLAN PRODUCT?
YES
REPLAN PRODUCTION SCHEDULE
NO
REPLAN RAW MATERIAL DELIVERY
LAST TIME PERIOD ?
NO
C
YES
STOP

GENERAL SLAM MODEL



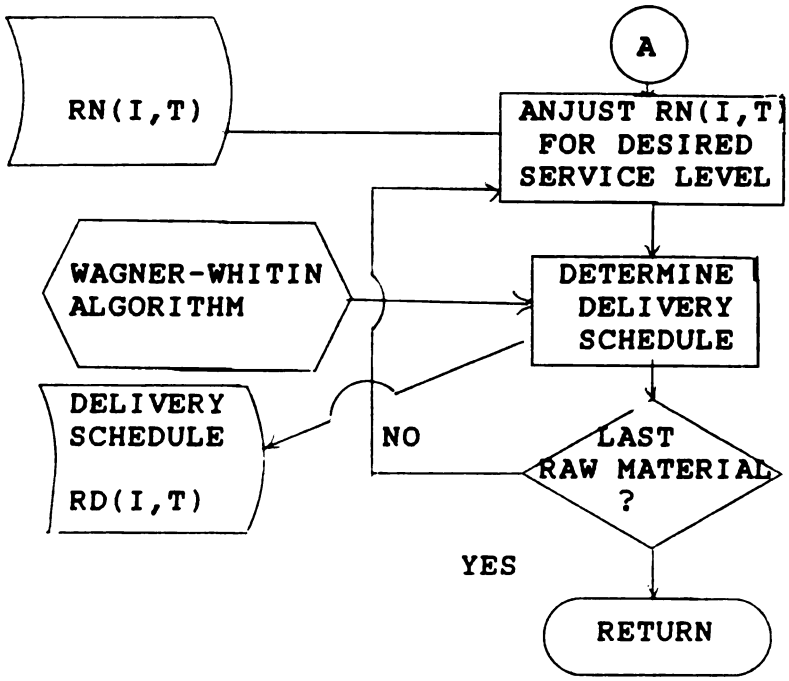
FORTRAN INITIALIZATION SUBROUTINE





Note: The remaining logic of the raw material ordering process is shown in this appendix and it depends on the raw material planning method employed, Modified EOQ, Modified lot-for-lot or stochastic dynamic programming, respectively.

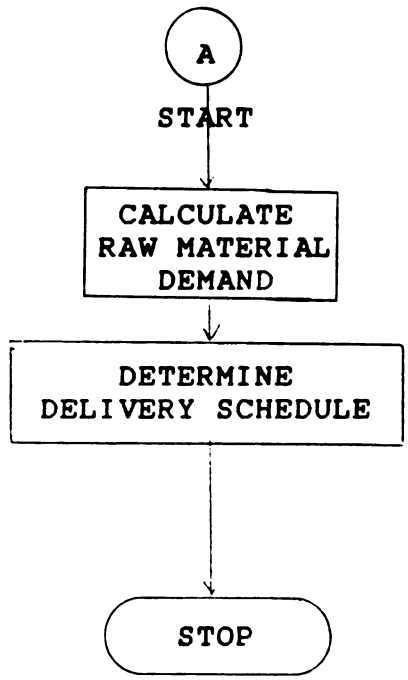
MODIFIED LOT-FOR-LOT ORDERING RULE



RN(I,T) = RN(I,T)* (UHI-ULO)*SL+ULO

SL = SERVICE LEVEL 50%,70% OR 90%

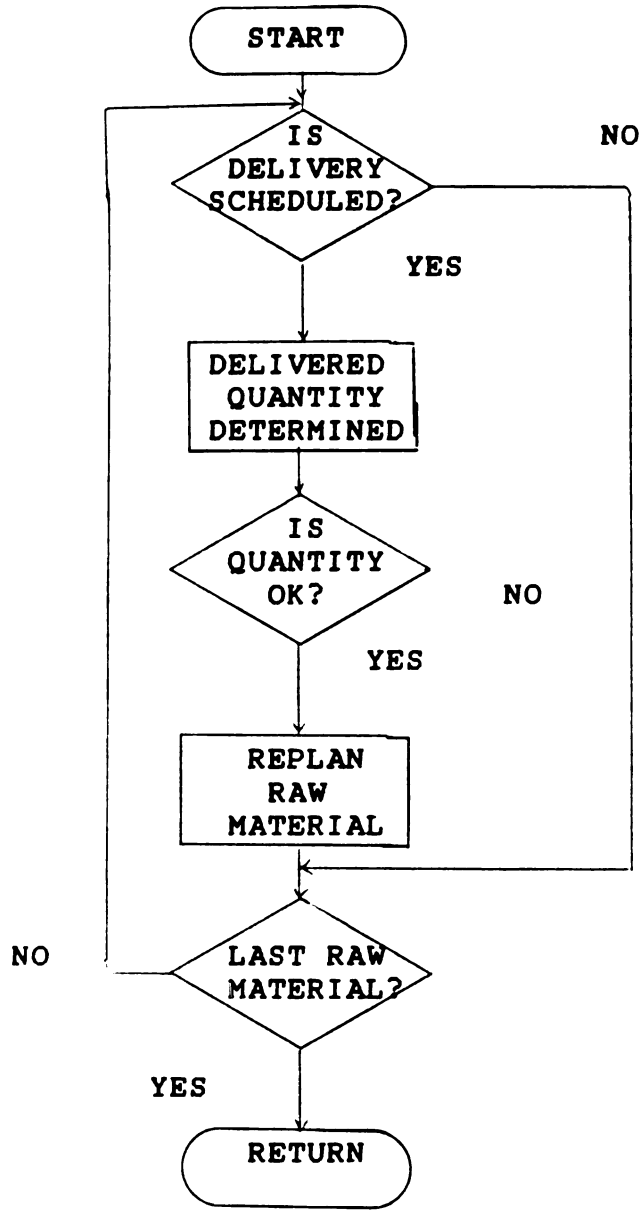
STOCHASTIC DYNAMIC PROGRAMMING ORDERING RULE



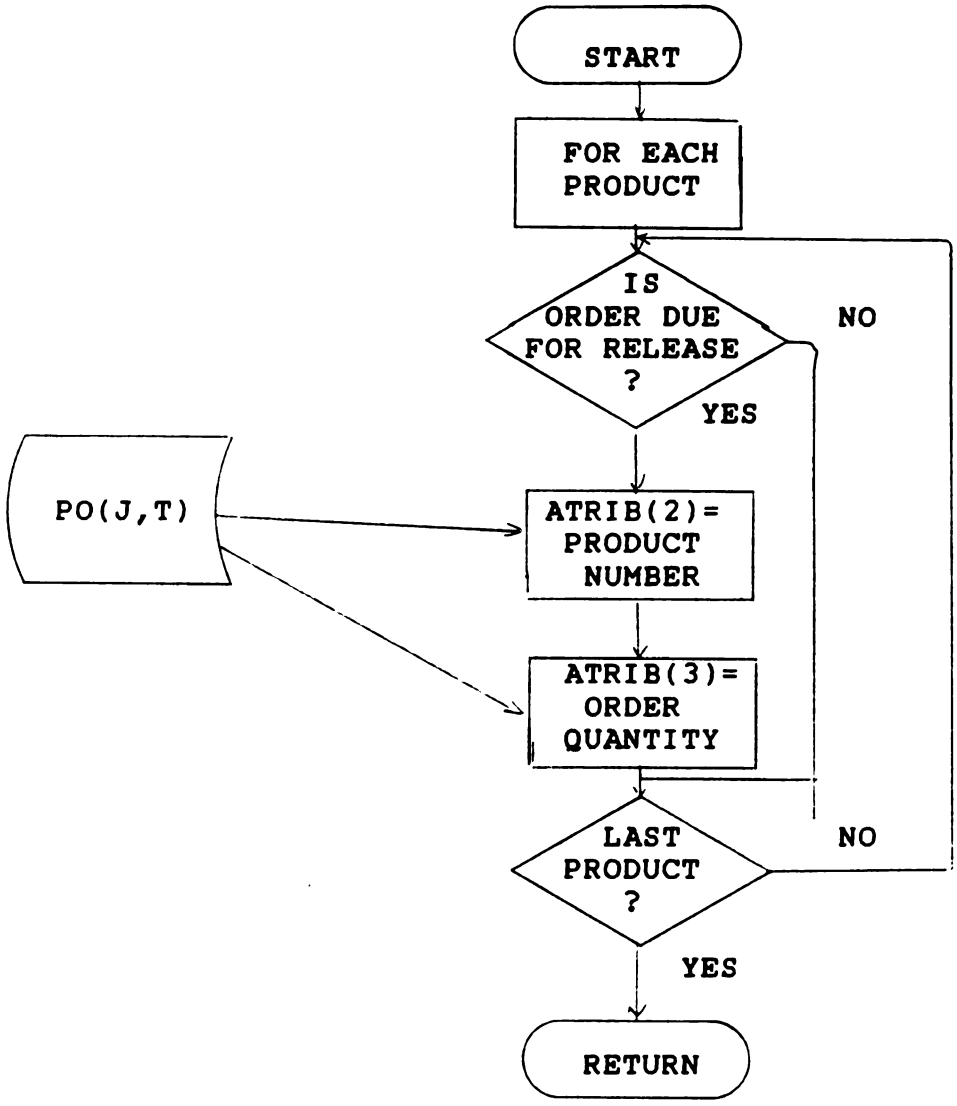
$$RN(I,T) = \sum PO(J,T)*A(I,J)$$

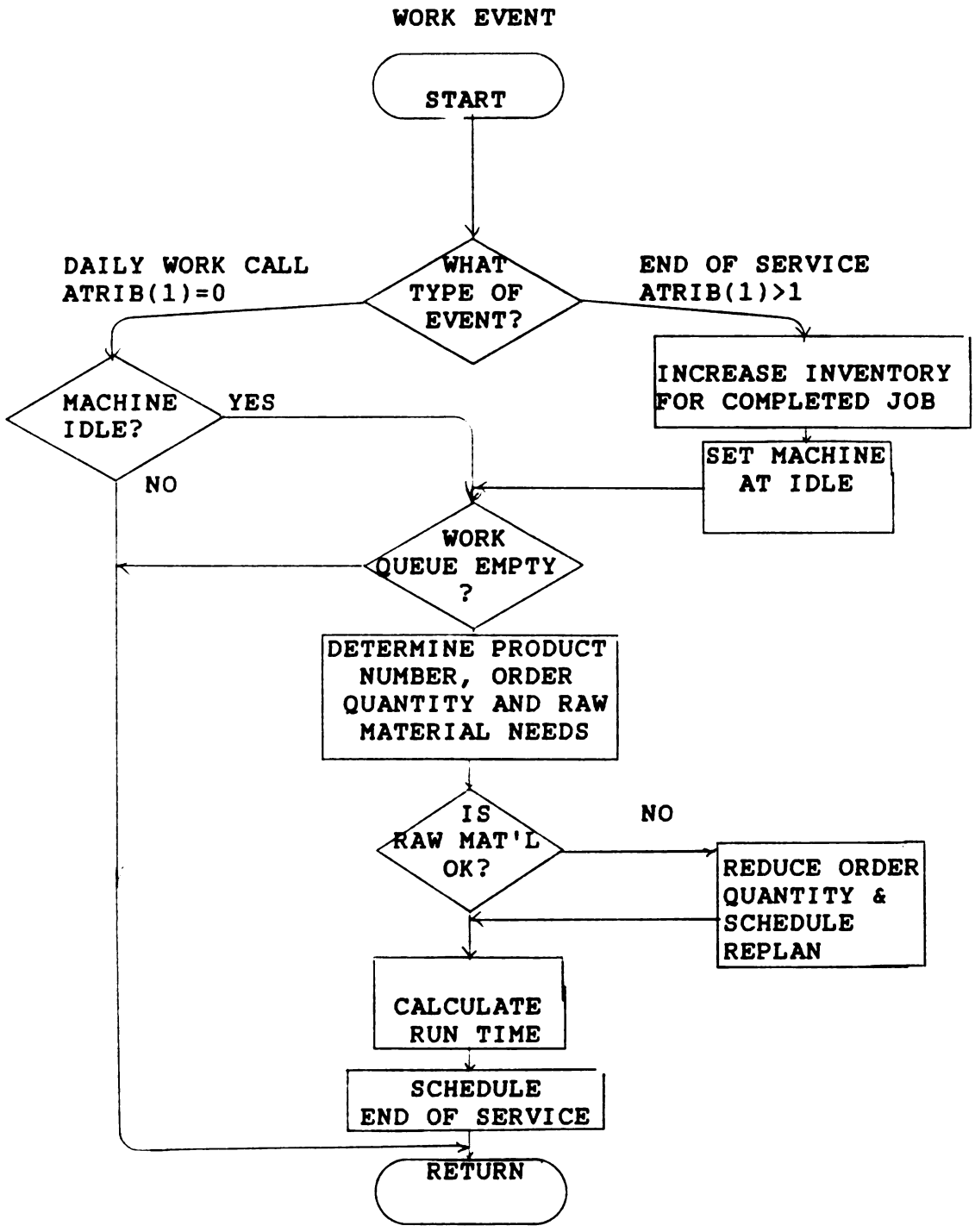
$$F_N(OQ/I) = \sum_{MIN}^{OQ} Ch(I+DQ-D)*P_{DQ} + \sum_{OQ}^{MAX} Cb(D-I-DQ)*P_{DQ}$$

RAW MATERIAL RECEIPTS

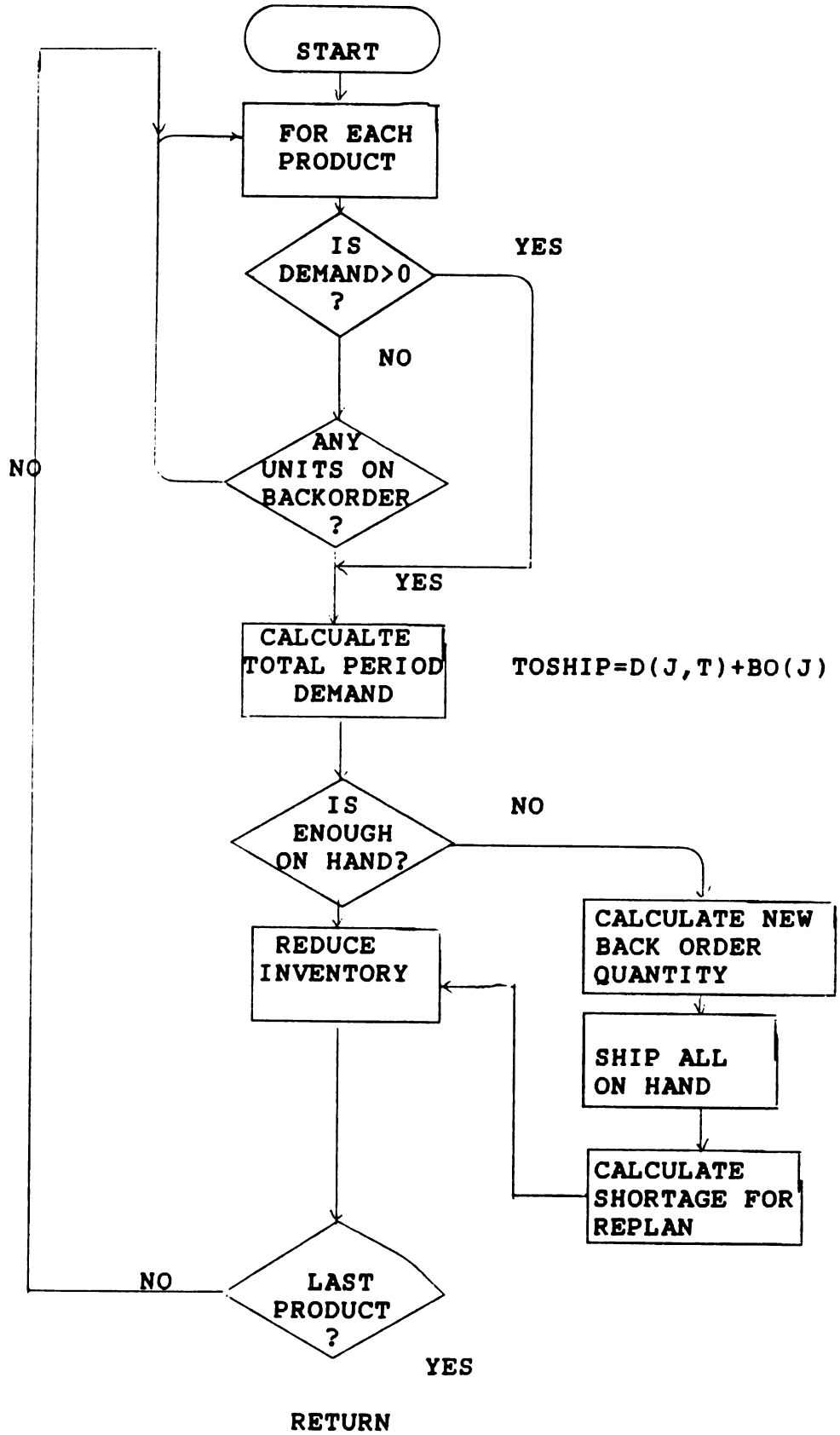


ORDER RELEASE

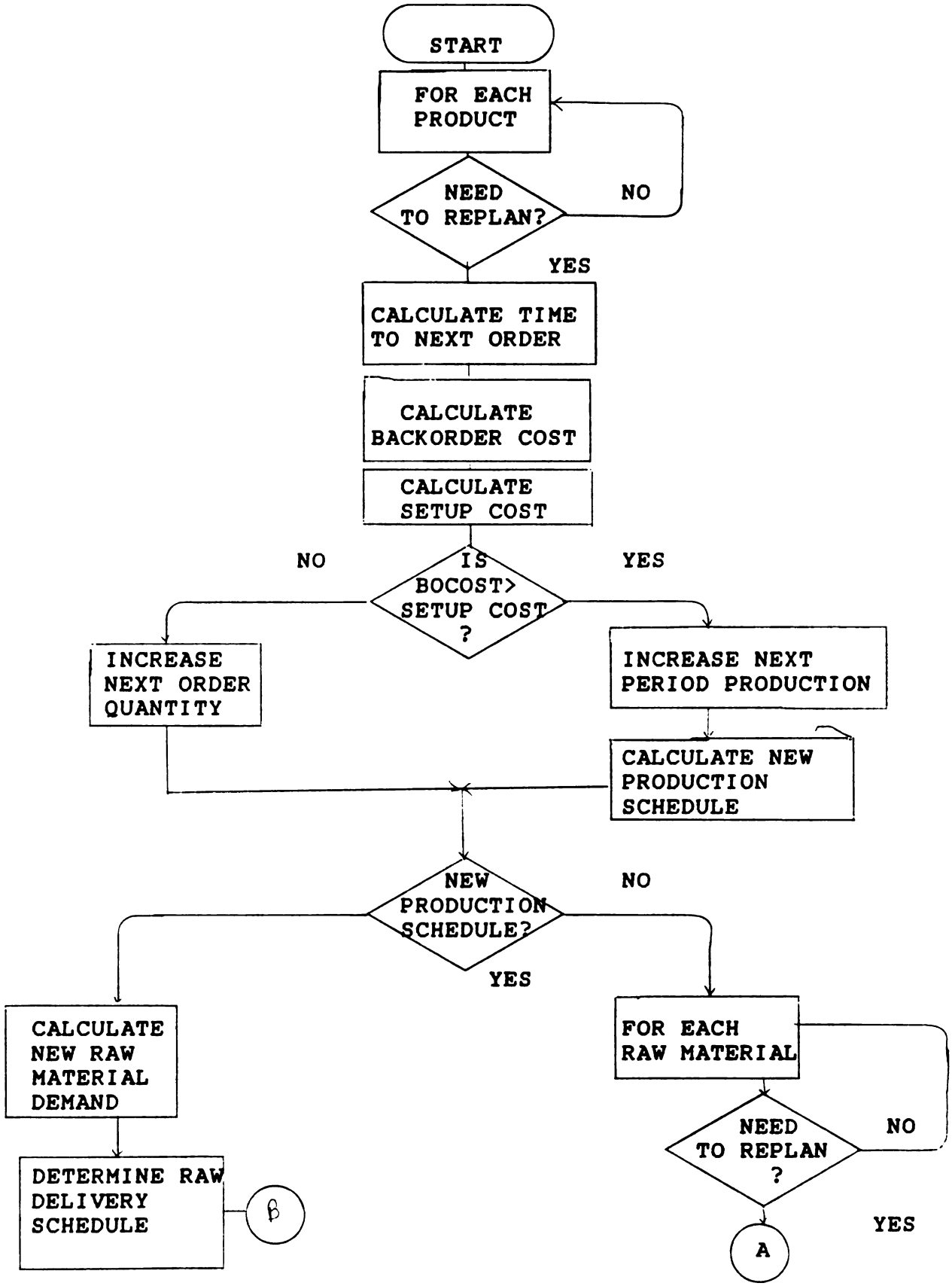


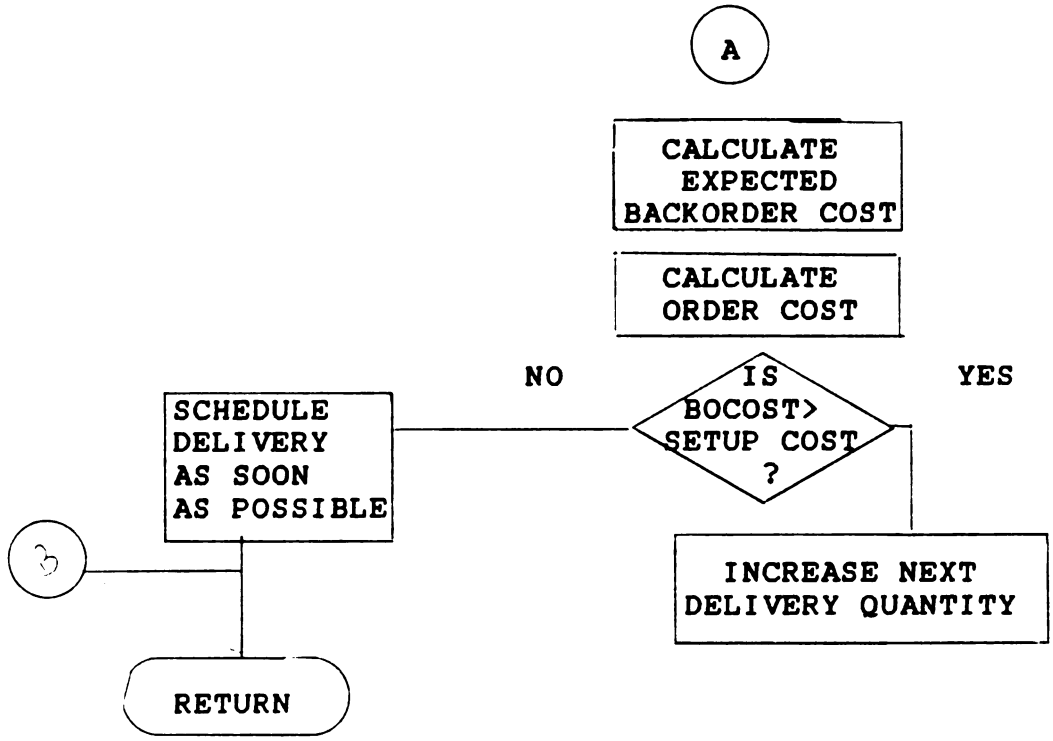

WORK EVENT
START
WHAT TYPE OF EVENT?
DAILY WORK CALL ATRIB(1)=0
END OF SERVICE ATRIB(1)>1
MACHINE IDLE?
YES
NO
INCREASE INVENTORY FOR COMPLETED JOB
SET MACHINE AT IDLE
WORK QUEUE EMPTY ?
DETERMINE PRODUCT NUMBER, ORDER QUANTITY AND RAW MATERIAL NEEDS
IS RAW MAT'L OK?
NO
REDUCE ORDER QUANTITY & SCHEDULE REPLAN
CALCULATE RUN TIME
SCHEDULE END OF SERVICE
RETURN

SHIP SUBROUTINE



REPLANNING SUBROUTINE




A
CALCULATE EXPECTED BACKORDER COST
CALCULATE ORDER COST
IS BOCOST> SETUP COST ?
NO
YES
SCHEDULE DELIVERY AS SOON AS POSSIBLE
INCREASE NEXT DELIVERY QUANTITY
3
RETURN

APPENDIX C

Modified EOQ Model FORTRAN Listing

```
$STORAGE:2
$NOTSTRICT
$NOTLARGE
$NOFLOATCALLS
$pagesize:65
      PROGRAM MAIN
      DIMENSION NSET(16000)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,
     1MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
      COMMON QSET(16000)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=16000
      NCRDR=5
      NPRNT=0
      NTAPE=7
      CALL SLAM
      STOP
      END
C
C*****************************
C
      SUBROUTINE INTLC
C
C     INITIALIZE SUBROUTINE
C
C     DIMENSION AND SET REAL AND INTEGER VARIABLES
C
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,
     1MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT
     1,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),
     1EOQ(5),M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50)
     1,BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      DIMENSION AVGRAW(5),SDRAW(5),SDFIN(10),AVGFIN(10)
     1,R1(5),R2(5),P1(10),P2(10)
C
      REAL M
C
C
```

```
C      SET SERVER IDLE OR BUSY,0=IDLE,1=BUSY
C
       XX(20)=0.0
C
C      INITIAL SUM OF ORDER COST,SETUP TIME,BACKORDER COST
C      # OF REPLANS
C
       XX(16)=1.0
       XX(21)=0.0
       XX(22)=0.0
       XX(23)=0.0
       XX(24)=0.0
       XX(25)=0.0
       NS=INT(XX(16))
C
C      CALCULATE UPPER AND LOWER DISTRIBUTION LIMITS
C
       ULO=1.-.5*3.464*XX(19)
       UHI=1.+.5*3.464*XX(19)
C
C      INITIALIZE NUMBER OF RAW MATERIALS AND PRODUCTS
C      AND NUMBER OF TIME PERIODS
C
       NRAW = 5
       NPROD = 10
       NTIME = 50
C
C
C      OPEN DATA FILE
C
       OPEN (1,FILE = 'DATADML', STATUS = 'OLD')
C
C      INPUT RAW MATERIAL REQUIREMENTS
C
       DO 19 I=1,NRAW
       DO 19 J=1,NPROD
       A(I,J)=.0
19     CONTINUE
C
       DO 2 K = 1,28
       READ (1,1)J,I,A(I,J)
1      FORMAT(I3,I3,F3.1)
2      CONTINUE
C
C
C      INPUT RUN TIME
C
       DO 4 K=1,NPROD
       READ (1,3)RUN(K)
3      FORMAT(F5.4)
4      CONTINUE
C
C
```

```
C      INPUT RAW MATERIAL COST
C
       DO 6 K=1,NRAW
       READ (1,5)RAW(K)
       RAWHOLD(K)=RAW(K)*XX(17)
5      FORMAT(F6.5)
6      CONTINUE
C
C      INPUT FINISHED GOODS COST
C
       DO 8 K=1,NPROD
       READ (1,7)FIN(K)
       FINHOLD(K)=FIN(K)*XX(17)
7      FORMAT(F3.1)
8      CONTINUE
C
C
C     INITIALIZE DEMAND MATRIX
C
       DO 15 J=1,NPROD
       DO 15 IT=NS,NTIME
       M(J,IT)=0.0
       D(J,IT)=0.0
15     CONTINUE
C
C      INPUT DEMAND QUANTITIES
C
       OPEN (2,FILE = 'DEMAND', STATUS = 'OLD')
C
13     READ (2,11)IT,J,X
       IF(IT.GT.NTIME)GOTO 12
       M(J,IT)=X
       D(J,IT)=M(J,IT)
11     FORMAT(I4,I4,F8.0)
       GOTO 13
12     CONTINUE
C
       NPROD=10
C
C              CALL WAGNER-WHITIN ALGORITHM
C
       DO 16 JJ=1,NPROD
       CALL WAGWIT(JJ)
16     CONTINUE
C
C              CALL BACKWARD FINITE LOADING
C
       CALL BFL
C
C
C      INITIALIZE RAW MATERIAL DEMAND AND DELIVERY MATRIX
C
       DO 29 I=1,NRAW
```

```
      R1(I)=0.0
      R2(I)=0.0
      DO 29 IT=NS,NTIME
      RN(I,IT)=0.0
      RD(I,IT)=0.0
29    CONTINUE
C
C     CALCULATE RAW MATERIAL DEMAND
C
      DO 30 I = 1,NRAW
      DO 30 J=1,NPROD
      P1(J)=0.0
      P2(J)=0.0
      DO 30 IT=NS,NTIME
      RRAW=PO(J,IT)*A(I,J)
      IRRAW=INT(RRAW+.5)
      RRAW=REAL(IRRAW)
      RN(I,IT)=RRAW+RN(I,IT)
30    CONTINUE
C
C     SUM DEMAND AND RAW MATERIAL USAGE TO
C     CALCULATE AVERAGE AND STANDARD DEVIATION
C
      DO 35 I=1,NRAW
      DO 35 IT=NS,NTIME
      R1(I)=RN(I,IT)+R1(I)
      R2(I)=(RN(I,IT))*(RN(I,IT))+R2(I)
35    CONTINUE
C
C     CALCULATE AVERAGE AND STANDARD DEVIATION
C     FOR RAW MATERIAL
C
      DO 31 I=1,NRAW
      AVGRAW(I)=R1(I)/REAL(NTIME)
      SDRAW(I)=SQRT((R2(I)-REAL(NTIME)*AVGRAW(I)**2)/
     1(REAL(NTIME)))
31    CONTINUE
C
C     SUM OF DEMAND TO CALCULAT AVG. AND S.D.
C
      DO 36 J=1,NPROD
      DO 36 IT=NS,NTIME
      P1(J)=M(J,IT)+P1(J)
      P2(J)=(M(J,IT))*(M(J,IT))+P2(J)
36    CONTINUE
C
C     CALCULATE AVERAGE AND STANDARD DEVIATION
C     FOR FINISHED PRODUCTS
C
      DO 32 J=1,NPROD
      AVGFIN(J)=P1(J)/REAL(NTIME)
      SDFIN(J)=SQRT((P2(J)-REAL(NTIME)*AVGFIN(J)**2)/
     1(REAL(NTIME)))
```

```
32    CONTINUE
C
C     SCHEDULE FIRST SET OF EVENTS
C
      DTIME=0.0
      ATRIB(1)=0.0
      ATRIB(2)=0.0
      CALL SCHDL(1,DTIME,ATRIB)
C
      CALL SCHDL(2,DTIME,ATRIB)
C
      CALL SCHDL(3,DTIME,ATRIB)
C
      CALL SCHDL(4,DTIME,ATRIB)
C
C     INITIALIZE BACKORDERS ETC.
C
      NBO=0
      NFS=0
      DO 37 J=1,NPROD
      BO(J)=0.0
      REFIN(J)=0.0
37    CONTINUE
C
C     CALCULATE A(I,J) AVG, PROFIT(J), AND RAWPRO(I)
C
      NPROD=10
      DO 38 I=1,NRAW
      RAWPRO(I)=0.0
38    CONTINUE
      DO 39 J=1,NPROD
      PROFIT(J)=0.0
39    CONTINUE
      DO 42 I=1,NRAW
      DO 42 J=1,NPROD
      IF(A(I,J).EQ.0)GOTO 42
      PROFIT(J)=PROFIT(J)+A(I,J)*(1-RAW(I))
      RAWPRO(I)=RAWPRO(I)+A(I,J)*PROFIT(J)
42    CONTINUE
C
C     SET SAFETY STOCK LEVELS
C
      IF(XX(27).LT.1.0)GOTO 34
      DO 33 J=1,NPROD
      SAFE(J)=SDFIN(J)*2.0
      JJ=J+5
      XX(JJ)=REAL(INT(SAFE(J)+1.0))
33    CONTINUE
34    CONTINUE
C
C*************************************************************
C     START OF EOQ PLANNING MODULE
C*************************************************************
```

```
C
C       CALCULATE EOQ
C
        DO 50 I=1,NRAW
C
        KK=XX(18)*RAW(I)
        DDD=R1(I)
        CH=RAWHOLD(I)
        B=1.
        K=(UHI-ULO)/3.464
        EOQ(I)=SQRT((2.*KK*DDD)/(CH*(B**2+K**2)))
        EOQ(I)=REAL(NINT(EOQ(I)))
50      CONTINUE
C
C       CALCULATE DELIVERY SCHEDULE USING EOQ
C
        DO 60 I=1,NRAW
        SUMRN=0.0
        SUMRD=0.0
        DO 60 IT=NS,NTIME
C
C
        SUMRN = SUMRN + RN(I,IT)
55      IF (SUMRN.LE.SUMRD)GOTO 60
        RD(I,IT)=RD(I,IT)+EOQ(I)
        SUMRD=SUMRD+EOQ(I)
        GOTO 55
60      CONTINUE
C
        RETURN
        END
C
C*****************************
C*****************************
C

        SUBROUTINE EVENT(I)
C
        COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,II,
       1MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT
       1,TNOW,XX(100)
C
        COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),
       1EOQ(5),M(10,50)
       1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
       1NTIME,ULO,UHI
       1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50)
       1,BO(10),NBO,NFS
       1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
        REAL M
C
```

```
      GO TO (601,602,603,604,605,606),I
601   CALL DAILY
      RETURN
602   CALL RECEIVE
      RETURN
603   CALL RLEASE
      RETURN
604   CALL WORK
      RETURN
605   CALL SHIP
      RETURN
606   CALL REPLAN
      RETURN
      END
C
C*************************
C
      SUBROUTINE DAILY
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
C     CHECK TO SEE IF MODEL TIME ENDED
C
      IF(XX(16).GT.REAL(NTIME))GOTO 111
C             SCHEDULE SHIPMENTS
C
      DTIME=8.
      ATRIB(1)=0.0
      ATRIB(2)=0.0
C
      CALL SCHDL(5,DTIME,ATRIB)
C
C             SCHEDULE REPLANNING
C
      CALL SCHDL(6,DTIME,ATRIB)
C
C             SCHEDULE DAILY SCHEDULER
C
      CALL SCHDL(1,DTIME,ATRIB)
C
```

```
C              SCHEDULE RAW MATERIAL RECEIPTS
C
      CALL SCHDL(2,DTIME,ATRIB)
C
C              SCHEDULE ORDER RELEASE
C
      CALL SCHDL(3,DTIME,ATRIB)
C
C              SCHEDULE WORK
C
      CALL SCHDL(4,DTIME,ATRIB)
C
111   RETURN
      END
C
C*****************************
C
      SUBROUTINE RECEIVE
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
      IF(XX(16).GT.REAL(NTIME))GOTO 211
      JT=INT(XX(16))
C
      DO 210 I=1,NRAW
      IF(RD(I,JT).LT.1.0)GOTO 210
C
C     SUM ORDER COST
C
      XX(21)=XX(21)+XX(18)*RAW(I)
C
      OQ=RD(I,JT)
      UL=ULO*OQ
      UH=UHI*OQ
      DQ=UNFRM(UL,UH,2)
      DQ=REAL(INT(DQ+.5))
      XX(I)=XX(I)+DQ
      IF(XX(I).GE.OQ)GOTO 210
      RERAW(I)=OQ-DQ
210   CONTINUE
```

```
211    RETURN
       END
C
C*****************************
C
       SUBROUTINE RLEASE
C
       COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,
      1MFA,MSTOP,NCLNR
      1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
      1TNEXT,TNOW,XX(100)
C
       COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
      1,M(10,50)
      1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
      1NTIME,ULO,UHI
      1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
      1BO(10),NBO,NFS
      1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
       REAL M
C
       IF(XX(16).GT.REAL(NTIME))GOTO 212
       JT=INT(XX(16))
       DO 200 J=1,NPROD
       IF(PO(J,JT).EQ.O)GOTO 200
       ATRIB(1)=REAL(J)
       ATRIB(2)=PO(J,JT)
       CALL FILEM(1,ATRIB)
200    CONTINUE
212    RETURN
       END
C
C*****************************
C
       SUBROUTINE WORK
C
       COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
      1II,MFA,MSTOP,NCLNR
      1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
      1TNEXT,TNOW,XX(100)
C
       COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
      1,M(10,50)
      1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
      1NTIME,ULO,UHI
      1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
      1BO(10),NBO,NFS
      1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
       REAL M
C
       IF(XX(16).GT.REAL(NTIME))GOTO 491
```

```
C      CHECK ATRIB(1), IF 0, WORK CALLED AT BEGINNING OF DAY
C              IF > 0 THEN IT IS END OF SERVICE
C
       IF(ATRIB(1).EQ.0)GOTO 410
C
C      UPDATE INVENTORY FOR JUST FINISHED JOB
C
       JJ=INT(ATRIB(1))+5
       XX(JJ)=XX(JJ)+ATRIB(2)
C
C              SET SERVER TO IDLE
C
       XX(20)=0.0
C
       GOTO 420
410    CONTINUE
C
C      CHECK TO SEE IF SERVER IS IDLE
C
       IF (XX(20).EQ.1.)GOTO 490
C
C      CHECK TO SEE IF QUEUE IS EMPTY
C
420    IF (NNQ(1).EQ.0)GOTO 490
C
C      REMOVE FIRST JOB AND MAKE SERVER BUSY
C
       CALL RMOVE(1,1,ATRIB)
       XX(20)=1.
C
C      ADD SETUP TIME TO TOTAL SETUP TIME
C
       XX(22)=XX(22)+XX(18)*RUN(JJ-5)
C
C      CHECK FOR ADEQUATE RAW MATERIALS
C
       QR=1.0
       JJ=INT(ATRIB(1))
       DO 350 I=1,NRAW
       IF(A(I,JJ).EQ.0.)GOTO 350
       RR=ATRIB(2)*A(I,JJ)/XX(I)
       IF (RR.LE.QR)GOTO 350
       QR=RR
350    CONTINUE
       IF(QR.EQ.1)GOTO 360
       REFIN(JJ)=ATRIB(2)*(1.-1./QR)
       ATRIB(2)=REAL(INT(ATRIB(2)/QR+.5))
360    DTIME=(ATRIB(2)+XX(18))*RUN(JJ)
       DO 370 I=1,NRAW
       XX(I)=XX(I)-ATRIB(2)*A(I,JJ)
370    CONTINUE
       CALL SCHDL(4,DTIME,ATRIB)
490    CONTINUE
```

```
491    RETURN
       END
C
C*****************************
C
       SUBROUTINE SHIP
C
       COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
      1II,MFA,MSTOP,NCLNR
      1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
      1TNEXT,TNOW,XX(100)
C
       COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
      1,M(10,50)
      1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
      1NTIME,ULO,UHI
      1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
      1BO(10),NBO,NFS
      1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
       REAL M
C
       IF(XX(16).GT.REAL(NTIME))GOTO 451
       DO 450 J=1,NPROD
       JT=INT(XX(16))
       JJ=J+5
       IF(D(J,JT).GT.0)GOTO 444
       IF(BO(J).EQ.0)GOTO 450
444    TOSHIP=BO(J)+D(J,JT)
       IF(XX(JJ).GE.TOSHIP)GOTO 430
       NBO=NBO+1
       BO(J)=TOSHIP-XX(JJ)
       XX(JJ)=0.0
       GOTO 450
430    XX(JJ)=XX(JJ)-TOSHIP
       BO(J)=0.0
       NFS=NFS+1
450    CONTINUE
451    RETURN
       END
C
C*****************************
C
       SUBROUTINE REPLAN
C
       COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
      1II,MFA,MSTOP,NCLNR
      1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
      1TNEXT,TNOW,XX(100)
C
       COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
      1,M(10,50)
      1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
```

```
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
      WRITE(*,*)' IN REPLAN', INT(XX(16))
C
      XX(29)=.665*XX(1)+.613*XX(2)+.595*XX(3)+.370*XX(4)+
     1.455*XX(5)
      XX(30)=.1*(XX(1)+XX(2)+XX(3)+XX(4)+XX(5)+XX(6)+
     1XX(7)+XX(8)
     ++XX(9)+XX(10))
C
      IF(XX(16).GT.REAL(NTIME))GOTO 673
      WW=0.0
C
C     CHECK FOR SAFETY STOCK AND LEVELS
C
      IF(XX(27).EQ.0)GOTO 602
      DO 601 J=1,NPROD
      IF(XX(J+5).GE.SAFE(J))GOTO 601
      MNS=NS+1
      M(J,MNS)=M(J,MNS)+REFIN(J)+SAFE(J)-XX(J+5)
      JJ=J

      CALL WAGWIT(JJ)
      WW=1.0
      RM=1.0
      REFIN(J)=0.0
601   CONTINUE
C
602   CONTINUE
C
      DO 600 J=1,NPROD
C
C     CALCULATE BACKORDER UNITS
C
      XX(23)=XX(23)+BO(J)
C
      IF(REFIN(J).LT.1.0)GOTO 600
C
C     CALCULATE TIME TO NEXT ORDER
C
      TIME=XX(16)
605   TIME=TIME+1.
      IT=INT(TIME)
      IF(PO(J,IT).EQ.0)GOTO 605
C
C     CALCULATE BACKORDER COST AND SETUP COST
C
      BOCOST=(TIME-XX(16))*REFIN(J)*XX(17)
      SUCOST=FIN(J)*XX(18)
```

```
      IF(BOCOST.GT.SUCOST)GOTO 610
C
C     INCREASE NEXT ORDER
C
      PO(J,IT)=PO(J,IT)+REFIN(J)
      DO 606 I = 1,NRAW
      RERAW(I)=RERAW(I)+REAL(INT(REFIN(J)*A(I,J)+1.0))
606   CONTINUE
      REFIN(J)=0.0
      GOTO 600
610   WW=1.
C
C     CREATE NEW ORDER
C
      ITT=INT(XX(16)+1.)
      M(J,ITT)=M(J,ITT)+REFIN(J)
      JJ=J
      CALL WAGWIT(JJ)
      REFIN(J)=0.0
      WW=1.0
600   CONTINUE
C
C     IF M(J,T) HAS CHANGED, CALL BFL REPLAN RAW MATERIALS
C      WAGWIT ALREADY CALLED
C
      IF(WW.LT.1.0)GOTO 615
C
      XX(24)=XX(24)+1.
      CALL BFL
C
615   CONTINUE
C
C     REPLAN RAW MATERIALS
C
      IF(WW.LT.1.0)GOTO 669
C
C     REPLAN RAW MATERIALS
C     INCREMENT RAW MATERIAL REPLAN COUNTER
C
      XX(25)=XX(25)+1.0
C
C     INITIALIZE RAW MATERIAL DEMAND AND DELIVERY MATRIX
C
      DO 629 I=1,NRAW
      DO 629 IT=NS,NTIME
      RN(I,IT)=0.0
      RD(I,IT)=0.0
629   CONTINUE
C
C     CALCULATE RAW MATERIAL DEMAND
C
      DO 630 I = 1,NRAW
      DO 630 J=1,NPROD
```

```
      DO 630 IT=NS,NTIME
      RRAW=PO(J,IT)*A(I,J)
      IRRAW=INT(RRAW+.5)
      RRAW=REAL(IRRAW)
      RN(I,IT)=RRAW+RN(I,IT)
630   CONTINUE
C
C     CALCULATE DELIVERY SCHEDULE USING EOQ
C
      DO 660 I=1,NRAW
      SUMRN=0.0
      SUMRD=0.0
      DO 660 IT=NS,NTIME
C
C
      SUMRN = SUMRN + RN(I,IT)
655    IF (SUMRN.LE.SUMRD)GOTO 660
      RD(I,IT)=RD(I,IT)+EOQ(I)
      SUMRD=SUMRD+EOQ(I)
      GOTO 655
660   CONTINUE
      GOTO 672
C
C     ONLY ORDER RAW MATERIAL NOT DELIVERED
C
669   DO 670 I=1,NRAW
      IF(RERAW(I).LT.1.0)GOTO 670
      TIME=XX(16)
675   TIME=TIME+1.
      IT=INT(TIME)
      IF(IT.GT.NTIME)GOTO 677
      IF(RD(I,IT).LT.1.0)GOTO 675
      BOCOST=(TIME-XX(16))*RERAW(I)*RAWPRO(I)
      OCOST=XX(18)*RAW(I)
      IF(BOCOST.GT.OCOST)GOTO 680
677   RD(I,INT(XX(16)+1.))=RD(I,INT(XX(16)+1.))+RERAW(I)
      GOTO 670
      ITT=INT(XX(16)+1.)
680   RD(I,ITT)=RD(I,ITT)+RERAW(I)
670   RERAW(I)=0.0
      CONTINUE
672   XX(16)=XX(16)+1.
673   RETURN
      END
C
C*****************************
C
      SUBROUTINE WAGWIT(JJ)
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
```

```
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
      DIMENSION F(50),SUMH(50),JSTAR(50),K1(50)
      REAL MM(50)
C
C        INITIALIZE SET UP COST AND TIME
C
      AA=XX(18)*FIN(JJ)
      NN=NTIME
C
C*************************
C
      DO 710 K=NS,NN
      F(K)=999999
      SUMH(K)=0
      MM(K)=AA
710   CONTINUE
C
      F(NS)=MM(NS)
      JSTAR(NS)=NS
      NNS=NS+1
      DO 720 K=NNS,NN
      KM1=K-1
      DO 721 J=NS,KM1
      JM1=J-1
      SUMH(J)=SUMH(J)+FINHOLD(JJ)
      MM(J)=MM(J)+M(JJ,K)*SUMH(J)
      IF(J.EQ.NS)TEMP=MM(J)
      IF(J.GT.NS)TEMP=F(JM1)+MM(J)
      IF(TEMP.GE.F(K))GOTO 721
      F(K)=TEMP
      JSTAR(K)=J
721   CONTINUE
      TEMP=F(KM1)+MM(K)
      IF(TEMP.GE.F(K))GOTO 720
      F(K)=TEMP
      JSTAR(K)=K
720   CONTINUE
C
C        DETERMINE PERIODS OF PRODUCTION
C
      DO 722 I=NS,NN
      P(JJ,I)=0
722   CONTINUE
```

```
      KT=JSTAR(NN)
725   P(JJ,KT)=1
      IF(KT.EQ.NS)GOTO 735
      KT=JSTAR(KT-1)
      GOTO 725
735   CONTINUE
C
C        DETERMINE PRODUCTION ORDER QUANTITIES
C
      PTEMP=0
      I=NN
751   IF(I.LT.1)GOTO 750
      IF(P(JJ,I).EQ.0) GOTO 740
      P(JJ,I)=PTEMP+M(JJ,I)
      PTEMP=0
      GOTO 745
740   PTEMP=PTEMP+M(JJ,I)
745   I=I-1
      GOTO 751
750   CONTINUE
C
      RETURN
      END
C
C*****************************
C
      SUBROUTINE BFL
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
      DIMENSION CL(50)
C
C              INTIALIZE P,CL,NS,NN
C
      NN=NTIME
C
      DO 802 IT=NS,NN
      CL(IT)=8.
      DO 804 J=1,NPROD
      PO(J,IT)=0
```

```
804   CONTINUE
802   CONTINUE
C
C     START MAIN LOOP
C
      DO 1000 IT=NS,NN
      DO 1000 J=1,NPROD
      ITTEMP=IT
      IF(P(J,IT).EQ.0)GOTO 1000
C
C     COMPUTE RUN TIME FOR ORDER
C
      RT=XX(18)*RUN(J)+RUN(J)*P(J,IT)
C
C    IF THERE IS ENOUGH CAPACITY IN THE TIME TO RUN IT,
C    THEN SCHEDULE THAT JOB AND REDUCE CAPACITY IN THE
C    TIME PERIOD
C
C
890   IF(CL(ITTEMP)-RT.GE.0)GOTO 900
C
C     ELSE DECREMENT TIME, RUNTIME, AND CAPACITY
C
895   RT=RT-CL(ITTEMP)
      CL(ITTEMP)=0.0
      ITTEMP=ITTEMP-1
C
C     CHECK TO SEE IF TIME IS AT TNOW
C
      IF(ITTEMP.EQ.NS)GOTO 930
C
      IF(CL(ITTEMP)-RT.GE.0)GOTO 900
      GOTO 895
C
C     SCHEDULE ORDER IN THAT TIME PERIOD
C     AND REDUCE AVAILABLE CAPACITY
C
900   PO(J,ITTEMP)=PO(J,ITTEMP)+P(J,IT)
      CL(ITTEMP)=CL(ITTEMP)-RT
      GOTO 1000
C
930   PO(J,NS)=PO(J,NS)+P(J,IT)
      GOTO 1000

1000  CONTINUE
      RETURN
      END
```

Modified Lot-for-Lot Model FORTRAN Listing

```
$STORAGE:2
$NOTSTRICT
$NOTLARGE
$NOFLOATCALLS
$pagesize:65
      PROGRAM MAIN
      DIMENSION NSET(16000)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
      COMMON QSET(16000)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=16000
      NCRDR=5
      NPRNT=0
      NTAPE=7
      CALL SLAM
      STOP
      END
C
C*****************************
C
      SUBROUTINE INTLC
C
C     INITIALIZE SUBROUTINE
C
C     DIMENSION AND SET REAL AND INTEGER VARIABLES
C
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      DIMENSION AVGRAW(5),SDRAW(5),SDFIN(10),AVGFIN(10)
     1,R1(5),R2(5),P1(10),P2(10),F(50),SUMH(50),
     1JSTAR(50),K1(50)
C
      REAL M,MM(50)
C
C
C     SET SERVER IDLE OR BUSY,0=IDLE,1=BUSY
```

```
C
      XX(20)=0.0
C
C     INITIAL OF ORDER COST,SETUP TIME,BACKORDER COST
C     # OF REPLANS
C
      XX(16)=1.0
      XX(21)=0.0
      XX(22)=0.0
      XX(23)=0.0
      XX(24)=0.0
      XX(25)=0.0
      NS=INT(XX(16))
C
C     CALCULATE UPPER AND LOWER DISTRIBUTION LIMITS
C
      ULO=1.-.5*3.464*XX(19)
      UHI=1.+.5*3.464*XX(19)
C
C     INITIALIZE NUMBER OF RAW MATERIALS AND PRODUCTS
C     AND NUMBER OF TIME PERIODS
C
      NRAW = 5
      NPROD = 10
      NTIME = 50
C
C
C     OPEN DATA FILE
C
      OPEN (1,FILE = 'DATADML', STATUS = 'OLD')
C
C     INPUT RAW MATERIAL REQUIREMENTS
C
      DO 19 I=1,NRAW
      DO 19 J=1,NPROD
      A(I,J)=.0
19    CONTINUE
C
      DO 2 K = 1,28
      READ (1,1)J,I,A(I,J)
1     FORMAT(I3,I3,F3.1)
2     CONTINUE
C
C
C     INPUT RUN TIME
C
      DO 4 K=1,NPROD
      READ (1,3)RUN(K)
3     FORMAT(F5.4)
4     CONTINUE
C
C
C     INPUT RAW MATERIAL COST
```

```
C
      DO 6 K=1,NRAW
      READ (1,5)RAW(K)
      RAWHOLD(K)=RAW(K)*XX(17)
5     FORMAT(F6.5)
6     CONTINUE
C
C     INPUT FINISHED GOODS COST
C
      DO 8 K=1,NPROD
      READ (1,7)FIN(K)
      FINHOLD(K)=FIN(K)*XX(17)
7     FORMAT(F3.1)
8     CONTINUE
C
C
C    INITIALIZE DEMAND MATRIX
C
      DO 15 J=1,NPROD
      DO 15 IT=NS,NTIME
      M(J,IT)=0.0
      D(J,IT)=0.0
15    CONTINUE
C
C     INPUT DEMAND QUANTITIES
C
      OPEN (2,FILE = 'DEMAND', STATUS = 'OLD')
C
13    READ (2,11)IT,J,X
      IF(IT.GT.NTIME)GOTO 12
      M(J,IT)=X
      D(J,IT)=M(J,IT)
11    FORMAT(I4,I4,F8.0)
      GOTO 13
12    CONTINUE
C
C
C
      NPROD=10
C
C             CALL WAGNER-WHITIN ALGORITHM
C
      DO 16 JJ=1,NPROD
      CALL WAGWIT(JJ)
16    CONTINUE
C
C             CALL BACKWARD FINITE LOADING
C
      CALL BFL
C
C
C     INITIALIZE RAW MATERIAL DEMAND AND DELIVERY MATRIX
C
```

```
      DO 29 I=1,NRAW
      DO 29 IT=NS,NTIME
      RN(I,IT)=0.0
      RD(I,IT)=0.0
      R1(I)=0.0
      R2(I)=0.0
29    CONTINUE
C
C     CALCULATE RAW MATERIAL DEMAND
C
      DO 30 I = 1,NRAW
      DO 30 J=1,NPROD
      P1(J)=0.0
      P2(J)=0.0
      DO 30 IT=NS,NTIME
      RRAW=PO(J,IT)*A(I,J)
      IRRAW=INT(RRAW+.5)
      RRAW=REAL(IRRAW)
      RN(I,IT)=RRAW+RN(I,IT)
30    CONTINUE
C
C     SUM DEMAND AND RAW MATERIAL USAGE TO
C     CALCULATE AVERAGE AND STANDARD DEVIATION
C
      DO 35 I=1,NRAW
      DO 35 IT=NS,NTIME
      R1(I)=RN(I,IT)+R1(I)
      R2(I)=(RN(I,IT))*(RN(I,IT))+R2(I)
35    CONTINUE
C
C     CALCULATE AVERAGE AND STANDARD DEVIATION
C     FOR RAW MATERIAL
C
      DO 31 I=1,NRAW
      AVGRAW(I)=R1(I)/REAL(NTIME)
      SDRAW(I)=SQRT((R2(I)-REAL(NTIME)*AVGRAW(I)**2)/
     1(REAL(NTIME)))
31    CONTINUE
C
C     SUM OF DEMAND TO CALCULATE AVG. AND S.D.
C
      DO 36 J=1,NPROD
      DO 36 IT=NS,NTIME
      P1(J)=M(J,IT)+P1(J)
      P2(J)=(M(J,IT))*(M(J,IT))+P2(J)
36    CONTINUE
C
C     CALCULATE AVERAGE AND STANDARD DEVIATION
C     FOR FINISHED PRODUCTS
C
      DO 32 J=1,NPROD
      AVGFIN(J)=P1(J)/REAL(NTIME)
      SDFIN(J)=SQRT((P2(J)-REAL(NTIME)*AVGFIN(J)**2)/
```

```
     1(REAL(NTIME)))
32    CONTINUE
C
C     SCHEDULE FIRST SET OF EVENTS
C
      DTIME=0.0
      ATRIB(1)=0.0
      ATRIB(2)=0.0
      CALL SCHDL(1,DTIME,ATRIB)
C
      CALL SCHDL(2,DTIME,ATRIB)
C
      CALL SCHDL(3,DTIME,ATRIB)
C
      CALL SCHDL(4,DTIME,ATRIB)
C
C     INITIALIZE BACKORDERS ETC.
C
      NBO=0
      NFS=0
      DO 37 J=1,NPROD
      BO(J)=0.0
      REFIN(J)=0.0
37    CONTINUE
C
C     CALCULATE A(I,J) AVG, PROFIT(J), AND RAWPRO(I)
C
      NPROD=10
      DO 38 I=1,NRAW
      RAWPRO(I)=0.0
38    CONTINUE
      DO 39 J=1,NPROD
      PROFIT(J)=0.0
39    CONTINUE
      DO 42 I=1,NRAW
      DO 42 J=1,NPROD
      IF(A(I,J).EQ.0)GOTO 42
      PROFIT(J)=PROFIT(J)+A(I,J)*(1-RAW(I))
      RAWPRO(I)=RAWPRO(I)+A(I,J)*PROFIT(J)
42    CONTINUE
C
C
C     SET SAFETY STOCK LEVELS
C
      IF(XX(27).EQ.0.0)GOTO 34
      DO 33 J=1,NPROD
      SAFE(J)=SDFIN(J)*2.0
      JJ=J+5
      XX(JJ)=SAFE(J)
33    CONTINUE
34    CONTINUE
C
C     PLAN RAW MATERIALS
```

```
C
      CALL RAWORD
C
C
      RETURN
      END
C
C*****************************
C
      SUBROUTINE EVENT(I)
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
      GO TO (601,602,603,604,605,606),I
601   CALL DAILY
      RETURN
602   CALL RECEIVE
      RETURN
603   CALL RLEASE
      RETURN
604   CALL WORK
      RETURN
605   CALL SHIP
      RETURN
606   CALL REPLAN
      RETURN
      END
C
C*****************************
C
      SUBROUTINE DAILY
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
```

```
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
C     CHECK TO SEE IF MODEL TIME ENDED
C
      IF(XX(16).GT.REAL(NTIME))GOTO 111
C             SCHEDULE SHIPMENTS
C
      DTIME=8.
      ATRIB(1)=0.0
      ATRIB(2)=0.0
C
      CALL SCHDL(5,DTIME,ATRIB)
C
C             SCHEDULE REPLANNING
C
      CALL SCHDL(6,DTIME,ATRIB)
C
C             SCHEDULE DAILY SCHEDULER
C
      CALL SCHDL(1,DTIME,ATRIB)
C
C             SCHEDULE RAW MATERIAL RECEIPTS
C
      CALL SCHDL(2,DTIME,ATRIB)
C
C             SCHEDULE ORDER RELEASE
C
      CALL SCHDL(3,DTIME,ATRIB)
C
C             SCHEDULE WORK
C
      CALL SCHDL(4,DTIME,ATRIB)
C
111   RETURN
      END
C
C**************************
C
      SUBROUTINE RECEIVE
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
```

```
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
      IF(XX(16).GT.REAL(NTIME))GOTO 211
      JT=INT(XX(16))
C
      DO 210 I=1,NRAW
      IF(RD(I,JT).LT.1.0)GOTO 210
      IF(XX(I).GE.RD(I,JT))GOTO 210
      OQ=RD(I,JT)-XX(I)
C
C     SUM ORDER COST
C
      XX(21)=XX(21)+XX(18)*RAW(I)
C
      UL=ULO*OQ
      UH=UHI*OQ
      DQ=UNFRM(UL,UH,2)
      DQ=REAL(INT(DQ+.5))
      XX(I)=XX(I)+DQ
      IF(DQ.GE.OQ)GOTO 210
      RERAW(I)=OQ-DQ
210   CONTINUE
211   RETURN
      END
C
C*****************************
C
      SUBROUTINE RLEASE
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
      IF(XX(16).GT.REAL(NTIME))GOTO 212
      JT=INT(XX(16))
      DO 200 J=1,NPROD
      IF(PO(J,JT).EQ.0)GOTO 200
```

```
      ATRIB(1)=REAL(J)
      ATRIB(2)=PO(J,JT)
      CALL FILEM(1,ATRIB)
200   CONTINUE
212   RETURN
      END
C
C*************************
C
      SUBROUTINE WORK
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
      IF(XX(16).GT.REAL(NTIME))GOTO 491
C
C   CHECK ATRIB(1), IF 0, WORK CALLED AT BEGINNING OF DAY
C            IF > 0 THEN IT IS END OF SERVICE
C
      IF(ATRIB(1).EQ.0)GOTO 410
C
C     UPDATE INVENTORY FOR JUST FINISHED JOB
C
      JJ=INT(ATRIB(1))+5
      XX(JJ)=XX(JJ)+ATRIB(2)
C
C             SET SERVER TO IDLE
C
      XX(20)=0.0
C
      GOTO 420
410   CONTINUE
C
C     CHECK TO SEE IF SERVER IS IDLE
C
      IF (XX(20).EQ.1.)GOTO 490
C
C     CHECK TO SEE IF QUEUE IS EMPTY
C
420   IF (NNQ(1).EQ.0)GOTO 490
C
```

```
C      REMOVE FIRST JOB AND MAKE SERVER BUSY
C
       CALL RMOVE(1,1,ATRIB)
       XX(20)=1.
C
C      ADD SETUP TIME TO TOTAL SETUP TIME
C
       XX(22)=XX(22)+XX(18)*RUN(JJ-5)
C
C      CHECK FOR ADEQUATE RAW MATERIALS
C
       QR=1.0
       JJ=INT(ATRIB(1))
       DO 350 I=1,NRAW
       IF(A(I,JJ).EQ.0.)GOTO 350
       RR=ATRIB(2)*A(I,JJ)/XX(I)
       IF (RR.LE.QR)GOTO 350
       QR=RR
350    CONTINUE
       IF(QR.EQ.1.0)GOTO 360
       Q=ATRIB(2)
       ATRIB(2)=REAL(INT(ATRIB(2)/QR))
       REFIN(JJ)=Q-ATRIB(2)
360    DTIME=(ATRIB(2)+XX(18))*RUN(JJ)
       DO 370 I=1,NRAW
       XX(I)=XX(I)-ATRIB(2)*A(I,JJ)
370    CONTINUE
       CALL SCHDL(4,DTIME,ATRIB)
490    CONTINUE
491    RETURN
       END
C
C*****************************
C
       SUBROUTINE SHIP
C
       COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
      1II,MFA,MSTOP,NCLNR
      1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
      1TNEXT,TNOW,XX(100)
C
       COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
      1,M(10,50)
      1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
      1NTIME,ULO,UHI
      1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
      1BO(10),NBO,NFS
      1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
       REAL M
C
       IF(XX(16).GT.REAL(NTIME))GOTO 451
       DO 450 J=1,NPROD
```

```
      JT=INT(XX(16))
      JJ=J+5
      IF(D(J,JT).GT.0)GOTO 444
      IF(BO(J).EQ.0)GOTO 450
444   TOSHIP=BO(J)+D(J,JT)
      IF(XX(JJ).GE.TOSHIP)GOTO 430
      NBO=NBO+1
      BO(J)=TOSHIP-XX(JJ)
      XX(JJ)=0.0
      GOTO 450
430   XX(JJ)=XX(JJ)-TOSHIP
      BO(J)=0.0
      NFS=NFS+1
450   CONTINUE
451   RETURN
      END
C
C*************************
C
      SUBROUTINE REPLAN
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
      DIMENSION F(50),SUMH(50),JSTAR(50),K1(50)
      REAL MM(50)
C
      WRITE(*,*)' IN REPLAN',XX(16)
C
      XX(29)=XX(1)*RAW(1)+XX(2)*RAW(2)+XX(3)*RAW(3)
     1+XX(4)*RAW(4)+XX(5)*RAW(5)
C
      XX(30)=XX(6)+XX(7)+XX(8)+XX(9)+XX(10)+XX(11)
     ++XX(12)+XX(13)+XX(14)+XX(15)
      IF(XX(16).GT.REAL(NTIME))GOTO 673
      WW=0.0
C
C     CHECK FOR SAFETY STOCK AND LEVELS
C
      IF(XX(27).EQ.0)GOTO 602
      DO 601 J=1,NPROD
      IF(XX(J+5).GE.SAFE(J))GOTO 601
```

```
      MNS=NS+1
      M(J,MNS)=M(J,MNS)+REFIN(J)+SAFE(J)-XX(J+5)
      JJ=J
      CALL WAGWIT(JJ)
      WW=1.0
      REFIN(J)=0.0
601   CONTINUE
C
602   CONTINUE
C
      DO 600 J=1,NPROD
C
C     CALCULATE BACKORDER UNITS
C
      XX(23)=XX(23)+BO(J)
C
      IF(REFIN(J).LT.1.0)GOTO 600
C
C     CALCULATE TIME TO NEXT ORDER
C
      TIME=XX(16)
605   TIME=TIME+1.
      IT=INT(TIME)
      IF(PO(J,IT).EQ.0)GOTO 605
C
C     CALCULATE BACKORDER COST AND SETUP COST
C
      BOCOST=(TIME-XX(16))*REFIN(J)*XX(17)
      SUCOST=FIN(J)*XX(18)
      IF(BOCOST.GT.SUCOST)GOTO 610
C
C     INCREASE NEXT ORDER
C
      PO(J,IT)=PO(J,IT)+REFIN(J)
      DO 606 I = 1,NRAW
      RERAW(I)=RERAW(I)+REAL(INT(REFIN(J)*A(I,J)+1.0))
606   CONTINUE
      REFIN(J)=0.0
      GOTO 600
610   WW=1.
C
C     CREATE NEW ORDER
C
      ITT=INT(XX(16)+1.)
      M(J,ITT)=M(J,ITT)+REFIN(J)
      JJ=J
      CALL WAGWIT(JJ)
      REFIN(J)=0.0
      WW=1.0
600   CONTINUE
C
C     IF M(J,T) HAS CHANGED, CALL BFL, REPLAN RAW MATERIALS
C      WAGWIT ALREADY CALLED
```

```
C
      IF(WW.LT.1.0)GOTO 615
C
      XX(24)=XX(24)+1.
      CALL BFL
C
615   CONTINUE
C
C     REPLAN RAW MATERIALS
C
      IF(WW.LT.1.0)GOTO 669
C
C     REPLAN RAW MATERIALS
C     INCREMENT RAW MATERIAL REPLAN COUNTER
C
      CALL RAWORD
      GOTO 672
C
C     ONLY ORDER RAW MATERIAL NOT DELIVERED
C
669   DO 670 I=1,NRAW
      IF(RERAW(I).LT.1.0)GOTO 670
      TIME=XX(16)
675   TIME=TIME+1.
      IT=INT(TIME)
      IF(IT.GT.NTIME)GOTO 677
      IF(RD(I,IT).LT.1.0)GOTO 675
      BOCOST=(TIME-XX(16))*RERAW(I)*RAWPRO(I)
      OCOST=XX(18)*RAW(I)
      IF(BOCOST.GT.OCOST)GOTO 680
677   RD(I,INT(XX(16)+1.))=RD(I,INT(XX(16)+1.))+RERAW(I)
      GOTO 670
      ITT=INT(XX(16)+1.)
680   RD(I,ITT)=RD(I,ITT)+RERAW(I)
670   RERAW(I)=0.0
      CONTINUE
672   XX(16)=XX(16)+1.
      XX(23)=.1*XX(23)
673   RETURN
      END
C
C*****************************
C
      SUBROUTINE WAGWIT(JJ)
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
```

```
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
      DIMENSION F(50),SUMH(50),JSTAR(50),K1(50)
      REAL MM(50)
C
C
C        INITIALIZE SET UP COST AND TIME
C
      AA=XX(18)*FIN(JJ)
      NN=NTIME
C
C*************************
C
      DO 710 K=NS,NN
      F(K)=999999
      SUMH(K)=0
      MM(K)=AA
710   CONTINUE
C
      F(NS)=MM(NS)
      JSTAR(NS)=NS
      NNS=NS+1
      DO 720 K=NNS,NN
      KM1=K-1
      DO 721 J=NS,KM1
      JM1=J-1
      SUMH(J)=SUMH(J)+FINHOLD(JJ)
      MM(J)=MM(J)+M(JJ,K)*SUMH(J)
      IF(J.EQ.NS)TEMP=MM(J)
      IF(J.GT.NS)TEMP=F(JM1)+MM(J)
      IF(TEMP.GE.F(K))GOTO 721
      F(K)=TEMP
      JSTAR(K)=J
721   CONTINUE
      TEMP=F(KM1)+MM(K)
      IF(TEMP.GE.F(K))GOTO 720
      F(K)=TEMP
      JSTAR(K)=K
720   CONTINUE
C
C        DETERMINE PERIODS OF PRODUCTION
C
      DO 722 I=NS,NN
      P(JJ,I)=0
722   CONTINUE
      KT=JSTAR(NN)
725   P(JJ,KT)=1
      IF(KT.EQ.NS)GOTO 735
```

```
      KT=JSTAR(KT-1)
      GOTO 725
735   CONTINUE
C
C        DETERMINE PRODUCTION ORDER QUANTITIES
C
      PTEMP=0
      I=NN
751   IF(I.LT.1)GOTO 750
      IF(P(JJ,I).EQ.0) GOTO 740
      P(JJ,I)=PTEMP+M(JJ,I)
      PTEMP=0
      GOTO 745
740   PTEMP=PTEMP+M(JJ,I)
745   I=I-1
      GOTO 751
750   CONTINUE
C
      RETURN
      END
C
C*****************************
C
      SUBROUTINE BFL
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
      DIMENSION CL(50)
C
C              INTIALIZE P,CL,NS,NN
C
      NN=NTIME
C
      DO 802 IT=NS,NN
      CL(IT)=8.
      DO 804 J=1,NPROD
      PO(J,IT)=0
804   CONTINUE
802   CONTINUE
C
```

```
C      START MAIN LOOP
C
       DO 1000 IT=NS,NN
       DO 1000 J=1,NPROD
       ITTEMP=IT
       IF(P(J,IT).EQ.0)GOTO 1000
C
C      COMPUTE RUN TIME FOR ORDER
C
       RT=XX(18)*RUN(J)+RUN(J)*P(J,IT)
C
C     IF THERE IS ENOUGH CAPACITY IN THE TIME TO RUN IT,
C     THEN SCHEDULE THAT JOB AND REDUCE CAPACITY IN THE
C     TIME PERIOD
C
C
890    IF(CL(ITTEMP)-RT.GE.0)GOTO 900
C
C      ELSE DECREMENT TIME, RUNTIME, AND CAPACITY
C
895    RT=RT-CL(ITTEMP)
       CL(ITTEMP)=0.0
       ITTEMP=ITTEMP-1
C
C      CHECK TO SEE IF TIME IS AT TNOW
C
       IF(ITTEMP.EQ.NS)GOTO 930
C
       IF(CL(ITTEMP)-RT.GE.0)GOTO 900
       GOTO 895
C
C      SCHEDULE ORDER IN THAT TIME PERIOD
C      AND REDUCE AVAILABLE CAPACITY
C
900    PO(J,ITTEMP)=PO(J,ITTEMP)+P(J,IT)
       CL(ITTEMP)=CL(ITTEMP)-RT
       GOTO 1000
C
930    PO(J,NS)=PO(J,NS)+P(J,IT)
       GOTO 1000

1000   CONTINUE
       RETURN
       END
C
C*****************************
C
       SUBROUTINE RAWORD
C
       COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
      1II,MFA,MSTOP,NCLNR
      1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
      1TNEXT,TNOW,XX(100)
```

```
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS
C
      REAL M
C
      DIMENSION F(50),SUMH(50),JSTAR(50),K1(50)
      REAL MM(50)
C
C
C     REPLAN RAW MATERIALS
C     INITIALIZE RAW MATERIAL DEMAND AND DELIVERY MATRIX
C
C     INCREMENT REPLANNING COUNTER
C
      XX(25)=XX(25)+1.0
C
      DO 629 I=1,NRAW
      DO 629 IT=NS,NTIME
      RN(I,IT)=0.0
      RD(I,IT)=0.0
629   CONTINUE
C
C     CALCULATE RAW MATERIAL DEMAND
C
      DO 630 I = 1,NRAW
      DO 630 J=1,NPROD
      DO 630 IT=NS,NTIME
      RRAW=PO(J,IT)*A(I,J)
      IRRAW=INT(RRAW+.5)
      RRAW=REAL(IRRAW)
      RN(I,IT)=RRAW+RN(I,IT)
630   CONTINUE
C
C     ****************************************************
C              START OF L4L PLANNING MODULE
C     ****************************************************
C
C              CALCULATE CORRECTION FACTOR FOR SERVICE LEVEL
C
      CF=XX(26)*(UHI-ULO)+ULO
C
C              ADJUST RAW MATERIAL NEEDS
C
      DO 1150 I=1,NRAW
      DO 1150 IT=NS,NTIME
      RN(I,IT)=RN(I,IT)*CF
1150  CONTINUE
```

```
C
C        SET UP DO LOOP FOR EACH RAW MATERIAL
C
      DO 1190 III=1,NRAW
C
C        INITIALIZE SET UP COST AND TIME
C
      AA=XX(18)*RAW(III)
      NN=NTIME
C
C*************************
C
      DO 1160 K=NS,NN
      F(K)=999999
      SUMH(K)=0
      MM(K)=AA
1160  CONTINUE
C
      F(NS)=MM(NS)
      JSTAR(NS)=NS
      NNS=NS+1
      DO 1170 K=NNS,NN
      KM1=K-1
      DO 1171 J=NS,KM1
      JM1=J-1
      SUMH(J)=SUMH(J)+RAWHOLD(III)
      MM(J)=MM(J)+RN(III,K)*SUMH(J)
      IF(J.EQ.NS)TEMP=MM(J)
      IF(J.GT.NS)TEMP=F(JM1)+MM(J)
      IF(TEMP.GE.F(K))GOTO 1171
      F(K)=TEMP
      JSTAR(K)=J
1171  CONTINUE
      TEMP=F(KM1)+MM(K)
      IF(TEMP.GE.F(K))GOTO 1170
      F(K)=TEMP
      JSTAR(K)=K
1170  CONTINUE
C
C        DETERMINE PERIODS OF DELIVERY
C
      DO 1172 I=NS,NN
      RD(III,I)=0
1172  CONTINUE
      KT=JSTAR(NN)
1175  RD(III,KT)=1
      IF(KT.EQ.NS)GOTO 1173
      KT=JSTAR(KT-1)
      GOTO 1175
1173  CONTINUE
C
C        DETERMINE DELIVERY QUANTITIES
C
```

```
      PTEMP=0
      I=NN
1186  IF(I.LT.1)GOTO 1184
      IF(RD(III,I).EQ.0) GOTO 1180
      RD(III,I)=PTEMP+RN(III,I)
      PTEMP=0
      GOTO 1182
1180  PTEMP=PTEMP+RN(III,I)
1182  I=I-1
      GOTO 1186
1184  CONTINUE
C
1190  CONTINUE
C
C     SET UP LOOP TO INTEGERIZE RD(I,IT)
C
      DO 1195 I=1,NRAW
      DO 1195 IT=NS,NTIME
      RD(I,IT)=REAL(INT(RD(I,IT)+1.))
1195  CONTINUE
      RETURN
      END
```

Sochastic Dynamic Programming Model Fortran Listing

```
$STORAGE:2
$NOTSTRICT
$NOTLARGE
$NOFLOATCALLS
$pagesize:65
      PROGRAM MAIN
      DIMENSION NSET(16000)
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
      COMMON QSET(16000)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=16000
      NCRDR=5
      NPRNT=0
      NTAPE=7
      CALL SLAM
      STOP
      END
C
C*****************************
C
      SUBROUTINE INTLC
C
C     INITIALIZE SUBROUTINE
C
C     DIMENSION AND SET REAL AND INTEGER VARIABLES
C
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
      DIMENSION AVGRAW(5),SDRAW(5),SDFIN(10),AVGFIN(10)
     1,R1(5),R2(5),P1(10),P2(10),F(50),SUMH(50),
     1JSTAR(50),K1(50)
C
      REAL M,MM(50)
C
C
C     SET SERVER IDLE OR BUSY,0=IDLE,1=BUSY
```

```
C
      XX(20)=0.0
C
C     INITIAL SUM OF ORDER COST,SETUP TIME,BACKORDER
C     COST # OF REPLANS
C
      XX(16)=1.0
      XX(21)=0.0
      XX(22)=0.0
      XX(23)=0.0
      XX(24)=0.0
      NS=INT(XX(16))
C
C     CALCULATE UPPER AND LOWER DISTRIBUTION LIMITS
C
      ULO=1.-.5*3.464*XX(19)
      UHI=1.+.5*3.464*XX(19)
C
C     INITIALIZE NUMBER OF RAW MATERIALS AND PRODUCTS
C     AND NUMBER OF TIME PERIODS
C
      NRAW = 5
      NPROD = 10
      NTIME = 50
C
C
C     OPEN DATA FILE
C
      OPEN (1,FILE = 'DATADML.SDP', STATUS = 'OLD')
C
C     INPUT RAW MATERIAL REQUIREMENTS
C
      DO 19 I=1,NRAW
      DO 19 J=1,NPROD
      A(I,J)=.0
19    CONTINUE
C
      DO 2 K = 1,28
      READ (1,1)J,I,A(I,J)
1     FORMAT(I3,I3,F3.1)
2     CONTINUE
C
C
C     INPUT RUN TIME
C
      DO 4 K=1,NPROD
      READ (1,3)RUN(K)
3     FORMAT(F5.4)
4     CONTINUE
C
C
C     INPUT RAW MATERIAL COST
C
```

```
      DO 6 K=1,NRAW
      READ (1,5)RAW(K)
      RAWHOLD(K)=RAW(K)*XX(17)
5     FORMAT(F6.5)
6     CONTINUE
C
C     INPUT FINISHED GOODS COST
C
      DO 8 K=1,NPROD
      READ (1,7)FIN(K)
      FINHOLD(K)=FIN(K)*XX(17)
7     FORMAT(F3.1)
8     CONTINUE
C
C     INPUT FINISHED GOODS PROFIT
C
      DO 20 K = 1,NPROD
      READ(1,28)PROFIT(K)
28    FORMAT(F5.4)
20    CONTINUE
C
C     INPUT AVERAGE RAW MATERIAL PROFIT
C
      DO 22 I = 1,NRAW
      READ(1,21)RAWPRO(I)
21    FORMAT(F5.4)
22    CONTINUE
C
C     INPUT AVERAGE A(I,J) FOR EACH RAW MATERIAL
C
      DO 23 I=1,NRAW
      READ(1,24)AAVG(I)
24    FORMAT(F5.4)
23    CONTINUE
C
C    INITIALIZE DEMAND MATRIX
C
      DO 15 J=1,NPROD
      DO 15 IT=NS,NTIME
      M(J,IT)=0.0
      D(J,IT)=0.0
15    CONTINUE
C
C     INPUT DEMAND QUANTITIES
C
      OPEN (2,FILE = 'DEMAND', STATUS = 'OLD')
C
13    READ (2,11)IT,J,X
      IF(IT.GT.NTIME)GOTO 12
      M(J,IT)=X
      D(J,IT)=M(J,IT)
11    FORMAT(I4,I4,F8.0)
      GOTO 13
```

```
12    CONTINUE
C
C             CALL WAGNER-WHITIN ALGORITHM
C
      WRITE(*,*)' CALL WAGWIT'
      DO 16 JJ=1,NPROD
      CALL WAGWIT(JJ)
16    CONTINUE
C
C             CALL BACKWARD FINITE LOADING
C
      WRITE(*,*)'       CALL BFL'
      CALL BFL
C
C     INITIALIZE RAW MATERIAL DEMAND AND DELIVERY MATRIX
C
      DO 29 I=1,NRAW
      DO 29 IT=NS,NTIME
      RN(I,IT)=0.0
      RD(I,IT)=0.0
      R1(I)=0.0
      R2(I)=0.0
29    CONTINUE
C
C     CALCULATE RAW MATERIAL DEMAND
C
      DO 30 I = 1,NRAW
      DO 30 J=1,NPROD
      P1(J)=0.0
      P2(J)=0.0
      DO 30 IT=NS,NTIME
      RRAW=PO(J,IT)*A(I,J)
      IRRAW=INT(RRAW+.5)
      RRAW=REAL(IRRAW)
      RN(I,IT)=RRAW+RN(I,IT)
30    CONTINUE
C
C     SUM DEMAND AND RAW MATERIAL USAGE TO
C     CALCULATE AVERAGE AND STANDARD DEVIATION
C
      DO 35 I=1,NRAW
      DO 35 IT=NS,NTIME
      R1(I)=RN(I,IT)+R1(I)
      R2(I)=(RN(I,IT))*(RN(I,IT))+R2(I)
35    CONTINUE
C
C     CALCULATE AVERAGE AND STANDARD DEVIATION
C     FOR RAW MATERIAL
C
      DO 31 I=1,NRAW
      AVGRAW(I)=R1(I)/REAL(NTIME)
      SDRAW(I)=SQRT((R2(I)-REAL(NTIME)*AVGRAW(I)**2)/
     1(REAL(NTIME)))
```

```
31    CONTINUE
C
C     SUM OF DEMAND TO CALCULAT AVG. AND S.D.
C
      DO 36 J=1,NPROD
      DO 36 IT=NS,NTIME
      P1(J)=M(J,IT)+P1(J)
      P2(J)=(M(J,IT))*(M(J,IT))+P2(J)
36    CONTINUE
C
C     CALCULATE AVERAGE AND STANDARD DEVIATION
C     FOR FINISHED PRODUCTS
C
      DO 32 J=1,NPROD
      AVGFIN(J)=P1(J)/REAL(NTIME)
      SDFIN(J)=SQRT((P2(J)-REAL(NTIME)*AVGFIN(J)**2)/
     1(REAL(NTIME)))
32    CONTINUE
C
C     SCHEDULE FIRST SET OF EVENTS
C
      DTIME=0.0
      ATRIB(1)=0.0
      ATRIB(2)=0.0
      CALL SCHDL(1,DTIME,ATRIB)
C
      CALL SCHDL(2,DTIME,ATRIB)
C
      CALL SCHDL(3,DTIME,ATRIB)
C
      CALL SCHDL(4,DTIME,ATRIB)
C
C     INITIALIZE BACKORDERS ETC.
C
      NBO=0
      NFS=0
      DO 37 J=1,NPROD
      BO(J)=0.0
      REFIN(J)=0.0
37    CONTINUE
C
C     SET SAFETY STOCK LEVELS
C
      IF(XX(27).EQ.0.0)GOTO 34
      DO 33 J=1,NPROD
      SAFE(J)=SDFIN(J)*2.0
      JJ=J+5
      XX(JJ)=SAFE(J)
33    CONTINUE
C
34    NPROD=10
C
C     CALL RAW MATERIAL ORDERING SUBROUTINE
```

```
C
      CALL RAWORD
C
C
C
      WRITE(*,*)' INTLC DONE'
      RETURN
      END
C
C*****************************
C*****************************
C
      SUBROUTINE EVENT(I)
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
      REAL M
C
      GO TO (601,602,603,604,605,606),I
601   CALL DAILY
      RETURN
602   CALL RECEIVE
      RETURN
603   CALL RLEASE
      RETURN
604   CALL WORK
      RETURN
605   CALL SHIP
      RETURN
606   CALL REPLAN
      RETURN
      END
C
C*****************************
C
      SUBROUTINE DAILY
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
```

```
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     2NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
      REAL M
C
C     CHECK TO SEE IF MODEL TIME ENDED
C
      IF(XX(16).GT.REAL(NTIME))GOTO 111
C             SCHEDULE SHIPMENTS
C
      DTIME=8.
      ATRIB(1)=0.0
      ATRIB(2)=0.0
C
      CALL SCHDL(5,DTIME,ATRIB)
C
C             SCHEDULE REPLANNING
C
      CALL SCHDL(6,DTIME,ATRIB)
C
C             SCHEDULE DAILY SCHEDULER
C
      CALL SCHDL(1,DTIME,ATRIB)
C
C             SCHEDULE RAW MATERIAL RECEIPTS
C
      CALL SCHDL(2,DTIME,ATRIB)
C
C             SCHEDULE ORDER RELEASE
C
      CALL SCHDL(3,DTIME,ATRIB)
C
C             SCHEDULE WORK
C
      CALL SCHDL(4,DTIME,ATRIB)
C
111   RETURN
      END
C
C*****************************
C
      SUBROUTINE RECEIVE
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
```

```
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
      REAL M
C
      IF(XX(16).GT.REAL(NTIME))GOTO 211
      JT=INT(XX(16))
C
      DO 210 I=1,NRAW
      IF(RD(I,JT).LT.1.0)GOTO 210
      IF(XX(I).GE.RD(I,JT))GOTO 210
C
C     SUM ORDER COST
C
      XX(21)=XX(21)+XX(18)*RAW(I)
C
      OQ=RD(I,JT)
      UL=ULO*OQ
      UH=UHI*OQ
      DQ=UNFRM(UL,UH,2)
      DQ=REAL(INT(DQ+.5))
      XX(I)=XX(I)+DQ
      IF(XX(I).GE.OQ)GOTO 210
      RERAW(I)=OQ-DQ
210   CONTINUE
211   RETURN
      END
C
C*****************************
C
      SUBROUTINE RLEASE
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     2NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
      REAL M
C
```

```
      IF(XX(16).GT.REAL(NTIME))GOTO 212
      JT=INT(XX(16))
      DO 200 J=1,NPROD
      IF(PO(J,JT).EQ.0)GOTO 200
      ATRIB(1)=REAL(J)
      ATRIB(2)=PO(J,JT)
      CALL FILEM(1,ATRIB)
200   CONTINUE
212   RETURN
      END
C
C*************************
C
      SUBROUTINE WORK
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100)
     1,TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
      REAL M
C
      IF(XX(16).GT.REAL(NTIME))GOTO 491
C
C   CHECK ATRIB(1), IF 0, WORK CALLED AT BEGINNING OF DAY
C   IF > 0 THEN IT IS END OF SERVICE
C
      IF(ATRIB(1).EQ.0)GOTO 410
C
C     UPDATE INVENTORY FOR JUST FINISHED JOB
C
      JJ=INT(ATRIB(1))+5
      XX(JJ)=XX(JJ)+ATRIB(2)
C
C              SET SERVER TO IDLE
C
      XX(20)=0.0
C
      GOTO 420
410   CONTINUE
C
C     CHECK TO SEE IF SERVER IS IDLE
C
      IF (XX(20).EQ.1.)GOTO 490
C
```

```
C     CHECK TO SEE IF QUEUE IS EMPTY
C
420   IF (NNQ(1).EQ.0)GOTO 490
C
C     REMOVE FIRST JOB AND MAKE SERVER BUSY
C
      CALL RMOVE(1,1,ATRIB)
      XX(20)=1.
C
C     ADD SETUP TIME TO TOTAL SETUP TIME
C
      XX(22)=XX(22)+XX(18)*RUN(JJ-5)
C
C     CHECK FOR ADEQUATE RAW MATERIALS
C
      QR=1.0
      JJ=INT(ATRIB(1))
      DO 350 I=1,NRAW
      IF(A(I,JJ).EQ.0.)GOTO 350
      RR=ATRIB(2)*A(I,JJ)/XX(I)
      IF (RR.LE.QR)GOTO 350
      QR=RR
350   CONTINUE
      IF(QR.EQ.1.0)GOTO 360
      Q=ATRIB(2)
      ATRIB(2)=REAL(INT(ATRIB(2)/QR))
      REFIN(JJ)=Q-ATRIB(2)
360   DTIME=(ATRIB(2)+XX(18))*RUN(JJ)
      DO 370 I=1,NRAW
      XX(I)=XX(I)-ATRIB(2)*A(I,JJ)
370   CONTINUE
      CALL SCHDL(4,DTIME,ATRIB)
490   CONTINUE
491   RETURN
      END
C
C*****************************
C
      SUBROUTINE SHIP
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     2BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
```

```
      REAL M
C
      IF(XX(16).GT.REAL(NTIME))GOTO 451
      DO 450 J=1,NPROD
      JT=INT(XX(16))
      JJ=J+5
      IF(D(J,JT).GT.0)GOTO 444
      IF(BO(J).EQ.0)GOTO 450
444   TOSHIP=BO(J)+D(J,JT)
      IF(XX(JJ).GE.TOSHIP)GOTO 430
      NBO=NBO+1
      BO(J)=TOSHIP-XX(JJ)
      XX(JJ)=0.0
      GOTO 450
430   XX(JJ)=XX(JJ)-TOSHIP
      BO(J)=0.0
      NFS=NFS+1
450   CONTINUE
451   RETURN
      END
C
C*****************************
C
      SUBROUTINE REPLAN
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     2TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
      REAL M
      DIMENSION F(50),SUMH(50),JSTAR(50),K1(50)
      REAL MM(50)
C
      WRITE(*,*)' IN REPLAN',INT(XX(16))
C
      IF(XX(16).GT.REAL(NTIME))GOTO 673
C
      XX(29)=.665*XX(1)+.613*XX(2)+.
     1595*XX(3)+.37*XX(4)+.455*XX(5)
      XX(30)=XX(6)+XX(7)+XX(8)+XX(9)+XX(10)+XX(11)
     1+XX(12)+XX(13)+
     +XX(14)+XX(15)
C
      WW=0.0
```

```
C
C     CHECK FOR SAFETY STOCK AND LEVELS
C
      IF(XX(27).EQ.0)GOTO 602
      DO 601 J=1,NPROD
      IF(XX(J+5).GE.SAFE(J))GOTO 601
      MNS=NS+1
      M(J,MNS)=M(J,MNS)+REFIN(J)+SAFE(J)-XX(J+5)
      JJ=J
      CALL WAGWIT(JJ)
      WW=1.0
      REFIN(J)=0.0
601   CONTINUE
C
602   CONTINUE
C
      DO 600 J=1,NPROD
C
C     CALCULATE BACKORDER UNITS
C
      XX(23)=XX(23)+BO(J)
C
      IF(REFIN(J).LT.1.0)GOTO 600
C
C     CALCULATE TIME TO NEXT ORDER
C
      TIME=XX(16)
605   TIME=TIME+1.
      IT=INT(TIME)
      IF(PO(J,IT).EQ.0)GOTO 605
C
C     CALCULATE BACKORDER COST AND SETUP COST
C
      BOCOST=(TIME-XX(16))*REFIN(J)*XX(17)
      SUCOST=FIN(J)*XX(18)
      IF(BOCOST.GT.SUCOST)GOTO 610
C
C     INCREASE NEXT ORDER
C
      PO(J,IT)=PO(J,IT)+REFIN(J)
      DO 606 I = 1,NRAW
      RERAW(I)=RERAW(I)+REAL(INT(REFIN(J)*A(I,J)+1.0))
606   CONTINUE
      REFIN(J)=0.0
      GOTO 600
610   WW=1.
C
C     CREATE NEW ORDER
C
      ITT=INT(XX(16)+1.)
      M(J,ITT)=M(J,ITT)+REFIN(J)
      JJ=J
      CALL WAGWIT(JJ)
```

```
      REFIN(J)=0.0
      WW=1.0
600   CONTINUE
C
C    IF M(J,T) HAS CHANGED, CALL BFL, REPLAN RAW MATERIALS
C       WAGWIT ALREADY CALLED
C
      IF(WW.LT.1.0)GOTO 615
C
      XX(24)=XX(24)+1.
      CALL BFL
C
615   CONTINUE
C
C     REPLAN RAW MATERIALS
C
      IF(WW.LT.1.0)GOTO 669
C
C
C     REPLAN RAW MATERIALS
C     INITIALIZE RAW MATERIAL DEMAND AND DELIVERY MATRIX
C
      DO 629 I=1,NRAW
      DO 629 IT=NS,NTIME
      RN(I,IT)=0.0
      RD(I,IT)=0.0
629   CONTINUE
C
C     CALCULATE RAW MATERIAL DEMAND
C
      DO 630 I = 1,NRAW
      DO 630 J=1,NPROD
      DO 630 IT=NS,NTIME
      RRAW=PO(J,IT)*A(I,J)
      IRRAW=INT(RRAW+.5)
      RRAW=REAL(IRRAW)
      RN(I,IT)=RRAW+RN(I,IT)
630   CONTINUE
C
C     CALL RAW MATERIAL ORDERING SUBROUTINE
C
      CALL RAWORD
C
      GOTO 672
C
C     ONLY ORDER RAW MATERIAL NOT DELIVERED
C
669   DO 670 I=1,NRAW
      IF(RERAW(I).LT.1.0)GOTO 670
      TIME=XX(16)
675   TIME=TIME+1.
      IT=INT(TIME)
      IF(IT.GT.NTIME)GOTO 677
```

```
      IF(RD(I,IT).LT.1.0)GOTO 675
      BOCOST=(TIME-XX(16))*RERAW(I)*RAWPRO(I)
      OCOST=XX(18)*RAW(I)
      IF(BOCOST.GT.OCOST)GOTO 680
677   RD(I,INT(XX(16)+1.))=RD(I,INT(XX(16)+1.))+RERAW(I)
      GOTO 670
      ITT=INT(XX(16)+1.)
680   RD(I,ITT)=RD(I,ITT)+RERAW(I)
670   RERAW(I)=0.0
      CONTINUE
672   XX(16)=XX(16)+1.
673   RETURN
      END
C
C*****************************
C
      SUBROUTINE WAGWIT(JJ)
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
      REAL M
C
      DIMENSION F(50),SUMH(50),JSTAR(50),K1(50)
      REAL MM(50)
C
C
C        INITIALIZE SET UP COST AND TIME
C
      AA=XX(18)*FIN(JJ)
      NN=NTIME
C
C*************************
C
      DO 710 K=NS,NN
      F(K)=999999
      SUMH(K)=0
      MM(K)=AA
710   CONTINUE
C
      F(NS)=MM(NS)
      JSTAR(NS)=NS
      NNS=NS+1
```

```
      DO 720 K=NNS,NN
      KM1=K-1
      DO 721 J=NS,KM1
      JM1=J-1
      SUMH(J)=SUMH(J)+FINHOLD(JJ)
      MM(J)=MM(J)+M(JJ,K)*SUMH(J)
      IF(J.EQ.NS)TEMP=MM(J)
      IF(J.GT.NS)TEMP=F(JM1)+MM(J)
      IF(TEMP.GE.F(K))GOTO 721
      F(K)=TEMP
      JSTAR(K)=J
721   CONTINUE
      TEMP=F(KM1)+MM(K)
      IF(TEMP.GE.F(K))GOTO 720
      F(K)=TEMP
      JSTAR(K)=K
720   CONTINUE
C
C        DETERMINE PERIODS OF PRODUCTION
C
      DO 722 I=NS,NN
      P(JJ,I)=0
722   CONTINUE
      KT=JSTAR(NN)
725   P(JJ,KT)=1
      IF(KT.EQ.NS)GOTO 735
      KT=JSTAR(KT-1)
      GOTO 725
735   CONTINUE
C
C        DETERMINE PRODUCTION ORDER QUANTITIES
C
      PTEMP=0
      I=NN
751   IF(I.LT.1)GOTO 750
      IF(P(JJ,I).EQ.0) GOTO 740
      P(JJ,I)=PTEMP+M(JJ,I)
      PTEMP=0
      GOTO 745
740   PTEMP=PTEMP+M(JJ,I)
745   I=I-1
      GOTO 751
750   CONTINUE
      RETURN
      END
C
C*****************************
C
      SUBROUTINE BFL
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
```

```
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     1NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     1BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
      REAL M
C
      DIMENSION CL(50)
C
C             INTIALIZE P,CL,NS,NN
C
      NN=NTIME
C
      DO 802 IT=NS,NN
      CL(IT)=8.
      DO 804 J=1,NPROD
      PO(J,IT)=0
804   CONTINUE
802   CONTINUE
C
C     START MAIN LOOP
C
      DO 1000 IT=NS,NN
      DO 1000 J=1,NPROD
      ITTEMP=IT
      IF(P(J,IT).EQ.0)GOTO 1000
C
C     COMPUTE RUN TIME FOR ORDER
C
      RT=XX(18)*RUN(J)+RUN(J)*P(J,IT)
C
C    IF THERE IS ENOUGH CAPACITY IN THE TIME TO RUN IT,
C    THEN SCHEDULE THAT JOB AND REDUCE CAPACITY IN THE
C    TIME PERIOD
C
C
890   IF(CL(ITTEMP)-RT.GE.0)GOTO 900
C
C     ELSE DECREMENT TIME, RUNTIME, AND CAPACITY
C
895   RT=RT-CL(ITTEMP)
      CL(ITTEMP)=0.0
      ITTEMP=ITTEMP-1
C
C     CHECK TO SEE IF TIME IS AT TNOW
C
      IF(ITTEMP.EQ.NS)GOTO 930
C
```

```
      IF(CL(ITTEMP)-RT.GE.0)GOTO 900
      GOTO 895
C
C     SCHEDULE ORDER IN THAT TIME PERIOD
C     AND REDUCE AVAILABLE CAPACITY
C
900   PO(J,ITTEMP)=PO(J,ITTEMP)+P(J,IT)
      CL(ITTEMP)=CL(ITTEMP)-RT
      GOTO 1000
C
930   PO(J,NS)=PO(J,NS)+P(J,IT)
      GOTO 1000

1000  CONTINUE
      RETURN
      END
C
C*****************************
C
      SUBROUTINE RAWORD
C
      COMMON/SCOM1/ ATRIB(100),DD(100),DDL(100),DTNOW,
     1II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     1TNEXT,TNOW,XX(100)
C
      COMMON/DAVE/ A(5,10),RUN(10),RAW(5),FIN(10),EOQ(5)
     1,M(10,50)
     1,P(10,50),PO(10,50),RN(5,50),RD(5,50),NRAW,NPROD,
     2NTIME,ULO,UHI
     1,RERAW(5),REFIN(10),RAWHOLD(5),FINHOLD(10),D(10,50),
     2BO(10),NBO,NFS
     1,RAWPRO(5),PROFIT(10),SAFE(10),NS,AAVG(5)
C
      REAL M
C
      DIMENSION F(50),SUMH(50),JSTAR(50),K1(50)
      REAL MM(50)
C
      XX(25)=XX(25)+1.0
C
C      INITIALIZE RAW MATERIAL DEMAND AND DELIVERY MATRIX
C
      DO 629 I=1,NRAW
      DO 629 IT=NS,NTIME
      RN(I,IT)=0.0
      RD(I,IT)=0.0
629   CONTINUE
C
C     CALCULATE NEW RAW MATERIAL DEMAND
C
      DO 630 I=1,NRAW
      DO 630 J=1,NPROD
```

```
      DO 630 IT=NS,NTIME
      RRAW=PO(J,IT)*A(I,J)
      IRRAW=INT(RRAW+.5)
      RRAW=REAL(IRRAW)
      RN(I,IT)=RRAW+RN(I,IT)
630   CONTINUE
C
C        SET UP DO LOOP FOR EACH RAW MATERIAL
C
      DO 90 III=1,NRAW
C
C        INITIALIZE SET UP COST AND TIME
C
      AA=XX(18)*RAW(III)
      NN=NTIME
C
      DO 60 K=NS,NN
      F(K)=999999
      SUMH(K)=0
C
C
      OQ=RN(III,NS)
      OQ1=OQ
C
      SL=((RAWPRO(III)+RAW(III))*XX(17)/AAVG(III))/
     +((RAWPRO(III)+RAW(III))*XX(17)/AAVG(III)+RAWHOLD(III))
C
      UQ=REAL(INT(OQ*UHI+1.0))
      LQ=REAL(INT(OQ*ULO))
      OQ=LQ+(UQ-LQ)*SL
      OQ=REAL(INT(OQ+1.0))
      UQ=REAL(INT(OQ*UHI+1.0))
      LQ=REAL(INT(OQ*ULO))
C
      T1=(RAWPRO(III)+RAW(III))*XX(17)/AAVG(III)*(OQ1-LQ)/
     +2.0*(OQ1-LQ+1.0)/(UQ-LQ+1.0)
      T2=RAWHOLD(III)*(UQ-OQ1)/2.0*(UQ-OQ1+1.0)/(UQ-LQ+1.0)
      MM(K)=AA+T1+T2
60    CONTINUE
C
      F(NS)=MM(NS)
      JSTAR(NS)=NS
      NNS=NS+1
      DO 70 K=NNS,NN
      KM1=K-1
      DO 71 J=NS,KM1
      JM1=J-1
      SUMH(J)=SUMH(J)+RAWHOLD(III)
C
      OQ=RN(III,K)
      OQ1=OQ
C
      SL=((RAWPRO(III)+RAW(III))*XX(17)/AAVG(III))/
```

```
     +((RAWPRO(III)+RAW(III))*XX(17)/
     1AAVG(III)+RAWHOLD(III))
C
      UQ=REAL(INT(OQ*UHI+1.0))
      LQ=REAL(INT(OQ*ULO))
      OQ=LQ+(UQ-LQ)*SL
      OQ=REAL(INT(OQ+1.0))
      UQ=REAL(INT(OQ*UHI+1.0))
      LQ=REAL(INT(OQ*ULO))
C
      T1=(RAWPRO(III)+RAW(III))*XX(17)/AAVG(III)*(OQ1-LQ)/
     +2.0*(OQ1-LQ+1.0)/(UQ-LQ+1.0)
      T2=RAWHOLD(III)*(UQ-OQ1)/2.0*(UQ-OQ1+1.0)/(UQ-LQ+1.0)
      MM(J)=MM(J)+T1+T2+OQ1*SUMH(J)
      IF(J.EQ.NS)TEMP=MM(J)
      IF(J.GT.NS)TEMP=F(JM1)+MM(J)
      IF(TEMP.GE.F(K))GOTO 71
      F(K)=TEMP
      JSTAR(K)=J
71    CONTINUE
      TEMP=F(KM1)+MM(K)
      IF(TEMP.GE.F(K))GOTO 70
      F(K)=TEMP
      JSTAR(K)=K
70    CONTINUE
C
C        DETERMINE PERIODS OF DELIVERY
C
      DO 72 I=NS,NN
      RD(III,I)=0
72    CONTINUE
      KT=JSTAR(NN)
75    RD(III,KT)=1.
      IF(KT.EQ.NS)GOTO 73
      KT=JSTAR(KT-1)
      GOTO 75
73    CONTINUE
C
C        DETERMINE DELIVERY QUANTITIES
C
      PTEMP=0
      I=NN
86    IF(I.LT.1)GOTO 84
      IF(RD(III,I).EQ.0) GOTO 80
      RD(III,I)=PTEMP+RN(III,I)
      PTEMP=0
      GOTO 82
80    PTEMP=PTEMP+RN(III,I)
82    I=I-1
      GOTO 86
84    CONTINUE
C
90    CONTINUE
```

```
C
C     ADJUST RD(I,IT) TO QUANTITY USED IN CALCULATIONS
C
      DO 95 I=1,NRAW
      SL=((RAWPRO(I)+RAW(I))*XX(17)/AAVG(I))/
     +((RAWPRO(I)+RAW(I))*XX(17)/AAVG(I)+RAWHOLD(I))
      DO 95 IT=NS,NTIME
      IF (RD(I,IT).LT.1.0)GOTO 95
      OQ=RD(I,IT)
      UQ=REAL(INT(OQ*UHI+1.))
      LQ=REAL(INT(OQ*ULO))
      RD(I,IT)=LQ+SL*(UQ-LQ)
95    CONTINUE
      RETURN
      END
```

Modified EOQ Model SLAM Listing

```
GEN,LYTH,TEST,8/12/86;
LIMITS,1,2,50;
INTLC,XX(16)=1.0;
INTLC,XX(17)=0.1;
INTLC,XX(18)=250.0;
INTLC,XX(19)=0.03;
INTLC,XX(27)=1.0;
TIMST,XX(1),RAW MATERIAL 1;
TIMST,XX(2),RAW MATERIAL 2;
TIMST,XX(3),RAW MATERIAL 3;
TIMST,XX(4),RAW MATERIAL 4;
TIMST,XX(5),RAW MATERIAL 5;
TIMST,XX(6), PRODUCT 1;
TIMST,XX(7), PRODUCT 2;
TIMST,XX(8), PRODUCT 3;
TIMST,XX(9), PRODUCT 4;
TIMST,XX(10), PRODUCT 5;
TIMST,XX(11), PRODUCT 6;
TIMST,XX(12), PRODUCT 7;
TIMST,XX(13), PRODUCT 8;
TIMST,XX(14), PRODUCT 9;
TIMST,XX(15), PRODUCT 10;
TIMST,XX(20),SERVER UTIL;
TIMST,XX(21),ORDER COST;
TIMST,XX(22),SETUP TIME;
TIMST,XX(23),BACKORDER UNITS;
TIMST,XX(24),# PRODUCT REPLANS;
TIMST,XX(25),# RAW MAT REPLANS;
TIMST,XX(29),RAW MATL VALUE;
TIMST,XX(30),FIN GOOD VALUE;
INITIALIZE,,400,,,;
FIN;
```

Modified Lot-for-Lot 50% Service Level Model

```
GEN,LYTH,TEST,8/12/86;
LIMITS,1,2,50;
INTLC,XX(16)=1.0;
INTLC,XX(17)=0.2;
INTLC,XX(18)=250.0;
INTLC,XX(19)=0.03;
INTLC,XX(26)=0.5;
INTLC,XX(27)=1.0;
TIMST,XX(1),RAW MATERIAL 1;
TIMST,XX(2),RAW MATERIAL 2;
TIMST,XX(3),RAW MATERIAL 3;
TIMST,XX(4),RAW MATERIAL 4;
TIMST,XX(5),RAW MATERIAL 5;
TIMST,XX(6), PRODUCT 1;
TIMST,XX(7), PRODUCT 2;
TIMST,XX(8), PRODUCT 3;
TIMST,XX(9), PRODUCT 4;
TIMST,XX(10), PRODUCT 5;
TIMST,XX(11), PRODUCT 6;
TIMST,XX(12), PRODUCT 7;
TIMST,XX(13), PRODUCT 8;
TIMST,XX(14), PRODUCT 9;
TIMST,XX(15), PRODUCT 10;
TIMST,XX(20),SERVER UTIL;
TIMST,XX(21),ORDER COST;
TIMST,XX(22),SETUP TIME;
TIMST,XX(23),BACKORDER UNITS;
TIMST,XX(24),# PRODUCT REPLANS;
TIMST,XX(25),# RAW MAT REPLANS;
TIMST,XX(29),RAW MATL VALUE;
TIMST,XX(30),FIN GOOD VALUE;
INITIALIZE,,400,,,;
FIN;
```

Modified Lot-for-Lot 70% Service Level Model

```
GEN,LYTH,TEST,8/12/86;
LIMITS,1,2,50;
INTLC,XX(16)=1.0;
INTLC,XX(17)=0.2;
INTLC,XX(18)=250.0;
INTLC,XX(19)=0.10;
INTLC,XX(26)=0.7;
INTLC,XX(27)=0.0;
TIMST,XX(1),RAW MATERIAL 1;
TIMST,XX(2),RAW MATERIAL 2;
TIMST,XX(3),RAW MATERIAL 3;
TIMST,XX(4),RAW MATERIAL 4;
TIMST,XX(5),RAW MATERIAL 5;
TIMST,XX(6), PRODUCT 1;
TIMST,XX(7), PRODUCT 2;
TIMST,XX(8), PRODUCT 3;
TIMST,XX(9), PRODUCT 4;
TIMST,XX(10), PRODUCT 5;
TIMST,XX(11), PRODUCT 6;
TIMST,XX(12), PRODUCT 7;
TIMST,XX(13), PRODUCT 8;
TIMST,XX(14), PRODUCT 9;
TIMST,XX(15), PRODUCT 10;
TIMST,XX(20),SERVER UTIL;
TIMST,XX(21),ORDER COST;
TIMST,XX(22),SETUP TIME;
TIMST,XX(23),BACKORDER UNITS;
TIMST,XX(24),# PRODUCT REPLANS;
TIMST,XX(25),# RAW MAT REPLANS;
TIMST,XX(29),RAW MATL VALUE;
TIMST,XX(30),FIN GOOD VALUE;
INITIALIZE,,400,,,;
FIN;
```

Modified Lot-for-Lot 90% Service Level Model

```
GEN,LYTH,TEST,8/12/86;
LIMITS,1,2,50;
INTLC,XX(16)=1.0;
INTLC,XX(17)=0.2;
INTLC,XX(18)=250.0;
INTLC,XX(19)=0.03;
INTLC,XX(26)=0.9;
INTLC,XX(27)=1.0;
TIMST,XX(1),RAW MATERIAL 1;
TIMST,XX(2),RAW MATERIAL 2;
TIMST,XX(3),RAW MATERIAL 3;
TIMST,XX(4),RAW MATERIAL 4;
TIMST,XX(5),RAW MATERIAL 5;
TIMST,XX(6), PRODUCT 1;
TIMST,XX(7), PRODUCT 2;
TIMST,XX(8), PRODUCT 3;
TIMST,XX(9), PRODUCT 4;
TIMST,XX(10), PRODUCT 5;
TIMST,XX(11), PRODUCT 6;
TIMST,XX(12), PRODUCT 7;
TIMST,XX(13), PRODUCT 8;
TIMST,XX(14), PRODUCT 9;
TIMST,XX(15), PRODUCT 10;
TIMST,XX(20),SERVER UTIL;
TIMST,XX(21),ORDER COST;
TIMST,XX(22),SETUP TIME;
TIMST,XX(23),BACKORDER UNITS;
TIMST,XX(24),# PRODUCT REPLANS;
TIMST,XX(25),# RAW MAT REPLANS;
TIMST,XX(29),RAW MAT'L VALUE;
TIMST,XX(30),FIN GOODS VALUE;
INITIALIZE,,400,,,;
FIN;
```

Stochastic Dynamic Programming SLAM Model

```
GEN,LYTH,TEST,8/12/86;
LIMITS,1,2,50;
INTLC,XX(16)=1.0;
INTLC,XX(17)=0.2;
INTLC,XX(18)=50.0;
INTLC,XX(19)=0.10;
INTLC,XX(27)=1.0;
TIMST,XX(1),RAW MATERIAL 1;
TIMST,XX(2),RAW MATERIAL 2;
TIMST,XX(3),RAW MATERIAL 3;
TIMST,XX(4),RAW MATERIAL 4;
TIMST,XX(5),RAW MATERIAL 5;
TIMST,XX(6), PRODUCT 1;
TIMST,XX(7), PRODUCT 2;
TIMST,XX(8), PRODUCT 3;
TIMST,XX(9), PRODUCT 4;
TIMST,XX(10), PRODUCT 5;
TIMST,XX(11), PRODUCT 6;
TIMST,XX(12), PRODUCT 7;
TIMST,XX(13), PRODUCT 8;
TIMST,XX(14), PRODUCT 9;
TIMST,XX(15), PRODUCT 10;
TIMST,XX(20),SERVER UTIL;
TIMST,XX(21),ORDER COST;
TIMST,XX(22),SETUP TIME;
TIMST,XX(23),BACKORDER UNITS;
TIMST,XX(24),# PRODUCT REPLANS;
TIMST,XX(25),# RAW MAT REPLANS;
TIMST,XX(29),RAW MAT'L VALUE;
TIMST,XX(30),FIN GOODS VALUE;
INITIALIZE,,400,,,;
FIN;
```

BIBLIOGRAPHY

Ashapa, Myron R., "Basic PIC Techniques as Applied in a Repetitive/Process Industry", American Production and Inventory Control Society 24th Annual International Conference Proceedings, 1981, pp. 307 - 310.

Berry, William L., "Lot Sizing Procedures for Requirements Planning Systems: A Framework for Analysis", Production and Inventory Management, Vol. 13, No. 2, Second Quarter, 1972, pp. 19 - 34.

Bialous, Rita, "Maintenance Resource Planning: The Real MRP for Process Industries", American Production and Inventory Control Society 26th Annual International Conference Proceedings, 1983, pp. 96 - 99.

Bolander, Steven F., Richard C. Heard, Samuel M. Seward, and Sam G. Taylor, Manufacturing Planning and Control In Process Industries, American Production and Inventory Control Society, 1981.

Bolander, Steven F. and Sam G. Taylor, "A Framework for Manufacturing Resource Planning in the Process Industries", Inventories and Production Magazine, Vol. 2, No. 2, 1982.

Brown, R. G., Materials Management Systems, New York, Wiley, 1977.

Buffa, E. S. and J. G. Miller, Production and Inventory Systems: Planning and Control, Irwin, Inc., Homewood, Illinois, 1979.

Burt, J., "Master Production Scheduling Considerations for Process Industries", American Production and Inventory Control Society 23rd Annual Conference Proceedings, 1980, ppl 417 - 418.

Census of Manufacturing, 1982, United States Census Bureau, 1982.

Cooper, J. H., "Manufacturing Management in the Process Industries", American Production and Inventory Control Society 28th Annual Conference Proceedings, 1985, pp. 154 - 161.

Dantzig, George B., "Linear Programming under Uncertainty", Mangement Science, Vol. 1, No. 3 and 4, April - July, 1955, pp. 197 - 206.

Dobler, Donald W., Lamar Lee, Jr., and David N. Burt, Purchasing and Materials Management, McGraw-Hill Book Company, New York, 1984.

Duvall, Thomas J., and Richard E. Hoffman, "Planning and Control in Meat Packing", American Production and Inventory Control Society 26th Annual International Conference Proceedings, 1983, pp. 100 - 105.

Evans, James R., "An Efficient Implementation of the Wagner-Whitin Algorithm for Dynamic Lot-Sizing", Journal of Operations Management, Vol. 5, No. 2, February 1985, pp.229 - 236.

Evers, William H., "A New Model for Stochastic Linear Programming", Management Science, Vol. 13, No. 9, May, 1967, pp. 680 - 693.

Finch, Byron J., "Production Planning and Control in Process Industries: A Study of Methods Used to Accomplish Planning and Control Functions and Characteristics Instrumental in Method Selection", Unpublished Doctoral Dissertation, University of Georgia, 1986.

Galligan, Stephen C., and Panna Hazarika, "Shop Floor Control in Continuous Production Flow Environment", Production and Inventory Management, Vol. 22, No. 4, Fourth Quarter, 1982, pp.87 - 119.

Golovin, Lewis, "Product Blending: A Simulation Case Study in Double-Time", Interfaces, Vol. 9, No. 5, November, 1979, pp. 64 - 75

Goode, H. P. and S. Saltzman, "Computing Optimum Shrinkage Allowances for Small Order Sizes", The Journal of Industrial Engineering, Vol. 12, No. 5, January-February 1961, pp. 57 - 61.

Gopal, Christopher, "Planning in Process Industries", Production and Inventory Management Review, Vol. 6, No. 3, March 1986, pp. 46 - 52.

Haglund, E. A., "Primary Metals--We're Different", Production and Inventory Management, Vol. 22, No. 3, Third Quarter, 1981, pp. 21 - 26.

Hair, Joseph F., Jr., Rolph E. Anderson, Ronald L. Tatham, Multivariate Data Analysis with Readings, Macmillan Publishing Company, New York, 1987.

Hall, Robert W., Zero Inventories, Dow Jones-Irwin, Homewood, Illinois, 1983.

Hax, A. C., "The Design of Large Scale Logistics Systems: A Survey and and Approach", from W. H. Marlow (Editor), Modern Trends in Logistics Research, The MIT Press, Cambridge, Mass., 1976.

Hillier, Frederick S., and Gerald J. Liebermann, Introduction to Operations Research, Holden-Day, Inc. Oakland, California, 1980.

Hillier, Frederick S., "Reject Allowances for Job Lot Orders", The Journal of Industrial Engineering, Vol 14, No. 6, January-February 1963, pp. 311 - 316.

Hoffman, William C., "MRPII at a Paper Goods Plant-Case Study", American Production and Inventory Control Society 24th Annual International Conference Proceedings, 1981, pp. 226 - 228.

Holstein, W. K., "Production Planning and Control Integrated", Harvard Business Review, May-June, 1968.

Horngren, Charles T., Cost Accounting: A Managerial Emphasis, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1967.

Hegseth, Merton A., "The Challenge of Operation Yield", Production and Inventory Managment, Vol. 24, No. 1, First Quarter, 1984, pp. 4 - 9.

Hyman, Warren, "Batch Costing and Control in the Process Industries", American Production and Inventory Control Society 24th Annual International Conference Proceedings, 1981, pp. 215-218.

Juran, J.M., and Frank M. Gryna, Jr., Quality Planning and Analysis, McGraw-Hill Book Company, New York, 1980.

Juran, J.M., Frank M. Gryna, Jr.,and R. S. Bingham, Jr., Editors, Quality Control Handbook, McGraw-Hill Book Company, New York, 1974.

Kalro, A. H., and M. M. Gohil, "A lot size model with backlogging when the amount received is uncertain", International Journal of Production Research, Vol. 22, N. 6, 1982, pp. 775-786.

Karlin, S., Arrow, K. J. and Scarf, H. R., "One Stage Models with Uncertainty", Studies in the Mathematical Theory of Inventory and Production, Stanford University Press, Stanford, CA, 1958.

Kiekhaefer, F. C., and J. R. Williams, "MRP Implementation: An Alternative Approach for Process Manufacturing", American Production and Inventory Control Society 25th Annual International conference Proceedings, 1982, pp. 537 - 541.

Kochalka, T. S., "MRP in a Process Industry--Why Wait?", Production and Inventory Management, Vol. 18, No. 4, Fourth Quarter, 1978, p. 17 - 20.

Keppel, Geoffrey, Design and Analysis: A Researcher's Handbook, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1973.

Keppel, Geoffrey, Design and Analysis: A Researcher's Handbook, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1982.

Kirk, Roger E., Experimental Design: Procedures for the Behavioral Sciences, Brooks/Cole Publishing Co., Belmont, California, 1982.

Law, Averill M. and W. David Kelton, Simullation Modeling and Analysis, McGraw-Hill Book Company, New York, 1982).

Levitan, R. E., "The Optimal Reject Allowance Problem", Management Science, Vol. 6, No. 5, January, 1969, pp. 172 - 187.

Liberatore, Matthew J., "Using MRP and EOQ/Safety Stock for Raw Materials Inventory Control: Discussion and Case Study", Interfaces, Vol. 9, No. 2, Pt. 1, February, 1979, pp. 1 -7.

Llewellyn, R. W., "Order Sizes for Job-Lot Manufacturing", The Journal of Industrial Engineering, Vol. 5, No. 11, May-June 1959, pp. 176 - 180.

Lyons, Norman R., "Resource Planning for Randomly Arriving Stochastic Jobs", Management Science, Vol. 21, No. 8, April, 1975, pp. 931 - 936.

Madansky, A., "Methods of Solution of Linear Programs under Uncertainty", Operations Research, Volume 10, No. 4, July/August 1962, pp. 463-471.

Magee, J. F. and D. M. Boodman, Production Planning and Control, McGraw-Hill, New York, 1967.

Mazzola, Joseph B., William F. McCoy, Harvey M. Wagner, "Algorithms and Heuristics for Variable-Yield Lot-Sizing", Graduate School of Business Administration, University of North Carolina, Working Paper 85-02,Chapel Hill, N. C., (1985)

Mehra, Satish, "Adjusting Material Requiremetns for Shrinkage", Production and Inventory Managment, Vol. 21, No. 1, First Quarter, 1980, pp. 13 - 16.

Meyer, David A., "Materials Managment in a Rework Shop", American Production and Inventory Control Society 23rd Annual International Conference Proceedings, 1980, pp. 108 - 111.

Miller, Jeffrey G., and Margaret B. W. Graham, "Production/Operations Management: Agenda for the '80s", Decision Sciences, Vol. 12, No. 4, October, 1981, pp. 547 - 571.

Mize, J. H., C. R. White and G. N. Stilian, Operations Planning and Control, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1971.

Moder, Joseph J., and Salah E. Elmaghraby, Editors, Handbook of Operations Research, Van Nostrand Reinhold Company, New York, 1978.

Nelson, Nancy, "MRP and Inventory and Production Control in Process Industries", Production and Inventory Managment, Vol. 24, No. 2, Fourth Quarter, 1983, pp. 15 - 22.

New, Colin and John Mapes, "MRP With High Uncertain Yield Losses", Journal of Operations Management, Vol.4, No. 4, August, 1984, pp. 315 - 330.

Novitsky, Michael P., "Process Industries--Where are You?", Production and Inventory Management Journal, Vol. 24, No. 1, First Quarter, 1983, pp. 118 - 121.

Novitsky, Michael P., "Master Production Scheduling in Process Industries", Production and Inventory Management, Vol 25, No. 1, First Quarter, 1984, pp. 48 - 53.

Orlicky, Joseph, Materials Requirements Planning, McGraw-Hill Book Company, New York, 1975.

Pritsker, A. Alan B. and Claude D. Pegden, Introduction to Simulation and SLAM, John Wiley & Sons, New York, 1979.

Putnam, A. O., E. R. Barlow and G. N. Stilian, Unified Operations Management, Rath & Strong, Boston, 1963.

Ritzmann, Larry P., Barry E. King and Lee J. Krajewski, "Manufacturing Performance--Pulling the Right Levers", Harvard Business Review, Vol. 62, No. 2, March-April 1984, pp. 143 - 152.

Rosenthal, Roger and Ralph L. Rosnow, Essentials of Behavioral Research: Methods and Data Analysis, McGraw-Hill, New York, 1984.

Ross, Sheldon, Introduction to Stochastic Dynamic Programming, Academic Press, New York, 1983.

Schmitt, Thomas, "Resolving Uncertainty in Manufacturing Systems", Journal of Operations Management, Vol. 4, No. 4, August 1984, pp. 331 - 346.

Scott, W. Richard, Organizations: Rational, Natural, and Open Systems, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1981

Sepehri, M., E. A. Silver and C. New, "A Heuristic for Multiple Lot Sizing For an Order Under Variable Yield", IIE Transactions, March 1986, pp. 63 - 69.

Silver, Edward A., "Establishing the Order Quantity When the Amount Received is Uncertain", INFOR, Vol. 14, No. 1, February 1976, pp. 32 - 39.

Taylor, Sam, "Production and Inventory Management in the Process Industries: A State of the Art Survey", Production and Inventory Managment, Vol. 20, No. 1, First Quarter, 1979, pp. 1-16.

Taylor, Sam G., Samuel M. Seward, and Steven F. Bolander, "Why the Process Industries are Different", Production and Inventory Managment, Vol. 22, No. 4, Fourth Quarter, 1981, pp. 9 -24.

Thompson, Karen, "MRPII in the Repetitive Manufacturing Environment", Production and Inventory Management, Vol. 24, No. 4, Fourth Quarter, 1983, pp. 1 - 13.

Thompson, James D., Organizations in Action, McGraw-Hill, New York, 1967.

Tiber, Joseph S., "Use of the Dynamic Bill in Process Industries", Process Industries Seminar Proceedings, April 1981, pp.33-38.

Vitt, Lawrence D., "A Framework for Planning and Information System Design", Process Industries Seminar Proceedings, April 1981, pp. 39 - 45.

Vollman, Thomas E., William L. Berry and Clay Whybark, Manufacturing Planning and Control Systems, Richard D. Irwin, Inc., Homewood, Illinois, 1984.

Wadsworth, H. and S. H. Chang, "The Reject Allowance Problem: An Analysis and Application to Job Lot Production", The Journal of Industrial Engineering, Vol. 15, No. 5, May-June 1964, pp. 127 - 131.

Wallace, Thomas F., Editor, APICS Dictionary, American Production and Inventory Control Society, Inc., Falls Church, Virginia, 1984.

Whybark, D. Clay, and J. Gregg Williams, "Material Requirements Planning Under Uncertainty", Decision Sciences, Vol. 7, No. 4, pp. 595 - 606.

Wight, O. W., Production and Inventory Management in the Computer Age, Cahnes, Boston, 1974.

Williams, Joe L., Thomas R. Minnich, Freeman G. Rohlfing, and Alan P. Chmelewski, "Application of Manufacturing Resource Planning to Specialty Metals--A Batch Process Industry", Production and Inventory Managment, Fourth Quarter, 1983, pp. 51 - 65.

MICHIGAN STATE UNIV. LIBRARIES
31293010907552