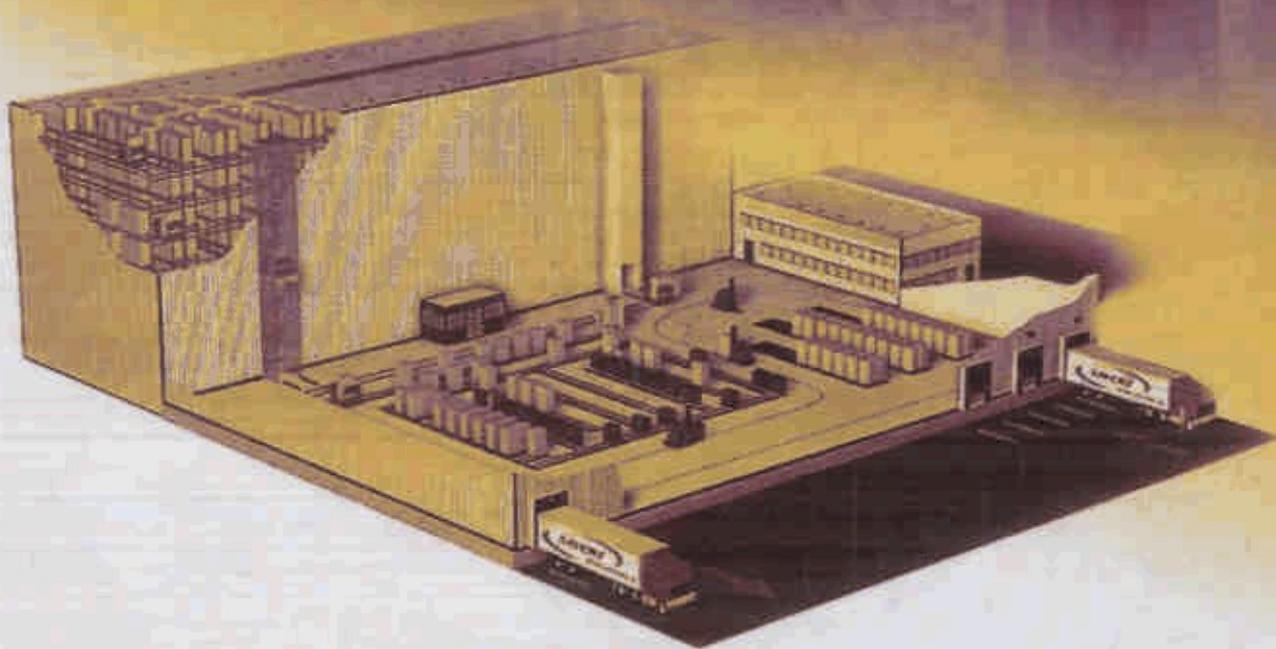


FACILITIES DESIGN

Third Edition



Sunderesh S. Heragu

Contents

Preface	xiii
Acknowledgments.....	xv
Author	xvii

Chapter 1 Introduction to Facility Design	1
1.1 Introduction.....	1
1.2 Facility Layout	3
1.3 Types of Layout Problems.....	4
1.3.1 Service Systems Layout Problem	5
1.3.2 Manufacturing Layout Problem	9
1.3.3 Warehouse Layout Problem.....	10
1.3.4 Nontraditional Layout Problems	10
1.4 Summary.....	10
1.5 Review Questions and Exercises.....	12

Chapter 2 Product and Equipment Analysis	13
2.1 Introduction.....	13
2.2 Product Analysis	13
2.2.1 Bill of Materials.....	13
2.2.2 Assembly Charts.....	13
2.2.3 Engineering Drawing	16
2.2.4 Route Sheet.....	16
2.2.5 Operation Process Chart	18
2.3 Equipment Selection	18
2.3.1 Traditional Model.....	20
2.3.1.1 Example 1.....	21
2.3.2 Linear Integer Programming Models.....	22
2.3.2.1 Comprehensive Equipment Selection Model	24
2.3.2.2 MH Equipment Selection Model	25
2.3.2.3 Production Equipment Selection Model	25
2.3.2.4 Equipment Selection Model	26
2.3.2.5 Example 2.....	26
2.3.3 Queuing Model.....	28
2.3.3.1 Example 3.....	28
2.4 Personnel Requirement Analysis	29
2.4.1 Example 4.....	30
2.4.1.1 Solution	30
2.5 Space Requirement and Availability.....	31
2.6 Summary.....	31
2.7 Review Questions and Exercises.....	33

Chapter 3	Process and Material Flow Analysis.....	37
3.1	Introduction.....	37
3.2	Data Requirement for Layout Decisions.....	37
3.2.1	Flow Patterns.....	37
3.2.1.1	Common Flow Patterns.....	38
3.2.1.2	Five Types of Layout.....	39
3.2.2	Flow Process Chart.....	42
3.2.3	Flow Diagram.....	43
3.2.4	Flow Data.....	43
3.2.4.1	Qualitative Flow Data.....	44
3.2.4.2	Relationship Chart.....	44
3.2.4.3	Quantitative Flow Data.....	46
3.2.5	Distance Measures.....	46
3.2.5.1	Euclidean.....	47
3.2.5.2	Squared Euclidean.....	47
3.2.5.3	Rectilinear.....	48
3.2.5.4	Tchebychev.....	48
3.2.5.5	Aisle Distance.....	48
3.2.5.6	Adjacency.....	48
3.2.5.7	Shortest Path.....	49
3.2.6	Layout Evaluation Criteria.....	49
3.2.6.1	Notation.....	50
3.3	Tools for Presenting Layout Designs.....	51
3.3.1	Drawings.....	51
3.3.2	Templates.....	51
3.3.3	Three-Dimensional Physical Models.....	52
3.3.4	Computer Software Tools.....	52
3.4	Guidelines for Data Development and Generation.....	53
3.4.1	Obtaining Basic Data.....	54
3.4.2	Extracting Relevant Data.....	55
3.4.3	Generating Data in the Required Format.....	55
3.4.4	Sharing Preliminary Data and Obtaining Feedback.....	59
3.4.5	Documenting Data.....	59
3.5	Case Study: Application of Methodology at a Manufacturing Company.....	59
3.6	Summary.....	62
3.7	Review Questions and Exercises.....	62
Chapter 4	Traditional Approaches to Facility Layout.....	67
4.1	Introduction.....	67
4.2	Systematic Layout Planning.....	68
4.3	Special Considerations in Office Layout.....	72
4.4	Office Planning Project for a Mortgage Company.....	77
4.4.1	Evaluation.....	77
4.4.2	Planning.....	77
4.4.3	Site Selection.....	78
4.4.4	Design and Layout.....	78
4.5	Engineering Design Problem Approach.....	81
4.5.1	Identify the Problem.....	81
4.5.2	Gather the Required Data.....	82

4.5.3	Formulate a Model for the Problem	82
4.5.4	Develop an Algorithm for the Model and Solve It	83
4.5.5	Generate Alternate Solutions, Evaluate, and Select	83
4.5.6	Implement the Solution	84
4.5.7	Continuously Review after Implementation	84
4.6	Code Compliance, OSHA, ADA Regulations, and Other Considerations in Facility Design	84
4.6.1	Support Facilities	84
4.6.1.1	Cafeteria	85
4.6.1.2	Locker Rooms	86
4.6.1.3	Water Closets, Sinks, Showers, and Drinking Fountains	86
4.6.1.4	Parking Lots	87
4.6.1.5	Exercise Area	87
4.6.2	ADA	88
4.6.3	OSHA Regulations	91
4.6.3.1	Noise	92
4.6.3.2	Lighting	93
4.6.3.3	Ventilation	94
4.7	Summary	94
4.8	Review Questions and Exercises	95
Chapter 5	Basic Algorithms and Software for the Layout Problem	99
5.1	Algorithms for the Layout Problem	99
5.2	Construction Algorithms	100
5.2.1	Modified Spanning Tree Algorithm for the Single-Row Layout Problem	100
5.2.1.1	Example 1	101
5.2.2	Graph Theoretic Approach	103
5.2.2.1	A Heuristic Algorithm for Identifying Maximal PAG	106
5.2.2.2	Example 2	106
5.3	Improvement Algorithms	109
5.3.1	2-Opt Algorithm	110
5.3.1.1	Example 3	111
5.3.2	3-Opt Algorithm	112
5.4	Hybrid Algorithms	113
5.5	Layout Software	113
5.5.1	CRAFT	113
5.5.1.1	Example 4	116
5.5.2	BLOCPLAN	118
5.5.2.1	Example 5	120
5.5.3	PFAST	120
5.5.4	Factory Suite of Programs	129
5.5.4.1	FactoryCAD	129
5.5.4.2	FactoryFLOW	130
5.5.4.3	Plant Simulation	131
5.5.5	Layout-iQ	131
5.5.6	VIP-PLANOPT	133
5.5.7	Flow Path Calculator	135
5.6	Relayout and Multiple-Floor Layout	138
5.7	Summary	142
5.8	Review Questions and Exercises	142

Chapter 6	Group Technology and Facilities Layout	149
6.1	Introduction	149
6.2	Clustering Approach	153
6.2.1	Rank Order Clustering Algorithm	153
6.2.1.1	Example 1	154
6.2.2	Bond Energy Algorithm	156
6.2.2.1	Example 2	157
6.2.3	Row and Column Masking Algorithm	158
6.2.3.1	Example 3	159
6.2.4	Similarity Coefficient Algorithm	159
6.2.4.1	Example 4	161
6.2.5	Mathematical Programming Approach	162
6.2.5.1	p -Median Model	163
6.3	Implementation of Group Technology Principles	166
6.4	Design and Planning Issues in Cellular Manufacturing Systems	166
6.4.1	Machine Capacity	166
6.4.2	Safety and Technological Considerations	167
6.4.3	Upper Bound on the Number of Machine Cells and Size of a Cell	167
6.4.4	Minimization of Intercellular and Intracellular Material-Handling Cost	167
6.4.5	Machine Utilization	167
6.4.6	Cost Minimization	168
6.4.7	Scheduling of Jobs in Individual Cells	169
6.4.8	Throughput Rate Maximization	169
6.5	Project on Machine Grouping and Layout	169
6.6	Summary	180
6.7	Review Questions and Exercises	186
Chapter 7	Models for the Layout Problem	193
7.1	Models	193
7.2	Algorithms	194
7.3	Generic Modeling Tools	195
7.3.1	Mathematical Programming Models	195
7.3.2	Queuing and Queuing Network Models	196
7.3.3	Simulation Model	197
7.4	Models for the Single-Row Layout Problem	198
7.4.1	ABSMODEL 1	202
7.4.1.1	Example 1	205
7.4.2	LMIP 1	208
7.4.2.1	Example 2	209
7.5	Models for the Multirow Layout Problem with Departments of Equal Area	212
7.5.1	Quadratic Assignment Problem	212
7.5.1.1	Example 3	215
7.6	Model for the Multirow Layout Problem with Departments of Unequal Area	218
7.6.1	ABSMODEL 2	218
7.6.1.1	Example 4	219
7.6.2	Loop Layout Problem	222
7.6.2.1	LMIP 2	223

7.6.3	Linear Programming Model to Develop a Layout Given a Block Plan	225
7.6.3.1	BlockPlan LP	225
7.6.3.2	Example 5	226
7.7	Discussion of Models	231
7.8	Review Questions and Exercises.....	232
Chapter 8	Advanced Algorithms for the Layout Problem	237
8.1	Introduction.....	237
8.2	Optimal Algorithms.....	237
8.2.1	Branch-and-Bound Algorithm.....	238
8.2.1.1	Example 1	242
8.2.2	Benders' Decomposition Algorithm	245
8.2.2.1	Example 2	248
8.2.3	Making Benders' Decomposition More Efficient	256
8.2.4	Modified Benders' Decomposition Algorithm.....	259
8.3	Heuristic Algorithms.....	259
8.3.1	Simulated Annealing Algorithm.....	260
8.3.1.1	Example 3.....	264
8.3.2	Modified Penalty Algorithm	266
8.3.2.1	Example 4	268
8.3.3	Hybrid Simulated Annealing Algorithm.....	269
8.3.3.1	Example 5	271
8.3.4	Tabu Search	272
8.3.4.1	Tabu Navigation Algorithm	272
8.3.5	Genetic Algorithm	274
8.4	Multicriteria Layout Problems	278
8.4.1	Quantitative Model.....	278
8.4.2	Qualitative Model.....	279
8.4.3	Multi-Objective Model.....	279
8.5	Optimal Approach to Solving CMS Design Problems	280
8.5.1	Model Description.....	280
8.5.1.1	Nonlinear CMS Design Model	282
8.5.1.2	Linear CMS Design Model.....	283
8.5.2	Solution Algorithm: Benders' Decomposition	284
8.5.2.1	Model <i>P</i> (Primal Problem).....	284
8.5.2.2	Model <i>D</i> (Dual Problem)	284
8.5.2.3	Model <i>M</i> (Master Problem).....	285
8.5.2.4	Model <i>M'</i> (Modified Master Problem).....	285
8.5.2.5	Example 6.....	286
8.6	Next-Generation Factory Layouts.....	288
8.6.1	The Need for Stochastic Analysis of Layout Problems.....	290
8.6.2	Three-Phase Approach for Next-Generation Factory Layouts	292
8.6.2.1	Generate Candidate Layouts	293
8.6.2.2	Choosing between Existing and Candidate Layouts.....	294
8.6.2.3	Refinement of Selected Layout	295
8.7	Summary.....	297
8.8	Review Questions and Exercises.....	297

Chapter 9	Material Handling	301
9.1	Introduction.....	301
9.2	Multimedia-Based Educational Software Module for Learning the 10 Principles.....	303
9.3	Material-Handling Principles	308
9.3.1	Unit Load Principle	311
9.3.2	Space Utilization Principle.....	313
9.4	Types of Material-Handling Devices.....	314
9.4.1	Conveyors	315
9.4.2	Palletizers	326
9.4.3	Pallet Lifting Devices.....	328
9.4.4	Trucks	329
9.4.5	Robots.....	332
9.4.6	Automated Guided Vehicles.....	334
9.4.7	Hoists, Cranes, and Jibs.....	335
9.4.8	Warehouse Material-Handling Devices	339
9.5	Material-Handling System in Action.....	339
9.6	Automated Guided Vehicle Systems.....	342
9.7	Models for Material-Handling System Design	345
9.7.1	Rule of Thumb Approach.....	345
9.7.2	Deterministic Approach	345
9.7.2.1	MHD Selection and Assignment Model.....	345
9.7.3	Probabilistic Approach	351
9.7.3.1	Queuing Model for MHS Design.....	352
9.7.4	Static and Probabilistic Approach.....	353
9.7.4.1	Example 3.....	354
9.7.5	Knowledge-Based Approach.....	355
9.7.5.1	Expert System for Industrial Truck Selection.....	356
9.8	Material-Handling System Operational Issues	356
9.8.1	Deterministic Approach	359
9.8.1.1	Model for Conveyor Performance Analysis.....	359
9.8.2	Probabilistic Approach.....	362
9.8.2.1	Queuing and Queuing Network Models for MHS Performance Analysis	362
9.9	Summary.....	366
9.10	Review Questions and Exercises.....	366
Chapter 10	Storage and Warehousing	369
10.1	Introduction.....	369
10.2	Warehouse Functions	369
10.3	Material-Handling and Storage Systems Used in Warehouses.....	371
10.3.1	Storage Medium	371
10.3.2	Storage and Retrieval Systems	376
10.4	Automated Storage and Retrieval Systems in Action.....	382
10.5	Autonomous Vehicle Storage and Retrieval System.....	386
10.6	Automatic Identification.....	388
10.6.1	Radio Frequency Identification.....	388

10.7	Warehouse Design.....	395
10.7.1	Warehouse Location.....	395
10.7.2	Overall Layout of a Warehouse.....	395
10.7.3	Location and Layout of Docks.....	397
10.7.4	Rack Design.....	398
10.7.4.1	Rack Design Model.....	398
10.7.5	Design Model for Warehouse Space Allocation.....	400
10.7.5.1	Example 2.....	405
10.7.6	Spreadsheet-Based Tool for Designing AS/RS.....	406
10.7.6.1	Example 3.....	406
10.7.7	Block Stacking.....	406
10.7.8	Storage Policies.....	409
10.7.8.1	Design Model for Dedicated Storage Policy.....	411
10.7.8.2	Design Model for the Cube-per-Order Index Policy.....	413
10.7.8.3	Design Model for Random Storage Policy.....	416
10.7.9	Travel Time Models.....	417
10.8	Warehouse Operations.....	419
10.8.1	Order-Picking Sequence Problem.....	419
10.8.1.1	Convex Hull Heuristic Algorithm.....	421
10.8.1.2	Software for Solving the Traveling Salesman Problem.....	423
10.8.2	Routing Problem.....	424
10.9	Multimedia CD for Designing a Distribution Center.....	425
10.10	Summary.....	427
10.11	Review Questions and Exercises.....	428
 Chapter 11 Basic Models for the Location Problem.....		435
11.1	Introduction.....	435
11.2	Important Factors in Location Decisions.....	438
11.3	Techniques for Discrete Space Location Problems.....	440
11.3.1	Qualitative Analysis.....	440
11.3.1.1	Example 1.....	440
11.3.2	Quantitative Analysis.....	441
11.3.2.1	Transportation Simplex Algorithm.....	443
11.3.2.2	Example 2.....	444
11.3.2.3	Example 3.....	446
11.3.3	Hybrid Analysis.....	450
11.3.3.1	Example 4.....	451
11.4	Techniques for Continuous Space Location Problems.....	452
11.4.1	Median Method.....	452
11.4.1.1	Example 5.....	455
11.4.2	Contour-Line Method.....	459
11.4.2.1	Algorithm for Drawing Contour Lines.....	459
11.4.3	Gravity Method.....	463
11.4.3.1	Example 7.....	464
11.4.4	Weiszfeld Method.....	464
11.4.4.1	Example 8.....	466
11.5	Facility Location Case Study.....	467

11.6	Summary	469
11.7	Review Questions and Exercises.....	470
Chapter 12	Advanced Location and Routing Models	477
12.1	Introduction	477
12.2	Location Models	477
12.2.1	Multiple-Facility Problems with Rectilinear Distances.....	478
12.2.1.1	Nonlinear Model	478
12.2.1.2	Linear Model	479
12.2.1.3	Example 1.....	479
12.2.2	Multiple-Facility Problems with Euclidean Distances	482
12.2.2.1	Unconstrained, Nonlinear Model.....	482
12.2.2.2	Example 2.....	483
12.3	Allocation Model	485
12.3.1	Network Flow Optimization	485
12.3.1.1	Network Flow Model.....	485
12.3.1.2	Network Simplex Algorithm	486
12.3.1.3	Example 3.....	487
12.3.2	Two-Stage Transportation	489
12.3.2.1	LP Model.....	489
12.3.2.2	Example 4.....	491
12.3.3	Vehicle Routing Problem	493
12.3.3.1	VRP Model.....	493
12.4	Location–Allocation Models	496
12.4.1	Set Covering Problem	496
12.4.1.1	Set Covering Model	497
12.4.1.2	Greedy Heuristic for the Set Covering Model	497
12.4.1.3	Example 5.....	497
12.4.2	Uncapacitated Location–Allocation Problem	499
12.4.2.1	MIP Model	500
12.4.2.2	Equivalent MIP Model.....	500
12.4.2.3	Uncapacitated Location–Allocation Model	502
12.4.2.4	Branch-and-Bound Algorithm for the Uncapacitated Location–Allocation Model	503
12.4.2.5	Example 6.....	504
12.4.3	Comprehensive Location–Allocation	507
12.4.3.1	Comprehensive Location–Allocation Model	509
12.4.3.2	Model TP.....	510
12.4.3.3	Model TP_i	511
12.4.3.4	Model DTP_i	511
12.4.3.5	Model MP.....	512
12.4.3.6	Modified Benders, Decomposition Algorithm.....	512
12.5	Summary	512
12.6	Review Questions and Exercises.....	513
Appendix	521
References	583
Index	593