

Contents

Preface	xv
1. ROBOTIC CELLS IN PRACTICE	1
1.1 Cellular Manufacturing	2
1.2 Robotic Cell Flowshops	3
1.3 Throughput Optimization	7
1.4 Historical Overview	9
1.5 Applications	11
2. A CLASSIFICATION SCHEME FOR ROBOTIC CELLS AND NOTATION	15
2.1 Machine Environment	15
2.1.1 Number of Machines	15
2.1.2 Number of Robots	16
2.1.3 Types of Robots	17
2.1.4 Cell Layout	17
2.2 Processing Characteristics	17
2.2.1 Pickup Criterion	17
2.2.2 Travel-Time Metric	18
2.2.3 Number of Part-Types	20
2.3 Objective Function	20
2.4 An $\alpha \beta \gamma$ Classification for Robotic Cells	20
2.5 Cell Data	24
2.5.1 Processing Times	24
2.5.2 Loading and Unloading Times	24
2.5.3 Notations for Cell States and Robot Actions	25
3. CYCLIC PRODUCTION	29
3.1 Operating Policies and Dominance of Cyclic Solutions	29

3.2	Cycle Times	34
3.2.1	Waiting Times	34
3.2.2	Computation of Cycle Times	35
3.2.3	Lower Bounds on Cycle Times	39
3.3	Optimal 1-Unit Cycles	40
3.3.1	Special Cases	40
3.3.2	General Cases: Constant Travel-Time Cells	43
3.3.2.1	Optimization over Basic Cycles	51
3.3.3	General Cases: Additive and Euclidean Travel-Time Cells	61
3.4	Calculation of Makespan of a Lot	63
3.4.1	A Graphical Approach	63
3.4.2	Algebraic Approaches	64
3.5	Quality of 1-Unit Cycles and Approximation Results	65
3.5.1	Additive Travel-Time Cells	66
3.5.1.1	Pyramidal Cycles	68
3.5.1.2	A 1.5-Approximation Algorithm	68
3.5.1.3	A 10/7-Approximation for Additive Cells	74
3.5.2	Constant Travel-Time Cells	87
3.5.2.1	A 1.5-Approximation Algorithm	89
3.5.3	Euclidean Travel-Time Cells	94
4.	DUAL-GRIPPER ROBOTS	101
4.1	Additional Notation	102
4.2	Cells with Two Machines	104
4.3	A Cyclic Sequence for m -Machine Dual-Gripper Cells	107
4.4	Dual-Gripper Cells with Small Gripper Switch Times	114
4.5	Comparing Dual-Gripper and Single-Gripper Cells	116
4.6	Comparison of Productivity: Computational Results	122
4.7	Efficiently Solvable Cases	128
4.8	Single-Gripper Cells with Output Buffers at Machines	131
4.9	Dual-Gripper Robotic Cells: Constant Travel Time	141
4.9.1	Lower Bounds and Optimal Cycles: m -Machine Simple Robotic Cells	143
4.9.2	One-Unit Cycles	144
4.9.3	Multi-Unit Cycles	146
5.	PARALLEL MACHINES	153
5.1	Single-Gripper Robots	154
5.1.1	Definitions	154
5.1.2	k -Unit Cycles and Blocked Cycles	156

5.1.2.1	Structural Results for k -Unit Cycles	156
5.1.2.2	Blocked Cycles	157
5.1.3	LCM Cycles	165
5.1.4	Practical Implications	169
5.1.4.1	Optimal Cycle for a Common Case	169
5.1.4.2	Fewest Machines Required to Meet Timelines	171
5.2	Dual-Gripper Robots	171
5.2.1	Lower Bound on Per Unit Cycle Time	172
5.2.2	An Optimal Cycle	175
5.2.3	Improvement from Using a Dual-Gripper Robot or Parallel Machines	180
5.2.3.1	Installing a Dual-Gripper Robot in a Simple Robotic Cell	181
5.2.3.2	Installing Parallel Machines in a Single-Gripper Robot Cell	182
5.2.3.3	Installing a Dual-Gripper Robot in a Single-Gripper Robotic Cell with Parallel Machines	183
5.2.3.4	An Illustration on Data from Implemented Cells	187
6.	MULTIPLE-PART-TYPE PRODUCTION: SINGLE-GRIPPER ROBOTS	191
6.1	MPS Cycles and CRM Sequences	192
6.2	Scheduling Multiple Part-Types in Two-Machine Cells	194
6.3	Scheduling Multiple Part-Types in Three-Machine Cells	206
6.3.1	Cycle Time Derivations	207
6.3.2	Efficiently Solvable Special Cases	211
6.4	Steady-State Analyses	216
6.4.1	Reaching Steady State for the Sequence $CRM(\pi_2)$	217
6.4.2	Reaching Steady State for the Sequence $CRM(\pi_6)$	225
6.4.3	A Practical Guide to Initializing Robotic Cells	229
6.5	Intractable Cycles for Three-Machine Cells	231
6.5.1	MPS Cycles with the Sequence $CRM(\pi_2)$	231
6.5.2	MPS Cycles with the Sequence $CRM(\pi_6)$	238
6.5.3	Complexity of Three-Machine Robotic Cells	244
6.6	Scheduling Multiple Part-Types in Large Cells	247
6.6.1	Class U : Schedule Independent Problems	250
6.6.2	Class $V1$: Special Cases of the TSP	251
6.6.3	Class $V2$: NP-Hard TSP Problems	253
6.6.4	Class W : NP-Hard Non-TSP Problems	264
6.6.5	Overview	268
6.7	Heuristics for Three-Machine Problems	270
6.7.1	A Heuristic Under the Sequence $CRM(\pi_2)$	270

6.7.2	A Heuristic Under the Sequence $CRM(\pi_6)$	273
6.7.3	Computational Testing	274
6.7.4	Heuristics for General Three-Machine Problems	276
6.8	Heuristics for Large Cells	281
6.9	The Cell Design Problem	284
6.9.1	Forming Cells	285
6.9.2	Buffer Design	288
6.9.3	An Example	292
6.9.4	Computational Testing	293
7.	MULTIPLE-PART-TYPE PRODUCTION: DUAL-GRIPPER ROBOTS	297
7.1	Two-Machine Cells: Undominated CRM Sequences	300
7.2	Two-Machine Cells: Complexity	306
7.2.1	Cycle Time Calculation	306
7.2.2	Strong NP-Completeness Results	312
7.2.3	Polynomially Solvable Problems	318
7.3	Analyzing Two-Machine Cells with Small Gripper Switch Times	319
7.4	A Heuristic for Specific CRM Sequences	324
7.4.1	A Performance Bound for Heuristic Hard-CRM	325
7.5	A Heuristic for Two-Machine Cells	339
7.6	Comparison of Productivity: Single-Gripper Vs. Dual-Gripper Cells	340
7.7	An Extension to m -Machine Robotic Cells	342
8.	MULTIPLE-ROBOT CELLS	349
8.1	Physical Description of a Multiple-Robot Cell	350
8.2	Cycles in Multiple-Robot Cells	352
8.3	Cycle Times	354
8.4	Scheduling by a Heuristic Dispatching Rule	357
8.5	Computational Results	358
8.6	Applying an LCM Cycle to Implemented Cells	361
9.	NO-WAIT AND INTERVAL ROBOTIC CELLS	363
9.1	No-Wait Robotic Cells	363
9.2	Interval Pick-up Robotic Cells	369
10.	OPEN PROBLEMS	371
10.1	Simple Robotic Cells	371
10.2	Simple Robotic Cells with Multiple Part Types	376

<i>Contents</i>	xiii
10.3 Robotic Cells with Parallel Machines	376
10.4 Stochastic Data	377
10.5 Dual-Gripper Robots	377
10.6 Flexible Robotic Cells	378
10.7 Implementation Issues	378
10.7.1 Using Local Material Handling Devices	378
10.7.2 Revisiting Machines	379
Appendices	
Appendix A	383
A.1 1-Unit Cycles	383
A.1.1 1-Unit Cycles in Classical Notation	384
A.1.2 1-Unit Cycles in Activity Notation	385
Appendix B	387
B.1 The Gilmore-Gomory Algorithm for the TSP	387
B.1.1 The Two-Machine No-Wait Flowshop Problem	387
B.1.2 Formulating a TSP	388
B.1.3 The Gilmore-Gomory Algorithm	389
B.2 The Three-Machine No-Wait Flowshop Problem as a TSP	394
Copyright Permissions	409
Index	413

<http://www.springer.com/978-0-387-70987-1>

Throughput Optimization in Robotic Cells

Dawande, M.W.; Geismar, H.N.; Sethi, S.P.;

Sriskandarajah, C.

2007, XVI, 420 p., Hardcover

ISBN: 978-0-387-70987-1