Table of Contents

INTRODUCTION 1

1 AIRLINE PLANNING AND SCHEDULING 3

1.1 Production and Market of Airline Industry 3
1.1.1 International Air Traffic 3
1.1.2 The Product of a Scheduled Airline 4
1.1.3 The Role of Information and Communication Technology in Airlines 6

1.2 The Airline Scheduling Process 7
1.2.1 Types of Airline Schedules 7
1.2.2 Steps of the Airline Scheduling Process 8
1.2.3 Organizations of Airline Scheduling 10

1.3 Airline Product Planning 13
1.3.1 Block and Ground Time Estimation 13
1.3.2 Demand Estimation 13
1.3.3 Network Planning 17
1.3.4 Capacity Planning 18

1.4 Fleet Assignment 20

1.5 Flight Scheduling and Aircraft Routing 23
1.5.1 Phases in Solving the Routing and Scheduling Problem 23
1.5.2 Aircraft Maintenance Scheduling 24
1.5.3 Schedule Construction and Evaluation 24
1.5.4 Physical Aircraft Assignment 26

1.6 Crew Scheduling 26
1.6.1 The Crew Scheduling Problem 26
1.6.2 Types of Crew Work Rules 28
1.6.3 Basis for Crew Costs 30
1.6.4 „European" and „American" Crew Management 31
1.6.5 Solving the Crew Scheduling Problem 32

1.7 Airport Activities Scheduling 33
1.7.1 Flight Handling at an Airport 33
1.7.2 Gate Assignment 33

1.8 Execution-time Rescheduling 35

1.9 Yield Management 36

2 MODELS AND SYSTEMS FOR AIRLINE PRODUCTION PLANNING (STATE-OF-THE-ART) 41

2.1 Models for Network Planning and Demand Estimation 41
2.1.1 The Traditional Approach 41
2.1.2 Model Design Objectives 42
2.1.3 Common Framework for Network Planning Models 42
2.1.4 Building Hubs in a Hub-and-spoke Network 46

2.2 Systems for Fleet Assignment and Routing 48
2.2.1 The Fleet Assignment Problem 48
2.2.2 The System FLASH - Fleet Assignment Handling 49
2.2.3 Fleet Assignment with Integer Programming 51
2.2.4 The Original Model Formulation 54
2.2.5 The Delta Airlines' Coldstart System 58
2.2.6 Simulation of Flight Schedules 62

2.3 Set Partitioning Problems in Crew Scheduling 63

2.4 Methods to Solve Set Partitioning Problems 67
2.4.1 General Algorithms 67
2.4.2 The Crew Assignment System TRIP 69
2.4.3 Crew Scheduling Based on the GENCOL Software 73

2.5 Other Approaches in Crew Scheduling 74
2.5.1 Knowledge-based Systems in Crew Rostering 74
2.5.2 Heuristic Methods in Crew Scheduling 78

2.6 The Bidline Generation Problem 80

2.7 Gate Assignment Systems 83
2.7.1 Mathematical Optimization Models in Gate Assignment 83
2.7.2 Knowledge-based Systems for Gate Assignment 83
2.7.3 Knowledge-based Systems for Flight Handling 86

2.8 Dynamic Slot Allocation 87

2.9 Improving Airline Competitiveness 92
2.9.1 Competitive Advantages Achieved by Computer-aided Planning and Scheduling 93
2.9.2 Choosing the right solution 94

3 THE ROTATION GENERATION PROCESS 97

3.1 Problem Description 97

3.2 Optimal Aircraft Routing with Fixed Departure Times 99

3.3 The Aircraft Routing Problem with Time Windows 106

3.4 A Method for Aircraft Routing and Scheduling 108

3.5 New Methods for Aircraft Routing and Scheduling 112

3.6 Optimal Aircraft Routing with Time Windows 124
3.6.1 Fundamentals of Decision-making with Mathematical Programming 124
3.6.2 The Optimizer MOPS 127
3.6.3 Decision Support Systems Based on Mathematical Programming 128
3.6.4 Optimal Aircraft routing with Mixed-integer Programming 129

3.7 Incremental Scheduling 132

3.8 Schedule Simulation 133
3.8.1 Phases of a Simulation Procedure 133
3.8.2 Discrete System Simulation 135
3.8.3 Simulation of a Flight Schedule 136

4 SCHEDULING AS PROCESS-ORIENTED DECISION-MAKING 139

4.1 Components of a Scheduling Problem 139

4.2 Framework for Decision-making 141

4.3 Views of Decision-making 144
4.3.1 Framework for Aspects of Decision-making 144

4.4 Process-oriented Decision-making 150
4.4.1 A Framework for Process-oriented Decision-making 150
4.4.2 Scheduling as a Process 154

4.5 Requirements for a Scheduling Support System 155
4.5.1 The Nature of Scheduling Support 155
4.6 Architecture of a Scheduling Support System 159
4.6.1 Concepts of Problem, Model and Method 159

4.7 Modeling Paradigms for Computer-aided Scheduling 164

5 CONCEPT OF A SCHEDULING WORKBENCH 167

5.1 System Architecture 167

5.2 The Problem-definition Component 172

5.3 Problem and Schedule Management 175

5.4 Algorithmic Scheduling 180

5.5 Incremental Scheduling 184

5.6 The Knowledge Base 190

5.7 Schedule Simulation 194

5.8 Graphical Representation of Schedules 196

5.9 Implementations of the Workbench Concept 196
5.9.1 General Implementation Trends 196
5.9.2 QuickScheduler 198
5.9.3 Group Scheduling Assistant 198
5.9.4 Lufthansa Flight Scheduling Workbench 199
5.9.5 MIT Airline Scheduling Workstation 200

6 COOPERATIVE AIRLINE SCHEDULING 201

6.1 Organization of Distributed Scheduling 201
6.1.1 Applications of Distributed Scheduling in Airlines 201
6.1.2 Process of Schedule Construction 202
6.1.3 The Negotiation Process 204
6.1.4 Organization of Group Scheduling 204

6.2 Approaches to Computer Supported Cooperative Scheduling 208
6.2.1 Scheduling Process as Computer Supported Cooperative Work 208
6.2.2 Techniques in Group Decision Support Systems 211
6.2.3 Planning Methods in Distributed Artificial Intelligence 215

6.2.4 Comparison of Approaches to Scheduling 220
6.3 The System Group Scheduling Assistant 221
6.3.1 Goals and Environment 221
6.3.2 System Architecture 222
6.3.3 Negotiation Processes 224

7 CONCLUSIONS 229

8 LITERATURE 231

APPENDIX: GLOSSARY 247

Figures and Tables

Table 1-1: Operating cost structure of IATA members [AirExe91]. 5
Figure 1-1: An airline timetable (Lufthansa summer 1993). 8
Figure 1-2: Phases in production planning and control. 9
Figure 1-3: The airline scheduling process. 10
Figure 1-4: Organizations of airline schedule design. 11
Figure 1-5: The process of forecasting transportation demand [Teod88]. 16
Figure 1-6: Typical airline networks (Finland, Germany). 19
Figure 1-7: A hub-and-spoke network (United States). 19
Figure 1-8: Fleet types of Lufthansa German Airlines [Lufth92]. 22
Figure 1-9: A schematic process which an aircraft goes through. 23
Figure 1-10: Pairings in crew scheduling. 28
Figure 1-11: Tasks in flight handling at an airport. 34
Figure 1-12: Scheduled gate assignment at an airport. 35
Figure 1-13: Yield management in the airline scheduling process. 37
Figure 2-1: Common framework for route planning models [Still88]. 43
Figure 2-2: Build-a-hub model structure [Still88]. 47
Figure 2-3: Input to the FLASH system. 50
Figure 2-4: The 737 fleet represented in the FLASH system. 50
Figure 2-5: Feasible turns in a fleet allocation problem: A = arrival, D = departure. 52
Figure 2-6: Node aggregation in the time line network: a) the actual network, b) a mathematically equivalent network. 61
Figure 2-7: A typical crew pairing. 63
Figure 2-8: Constraint matrix of a set partitioning problem in staircase form. 68
Figure 2-9: An overview of the crew assignment system TRIP [Anbil91]. 69
Figure 2-10: The TRIP subproblem methodology [Anbil91]. 71
Figure 2-11: The crew rostering process (according to [Mori88]). 75
Figure 2-12: A crew schedule (see [Mori88]). 76
Figure 2-13: A knowledge-based crew rostering system [Mori88]. 77
Figure 2-14: The relationships between scheduled, original-controlled, and revised-controlled times. 89
Figure 2-15: Architecture of the ASAS system [Vasq91]. 90
Figure 3-1: The PUZZLE flight schedule [Frank90]. 98
Figure 3-2: Aircraft routing as a network flow problem. 100
Figure 3-3: A small airline network with block times. 102
Figure 3-4: A daily aircraft routing problem with fixed departure times. 102
Figure 3-5: Solutions to the problem in Fig. 3-4. 103
Figure 3-6: Algorithm for flight scheduling with fixed departure times. 105
Figure 3-7: The basic algorithm ROTATION. 119
Figure 3-8: Architecture of a DSS based on mathematical programming. 129
Figure 3-9: Comparison of heuristic and optimization methods. 131
Figure 4-1: A framework for decision support ([KeeSco78], modified). 143
Figure 4-2: Views of decision-making. 145
Figure 4-3: The decision-making/modeling process [Turb90]. 152

Figure 4-4: Classification of search methods [Turb90]. 153
Figure 4-5: Human and artificial decision-making. 156
Figure 4-6: Concepts for the classification of scheduling problems. 160
Figure 4-7: Architecture of a DSS for scheduling. 162
Figure 4-8: Application areas of modeling paradigms. 166
Figure 5-1: Components of a scheduling workbench. 168
Figure 5-2: Start-up window of SWB. 171
Figure 5-3: SWB main system menu. 171
Figure 5-4: Menu of the Scheduling Workbench component. 172
Figure 5-5: Main menu of the problem definition component DEF. 172
Figure 5-6: The problem-definition window of SWB. 173
Figure 5-7: A resource-definition window of SWB. 173
Figure 5-8: A resource-characterization window of SWB. 173
Figure 5-9: An activity-definition window of SWB. 174
Figure 5-10: A constraint-definition window of SWB. 174
Figure 5-11: An objective-definition window of SWB. 175
Figure 5-12: An input-representation (SHOW) window of SWB. 175
Figure 5-13: Data management within an airline. 176
Figure 5-14: Organization of the schedule generation process. 177
Figure 5-15: A standardized input format to rotation generation. 179
Figure 5-16: Algorithmic scheduling by the NEW option. 180
Figure 5-17: An algorithm running. 181
Figure 5-18: Optimization procedure: a) with MPS input file, b) using the internal format 183
Figure 5-19: The EDIT option. 185
Figure 5-20: The BROWSE option. 186
Figure 5-21: The PROPOSALS option: Generate gaps in rotations. 188
Figure 5-22: The PROPOSALS option: Change cities or times. 189
Figure 5-23: The object structure of flight scheduling [Lufth90]. 191
Figure 5-24: The SIMULATE option. 195
Figure 5-25: Time line at a given airport. 197
Figure 5-26: Browsing two schedules in Group Scheduling Assistant. 199
Figure 6-1: The group scheduling process. 203
Figure 6-2: A sample negotiation process. 205
Figure 6-3: A global schedule from the viewpoint of an individual scheduler. 206
Figure 6-4: Organizations of coordination and data storage. 207
Figure 6-5: Objects and speech acts (example from[Stein93]). 209
Figure 6-6: Architecture of a level-II and level-III GDSS [Sage91]. 212
Figure 6-7: Structure of a NSS for planning ([Jarke87], modified). 214
Figure 6-8: System architecture of Group Scheduling Assistant. 222
Figure 6-9: Conflict detection in Group Scheduling Assistant. 223
Table 6-1: Problem type specific message types of the GSA protocol. 226
Figure 6-10: Possible communication levels during negotiation. 227
Figure 6-11: Negotiation user interface in GSA. 228