Contents

Preface xix
Acknowledgments xxiii

CHAPTER 1: THE POWER OF NEW TECHNOLOGY 1

Why must management focus its resources on new technologies to maintain product competitiveness? This chapter explores answers to that question from the viewpoints of the system manufacturer, the customer, the component technologist, and the systems developer.

The Business View: The Dynamics of Investment 1
The Customer's View: Improved Products and Services 4
The Component and System Developer's View: Faster, Cheaper, Easier, Smaller, and Better Quality 5

CHAPTER 2: LEARNING FROM SYSTEMS PAST 7

This chapter discusses how key advances in component and application technologies from 1950 to the present have shaped computer systems and our view of those systems.

Computer Prices: 1950-1986 7
Key Technology Drivers: 1950-1987 7
From 1950 Through the Early 1960s 8
From the Mid-1960s Through the Early 1970s 10
From the Mid-1970s Through the Late 1970s 11
From 1980 to 1987 12
General System Trends: 1950-1987 14
Mainframes and Supercomputers 16
Midrange Systems 16
Special Systems 17
Personal Computers and Intelligent Work Stations 18
Systems of the Future 18

CHAPTER 3: THE METHODOLOGY OF PROJECTIONS 19

This chapter introduces a methodology for projecting component technology development and system models through the year 2000.

Model Forcing Functions 19
Modeling Component Changes: The Basic Steps 21
Step 1: Define Current Component Specifications 22
Step 2: Define Future Component Directions and Specifications 23
Step 3: Compare Component Specifications 24
Step 4: Assign Weighting Factors and Develop Future System Characteristics 26
Modeling Application Drivers 27
Modeling Other Factors 29
Software and Microcoding 29
Hardware Implementation Structure 30
Performance and Response Time Modeling: A Doublecheck 31
Put It All Together: Modeling System Trends 33

CHAPTER 4: PROJECTING THE COMPONENT TECHNOLOGY DRIVERS 34

What key hardware technologies will drive future systems design? This chapter answers this important question and discusses three possible time frames for total system conversion to the new technologies.

Setting Up the Technology Calendar 34
Overview 34
Selecting the Components and the Time Period 37

Filling in the Component Specifications 37
Logic/Specials 38
Memory 38
Packaging: First Level 38
Packaging: Second Level 39
Power 39
Connections 39
Design Systems 39
Magnetic Files 40
Optical Files 40
Evaluating Alternatives and the Competition 40
Selecting the Design Technologies 42
Plotting the Specifications for the Key Technologies 42
CMOS/GaAs 43
Bipolar Logic 45
Magnetic DASD 45
Optical DASD/Save/Restore (SR) 48
Fiber Optics Links 48
Reviewing the Results 51

CHAPTER 5: CREATING A GENERIC SYSTEM MODEL 52

This chapter discusses a 1987 system structure and develops a generic system model for evaluating the systems driving effects of future technology changes.

Selecting A Design Structure 53
Analyzing the Component Parts of a System 53
Projection Model: Relating the Present to the Future 56
The Example of the Processor 56
All Parts of the System 63
Approximating the Total System 67

CHAPTER 6: A GENERAL SYSTEM PROJECTIONS MODEL: 1987-2000 71

How will the identified technologies affect the cost, performance, capacity, and reliability of future systems? This chapter uses projections for the key hardware technologies in the system model developed in Chapter 5. Then it evaluates how each technology affects system performance, capacity, and reliability.

The System Technology Specifications: 1987-2000 72

System Calculations and Trends for Time Frames 1987-1991, 1987-1995, and 1987-2000 72
System Performance 72
System Capacity 81
System Manufacturing Costs 82
System Reliability 86
System Size Reduction 91
The Next Step 93

CHAPTER 7: FUTURE SYSTEMS DESCRIPTIONS FROM TECHNOLOGY PROJECTIONS 94

This chapter evaluates the cost, capacity, structure, and reliability of projected systems and discusses projections for internal system buses and subsystems (including projections for system response times).

Midrange Systems: An Example Analysis for Future Projections . . . 95
Cost and Capacity: Future Outlook for Midrange Systems . . . 96
Cost and Performance 101
Cost and Cost/Performance Trends with Uniprocessor Systems 108
System Reliability 110
Summary: Midrange System Changes: 1987-2000 111

CHAPTER 8: APPLICATION DRIVER'S EFFECT ON A SYSTEMS MODEL 122

How will emerging application drivers affect the system model? This chapter looks at the effects of knowledge-based (artificial intelligence), merged-voice, image, data, and graphics application drivers.

Overview 122
Natural Language Forms 122
Artificial Intelligence or Knowledge-Based Applications 123
Parallel Processing 123
Distributed Processing and Data Base 123
High Availability Systems 124
Personal Computers 124
Summary of Application Drivers 124
Knowledge-Based Applications 124
Summary: Knowledge-Based Applications 134
Voice, Data, and Image Applications 134
System Changes Caused by Application Drivers 143

I/O Bandwidth 143
System Structures 143
Summary 147

CHAPTER 9: SYSTEM IMPLEMENTATION 148

This chapter presents a view of parallel hardware structures that might be used to implement future computer systems. A summary of the projected performance and cost/performance effects are presented.

Basic Systems Interconnections: Bandwidth Growth 149
1986-1987 149
1987-1991 151
1991-2000 151
Parallel Processing: State of the Art 152
Uniprocessors and Parallel Processors: A View Into the Future . . . 154
Multiple Processor and Subsystems: A Future Approach to Achieve Parallelism 161
A System Developer's Approach to Getting Parallel System Architecture 165
System A Model 165
System B Model 169
Parallel Integrated Systems: An Alternative Structure 170
A System Developer's Approach to Getting Parallel Integrated System Architecture 171
System A Model 171
System B Model 174
Parallel Architecture Performance Advantage 177
Performance Prediction: 1987-2000 179
External System Connections for High Bandwidth 181
Summary: Future Systems Structures 185

CHAPTER 10: SYSTEM SOFTWARE AND MICROCODE ARCHITECTURE 187

How do software and microcoding changes affect system modeling? This chapter presents the histories and futures of software and microcoding as they have and will relate to the challenges of technology change.

History 188
Operating System Transparency to Hardware 192
Single-Level Storage 192
Object Orientation 192

Full Relational Data Base 192
Futures 193
User Interface Simplicity 193
Application Portability 193
Distributed Systems in Networks 194
Parallel Processing 195
Compute Intensive Applications 197
Problem-Solving Characteristics 197

CHAPTER 11: SUMMARY OF SYSTEM TRENDS 200

This chapter helps put the first ten chapters in perspective It summarizes modeling results from 1987 to 2000 from a total system view point.

The Business View: Customers and End Users 200
Value of Reduced System Price 202
Performance, Reliability and Capacity 202
Natural Language Forms 203
New Applications and Portability 204
Distribution Systems Intercommunications 205
The Systems Developers and Technologists Views 205
Reduced Cost With Increased Performance, Capacity, and Reliability 206
Natural Language Forms 208
New Applications, Portability, and Distributed Systems 209
Technology Growth: The Driver of Systems Changes 209
Technology Performance Drivers 210
Technology Capacity Drivers 210
Technology Cost Drivers 210
Technology Reliability Drivers 211
Application Drivers 211
Summary of Key System Drivers 211
1987-1991 212
1991-1995 213
1995-2000 214
Continued System Trends: 1988-2000 215
Mainframe and Super Computers 215
Midrange Systems 217
Special Systems 220
Personal Computers 221
Industry View of System Trends: 1950-2000 222
Large Systems: 1950 222
Application-Driven and Interactive Systems: 1969 224
Minicomputers: 1977 224

Personal Computers: 1980 225
Distributed Systems and Telephony: 1987 225
Application Portability and Knowledge-Based Systems: 1991 226
Parallel Processing and Commodity-Level Systems: 1995-2000 226

APPENDIX A: HARDWARE TECHNOLOGY SPECIFICATIONS: 1987-2000 228

This appendix presents the hardware specifications used to develop the generic system model in Chapter 6. The specifications change over three time frames: 1987-1991, 1987-1995, and 1987-2000.

System Capacity Calculation: 1987-2000 228
System Manufacturing Cost Calculation: 1987-2000 231
System Reliability Calculation: 1987-2000 235
System Size Calculation: 1987-2000 241

APPENDIX B: RESPONSE TIME MODEL 245

This appendix presents the approximation model used to make quantitative projections about how new technologies will affect computer system response times.

Model Description 246
Response Time Calculations 252

APPENDIX C: PERFORMANCE MODEL 259

This appendix presents the model used to analyze the performance and capacity of the projected system model. System characteristics such as bus rates, processor performance, transaction rates, and storage capacities are considered.

Model Description 259
Major Relationships 261
MIPS Calculation 261
Transactions Per Hour Calculation 262
DASD/SR Capacity Calculation 263
Memory Capacity Calculation 263
Detailed Performance, Cost, and Response Time Calculation 264

Calculations for the Data Contained in Figures C.3 and C.4 265
Processor MIPs 265
Transactions Per Hour Calculation 266
Communications and Number of End Users 266
DASD/SR 266
Memory 267
Cost Additions 267

BIBLIOGRAPHY 270

References Cited 270
Supplemental Reading 271

INDEX 273

Figures

		Page
1.1	Single-Product Value Increase for Investment Effort	1
1.2	Idealized Successive Product Life Cycles in a Business System	2
2.1	Key Technology Drivers: 1950-1987	9
2.2	IBM System Trends: 1950-1987	15
3.1	Methodology Model	20
3.2	Current System's Component Parts	22
3.3	Current System's Component Specification Categories	23
3.4	Structure for Listing Future Component Specifications	24
3.5	Diagrammed Integration of Current and Projected Component Specifications into Future Systems Specifications	25
3.6	Difference Between Future and Current Component Technologies Equals Projected Component Changes	25
3.7	The Position of Weighting Factors in Projecting System Parameters	26
3.8	Feedback Effects from Future Systems Model to Component Technology	27
3.9	Feedback Effects from Future Systems Model to Application Drivers	28
3.10	Feedback Effects from Future Component Technology to Future Systems	29

3.11	Feedback Effects of Future System Projections on Other Factors that Affect Current Systems	30
3.12	Performance Model	32
3.13	Response Time Model	32
3.14	Primary Factors Affecting Future System Trends	33
4.1a	Technology Calendar: 1986-1991	35
4.1b	Technology Calendar: 1991-2000	36
4.2	Competitor's Position on the Technology Calendar: 1986-1991	41
4.3	Aggregate Component Technologies for the System Model	43
4.4a-e	Trends In CMOS Logic and Memory Technology: 1986-2000	44
4.5a-d	Trends in Bipolar Logic 1986-2000	46
4.6	Trends in DASD Magnetic File Technology: 1986-2000	47
4.7a-d	Trends in DASD/SR Optical File Technology: 1986-2000	49
4.8a-c	Trends in Fiber Optic Links: 1970-2000	50
5.1	Generic System Hardware Model	54
5.2	Logic Circuit CMOS Chip Specification: 1987-1991	55
5.3	CMOS Specifications and i_c/i_f Ratios: 1987-1991	58
5.4	Summary of Processor Trend Calculation Results	60
5.5	Steps in Processor Model Calculations	61
5.6	Model Equations for All System Parts	64
5.7	CMOS Specifications and i_c/i_f Ratios for System Memory: 1987-1991	65
5.8	System Memory Comparisons: 1987-1991	67
5.9	System Performance Calculation: 1987-1991	69
6.1	Systems Technology Calendar: 1987-2000	73
6.2	System Performance Calculation: 1987-1991	74
6.3	System Performance Calculation: 1987-1995	75
6.4	System Performance Calculation: 1987-2000	76
6.5a-b	Trends in System Performance: System/Parts Performance Improvement Indicators	79
6.6a-b	Trends in System Performance: Transaction Per Hour and MIPs	80
6.7a-b	Trends in System Capacity	83
6.8a-b	Trends in System Costs	84
6.8c	Trends in System Cost Reduction	85
6.9a-b	System Reliability Improvement	88
6.9c	Component Technology Reliability Improvement	89
6.9d	Component Density vs Component Reliability Ratios	90
6.10	Example of CMOS Density and Reliability Indicators	91
6.11	Trends in System Size Reduction	92

7.1	Midrange Cost/Performance Example	95
7.2	System Cost and Capacity for Two Midrange Systems—1987	96
7.3	Midrange System Density/Capacity Calculation: 1987-2000 (Constant Cost)	97
7.4	Midrange System Cost Calculation: 1987-2000 (Fixed Design Point)	98
7.5	$6,000 System A Changes: 1987-2000	99
7.6	$100,000 System B Changes: 1987-2000	100
7.7	System Capacity Changes: 1987-2000	102
7.8	Entry System A Cost/Performance Trends: 1987-2000	104
7.9a-b	Entry System A Performance and Response Time: 1987-2000	105
7.10	High-End System B Cost/Performance Trends: 1987-2000	106
7.11a-b	High-End System B Performance and Response Time: 1987-2000	107
7.12	Computer Price and Cost Decrease Rate Per Year: 1970-2000	109
7.13	Midrange System Reliability Calculation: 1987-2000	110
7.14	System A Changes (Including Reliability): 1987-2000	112
7.15	System B Changes (Including Reliability): 1987-2000	113
7.16	Entry System A Cost/Performance/Reliability Trends: 1987-2000	114
7.17	High-End System B: Cost/Performance/Reliability Trends: 1987-2000	115
7.18a-b	Midrange System Summary: 1987-2000	116
7.19	System Trend	117
7.20	Future Midrange System Trends	120
8.1	Typical Software Operating System	126
8.2	Knowledge-Based Example	127
8.3a-b	Expert Systems—CPU MIPS Requirements Small Rules Base: Applications 1 and 2	128
8.4a-b	Expert System—CPU MIPS Requirements Large Rule Base: Application 3 (Subapplications 3-7)	129
8.5	MIPS Required for Knowledge-Based Applications Versus Technology Capability	131
8.6	Knowledge-Based Application 2 Calculation: 27 Rules/Transaction	132
8.7	Knowledge-Based Application 3 Calculation: 1400 Rules/Transaction	133
8.8	Cooperative Processing Bandwidth Model	134
8.9	Telecommunications Applications	136

8.10 Average Number of Bytes per Transaction for Selected Application Types . . . 137
8.11 Projected Weighted Average of Number of Bytes per User Transaction for Mixed Application Types: 1987-2000 . . . 138
8.12 MIPS Calculation for Natural Languages . . . 138
8.13 Processor MIPS Required for Voice, Image, and Data Applications . . . 140
8.14a-b Voice, Image Effect on Transaction Rate and Cost of Transaction . . . 141
8.15 User Information Growth Per Transaction . . . 142
8.16 Application Driver Effects on Systems and Technology . . . 144
8.17 Convergence of Semiconductor and DASD Costs . . . 146

9.1 System Hardware Trends . . . 150
9.2 Parallel Processing—Tightly Coupled Microprocessor . . . 153
9.3 Parallel Processing—Very Long Instruction Word Processor . . . 153
9.4 Parallel Processing—Arrayed Processors . . . 154
9.5 Example Uniprocessor Specifications . . . 155
9.6 Uniprocessor MIPS Calculation . . . 156
9.7 Uniprocessor MIP Trends . . . 157
9.8a-b Memory/Processor—1 Chip . . . 159
9.9 Memory/Processor Capacities Per Chip . . . 160
9.10 Processor/Memory Costs . . . 162
9.11 System Circuit and Memory Count . . . 163
9.12 Multiple Processor, Multisubsystems Chips . . . 164
9.13 Multiprocessor, Multisubsystem Architecture . . . 166
9.14 Chip Distribution for System A Multiprocessor in the Year 2000 . . . 168
9.15 System A Multiprocessor Specifications Range for Design Points in the Year 2000 . . . 168
9.16 Chip Distribution for System B Multiprocessor in the Year 2000 . . . 169
9.17 System B Multiprocessor Specifications Range for Design Points in the Year 2000 . . . 169
9.18 Normalized Transaction Size for System A and B . . . 170
9.19 Parallel Integration System Chips . . . 172
9.20 Parallel Integrated Systems . . . 173
9.21 Chip Distribution, System A Multi-CEC in Year 2000 . . . 174
9.22 Parallel Integrated Systems View . . . 175
9.23 System A Multi-CEC Specifications Range for Design Points in the Year 2000 . . . 176
9.24 Chip Distribution, System B Multi-CEC in the Year 2000 . . . 176

9.25 System B Multi-CEC Specification Range for Design Points in the Year 2000 176
9.26 Normalized Transaction Size for Systems A and B Using 1987 and the Year 2000 Transaction Information Densities 177
9.27a-b Improved Performance and Response Trends: 1987-2000 . . 178
9.28 Summary of System Performance Projection: 1987-2000 . . 180
9.29 Ring Configuration for High Bandwidth Fiber Optic LAN or WAN Networks 181
9.30 Single-Fiber Star Network for High Bandwidth 182
9.31 Optical Cross-Bar Switch Network for High Bandwidth . . . 183
9.32a-b Cluster Connections in System Networks 184

10.1 Early 1950s Application Programmer's System Viewpoint . . 189
10.2 Mid-1960s System With Operating System 189
10.3 Early 1970s System With Distributed Subsystems Processors 190
10.4 Late 1970s to Early 1980s Application-Driven System 190
10.5 Systems Software and Microcode Architecture 191
10.6 System Application Architecture (SAA) 194
10.7 Internal System Communication Enhancement 195
10.8 Transmission Data Rates 196
10.9 External Network Communications Enhancement 197
10.10 Subsystem-to-Subsystem Transfer of Noncoded Information 198

11.1 Future System Trends: 1987-2000 201
11.2 Key Technology Drivers 212
11.3 Key System Trends: 1987-2000 216
11.4 Summary of System Trends: 1950-2000 223

A.1 System Capacity Calculations: 1987-1991 229
A.2 System Capacity Calculations: 1987-1995 230
A.3 System Capacity Calculations: 1987-2000 230
A.4 System Cost Reduction Calculations: 1987-1991 232
A.5 System Cost Reduction Calculations: 1987-1995 233
A.6 System Cost Reduction Calculations: 1987-2000 234
A.7 Summary of Cost Reduction Calculations: 1987-2000 . . . 235
A.8 System Reliability Calculations: 1987-1991 238
A.9 System Reliability Calculations: 1991-1995 239
A.10 System Reliability Calculations: 1995-2000 240
A.11 Summary of Reliability Calculations: 1987-2000 241
A.12 System Size Calculations: 1987-1991 242
A.13 System Size Calculations: 1991-1995 243
A.14 System Size Calculations: 1995-2000 244

A.15 Summary of System Size Calculations: 1987-2000 244

B.1 Response Time Model 247
B.2 Relation of Aggregate System Response Times to Total User's Response Time 248
B.3 Response Times of a System Without Queuing 249
B.4 Response Times of a System With Queuing 249
B.5 Response Times of a Saturated System 250
B.6 Response Time Characteristics/Definitions 251
B.7 Sample System for Response Time Calculation 253
B.8 Response Time Calculation Results 257

C.1 Performance Model Definition 260
C.2 Total Performance Relationships 262
C.3 Entry-Level Midrange System Cost/Performance Calculations 264
C.4 High-End Midrange System Cost/Performance Calculations 265
C.5 Entry-Level Midrange System A Response Time Calculations 267
C.6 High-End Midrange System B Response Time Calculations 268