

INTERNATIONAL EDITION

THIRD EDITION

PRODUCT DESIGN AND DEVELOPMENT



KARL T. ULRICH
STEVEN D. EPPINGER

Contents

Chapter 1

Introduction 1

Characteristics of Successful Product Development	2
Who Designs and Develops Products?	3
Duration and Cost of Product Development	5
The Challenges of Product Development	6
Approach of This Book	6
<i>Structured Methods</i>	7
<i>Industrial Examples</i>	7
<i>Organizational Realities</i>	7
<i>Road Map of the Book</i>	8
References and Bibliography	10
Exercises	10
Thought Question	10

Chapter 2

Development Processes and Organizations 11

A Generic Development Process	12
Concept Development: The Front-End Process	16
Adapting the Generic Product Development Process	18
<i>Technology-Push Products</i>	18
<i>Platform Products</i>	20
<i>Process-Intensive Products</i>	20
<i>Customized Products</i>	20
<i>High-Risk Products</i>	20
<i>Quick-Build Products</i>	21
<i>Complex Systems</i>	21
Product Development Process Flows	22
The AMF Development Process	22
Product Development Organizations	23
<i>Organizations Are Formed by Establishing Links among Individuals</i>	23

Organizational Links May Be Aligned with Functions, Projects, or Both 25

Choosing an Organizational Structure 26

The AMF Organization	28
Summary	30
References and Bibliography	30
Exercises	31
Thought Questions	32

Chapter 3

Product Planning 33

The Product Planning Process	34
<i>Four Types of Product Development Projects</i>	35
<i>The Process</i>	36
Step 1: Identify Opportunities	37
Step 2: Evaluate and Prioritize Projects	38
<i>Competitive Strategy</i>	38
<i>Market Segmentation</i>	39
<i>Technological Trajectories</i>	40
<i>Product Platform Planning</i>	40
<i>Evaluating Fundamentally New Product Opportunities</i>	42
<i>Balancing the Portfolio</i>	43
Step 3: Allocate Resources and Plan Timing	43
<i>Resource Allocation</i>	44
<i>Project Timing</i>	45
<i>The Product Plan</i>	45
Step 4: Complete Pre-Project Planning	45
<i>Mission Statements</i>	47
<i>Assumptions and Constraints</i>	48
<i>Staffing and Other Pre-Project Planning Activities</i>	49
Step 5: Reflect on the Results and the Process	49
Summary	50
References and Bibliography	50
Exercises	52
Thought Questions	52

Chapter 4

Identifying Customer Needs 53

- Step 1: Gather Raw Data from Customers 56
 - Choosing Customers* 58
 - The Art of Eliciting Customer Needs Data* 59
 - Documenting Interactions with Customers* 60
- Step 2: Interpret Raw Data in Terms of Customer Needs 61
- Step 3: Organize the Needs into a Hierarchy 63
- Step 4: Establish the Relative Importance of the Needs 66
- Step 5: Reflect on the Results and the Process 67
- Summary 68
- References and Bibliography 68
- Exercises 69
- Thought Questions 70

Chapter 5

Product Specifications 71

- What Are Specifications? 72
- When Are Specifications Established? 73
- Establishing Target Specifications 74
 - Step 1: Prepare the List of Metrics* 75
 - Step 2: Collect Competitive Benchmarking Information* 79
 - Step 3: Set Ideal and Marginally Acceptable Target Values* 79
 - Step 4: Reflect on the Results and the Process* 83
- Setting the Final Specifications 83
 - Step 1: Develop Technical Models of the Product* 85
 - Step 2: Develop a Cost Model of the Product* 86
 - Step 3: Refine the Specifications, Making Trade-Offs Where Necessary* 88
 - Step 4: Flow Down the Specifications as Appropriate* 89
 - Step 5: Reflect on the Results and the Process* 91
- Summary 91
- References and Bibliography 92
- Exercises 93
- Thought Questions 93

Appendix

Target Costing 94

Chapter 6

Concept Generation 97

- The Activity of Concept Generation 98
 - Structured Approaches Reduce the Likelihood of Costly Problems* 99
 - A Five-Step Method* 99
- Step 1: Clarify the Problem 100
 - Decompose a Complex Problem into Simpler Subproblems* 101
 - Focus Initial Efforts on the Critical Subproblems* 103
- Step 2: Search Externally 104
 - Interview Lead Users* 104
 - Consult Experts* 105
 - Search Patents* 105
 - Search Published Literature* 106
 - Benchmark Related Products* 107
- Step 3: Search Internally 107
 - Both Individual and Group Sessions Can Be Useful* 108
 - Hints for Generating Solution Concepts* 109
- Step 4: Explore Systematically 110
 - Concept Classification Tree* 112
 - Concept Combination Table* 114
 - Managing the Exploration Process* 117
- Step 5: Reflect on the Results and the Process 119
- Summary 120
- References and Bibliography 121
- Exercises 122
- Thought Questions 122

Chapter 7

Concept Selection 123

- Concept Selection Is an Integral Part of the Product Development Process 124
- All Teams Use Some Method for Choosing a Concept 125
- A Structured Method Offers Several Benefits 128
- Overview of Methodology 129
- Concept Screening 130
 - Step 1: Prepare the Selection Matrix* 130
 - Step 2: Rate the Concepts* 131
 - Step 3: Rank the Concepts* 132
 - Step 4: Combine and Improve the Concepts* 132

Step 5: Select One or More Concepts	132
Step 6: Reflect on the Results and the Process	133
Concept Scoring	134
Step 1: Prepare the Selection Matrix	134
Step 2: Rate the Concepts	135
Step 3: Rank the Concepts	136
Step 4: Combine and Improve the Concepts	136
Step 5: Select One or More Concepts	136
Step 6: Reflect on the Results and the Process	137
Caveats	137
Summary	139
References and Bibliography	139
Exercises	140
Thought Questions	141
Appendix A Concept-Screening Matrix Example	142
Appendix B	
Concept-Scoring Matrix Example	143
 Chapter 8	
Concept Testing	145
Step 1: Define the Purpose of the Concept Test	147
Step 2: Choose a Survey Population	147
Step 3: Choose a Survey Format	148
Step 4: Communicate the Concept	149
<i>Matching the Survey Format with the Means of Communicating the Concept</i>	153
<i>Issues in Communicating the Concept</i>	153
Step 5: Measure Customer Response	155
Step 6: Interpret the Results	155
Step 7: Reflect on the Results and the Process	158
Summary	159
References and Bibliography	159
Exercises	160
Thought Questions	160
Appendix	
Estimating Market Sizes	161
 Chapter 9	
Product Architecture	163
What Is Product Architecture?	164
<i>Types of Modularity</i>	166
<i>When Is the Product Architecture Defined?</i>	167

Implications of the Architecture	167
<i>Product Change</i>	167
<i>Product Variety</i>	168
<i>Component Standardization</i>	169
<i>Product Performance</i>	169
<i>Manufacturability</i>	170
<i>Product Development Management</i>	171
Establishing the Architecture	171
Step 1: Create a Schematic of the Product	172
Step 2: Cluster the Elements of the Schematic	173
Step 3: Create a Rough Geometric Layout	175
Step 4: Identify the Fundamental and Incidental Interactions	176
Delayed Differentiation	177
Platform Planning	180
<i>Differentiation Plan</i>	180
<i>Commonality Plan</i>	181
<i>Managing the Trade-Off between Differentiation and Commonality</i>	181
Related System-Level Design Issues	182
<i>Defining Secondary Systems</i>	182
<i>Establishing the Architecture of the Chunks</i>	183
<i>Creating Detached Interface Specifications</i>	183
Summary	184
References and Bibliography	184
Exercises	186
Thought Questions	186
 Chapter 10	
Industrial Design	187
What Is Industrial Design?	189
Assessing the Need for Industrial Design	191
<i>Expenditures for Industrial Design</i>	191
<i>How Important Is Industrial Design to a Product?</i>	191
<i>Ergonomic Needs</i>	192
<i>Aesthetic Needs</i>	193
The Impact of Industrial Design	193
<i>Is Industrial Design Worth the Investment?</i>	193
<i>How Does Industrial Design Establish a Corporate Identity?</i>	196
The Industrial Design Process	196
<i>Investigation of Customer Needs</i>	197
<i>Conceptualization</i>	197

<i>Preliminary Refinement</i>	198
<i>Further Refinement and Final Concept Selection</i>	198
<i>Control Drawings</i>	199
<i>Coordination with Engineering, Manufacturing, and External Vendors</i>	199
<i>The Impact of Computer-Based Tools on the ID Process</i>	200
Management of the Industrial Design Process	201
<i>Timing of Industrial Design Involvement</i>	202
Assessing the Quality of Industrial Design	203
1. <i>Quality of the User Interfaces</i>	204
2. <i>Emotional Appeal</i>	205
3. <i>Ability to Maintain and Repair the Product</i>	205
4. <i>Appropriate Use of Resources</i>	205
5. <i>Product Differentiation</i>	206
Summary	206
References and Bibliography	206
Exercises	208
Thought Questions	208
 Chapter 11	
Design for Manufacturing	209
Design for Manufacturing Defined	211
<i>DFM Requires a Cross-Functional Team</i>	211
<i>DFM Is Performed throughout the Development Process</i>	211
<i>Overview of the DFM Process</i>	212
Step 1: Estimate the Manufacturing Costs	212
<i>Fixed Costs versus Variable Costs</i>	215
<i>The Bill of Materials</i>	215
<i>Estimating the Costs of Standard Components</i>	216
<i>Estimating the Costs of Custom Components</i>	217
<i>Estimating the Cost of Assembly</i>	218
<i>Estimating the Overhead Costs</i>	219
Step 2: Reduce the Costs of Components	220
<i>Understand the Process Constraints and Cost Drivers</i>	220
<i>Redesign Components to Eliminate Processing Steps</i>	221
<i>Choose the Appropriate Economic Scale for the Part Process</i>	221
<i>Standardize Components and Processes</i>	222
<i>Adhere to "Black Box" Component Procurement</i>	223
Step 3: Reduce the Costs of Assembly	223
<i>Keeping Score</i>	224
<i>Integrate Parts</i>	224
<i>Maximize Ease of Assembly</i>	225
<i>Consider Customer Assembly</i>	226
Step 4: Reduce the Costs of Supporting Production	226
<i>Minimize Systemic Complexity</i>	227
<i>Error Proofing</i>	227
Step 5: Consider the Impact of DFM Decisions on Other Factors	228
<i>The Impact of DFM on Development Time</i>	228
<i>The Impact of DFM on Development Cost</i>	228
<i>The Impact of DFM on Product Quality</i>	229
<i>The Impact of DFM on External Factors</i>	229
Results	229
Summary	231
References and Bibliography	232
Exercises	233
Thought Questions	233
Appendix A	
Materials Costs	235
Appendix B	
Component Manufacturing Costs	236
Appendix C	
Assembly Costs	242
Appendix D	
Cost Structures	243
 Chapter 12	
Prototyping	245
Prototype Basics	246
<i>What Is a Prototype?</i>	246
<i>Types of Prototypes</i>	247
<i>What Are Prototypes Used For?</i>	249
Principles of Prototyping	252
<i>Analytical Prototypes Are Generally More Flexible than Physical Prototypes</i>	252
<i>Physical Prototypes Are Required to Detect Unanticipated Phenomena</i>	252
<i>A Prototype May Reduce the Risk of Costly Iterations</i>	252
<i>A Prototype May Expedite Other Development Steps</i>	253

<i>A Prototype May Restructure Task Dependencies</i>	255
Prototyping Technologies	255
3D Computer Modeling	255
Free-Form Fabrication	256
Planning for Prototypes	257
Step 1: Define the Purpose of the Prototype	257
Step 2: Establish the Level of Approximation of the Prototype	258
Step 3: Outline an Experimental Plan	259
Step 4: Create a Schedule for Procurement, Construction, and Testing	259
Planning Milestone Prototypes	259
Summary	261
References and Bibliography	261
Exercises	262
Thought Questions	263

Chapter 13

Robust Design 265

What Is Robust Design?	266
Design of Experiments	268
The Robust Design Process	269
Step 1: Identify Control Factors, Noise Factors, and Performance Metrics	269
Step 2: Formulate an Objective Function	270
Step 3: Develop the Experimental Plan	271
Experimental Designs	271
Testing Noise Factors	273
Step 4: Run the Experiment	275
Step 5: Conduct the Analysis	275
Computing the Objective Function	275
Computing Factor Effects by Analysis of Means	276
Step 6: Select and Confirm Factor Setpoints	277
Step 7: Reflect and Repeat	277
Caveats	278
Summary	278
References and Bibliography	279
Exercises	280
Thought Questions	280
Appendix	
Orthogonal Arrays	281

Chapter 14

Patents and Intellectual Property 285

What Is Intellectual Property?	286
Overview of Patents	287
Utility Patents	288
Preparing a Disclosure	288
Step 1: Formulate a Strategy and Plan	290
Timing of Patent Applications	290
Type of Application	291
Scope of Application	292
Step 2: Study Prior Inventions	292
Step 3: Outline Claims	293
Step 4: Write the Description of the Invention	294
Figures	295
Writing the Detailed Description	295
Defensive Disclosure	296
Step 5: Refine Claims	297
Writing the Claims	297
Guidelines for Crafting Claims	300
Step 6: Pursue Application	300
Step 7: Reflect on the Results and the Process	302
Summary	302
References and Bibliography	303
Exercises	303
Thought Questions	303
Appendix A	
Trademarks	304
Appendix B	
Advice to Individual Inventors	304

Chapter 15

Product Development Economics 307

Elements of Economic Analysis	308
Quantitative Analysis	308
Qualitative Analysis	308
When Should Economic Analysis Be Performed?	309
Economic Analysis Process	310
Step 1: Build a Base-Case Financial Model	310
Estimate the Timing and Magnitude of Future Cash Inflows and Outflows	310
Compute the Net Present Value of the Cash Flows	312

<i>The Base-Case Financial Model Can Support Go/No-Go Decisions and Major Investment Decisions</i>	313
Step 2: Perform Sensitivity Analysis	313
<i>Development Cost Example</i>	314
<i>Development Time Example</i>	315
Step 3: Use Sensitivity Analysis to Understand Project Trade-Offs	316
<i>Six Potential Interactions</i>	316
<i>Trade-Off Rules</i>	318
<i>Limitations of Quantitative Analysis</i>	319
Step 4: Consider the Influence of the Qualitative Factors on Project Success	320
<i>Projects Interact with the Firm, the Market, and the Macro Environment</i>	320
Carrying Out Qualitative Analysis	322
Summary	323
References and Bibliography	324
Exercises	325
Thought Questions	325
Appendix A	
Time Value of Money and the Net Present Value Technique	325
Appendix B	
Modeling Uncertain Cash Flows Using Net Present Value Analysis	328

Chapter 16

Managing Projects 331

Understanding and Representing Tasks	332
<i>Sequential, Parallel, and Coupled Tasks</i>	332
<i>The Design Structure Matrix</i>	334
<i>Gantt Charts</i>	335
<i>PERT Charts</i>	336
<i>The Critical Path</i>	336
Baseline Project Planning	337
<i>The Contract Book</i>	337
<i>Project Task List</i>	337
<i>Team Staffing and Organization</i>	339
<i>Project Schedule</i>	340
<i>Project Budget</i>	341
<i>Project Risk Plan</i>	341
<i>Modifying the Baseline Plan</i>	342
Accelerating Projects	343
Project Execution	346
<i>Coordination Mechanisms</i>	346
<i>Assessing Project Status</i>	349
<i>Corrective Actions</i>	349
Postmortem Project Evaluation	350
Summary	351
References and Bibliography	352
Exercises	354
Thought Questions	354
Appendix	
Design Structure Matrix Example	354

Index 357