Book: Product Design and Development
Author(s): Karl Ulrich and Steven D. Eppinger

Ch. 1: Roadmap/Phases of Product Development

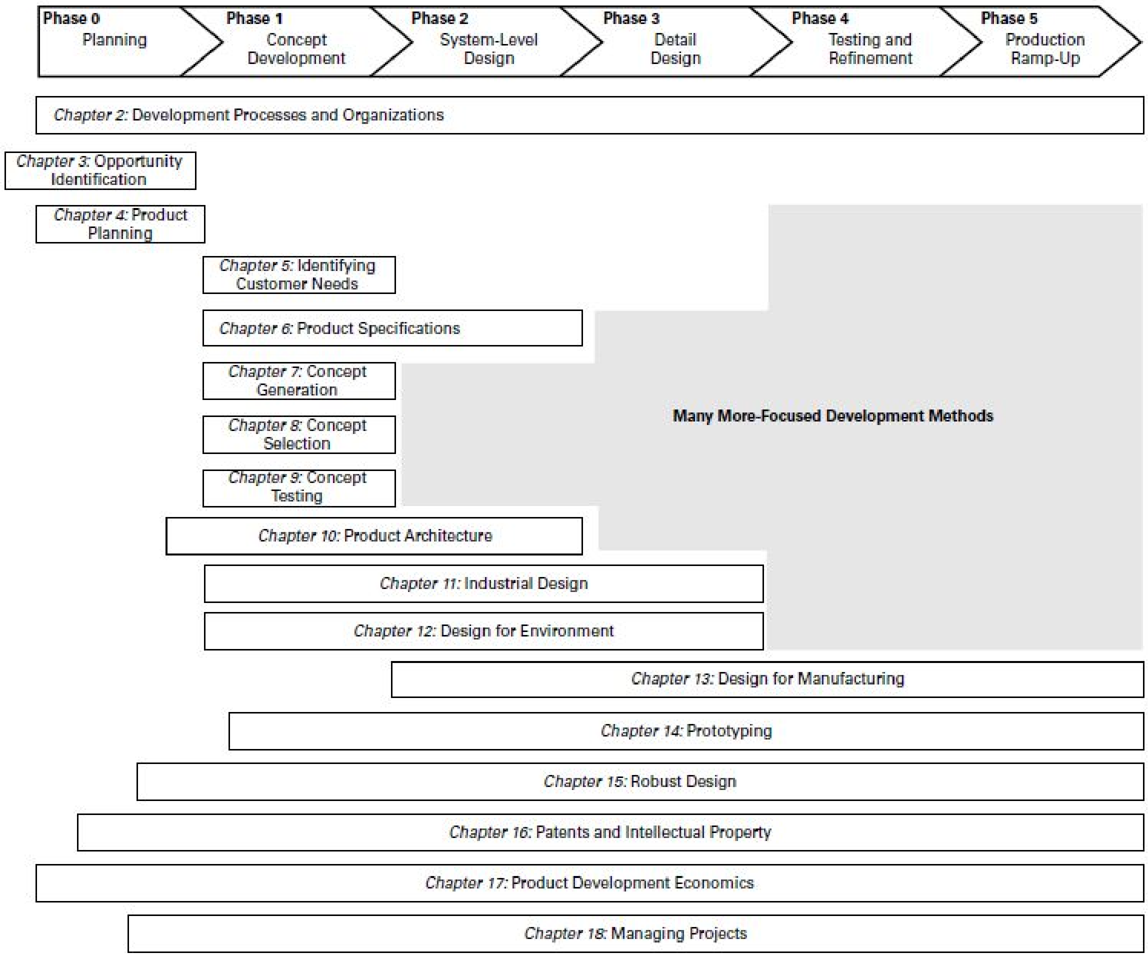


EXHIBIT 1-4 The product development process. The diagram shows where each of the integrative methods presented in the remaining chapters is most applicable.

Ch.2 → The Concept Development Process:

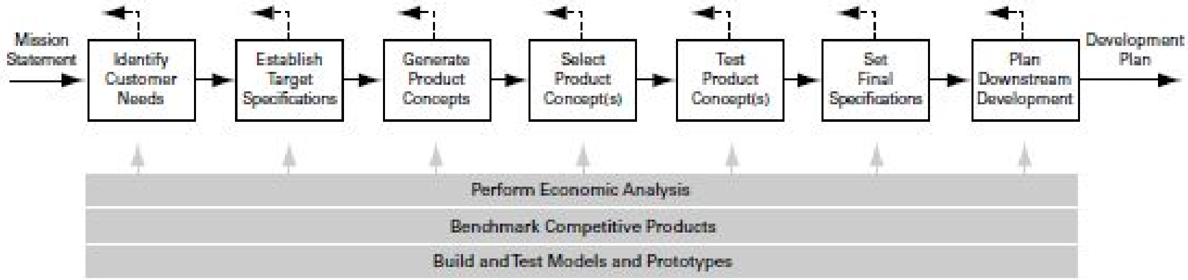
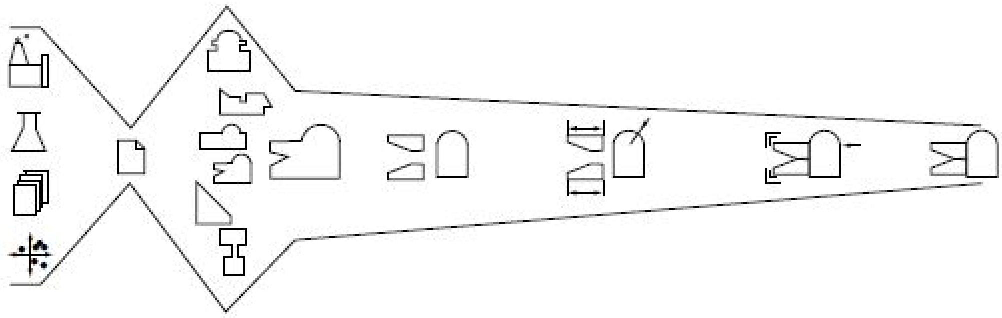


EXHIBIT 2-3 The many front-end activities comprising the concept development phase.



	Planning	Concept Development	System-Level Design	Detail Design	Testing and Refinement	Production Ramp-Up
Marketing	• Articulate market opportunity. • Define market segments.	• Collect customer needs. • Identify lead users. • Identify competitive products.	• Develop plan for product options and extended product family.	• Develop marketing plan.	• Develop promotion and launch materials. • Facilitate field testing.	• Place early production with key customers.
Design	• Consider product platform and architecture. • Assess new technologies.	• Investigate feasibility of product concepts. • Develop industrial design concepts. • Build and test experimental prototypes.	• Develop product architecture. • Define major sub-systems and interfaces. • Refine industrial design. • Preliminary component engineering.	• Define part geometry. • Choose materials. • Assign tolerances. • Complete industrial design control documentation.	• Test overall performance, reliability, and durability. • Obtain regulatory approvals. • Assess environmental impact. • Implement design changes.	• Evaluate early production output.
Manufacturing	• Identify production constraints. • Set supply chain strategy.	• Estimate manufacturing cost. • Assess production feasibility.	• Identify suppliers for key components. • Perform make-buy analysis. • Define final assembly scheme.	• Define piece-part production processes. • Design tooling. • Define quality assurance processes. • Begin procurement of long-lead tooling.	• Facilitate supplier ramp-up. • Refine fabrication and assembly processes. • Train workforce. • Refine quality assurance processes.	• Begin full operation of production system.
Other Functions	• Research: Demonstrate available technologies. • Finance: Provide planning goals. • General Management: Allocate project resources.	• Finance: Facilitate economic analysis. • Legal: Investigate patent issues.	• Finance: Facilitate make-buy analysis. • Service: Identify service issues.		• Sales: Develop sales plan.	• General Management: Conduct postproject review.

EXHIBIT 2-2 The generic product development process. Six phases are shown, including some of the typical tasks and responsibilities of the key business functions for each phase.

Process Type	Description	Distinct Features	Examples
Generic (Market-Pull) Products	The team begins with a market opportunity and selects appropriate technologies to meet customer needs.	Process generally includes distinct planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up phases.	Sporting goods, furniture, tools.
Technology-Push Products	The team begins with a new technology, then finds an appropriate market.	Planning phase involves matching technology and market. Concept development assumes a given technology.	Gore-Tex rainwear, Tyvek envelopes.
Platform Products	The team assumes that the new product will be built around an established technological subsystem.	Concept development assumes a proven technology platform.	Consumer electronics, computers, printers.
Process-Intensive Products	Characteristics of the product are highly constrained by the production process.	Either an existing production process must be specified from the start, or both product and process must be developed together from the start.	Snack foods, breakfast cereals, chemicals, semiconductors.
Customized Products	New products are slight variations of existing configurations.	Similarity of projects allows for a streamlined and highly structured development process.	Motors, switches, batteries, containers.
High-Risk Products	Technical or market uncertainties create high risks of failure.	Risks are identified early and tracked throughout the process. Analysis and testing activities take place as early as possible.	Pharmaceuticals, space systems.
Quick-Build Products	Rapid modeling and prototyping enables many design-build-test cycles.	Detail design and testing phases are repeated a number of times until the product is completed or time/budget runs out.	Software, cellular phones.
Complex Systems	System must be decomposed into several subsystems and many components.	Subsystems and components are developed by many teams working in parallel, followed by system integration and validation.	Airplanes, jet engines, automobiles.

EXHIBIT 2-4 Summary of variants of generic product development process.

Rally Point Phase	0. Project Registration	1. Concept Definition	2. Feasibility and Planning	3. Preliminary Design	4. Final Design	5. Product Verification	6. Process Verification	7. Launch	8. Post-Launch Assessment
Primary Goal	Define project and business unit needs	Develop project concept and charter	Create product description	Create preliminary detailed design	Detail and optimize design	Demonstrate product performance	Demonstrate process performance	Launch product	Identify lessons learned
Marketing and Sales	Identify customers and market size Describe competitive features and benefits Identify target cost and price	Capture voice of the customer Analyze customer needs Document customer needs	Develop marketing and sales plans Create phase-in and phase-out plans	Review concepts with customers		Initialize field trials	Complete field trials Finalize training plans	Finalize pricing and sales forecasts Complete sales and service training	Solicit customer feedback and satisfaction ratings Measure sales vs. forecast Complete phase-in and phase-out
Engineering	Identify project risks	Identify critical-to-quality specs Develop and select concepts Update project risks	Create functional specification and performance metrics Review concept selection Define product architecture Assess technical failures modes	Conduct a preliminary design review Build and test alpha prototypes Assess product failure modes	Freeze hardware and software design Complete engineering documentation Draft technical documentation Secure beta prototypes	Finalize design documentation Complete beta prototype and field testing Apply for regulatory approvals	Obtain regulatory approvals	Finalize product metrics	
Quality Assurance			Create preliminary test plan		Test beta prototypes for robustness	Complete quality assurance testing	Conduct process verification testing		
Manufacturing				Begin manufacturing process development Conduct a preliminary manufacturing process review	Finalize bill of materials (BOM) Develop manufacturing control plans	Update manufacturing control plans	Run manufacturing pilots Finalize manufacturing control plans		Register obsolete and scrap products
Purchasing				Create a supplier participation matrix Assess suppliers for certification	Identify long lead-time items		Verify supply chain readiness		
Legal		Search patents	Identify trade compliance issues	Identify potential patents	Prepare patent applications	Assure trade compliance			
Financial	Prepare preliminary business case	Refine business case	Complete financial package						Monitor return on investment
Project Management	Identify project timing, resources, and capital Prepare RP0 checklist & submit for approval	Assess team capabilities/skills Identify development team members Select a Rally Point process variant Prepare RP1 checklist & submit for approval	Plan integrated product development schedule Assign a project manager Update RP1 deliverables Prepare RP2 checklist & submit for approval	Update RP1-2 deliverables Prepare RP3 checklist & submit for approval	Update RP1-3 deliverables Prepare RP4 checklist & submit for approval	Update RP1-4 deliverables Prepare RP5 checklist & submit for approval	Update RP1-5 deliverables Prepare RP6 checklist & submit for approval	Finalize all deliverables Finalize launch plans and documentation Update RP1-6 deliverables Prepare RP7 checklist & submit for approval	Document best practices Prepare RP8 checklist & submit for approval

Courtesy of Tyco International

EXHIBIT 2-7 Key activities and the responsible functions comprising the Tyco Rally Point product development process.

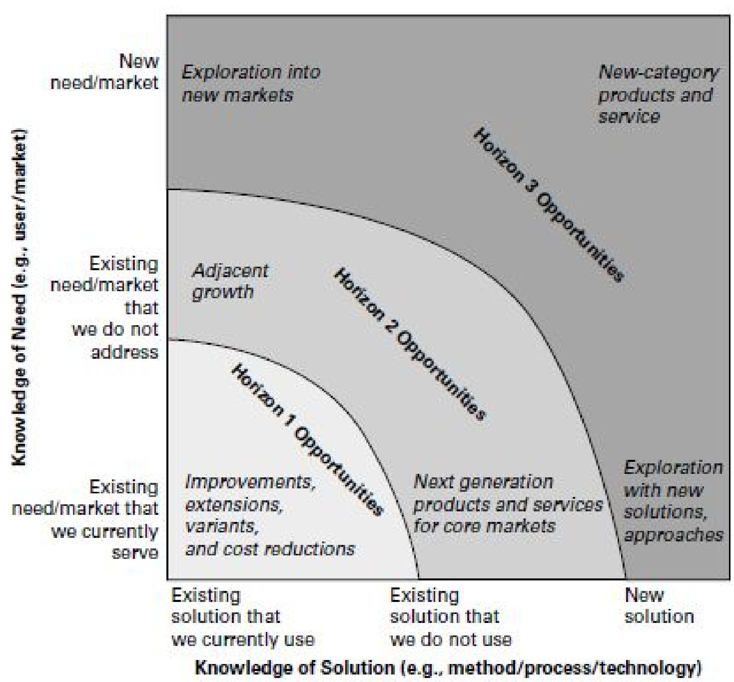


EXHIBIT 3-3 Types of opportunities. Horizons 1, 2, and 3 represent increasing levels of risk, reflecting different types of uncertainty.

Source: Terwiesch and Ulrich (2009)

Ch. 4: Product Planning Process

- 4 Types of P.D. projects
  - New Product Platforms
  - Derivatives of existing product platforms
  - Incremental Improvements to existing products
  - Fundamentally new products
- 5 step process
  - Identify Opportunities
  - Evaluate and Prioritize Projects
    - Competitive Strategy: Technology leadership, cost leadership, customer focus, imitative
    - Market Segmentation
    - Technological Trajectories
    - Product Platform Planning
    - Evaluating Fundamentally New Product Opportunities
  - Allocate Resources and Plan Timing
  - Complete Pre-project Planning

EXHIBIT 4-10
Mission statement for the Lakes project. This document summarizes the direction to be followed by the product development team. Many more details are appended to this mission statement, including the environmental goals, service objectives, and specific technologies identified for use in the Lakes platform.

Mission Statement: Multifunctional Office Document Machine	
Product Description	• Networkable, digital machine with copy, print, fax, and scan functions
Benefit Proposition	• Multiple document processing functions in one machine • Connected to office computer network
Key Business Goals	• Support Xerox strategy of leadership in digital office equipment • Serve as platform for all future B&W digital products and solutions • Capture 50% of digital product sales in primary market • Environmentally friendly • First product introduction 4th Q 1997
Primary Market	• Office departments, mid-volume (40–65 ppm, above 42,000 avg. copies/mo.)
Secondary Markets	• Quick-print market • Small "satellite" operations
Assumptions and Constraints	• New product platform • Digital imaging technology • Compatible with CentreWare software • Input devices manufactured in Canada • Output devices manufactured in Brazil • Image processing engine manufactured in both the United States and Europe
Stakeholders	• Purchasers and users • Manufacturing operations • Service operations • Distributors and resellers

    - Mission Statements
      - Brief, 1 sentence description of the product

        - Benefit Proposition
        - Key Business Goals
        - Target Market(s)
        - Assumptions and constraints that guide development effort
        - Stakeholders
    - Assumptions and Constraints
        - Manufacturing: Key Partners and Resources, Channels
        - Service: CR, Key Activities, Channels
        - Environment: Sustainability, VP

Ch. 5: Identifying Customer Needs

EXHIBIT 5-3
Mission statement for the cordless screwdriver.

Mission Statement: Screwdriver Project	
Product Description	• A handheld, power-assisted device for installing threaded fasteners
Benefit Proposition	• Drives screws more quickly and with less effort than by hand
Key Business Goals	• Product introduced in fourth quarter of 2010 • 50% gross margin • 10% share of cordless screwdriver market by 2012
Primary Market	• Do-it-yourself consumer
Secondary Markets	• Casual consumer • Light-duty professional
Assumptions	• Handheld • Power-assisted • Nickel-metal-hydride rechargeable battery technology
Stakeholders	• User • Retailer • Sales force • Service center • Production • Legal department

- Step 1: Gather Raw Data from Customers
    - Interviews, Focus Groups, Obs. product in use
    - Choose CS
    - Det. Customer Needs
    - Document Interactions with customers: audio/video, notes, photos
- Step 2: Interpret Data
    - Express needs in terms of *what* the product has to do, not *how*
    - Use positive phrasing
    - Express need as **attribute** of product

Guideline	Customer Statement	Need Statement—Right	Need Statement—Wrong
"What" not "how"	"Why don't you put protective shields around the battery contacts?"	The screwdriver battery is protected from accidental shorting.	The screwdriver battery contacts are covered by a plastic sliding door.
Specificity	"I drop my screwdriver all the time."	The screwdriver operates normally after repeated dropping.	The screwdriver is rugged.
Positive not negative	"It doesn't matter if it's raining; I still need to work outside on Saturdays."	The screwdriver operates normally in the rain.	The screwdriver is not disabled by the rain.
An attribute of the product	"I'd like to charge my battery from my cigarette lighter."	The screwdriver battery can be charged from an automobile cigarette lighter.	An automobile cigarette lighter adapter can charge the screwdriver battery.
Avoid "must" and "should"	"I hate it when I don't know how much juice is left in the batteries of my cordless tools."	The screwdriver provides an indication of the energy level of the battery.	The screwdriver should provide an indication of the energy level of the battery.

● Step 3: Determine *primary needs* from list of needs statements

The SD provides plenty of power to drive screws.
* The SD maintains power for several hours of heavy use.
** The SD can drive screws into hardwood.
The SD drives sheet metal screws into metal ductwork.
*** The SD drives screws faster than by hand.

The SD makes it easy to start a screw.
* The SD retains the screw before it is driven.
*! The SD can be used to create a pilot hole.

The SD works with a variety of screws.
** The SD can turn Phillips, Torx, socket, and hex head screws.
** The SD can turn many sizes of screws.

The SD can access most screws.
The SD can be maneuvered in tight areas.
** The SD can access screws at the end of deep, narrow holes.

The SD turns screws that are in poor condition.
The SD can be used to remove grease and dirt from screws.
The SD allows the user to work with painted screws.

The SD feels good in the user's hand.
*** The SD is comfortable when the user pushes on it.
*** The SD is comfortable when the user resists twisting.
* The SD is balanced in the user's hand.
! The SD is equally easy to use in right or left hands.
The SD weight is just right.
The SD is warm to touch in cold weather.
The SD remains comfortable when left in the sun.

The SD is easy to control while turning screws.
*** The user can easily push on the SD.
*** The user can easily resist the SD twisting.
The SD can be locked "on."
**! The SD speed can be controlled by the user while turning a screw.
* The SD remains aligned with the screw head without slipping.
** The user can easily see where the screw is.
* The SD does not strip screw heads.
* The SD is easily reversible.

The SD is easy to set up and use.
* The SD is easy to turn on.
* The SD prevents inadvertent switching off.
* The user can set the maximum torque of the SD.
*! The SD provides ready access to bits or accessories.
* The SD can be attached to the user for temporary storage.

The SD power is convenient.
* The SD is easy to recharge.
The SD can be used while recharging.
*** The SD recharges quickly.
The SD batteries are ready to use when new.
**! The user can apply torque manually to the SD to drive a screw.

The SD lasts a long time.
** The SD tip survives heavy use.
The SD can be hammered.
* The SD can be dropped from a ladder without damage.

The SD is easy to store.
* The SD fits in a toolbox easily.
** The SD can be charged while in storage.
The SD resists corrosion when left outside or in damp places.
*! The SD maintains its charge after long periods of storage.
The SD maintains its charge when wet.

The SD prevents damage to the work.
* The SD prevents damage to the screw head.
The SD prevents scratching of finished surfaces.

The SD has a pleasant sound when in use.

The SD looks like a professional quality tool.

The SD is safe.
The SD can be used on electrical devices.
*** The SD does not cut the user's hands.

EXHIBIT 5-8 Hierarchical list of primary and secondary customer needs for the cordless screwdriver. Importance ratings for the secondary needs are indicated by the number of *'s, with *** denoting critically important needs. Latent needs are denoted by !.

- Step 4: Establish Relative Importance of Needs

Cordless Screwdriver Survey

For each of the following cordless screwdriver features, please indicate on a scale of 1 to 5 how important the feature is to you. Please use the following scale:

1. Feature is undesirable. I would not consider a product with this feature.
2. Feature is not important, but I would not mind having it.
3. Feature would be nice to have, but is not necessary.
4. Feature is highly desirable, but I would consider a product without it.
5. Feature is critical. I would not consider a product without this feature.

Also indicate by checking the box to the right if you feel that the feature is unique, exciting, and/or unexpected.

Importance of feature on scale of 1 to 5		Check box if feature is unique, exciting, and/or unexpected.
______	The screwdriver maintains power for several hours of heavy use.	❑
______	The screwdriver can drive screws into hardwood.	❑
______	The screwdriver speed can be controlled by the user while turning a screw.	❑
______	The screwdriver has a pleasant sound when in use.	❑

And so forth.

EXHIBIT 5-9 Example importance survey (partial).

Ch. 6: Product Specifications

- Establish Target Specs
  - Metrics List, Needs-Metrics Matrix

Metric No.	Need Nos.	Metric	Imp.	Units
1	1, 3	Attenuation from dropout to handlebar at 10 Hz	3	dB
2	2, 6	Spring preload	3	N
3	1, 3	Maximum value from the Monster	5	g
4	1, 3	Minimum descent time on test track	5	s
5	4	Damping coefficient adjustment range	3	N-s/m
6	5	Maximum travel (26-in. wheel)	3	mm
7	5	Rake offset	3	mm
8	6	Lateral stiffness at the tip	3	kN/m
9	7	Total mass	4	kg
10	8	Lateral stiffness at brake pivots	2	kN/m
11	9	Headset sizes	5	in.
12	9	Steertube length	5	mm
13	9	Wheel sizes	5	List
14	9	Maximum tire width	5	in.
15	10	Time to assemble to frame	1	s
16	11	Fender compatibility	1	List
17	12	Instills pride	5	Subj.
18	13	Unit manufacturing cost	5	US$
19	14	Time in spray chamber without water entry	5	s
20	15	Cycles in mud chamber without contamination	5	k-cycles
21	16, 17	Time to disassemble/assemble for maintenance	3	s
22	17, 18	Special tools required for maintenance	3	List
23	19	UV test duration to degrade rubber parts	5	hr
24	19	Monster cycles to failure	5	Cycles
25	20	Japan Industrial Standards test	5	Binary
26	20	Bending strength (frontal loading)	5	kN

EXHIBIT 6-4 List of metrics for the suspension. The relative importance of each metric and the units for the metric are also shown. "Subj." is an abbreviation indicating that a metric is subjective.

	Need \ Metric	1 Attenuation from dropout to handlebar at 10 Hz	2 Spring preload	3 Maximum value from the Monster	4 Minimum descent time on test track	5 Damping coefficient adjustment range	6 Maximum travel (26-in. wheel)	7 Rake offset	8 Lateral stiffness at the tip	9 Total mass	10 Lateral stiffness at brake pivots	11 Headset sizes	12 Steertube length	13 Wheel sizes	14 Maximum tire width	15 Time to assemble to frame	16 Fender compatibility	17 Instills pride	18 Unit manufacturing cost	19 Time in spray chamber without water entry	20 Cycles in mud chamber without contamination	21 Time to disassemble/assemble for maintenance	22 Special tools required for maintenance	23 UV test duration to degrade rubber parts	24 Monster cycles to failure	25 Japan Industrial Standards test	26 Bending strength (frontal loading)
1	Reduces vibration to the hands	•		•	•																						
2	Allows easy traversal of slow, difficult terrain		•																								
3	Enables high-speed descents on bumpy trails	•		•	•																						
4	Allows sensitivity adjustment					•																					
5	Preserves the steering characteristics of the bike						•	•																			
6	Remains rigid during hard cornering		•						•																		
7	Is lightweight									•																	
8	Provides stiff mounting points for the brakes										•																
9	Fits a wide variety of bikes, wheels, and tires											•	•	•	•												
10	Is easy to install															•											
11	Works with fenders																•										
12	Instills pride																	•									
13	Is affordable for an amateur enthusiast																		•								
14	Is not contaminated by water																			•							
15	Is not contaminated by grunge																				•						
16	Can be easily accessed for maintenance																					•					
17	Allows easy replacement of worn parts																					•	•				
18	Can be maintained with readily available tools																						•				
19	Lasts a long time																							•	•		
20	Is safe in a crash																									•	•

EXHIBIT 6-5 The needs-metrics matrix.

- Collect Competitive Benchmark (how does our product compare to competitors)

Metric No.	Need Nos.	Metric	Imp.	Units	ST Tritrack	Maniray 2	Rox Tahx Quadra	Rox Tahx Ti 21	Tonka Pro	Gunhill Head Shox
1	1, 3	Attenuation from dropout to handlebar at 10 Hz	3	dB	8	15	10	15	9	13
2	2, 6	Spring preload	3	N	550	760	500	710	480	680
3	1, 3	Maximum value from the Monster	5	g	3.6	3.2	3.7	3.3	3.7	3.4
4	1, 3	Minimum descent time on test track	5	s	13	11.3	12.6	11.2	13.2	11
5	4	Damping coefficient adjustment range	3	N-s/m	0	0	0	200	0	0
6	5	Maximum travel (26-in. wheel)	3	mm	28	48	43	46	33	38
7	5	Rake offset	3	mm	41.5	39	38	38	43.2	39
8	6	Lateral stiffness at the tip	3	kN/m	59	110	85	85	65	130
9	7	Total mass	4	kg	1.409	1.385	1.409	1.364	1.222	1.100
10	8	Lateral stiffness at brake pivots	2	kN/m	295	550	425	425	325	650
11	9	Headset sizes	5	in.	1.000 1.125	1.000 1.125 1.250	1.000 1.125	1.000 1.125 1.250	1.000 1.125	NA
12	9	Steertube length	5	mm	150 180 210 230 255	140 165 190 215	150 170 190 210	150 170 190 210 230	150 190 210 220	NA
13	9	Wheel sizes	5	List	26 in.	26 in.	26 in.	26 in. 700C	26 in.	26 in.

EXHIBIT 6-6 Competitive benchmarking chart based on metrics.

- Set ideal and marginally acceptable Target Values

Metric No.	Need Nos.	Metric	Imp.	Units	Marginal Value	Ideal Value
1	1, 3	Attenuation from dropout to handlebar at 10 Hz	3	dB	>10	>15
2	2, 6	Spring preload	3	N	480–800	650–700
3	1, 3	Maximum value from the Monster	5	g	<3.5	<3.2
4	1, 3	Minimum descent time on test track	5	s	<13.0	<11.0
5	4	Damping coefficient adjustment range	3	N-s/m	0	>200
6	5	Maximum travel (26-in. wheel)	3	mm	33–50	45
7	5	Rake offset	3	mm	37–45	38
8	6	Lateral stiffness at the tip	3	kN/m	>65	>130
9	7	Total mass	4	kg	<1.4	<1.1
10	8	Lateral stiffness at brake pivots	2	kN/m	>325	>650
11	9	Headset sizes	5	in.	1.000 1.125	1.000 1.125 1.250
12	9	Steertube length	5	mm	150 170 190 210	150 170 190 210 230
13	9	Wheel sizes	5	List	26 in.	26 in. 700C
14	9	Maximum tire width	5	in.	>1.5	>1.75
15	10	Time to assemble to frame	1	s	<60	<35
16	11	Fender compatibility	1	List	None	All
17	12	Instills pride	5	Subj.	>3	>5
18	13	Unit manufacturing cost	5	US$	<85	<65
19	14	Time in spray chamber without water entry	5	s	>2300	>3600
20	15	Cycles in mud chamber without contamination	5	k-cycles	>15	>35
21	16, 17	Time to disassemble/assemble for maintenance	3	s	<300	<160
22	17, 18	Special tools required for maintenance	3	List	Hex	Hex
23	19	UV test duration to degrade rubber parts	5	hr	>250	>450
24	19	Monster cycles to failure	5	Cycles	>300k	>500k
25	20	Japan Industrial Standards test	5	Binary	Pass	Pass
26	20	Bending strength (frontal loading)	5	kN	>7.0	>10.0

EXHIBIT 6-8 The target specifications. Like the other information systems, this one is easily encoded with a spreadsheet as a simple extension to the list of specifications.

- Five-Step Process to set Final Specs.
    - Develop Technical Model
        - Predict value of metrics for set of design decisions

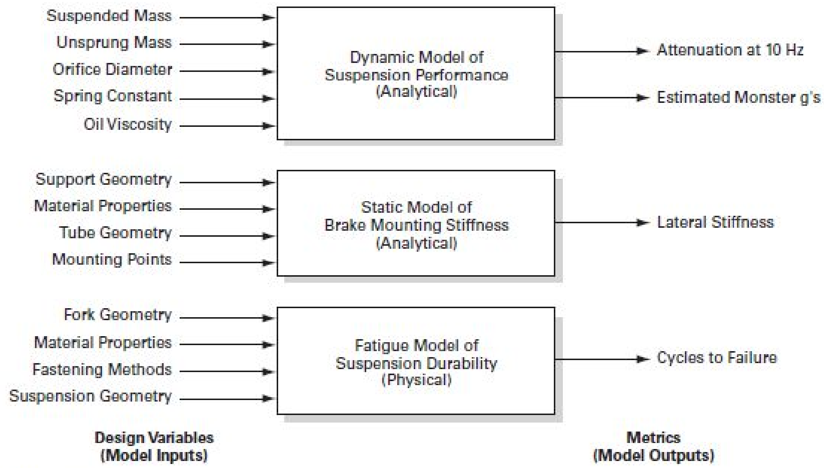


EXHIBIT 6-9 Models used to assess technical feasibility. Technical models may be analytical or physical approximations of the product concept.

- Develop Cost Model

Component	Qty/ Fork	High ($ ea.)	Low ($ ea.)	High Total ($/fork)	Low Total ($/fork)
Steertube	1	2.50	2.00	2.50	2.00
Crown	1	4.00	3.00	4.00	3.00
Boot	2	1.00	0.75	2.00	1.50
Lower tube	2	3.00	2.00	6.00	4.00
Lower tube top cover	2	2.00	1.50	4.00	3.00
Main lip seal	2	1.50	1.40	3.00	2.80
Slide bushing	4	0.20	0.18	0.80	0.72
Slide bushing spacer	2	0.50	0.40	1.00	0.80
Lower tube plug	2	0.50	0.35	1.00	0.70
Upper tube	2	5.50	4.00	11.00	8.00
Upper tube top cap	2	3.00	2.50	6.00	5.00
Upper tube adjustment knob	2	2.00	1.75	4.00	3.50
Adjustment shaft	2	4.00	3.00	8.00	6.00
Spring	2	3.00	2.50	6.00	5.00
Upper tube orifice cap	1	3.00	2.25	3.00	2.25
Orifice springs	4	0.50	0.40	2.00	1.60
Brake studs	2	0.40	0.35	0.80	0.70
Brake brace bolt	2	0.25	0.20	0.50	0.40
Brake brace	1	5.00	3.50	5.00	3.50
Oil (liters)	0.1	2.50	2.00	0.25	0.20
Misc. snap rings, o-rings	10	0.15	0.10	1.50	1.00
Decals	4	0.25	0.15	1.00	0.60
Assembly at $20/hr		30 min	20 min	10.00	6.67
Overhead at 25% of direct cost				20.84	15.74
Total				$104.19	$78.68

EXHIBIT 6-10 A bill of materials with cost estimates. This simple cost model allows early cost estimates to facilitate realistic trade-offs in the product specifications.

- Refine specs & make tradeoffs - Monster test

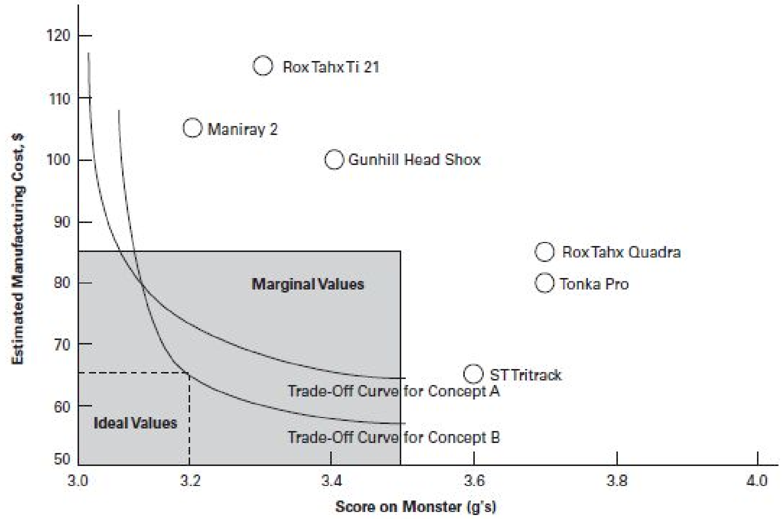


EXHIBIT 6-11 A competitive map showing estimated manufacturing cost versus score on the Monster test. Trade-off curves for two suspension concepts are also drawn on this map.

- Flow down specs, as appropriate

EXHIBIT 6-12 The final specifications.

No.	Metric	Unit	Value
1	Attenuation from dropout to handlebar at 10 Hz	dB>	12
2	Spring preload	N	600–650
3	Maximum value from the Monster	g	<3.4
4	Minimum descent time on test track	s	<11.5
5	Damping coefficient adjustment range	N-s/m	>100
6	Maximum travel (26-in. wheel)	mm	43
7	Rake offset	mm	38
8	Lateral stiffness at the tip	kN/m	>75
9	Total mass	kg	<1.4
10	Lateral stiffness at brake pivots	kN/m	>425
11	Headset sizes	in.	1.000 1.125
12	Steertube length	mm	150 170 190 210 230
13	Wheel sizes	List	26 in.
14	Maximum tire width	in.	>1.75
15	Time to assemble to frame	s	<45
16	Fender compatibility	List	Zefal
17	Instills pride	Subj.	>4
18	Unit manufacturing cost	US$	<80
19	Time in spray chamber without water entry	s	>3600
20	Cycles in mud chamber without contamination	k-cycles	>25
21	Time to disassemble/assemble for maintenance	s	<200
22	Special tools required for maintenance	List	Hex
23	UV test duration to degrade rubber parts	hr	>450
24	Monster cycles to failure	Cycles	>500k
25	Japan Industrial Standards test	Binary	Pass
26	Bending strength (frontal loading)	kN	>10.0

- Target Costing

Let M be the gross profit *margin* of a stage in the distribution channel.

$$M = \frac{(P - C)}{P}$$

where P is the price this stage charges its customers and C is the cost this stage pays for the product it sells. (Note that *mark-up* is similar to margin, but is defined slightly differently as $P/C - 1$, so that a margin of 50 percent is equivalent to a mark-up of 100 percent.)

Target cost, C, is given by the following expression:

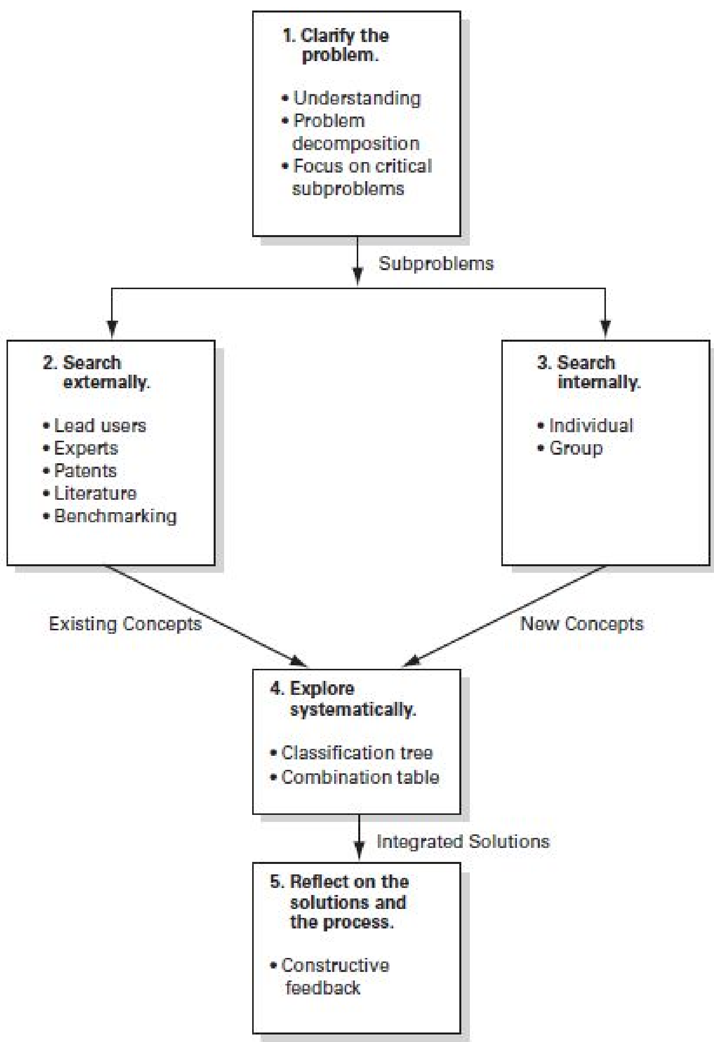
$$C = P \prod_{i=1}^{n} (1 - M_i)$$

where P is the price paid by the end user, n is the number of stages in the distribution channel, and M_i is the margin of the ith stage.

Ch. 7: Concept Generation

- Five-Step Method

EXHIBIT 7-3
The five-step concept generation method.



- Step 1: Clarify and decompose

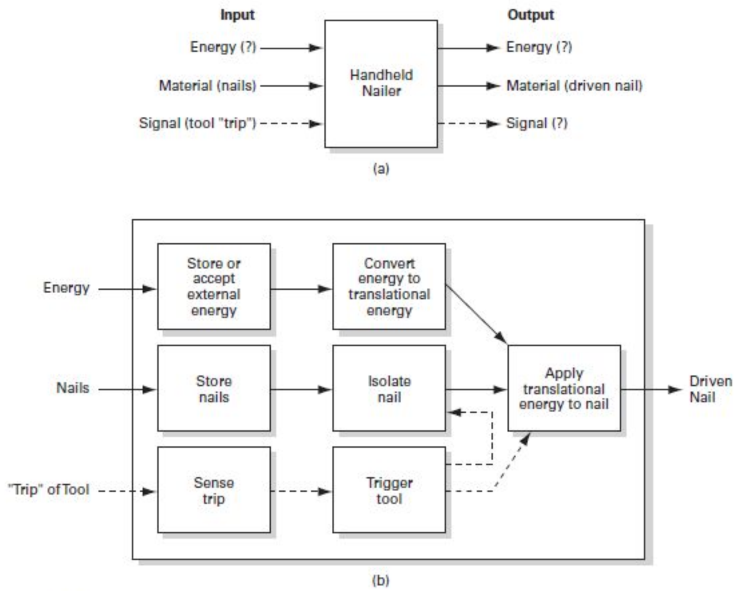


EXHIBIT 7-4 Function diagram of a handheld nailer arising from a functional decomposition: (a) overall "black box"; (b) refinement showing subfunctions.

- Step 2: External Search
    - Interview Lead Users, Consult Experts, Search Patents, Review Literature, Benchmark Related Products
- Step 3: Internal Search
    - Individual and Group generation of ideas/solution concepts
- Step 4: Systematic Exploration
    - Identify solutions to subproblems

EXHIBIT 7-6 Some of the solutions to the subproblems of (1) storing or accepting energy and (2) delivering translational energy to a nail.

Solutions to Subproblem of Storing or Accepting Energy

- Self-regulating chemical reaction emitting high-pressure gas
- Carbide (as for lanterns)
- Combusting sawdust from job site
- Gun powder
- Sodium azide (air bag explosive)
- Fuel-air combustion (butane, propane, acetylene, etc.)
- Compressed air (in tank or from compressor)
- Carbon dioxide in tank
- Electric wall outlet and cord
- High-pressure oil line (hydraulics)
- Flywheel with charging (spin-up)
- Battery pack on tool, belt, or floor
- Fuel cell
- Human power: arms or legs
- Methane from decomposing organic materials
- "Burning" like that of chemical hand warmers
- Nuclear reactions
- Cold fusion
- Solar electric cells
- Solar-steam conversion
- Steam supply line
- Wind
- Geothermal

Solutions to Subproblem of Applying Translational Energy to Nail

Single impact

Multiple impacts (tens or hundreds)

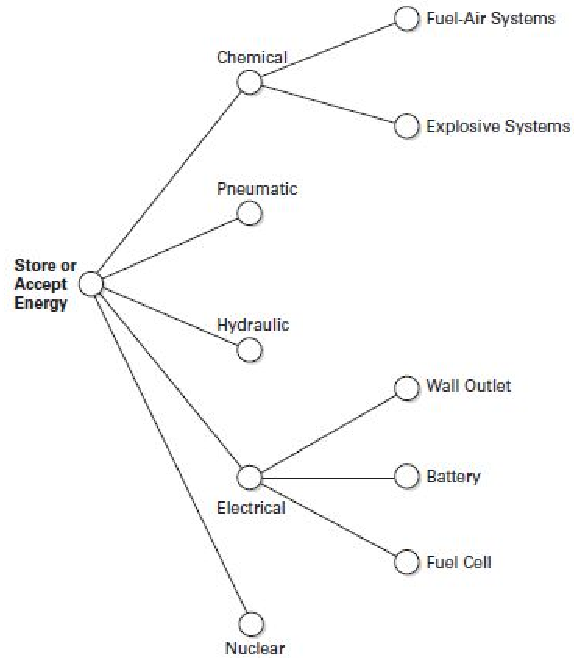
Multiple impacts (hundreds or thousands)

Push

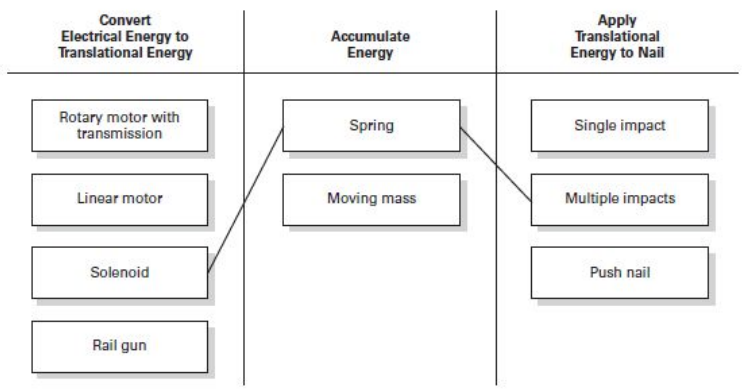
Twist-push

- Concept Classification Tree

EXHIBIT 7-7 A classification tree for the nailer energy source concept fragments.



- Concept Combination Table (w/ sketch)



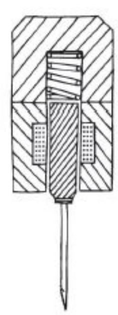


EXHIBIT 7-10 In this solution concept, a solenoid compresses a spring and then releases it repeatedly in order to drive the nail with multiple impacts.

- Step 5: Reflect on Solutions/Process

Ch. 8 & 9: Concept Selection & Testing

- Methods for Choosing
    - ***External decision:*** Concepts are turned over to the customer, client, or some other external entity for selection.
    - ***Product champion:*** An influential member of the product development team chooses a concept based on personal preference.
    - ***Intuition:*** The concept is chosen by its feel. Explicit criteria or trade-offs are not used. The concept just *seems* better.
    - ***Multivoting:*** Each member of the team votes for several concepts. The concept with the most votes is selected.
    - ***Web-based survey:*** Using an online survey tool, each concept is rated by many people to find the best ones.
    - ***Pros and cons:*** The team lists the strengths and weaknesses of each concept and makes a choice based upon group opinion.
    - ***Prototype and test:*** The organization builds and tests prototypes of each concept, making a selection based upon test data.
    - ***Decision matrices:*** The team rates each concept against prespecified selection criteria, which may be weighted.

- Five Steps of Concept Test
    - Step 1: Define Purpose of CT (Key questions, hypotheses, core assumptions to test)
    - Step 2: Choose Survey Pop. (smaller vs. larger sample size)
    - Step 3: Choose Survey Format (face-to-face, tele, post, e-mail, web)
    - Step 4: Communicate Concept
        - Verbal: Product Summary
        - Sketch
        - Photos/Rendering
        - Storyboard
        - Video
        - Simulation
        - Interactive multimedia
        - Phys. appearance model (3D CAD model)
        - Working prototype

  Internet/Web Survey is most appropriate, communicates all of the above, except last two
    - Step 5: Measure Customer Response
    - Step 6: Interpret Results
    - Step 7: Reflect on Results/Process

Estimating Market Sizes

Rough estimates of market size can often be made through comparisons with similar products or with known sizes of demographic groups. Exhibits 9-11 and 9-12 contain some numbers that may be useful.

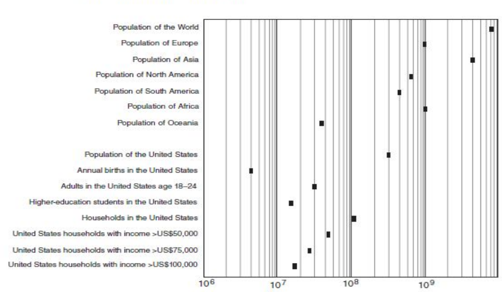


EXHIBIT 9-11 Approximate population and demographic data as of 2011.

Ch. 10: Product Architecture

- Modularity - division of products into chunks, for replaceability of components rather than whole
    - Product Change - changing components can influence functionality

      Some of the motives for product change are:

      - ***Upgrade:*** As technological capabilities or user needs evolve, some products can accommodate this evolution through upgrades. Examples include changing the processor board in a computer printer or replacing a pump in a cooling system with a more powerful model.
      - ***Add-ons:*** Many products are sold by a manufacturer as a basic unit, to which the user adds components, often produced by third parties, as needed. This type of change is common in the personal computer industry (e.g., third-party mass storage devices may be added to a basic computer).
      - ***Adaptation:*** Some long-lived products may be used in several different use environments, requiring adaptation. For example, machine tools may need to be converted from 220-volt to 110-volt power. Some engines can be converted from a gasoline to a propane fuel supply.
      - ***Wear:*** Physical elements of a product may deteriorate with use, necessitating replacement of the worn components to extend the useful life of the product. For example, many razors allow dull blades to be replaced, tires on vehicles can usually be replaced, most rotational bearings can be replaced, and many appliance motors can be replaced.
      - ***Consumption:*** Some products consume materials, which can then be easily replenished. For example, copiers and printers frequently contain print cartridges, cameras take film cartridges, glue guns consume glue sticks, torches have gas cartridges, and watches contain batteries, all of which are generally replaceable.
      - ***Flexibility in use:*** Some products can be configured by the user to provide different capabilities. For example, many cameras can be used with different lens and flash options, some boats can be used with several awning options, and fishing rods may accommodate several rod-reel configurations.
      - ***Reuse:*** In creating subsequent products, the firm may wish to change only a few functional elements while retaining the rest of the product intact. For example, consumer electronics manufacturers may wish to update a product line by changing only the user interface and enclosure while retaining the inner workings from a previous model.

      In each of these cases, a modular architecture allows the firm to minimize the *physical* changes required to achieve a *functional* change.
    - Product Variety (3 different types of finishes)
    - Component Standardization (using similar components in all products for easier reproducibility)
    - Manufacturability without compromising performance
        - Integration of components for multiple functionality from single physical element, reduce costs
        - Minimize number of total parts through component integration to decrease manufacturing costs and less breakdown of physical product into individual parts
    - Establishing the Architecture
        - Overall Schematic (Big Picture) → cluster/chunk elements (next page)
        - Rough Geom. Layout
        - Identify fundamental and incidental interactions

Schematic

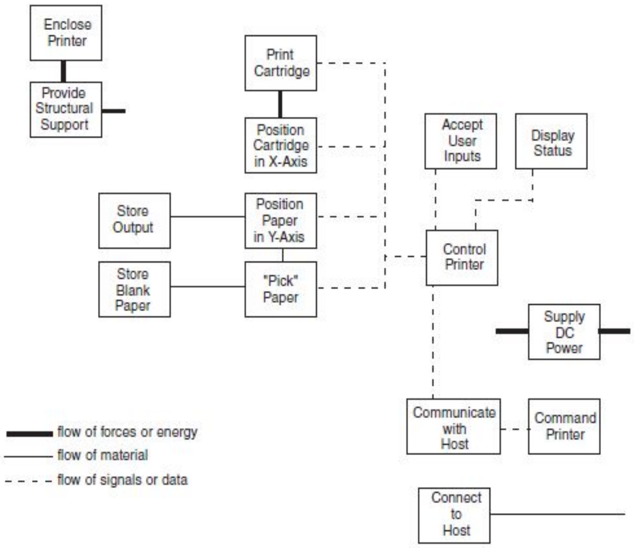


EXHIBIT 10-6 Schematic of the DeskJet printer. Note the presence of both functional elements (e.g., "Store Output") and physical elements (e.g., "Print Cartridge"). For clarity, not all connections among elements are shown.

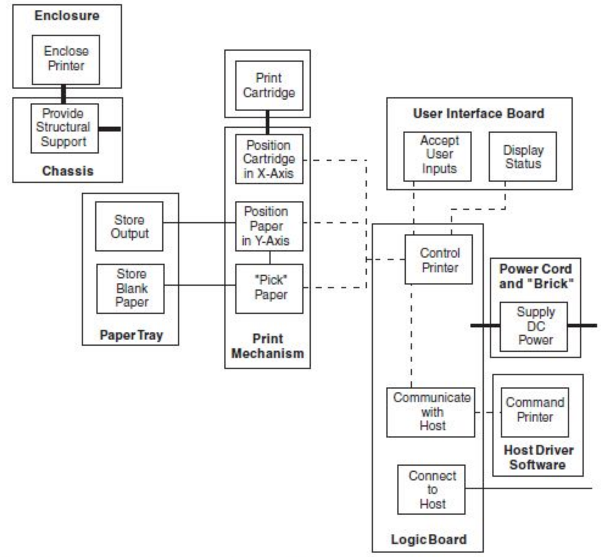
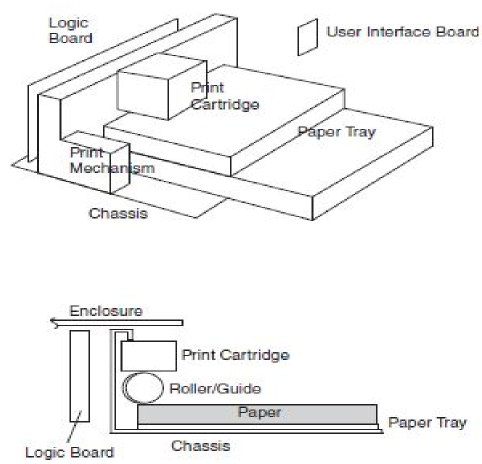


EXHIBIT 10-7 Clustering the elements into chunks. Nine chunks make up this proposed architecture for the DeskJet printer.

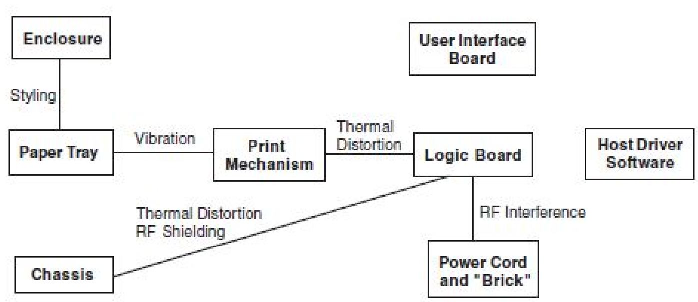
Geometric Layout

EXHIBIT 10-8 Geometric layout of the printer.



Fundamental and Incidental Interactions

EXHIBIT 10-9 Incidental interaction graph.



Ch. 11: Industrial Design (ID)

- ID in meeting needs of a product based on level of importance

Needs	Level of Importance (Low / Medium / High)	Explanation of Rating
Ergonomics		
Ease of use		Critical for a mobile telephone because it may be used frequently, may be needed in emergency situations, and can be operated by motorists while driving. The product's function must be communicated through its design.
Ease of maintenance		As with many integrated electronics products there is very little maintenance required.
Quantity of user interactions		There are many important user interactions such as entering text, dialing and storing numbers, sending and receiving calls, taking photos, Internet access.
Novelty of user interactions		Design solutions associated with some of the customer interactions were straightforward, such as the numeric keypad, because there is a wealth of human factors data that dictate the basic dimensions. However, other interfaces, such as the one-handed operation of such a thin phone, were quite different from earlier models and therefore required careful study.
Safety		There were few safety issues for ID to consider on the RAZR itself. However, because many customers use mobile telephones in automobiles, a line of Bluetooth wireless accessories needed to be designed for safe, convenient, hands-free operation.
Aesthetics		
Product differentiation		There were hundreds of models of mobile phones on the market when the RAZR was introduced. Its appearance was essential for differentiation.
Pride of ownership, fashion, or image		The RAZR was intended to be a highly visible product used by people for business and personal communication in public areas. It had to be stunningly attractive in everyday use.
Team motivation		The RAZR's novel form turned out to be an important inspiration to the development team and a selling point for senior management.

EXHIBIT 11-3 Assessing the importance of industrial design for Motorola's RAZR mobile phone.

- Process: Define Customer Needs → Conceptualize → Refine → Final Selection → CAD → Engineering, Manufacturing, External Vendors
- Technology vs. User-Driven Design

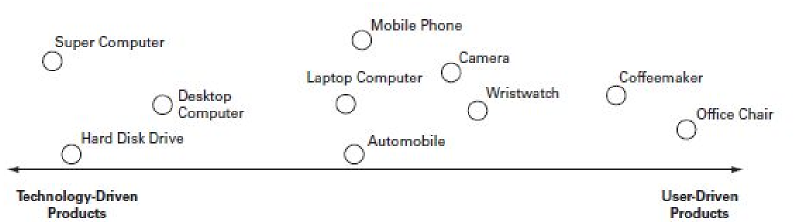


EXHIBIT 11-8 Classification of some common products on the continuum from technology-driven product to user-driven product.

- Timeline for ID & Role of ID based on Product Type

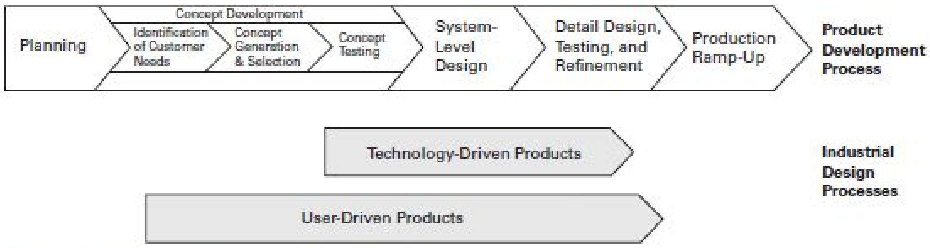


EXHIBIT 11-9 Relative timing of the industrial design process for two types of products.

Product Development Activity	Type of Product	
	Technology-Driven	**User-Driven**
Identification of Customer Needs	ID typically has no involvement.	ID works closely with marketing to identify customer needs. Industrial designers participate in focus groups or one-on-one customer interviews.
Concept Generation and Selection	ID works with marketing and engineering to ensure that human factors and user-interface issues are addressed. Safety and maintenance issues are often of primary importance.	ID generates multiple concepts according to the industrial design process flow described earlier.
Concept Testing	ID helps engineering to create prototypes, which are shown to customers for feedback.	ID leads in the creation of models to be tested with customers by marketing.
System-Level Design	ID typically has little involvement.	ID narrows down the concepts and refines the most promising approaches.
Detail Design, Testing, and Refinement	ID is responsible for packaging the product once most of the engineering details have been addressed. ID receives product specifications and constraints from engineering and marketing.	ID selects a final concept, then coordinates with engineering, manufacturing, and marketing to finalize the design.

EXHIBIT 11-10 The role of industrial design according to product type.

- Assessment of Quality

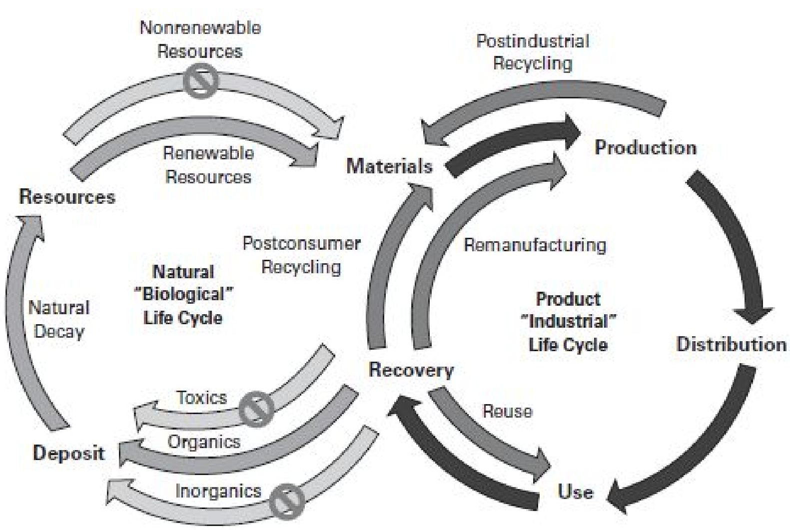
Assessment Category	Performance Rating (Low / Medium / High)	Explanation of Rating
1. Quality of the User Interface		In general, the RAZR was both easy to use and comfortable. Calls could be answered by simply opening the display, numbers and text could be easily entered using the keypad, and the functions were readily accessible using the navigation buttons. The RAZR's drawbacks included a keypad that could be difficult to use for customers with large fingers or long fingernails. In some markets, carriers had specified that Motorola customize the software interface in ways that negatively impacted usability.
2. Emotional Appeal		The RAZR had a high emotional appeal that stemmed from its ultra-thin form, pocketability, and finishes.
3. Ability to Maintain and Repair the Product		Although maintenance and repair were not of primary importance to the customer, the RAZR rated high in this category. The battery charged very quickly and could be removed and replaced easily.
4. Appropriate Use of Resources		The final design included only those features that satisfied real customer needs. Materials were selected for durability and manufacturability, to withstand extreme conditions, to meet environmental regulations, and to create an attractive appearance.
5. Product Differentiation		The RAZR's appearance was clearly unique. It was easily identified when viewed in a public area or next to a competitor's product.

EXHIBIT 11-11 Assessment of industrial design's role in the RAZR development project.

Ch. 12: Design for Environment

- Natural v. Product Life Cycles

EXHIBIT 12-3 The natural life cycle and the product life cycle.

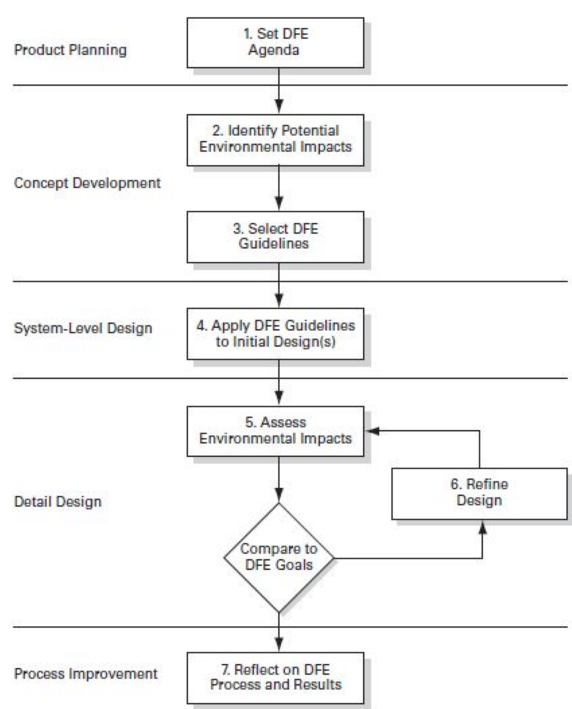


- Env. Impacts

  - ***Global warming:*** Scientific data and models show that the temperature of the earth is gradually increasing as a result of the accumulation of greenhouse gases, particulates, and water vapor in the upper atmosphere. This effect appears to be accelerating as a result of emissions of carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs), black carbon particles, and nitrogen oxides (NO_X) from industrial processes and products.
  - ***Resource depletion:*** Many of the raw materials used for production, such as iron ore, gas, oil, and coal, are nonrenewable and supplies are limited.
  - ***Solid waste:*** Products may generate solid waste throughout their life cycle. Some of this waste is recycled, but most is disposed in incinerators or landfills. Incinerators generate air pollution and toxic ash (which goes into landfills). Landfills may also create concentrations of toxic substances, generate methane gas (CH_4), and release groundwater pollutants.
  - ***Water pollution:*** The most common sources of water pollution are discharges from industrial processes, which may include heavy metals, fertilizers, solvents, oils, synthetic substances, acids, and suspended solids. Waterborne pollutants may affect groundwater, drinking water, and fragile ecosystems.
  - ***Air pollution:*** Sources of air pollution include emissions from factories, power-generating plants, incinerators, residential and commercial buildings, and motor vehicles. Typical pollutants include CO_2, NO_x, sulfur dioxide (SO_2), ozone (O_3), and volatile organic compounds (VOCs).
  - ***Land degradation:*** Land degradation concerns the adverse effects that raw material extraction and production, such as mining, farming, and forestry, have on the environment. The effects include reduced soil fertility, soil erosion, salinity of land and water, and deforestation.
  - ***Biodiversity:*** Biodiversity concerns the variety of plant and animal species, and is affected by land clearing for urban development, mining, and other industrial activities.
  - ***Ozone depletion:*** The ozone layer protects the earth against the harmful effects of the sun's radiation. It is degraded by reactions with nitric acid (created by the burning of fossil fuels) and chorine compounds (such as CFCs).

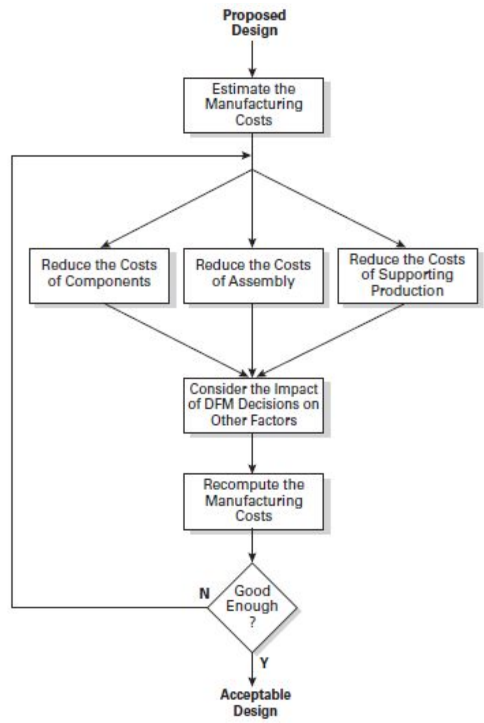
- Design for Env. (DFE)
  - Are materials safe for humans/env?
  - Can products be taken apart and recycled at end of life cycle?
  - Do materials contain recycled content and can parts be recycled?

EXHIBIT 12-4 The DFE process involves activities throughout the product development process.



Ch. 13: Design for Manufacturing (DFM)

EXHIBIT 13-3
The design for manufacturing (DFM) method.



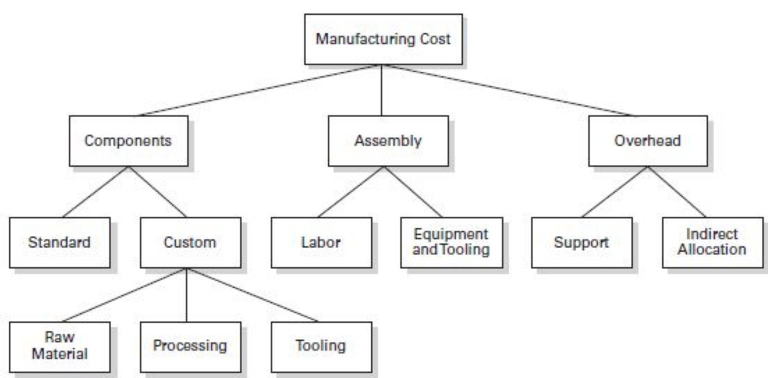


EXHIBIT 13-5 Elements of the manufacturing cost of a product.

- Component, Assembly, Transport, Material Costs

EXHIBIT 13-8
Assembly cost estimation for the PCV valve assembly of the redesigned intake manifold.

Component	Quantity	Handling Time	Insertion Time	Total Time
Valve	1	1.50	1.50	3.00
O-rings	2	2.25	4.00	12.50
Spring	1	2.25	6.00	8.25
Cover	1	1.95	6.00	7.95
Total Time (seconds)				**31.70**
Assembly Cost at $45/hour				**$0.40**

Source: Manual assembly tables in Boothroyd and Dewhurst, 1989

- Fixed vs. Variable Costs

EXHIBIT 13-7 Cost estimate for the original intake manifold. Note that the processing costs for casting and machining reflect the costs for a complete casting line and several machining stations.

Variable Cost		
Materials	5.7 kg aluminum at $2.25/kg	$12.83
Processing (casting)	150 units/hr at $530/hr	3.53
Processing (machining)	200 units/hr at $340/hr	1.70
Fixed Cost		
Tooling for casting	$160,000/tool at 500K units/tool (lifetime)	0.32
Machine tools and fixtures	$1,800,000/line at 10M units (lifetime)	0.18
Total Direct Cost		**$18.56**
Overhead charges		$12.09
Total Unit Cost		**$30.65**

EXHIBIT 13-9 Cost estimate for the redesigned intake manifold (two moldings).

Variable Cost		
Materials (manifold housing)	1.4 kg glass-filled nylon at $2.75/kg	$ 3.85
Materials (intake runner insert)	0.3 kg glass-filled nylon at $2.75/kg	0.83
Molding (manifold housing)	80 units/hr at $125/hr	1.56
Molding (intake runner insert)	100 units/hr at $110/hr	1.10
Fixed Cost		
Mold tooling (manifold housing)	$350,000/tool at 1.5M units/tool	$ 0.23
Mold tooling (intake runner insert)	$150,000/tool at 1.5M units/tool	0.10
Total Direct Cost		**$ 7.67**
Overhead charges		$ 5.99
Total Unit Cost		**$13.66**

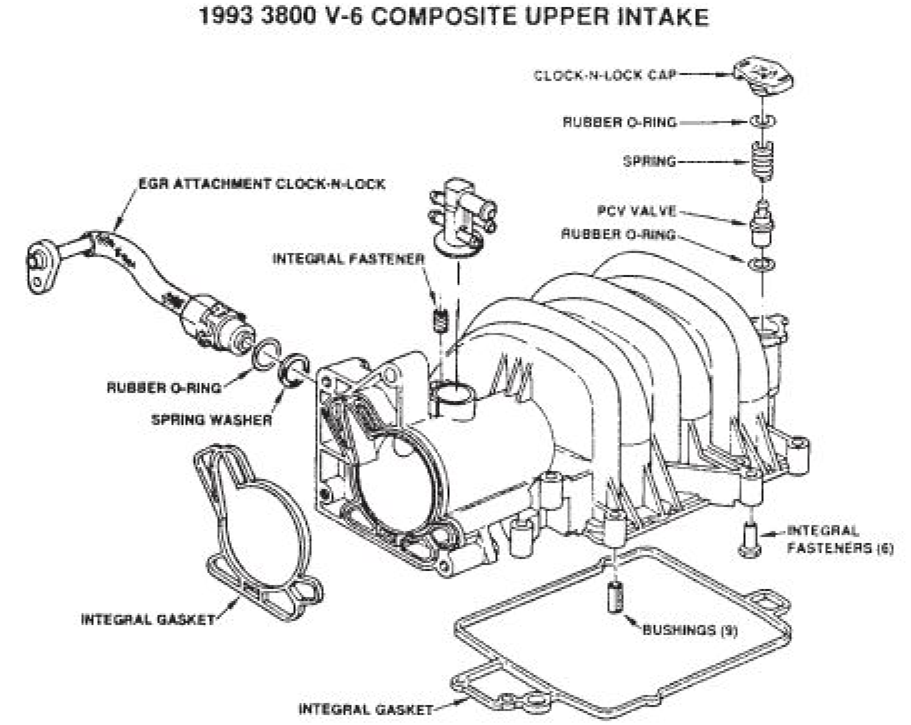
- Standard vs. Custom Components

Component	Purchased Materials	Processing (Machine + Labor)	Assembly (Labor)	Total Unit Variable Cost	Tooling and Other NRE, K$	Tooling Lifetime, K units	Total Unit Fixed Cost	Total Cost
Manifold machined casting	12.83	5.23		18.06	1960	500+	0.50	18.56
EGR return pipe	1.30		0.15	1.45				1.45
PCV assembly								
Valve	1.35		0.14	1.49				1.49
Gasket	0.05		0.13	0.18				0.18
Cover	0.76		0.13	0.89				0.89
Screws (3)	0.06		0.15	0.21				0.21
Vacuum source block assembly								
Block	0.95		0.13	1.08				1.08
Gasket	0.03		0.05	0.08				0.08
Screw	0.02		0.09	0.11				0.11
Total Direct Costs	17.35	5.23	0.95	23.53	1960		0.50	24.03
Overhead Charges	2.60	9.42	1.71				0.75	14.48
Total Cost								**38.51**

EXHIBIT 13-6 Indented bill of materials showing cost estimates for the original intake manifold and related components. The EGR (exhaust gas recirculation), PCV (positive crankcase ventilation), and vacuum block components are included here to facilitate comparison with the redesigned manifold assembly.

EXHIBIT 13-15
The redesigned intake manifold.

Courtesy of General Motors Corp.



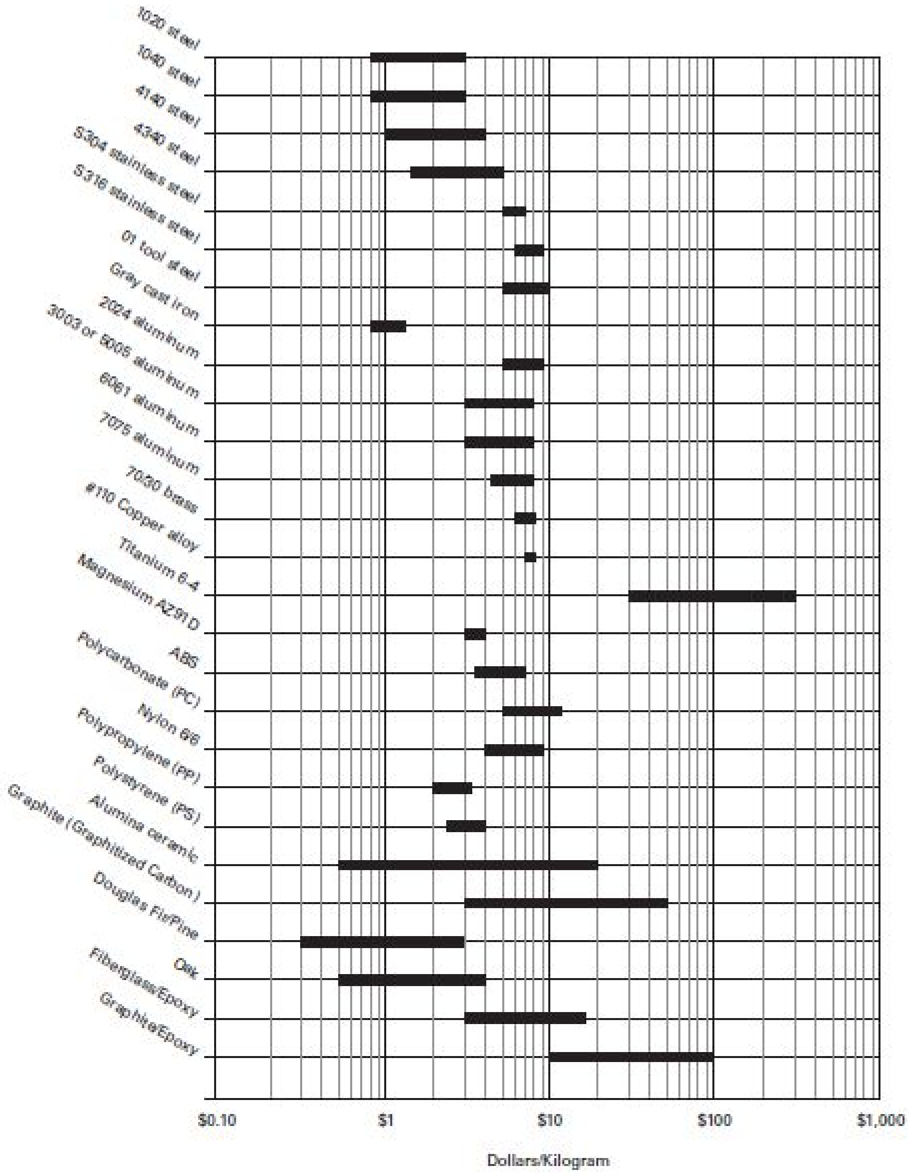
Component	Purchased Materials	Processing (Machine + Labor)	Assembly (Labor)	Total Unit Variable Cost	Tooling and Other NRE, K$	Tooling Lifetime, K units	Total Unit Fixed Cost	Total Cost
Manifold housing	3.85	1.56		5.41	350	1500	0.23	5.65
Intake runner insert	0.83	1.10	0.13	2.05	150	1500	0.10	2.15
Steel inserts (16)	0.32		1.00	1.32				1.32
EGR adapter	1.70		0.13	1.83				1.83
PCV valve								
Valve	0.85		0.04	0.89				0.89
O-rings(2)	0.02		0.16	0.18				0.18
Spring	0.08		0.10	0.18				0.18
Cover	0.02		0.10	0.12				0.12
Vacuum source block	0.04		0.06	0.10				0.10
Total Direct Costs	7.71	2.66	1.71	12.08	500		0.33	12.41
Overhead Charges	1.16	4.79	3.08				0.50	9.52
Total Cost								**21.93**

EXHIBIT 13-16 Cost estimate for the redesigned intake manifold.

Materials Costs

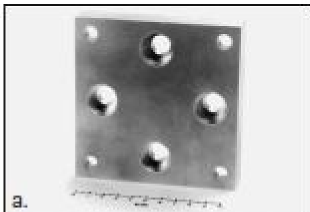
EXHIBIT 13-17
Range of costs for common engineering materials. Price ranges shown correspond to various grades and forms of each material, purchased in bulk quantities (2011 prices).

Source: Adapted from David G. Ullman, *The Mechanical Design Process*, third edition, McGraw-Hill, New York, 2003



Component Manufacturing Costs

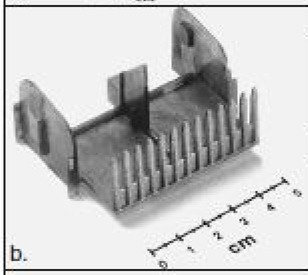
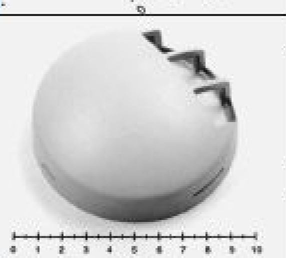
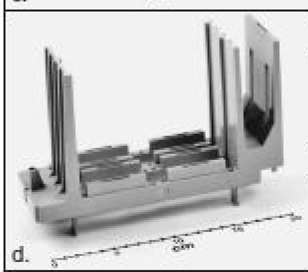
The exhibits in this appendix show example components and their cost data for computer-numerical control (CNC) machining (Exhibit 13-18), injection molding (Exhibit 13–19), progressive die stamping (Exhibit 13-20), and sand casting and investment casting (Exhibit 13-21). The purpose of these examples is to show, in general terms, what typical operations cost and how the cost structure of each process is affected by part complexity.

	Fixed Costs	***Variable Costs***	***Volume***	***Total Unit Cost***
 a.	Setup: 0.75 hr. at \$60/hr. Tooling: programming: 0.25 hr. at \$60/hr.	Material: \$9 ea. stock: 1.11 kg of 6061 aluminum Processing: 6 min./unit at \$60/hr.	1 10 100	\$75.00 \$21.00 \$15.50
 b.	Setup: 1.75 hr. at \$60/hr. Tooling: programming: 1.0 hr. at \$60/hr. Fixtures: \$150	Material: \$16 ea. stock: 1.96 kg of 6061 aluminum Processing: 55 min./unit at \$60/hr.	1 10 100	\$386.00 \$102.50 \$74.15
 c.	Setup: 5.5 hr. at \$60/hr. Tooling: programming: 2.0 hr. at \$60/hr.	Material: \$25 ea. stock: 4.60 kg of ultra-high molecular weight polyethylene Processing: 2.85 hr./unit at \$60/hr.	1 10 100	\$646.00 \$241.00 \$200.50
 d.	Setup: 2.0 hr. at \$60/hr. Tooling: programming: 2.0 hr. at \$60/hr.	Material: \$12 ea. stock: 1.50 kg of 6061 aluminum Processing: 6 hr./unit at \$60/hr.	1 10 100	\$612.00 \$396.00 \$374.40

Source: Photos by Stuart Cohen. Examples and data courtesy of Ramco, Inc.

Notes: 1. Programming time is a one-time expense and is included here in tooling costs.
2. Material prices assume low volumes and include cutting charges.
3. Processing costs include overhead charges.

EXHIBIT 13-18 **CNC machining cost examples**
CNC machining example components and cost data.

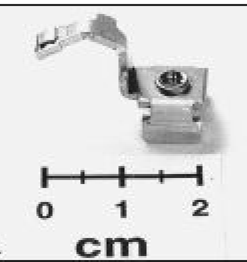
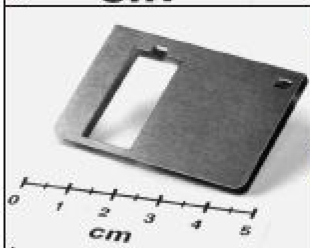
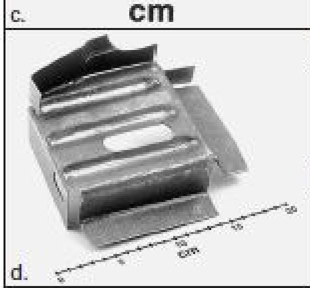
	Fixed Costs	*Variable Costs*	*Volume*	*Total Unit Cost*
 a.	Setup: Tooling: $18K 8 cavities/mold no actions	Material: $0.075 ea. 45 g of linear low density polyethylene (LLDPF) Processing: 1000 pcs/hr. on an 1800 KN press at $40/hr.	10K 100K 1M	$1.915 $0.295 $0.133
 b.	Setup: Tooling: $10K 1 cavity/mold no actions	Material: $0.244 ea. 10 g of steel-filled polycarbonate (PC) Processing: 160 pcs/hr. on a 900 KN press at $42/hr.	10K 100K 1M	$1.507 $0.607 $0.517
 c.	Setup: Tooling: $18K 2 cavities/mold no actions 3 retracting pins	Material: $0.15 ea. 22 g of modified polyphenylene oxide (PPO) Processing: 240 pcs/hr. on an 800 KN press at $42/hr.	10K 100K 1M	$2.125 $0.505 $0.343
 d.	Setup: Tooling: $80K 1 cavity/mold 1 action 4 retracting pins	Material: $2.58 ea. 227 g of polycarbonate (PC) with 8 brass inserts Processing: 95 pcs/hr. on a 2700 KN press at $48/hr.	10K 100K 1M	$11.085 $3.885 $3.165

Source: Photos by Stuart Cohen. Examples and data courtesy of Lee Plastics, Inc., and Digital Equipment Corporation

Notes: 1. Setup costs (only a few hours in each case) are negligible for high-volume injection molding.
2. Processing costs include overhead charges.

EXHIBIT 13-19 Injection molding cost examples

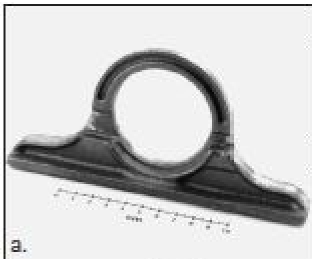
Injection molding example components and cost data.

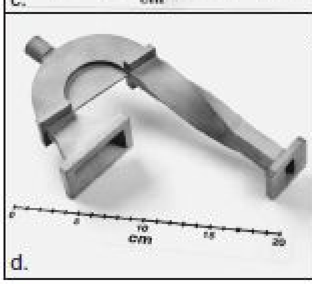
	Fixed Costs	Variable Costs	Volume	Total Unit Cost
 a.	Setup: Tooling: $22K	Material: $0.040 ea. 2.2g 70/30 Brass Processing: 3000 pcs/hr. on a 550 KN press at $63/hr.	100K 1M 10M	$0.281 $0.083 $0.063
 b.	Setup: Tooling: $71K	Material: $0.032 ea. 3.5 g 304 SST Processing: 4300 pcs/hr. on a 550 KN press at $140/hr.	100K 1M 10M	$0.775 $0.136 $0.072
 c.	Setup: Tooling: $11K	Material: $0.128 ea. 19.2 g 102 copper Processing: 4800 pcs/hr. on a 650 KN press at $50/hr.	100K 1M 10M	$0.248 $0.149 $0.140
 d.	Setup: Tooling: $195K	Material: $0.28 ea. 341 g galvanized steel Processing: 700 pcs/hr. on a 1000 KN press at $200/hr.	100K 1M 10M	$2.516 $0.761 $0.585

Source: Photos by Stuart Cohen. Examples and data courtesy of Brainin Advance Industries and other sources

Notes: 1. Setup costs (only a few hours in each case) are negligible for high-volume stamping.
2. Material weights represent the finished stampings. Material costs include scrap.
3. Hourly processing costs are not only driven by press size, but also can include ancillary processing equipment, such as in-die tapping.
4. Processing costs include overhead charges.

EXHIBIT 13-20 Stamping cost examples
Volume progressive die stamping example components and cost data.

	Fixed Costs	Variable Costs	Volume	Total Unit Cost
 a.	Setup: Tooling: $1.8K 8 impressions/pattern no core	Material: $0.53 ea. 570 g of gray cast iron Processing: 120 pcs/hr. at $46/hr.	10 100 1000	$180.91 $18.91 $2.71
 b.	Setup: Tooling: $2.4K 2 impressions/pattern 1 core	Material: $2.42 ea. 2,600 g of gray cast iron Processing: 30 pcs/hr. at $46/hr.	10 100 1000	$243.95 $27.95 $6.35

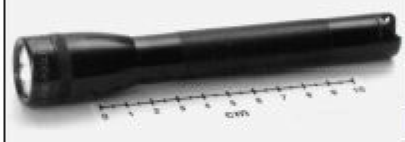
	Fixed Costs	Variable Costs	Volume	Total Unit Cost
 c.	Setup: Tooling: $1.5K no cores	Material: $0.713 ea. 260 g of yellow brass Processing: 4 pcs/hr. at $50/hr.	10 100 1000	$163.21 $28.21 $14.71
 d.	Setup: Tooling: $7K 3 cores	Material: $0.395 ea. 180 g of 712 aluminum Processing: 1 pc/hr. at $50/hr.	10 100 1000	$750.40 $120.40 $57.40

Source: Photos by Stuart Cohen. Examples and data courtesy of Cumberland Foundry Co., Inc. (sand casting), and Castronics, Inc. (investment casting)

Notes: 1. Setup is not generally charged in costing.
2. Processing costs include overhead charges.

EXHIBIT 13-21 Casting cost examples
Sand casting (top) and investment casting (bottom) example components and cost data.

Assembly Costs

Product	Part Data		Assembly Times (Seconds)	
	No. of Parts	16	Total	125.7
	No. of Unique Parts	12	Slowest Part	9.7
	No. of Fasteners	0	Fastest Part	2.9
	No. of Parts	34	Total	186.5
	No. of Unique Parts	25	Slowest Part	10.7
	No. of Fasteners	5	Fastest Part	2.6
	No. of Parts	49	Total	266.0
	No. of Unique Parts	43	Slowest Part	14.0
	No. of Fasteners	5	Fastest Part	3.5
	No. of Parts	56/17*	Total	277.0/138.0*
	No. of Unique Parts	44/12*	Slowest Part	8.0/8.0*
	No. of Fasteners	0/0*	Fastest Part	0.75/3.0*

Source: Photos by Stuart Cohen. Data obtained by using Boothroyd Dewhurst Inc. DFA software

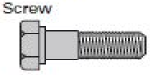
*Data for the mouse are given as: total components (including electronic)/mechanical components only.

Notes: 1. This table gives manual assembly times, which can be converted to assembly costs using applicable labor rates.

2. Assembly times shown include times for individual part handling and insertion, as well as other operations such as subassembly handling and insertion, reorientations, and heat riveting.

EXHIBIT 13-22 **Assembly costs**

Assembly data for common products. Obtained using Boothroyd Dewhurst Inc. DFA Software.

Component	Time (Seconds)			Component	Time (Seconds)		
	Min	Max	Avg		Min	Max	Avg
Screw 	7.5	13.1	10.3	Pin 	3.1	10.1	6.6
Snap-fit 	3.5	8.0	5.9	Spring 	2.6	14.0	8.3

Source: Manual assembly tables in Boothroyd and Dewhurst, 1989

EXHIBIT 13-23 Typical handling and insertion times for common components.

Appendix D

Cost Structures

Type of Firm	Cost Calculation
Electromechanical products manufacturer (Traditional cost structure)	Cost = (113%) × (Materials cost) + (360%) × (Direct labor cost)
Precision valve manufacturer (Activity-based cost structure)	Cost = (108%) × [(Direct labor cost) + (Setup labor cost) + (160%) × (Materials cost) + ($27.80) × (Machine hours) + ($2,000.00) × (Number of shipments)]
Heavy equipment component manufacturer (Activity-based cost structure)	Cost = (110%) × (Materials cost) + (109%) × [(211%) × (Direct labor cost) + ($16.71) × (Machine hours) + ($33.76) × (Setup hours) + ($114.27) × (Number of production orders) + ($19.42) × (Number of material handling loads) + ($487.00) × (Number of new parts added to the system)]

Sources, top to bottom: Unpublished company source; Harvard Business School cases: Destin Brass Products Co., 9-190-089, and John Deere Component Works, 9-187-107

Notes: 1. This table shows total costs per customer order.
2. Materials costs include costs of raw materials and purchased components.

EXHIBIT 13-24 Typical cost structures for manufacturing firms.

Ch. 14: Prototyping

- Types

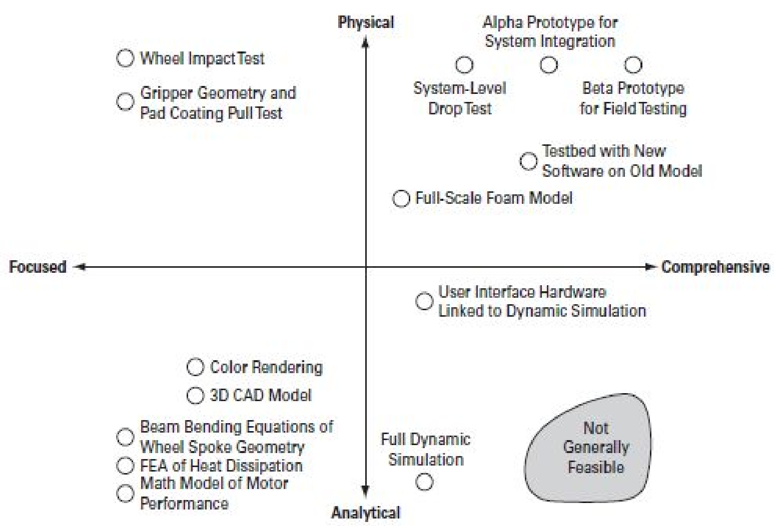


EXHIBIT 14-5 Types of prototypes. Prototypes can be classified according to the degree to which they are physical and the degree to which they implement all of the attributes of the product.

Ch. 17: Product Development Economics

- Base-case financial model based on cash flow from
  - Development cost, ramp-up cost, marketing/support cost, production cost, sales revenue

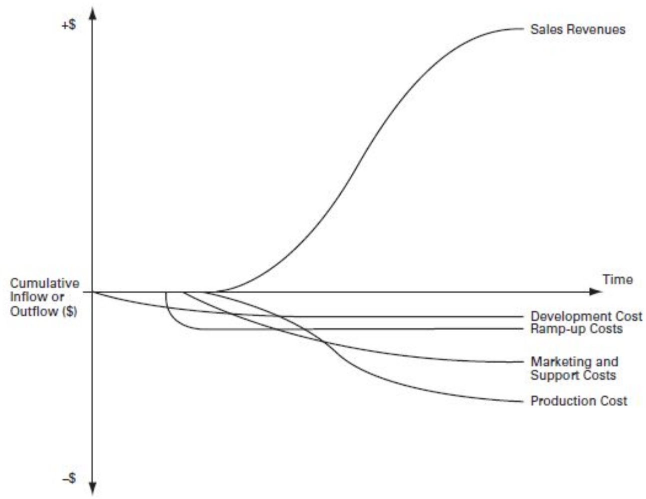


EXHIBIT 17-2 Typical cash flows for a successful new product.

EXHIBIT 17-3 CI-700 project budgets, sales volume forecasts, and production costs.

1. Development cost	$5 million
2. Ramp-up cost	$2 million
3. Marketing and support cost	$1 million/year
4. Unit production cost	$400/unit
5. Sales and production volume	20,000 units/year
6. Unit price	$800/unit

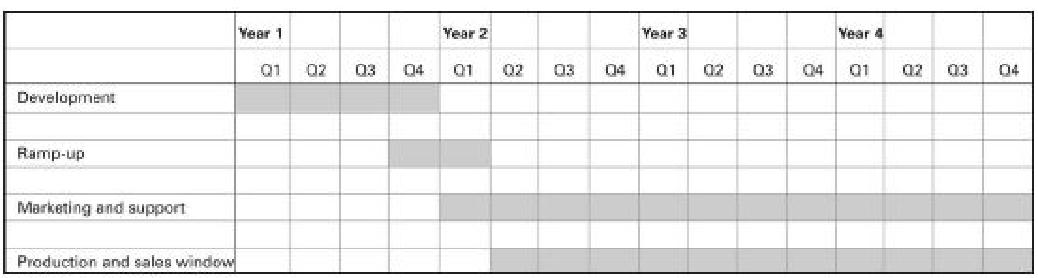


EXHIBIT 17-4 CI-700 project schedule from inception through market withdrawal.

	Year 1				Year 2				Year 3				Year 4			
($ values in thousands)	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Development cost	−1,250	−1,250	−1,250	−1,250												
Ramp-up cost				−1,000	−1,000											
Marketing & support cost					−250	−250	−250	−250	−250	−250	−250	−250	−250	−250	−250	−250
Production cost						−2,000	−2,000	−2,000	−2,000	−2,000	−2,000	−2,000	−2,000	−2,000	−2,000	−2,000
Production volume						5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Unit production cost						−0.4	−0.4	−0.4	−0.4	−0.4	−0.4	−0.4	−0.4	−0.4	−0.4	−0.4
Sales revenue						4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Sales volume						5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Unit price						0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

EXHIBIT 17-5 Merging the project financials and schedule into a cash flow table (all dollar values are in thousands in this and subsequent tables).

Compute the Net Present Value of the Cash Flows

Computing the NPV requires that the net cash flow for each period be determined, and then that this cash flow be converted to its present value (its value in today's dollars), as shown in Exhibit 17-6. Consider, for example, the calculations for year 3, first quarter:

1. The period cash flow is the sum of inflows and outflows:

Marketing cost	\$ –250,000
Product revenues	4,000,000
Production cost	–2,000,000
Period cash flow	\$1,750,000

2. The present value of this period cash flow discounted at 10 percent per year (2.5 percent per quarter) back to the first quarter of year 1 (a total of eight quarters) is

	Year 1				Year 2				Year 3				Year 4			
(\$ values in thousands)	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Development cost	–1,250	–1,250	–1,250	–1,250												
Ramp-up cost				–1,000	–1,000											
Marketing & support cost					–250	–250	–250	–250	–250	–250	–250	–250	–250	–250	–250	–250
Production cost						–2,000	–2,000	–2,000	–2,000	–2,000	–2,000	–2,000	–2,000	–2,000	–2,000	–2,000
Production volume						5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Unit production cost						–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4
Sales revenue						4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Sales volume						5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Unit price						0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Period Cash Flow	–1,250	–1,250	–1,250	–2,250	–1,250	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750
PV Year 1, r = 10%	–1,250	–1,220	–1,190	–2,089	–1,132	1,547	1,509	1,472	1,436	1,401	1,367	1,334	1,301	1,269	1,239	1,208
Project NPV	8,203															

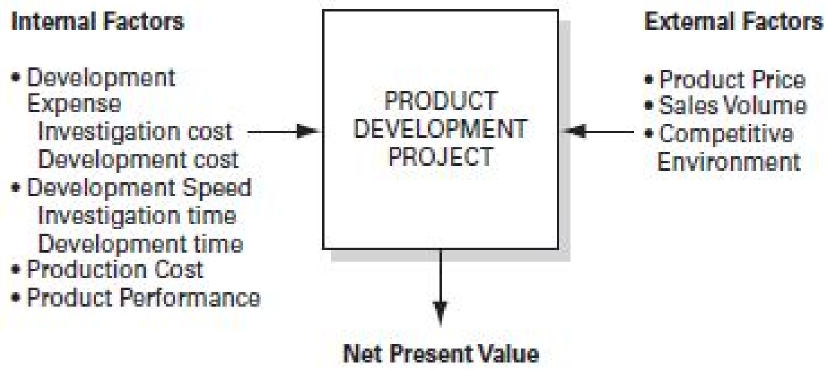
EXHIBIT 17-6 Total cash flows, present values, and net present value.

\$1,436,306. (The concepts of *present value, net present value,* and *discount rate* are reviewed in Appendix A.)

$$\frac{\$1{,}750{,}000}{1.025^8} = \$1{,}436{,}306$$

3. Project NPV is the sum of the discounted cash flows for each of the periods, or \$8,203,000. (Here and in the rest of the chapter we round financial figures to the nearest one thousand dollars.)

EXHIBIT 17-7 Key factors influencing product development profitability.



	Year 1				Year 2				Year 3				Year 4			
($ values in thousands)	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Development cost	–1,000	–1,000	–1,000	–1,000												
Ramp-up cost				–1,000	–1,000											
Marketing & support cost					–250	–250	–250	–250	–250	–250	–250	–250	–250	–250	–250	–250
Production cost						–2,000	–2,000	–2,000	–2,000	–2,000	–2,000	–2,000	–2,000	–2,000	–2,000	–2,000
Production volume						5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Unit production cost						–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4
Sales revenue						4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
Sales volume						5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Unit price						0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Period Cash Flow	–1,000	–1,000	–1,000	–2,000	–1,250	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750	1,750
PV Year 1, r = 10%	–1,000	–976	–952	–1,857	–1,132	1,547	1,509	1,472	1,438	1,401	1,367	1,334	1,301	1,269	1,239	1,208
Project NPV	9,167															

EXHIBIT 17-8 CI-700 financial model with 20 percent decrease in development spending.

Change in Development Cost, %	Development Cost, $ Thousands	Change in Development Cost, $ Thousands	Change in NVP, %	NPV, $ Thousands	Change in NPV, $ Thousands
50	7,500	2,500	–29.4	5,791	–2,412
20	6,000	1,000	–11.8	7,238	–964
10	5,500	500	–5.9	7,721	–482
base	5,000	base	0.0	8,203	0
–10	4,500	–500	5.9	8,685	482
–20	4,000	–1,000	11.8	9,167	964
–50	2,500	–2,500	29.4	10,615	2,412

EXHIBIT 17-9 CI-700's development cost sensitivities.

Ch. 18: Managing Projects

- Gantt Chart

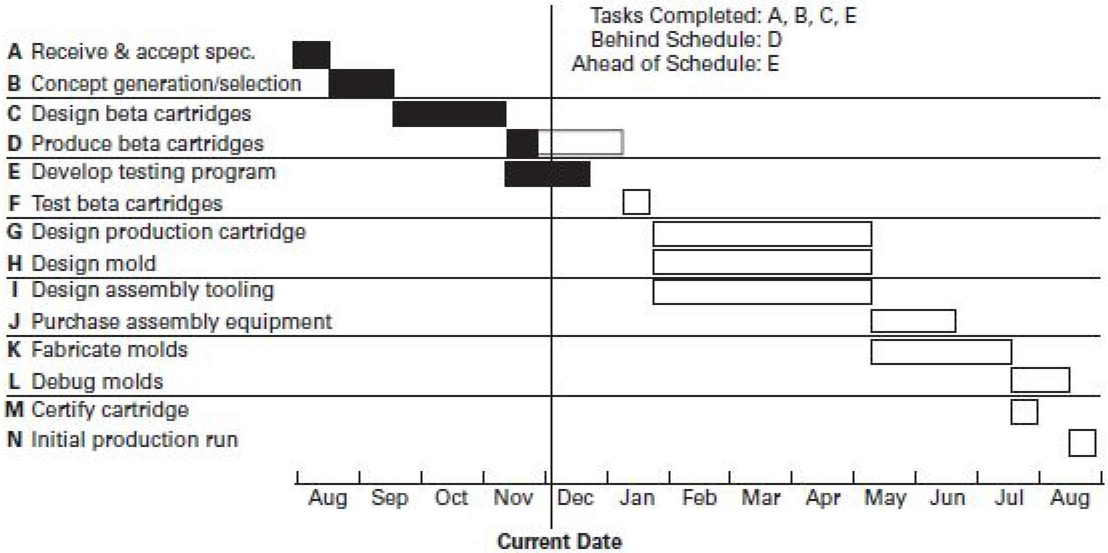


EXHIBIT 18-4 Gantt chart for the Cheetah project.

- Project Task List

EXHIBIT 18-6 Table of contents of a contract book for a project of moderate complexity.

Item	Approximate Pages	See Chapter(s)
Mission Statement	1	4
Customer Needs List	1–2	5
Competitive Analysis	1–2	3, 4, 5, 8, 9
Product Specifications	1–3	6
Sketches of Product Concept	1–2	7, 11
Concept Test Report	1–2	9
Sales Forecast	1–3	9, 17
Economic Analysis/Business Case	1–3	17
Environmental Impact Assessment	1–2	12
Manufacturing Plan	1–5	13
Project Plan		
Task List	1–5	2, 18
Design Structure Matrix	2–3	18
Team Staffing and Organization	1	2, 18
Schedule (Gantt and/or PERT)	1–2	18
Budget	1	18
Risk Plan	1	18
Project Performance Measurement Plan	1	18
Incentives	1	18
	Total 19–40 Pages	

EXHIBIT 18-13

Information systems that facilitate product development decision making, team consensus, and the exchange of information.

Development Activity	Information Systems Used
Product planning	Product segment map Technology roadmap Product-process change matrix Aggregate resource plan Product plan Mission statement
Customer needs identification	Customer needs lists
Concept generation	Function diagrams Concept classification tree Concept combination table Concept descriptions and sketches
Concept selection	Concept screening matrix Concept scoring matrix
Product specifications	Needs-metrics matrix Competitive benchmarking charts Specifications lists
System-level design	Schematic diagram Geometric layout Differentiation plan Commonality plan
Detailed design	Bill of materials Prototyping plan Environmental impact assessment
Industrial design	Aesthetic/ergonomic importance survey
Testing	Performance test reports Durability test reports
Product development economics	NPV analysis spreadsheet
Project management	Contract book Task list Design structure matrix Gantt chart PERT chart Staffing matrix Risk analysis Weekly status memo Buffer report Postmortem project report