Product design

Lecture Outline

- Design Process
- Rapid Prototyping and Concurrent Design
- Technology in Design
- Design Quality Reviews
- Design for Environment
- Quality Function Deployment
- Design for Robustness

Learning Objectives

- Explain product design process
- Calculate the reliability and availability of a product or service
- Understand the technologies involved in designing new products and their related production processes
- Utilize techniques for analyzing design failures and eliminating unnecessary design features
- Explain why and how each step of the product lifecycle can be changed for improved environmental stewardship, and provide examples of programs that support green efforts
- Use quality function deployment as a design tool

Key Questions

1. Is there a demand for it?
   - Market size
   - Demand profile
2. Can we do it?
   - **Manufacturability** - the *capability* of an organization to produce an item at an acceptable profit
   - **Serviceability** - the *capability* of an organization to provide a service at an acceptable cost or profit

Key Questions (contd.)

3. What level of quality is appropriate?
    - Customer expectations
    - Competitor quality
    - Fit with current offering
4. Does it make sense from an economic standpoint?
    - Liability issues, ethical considerations, sustainability issues, costs and profits

Design Process

1. Translate customer wants and needs into product and service requirements
2. Refine existing products and services
3. Develop new products and services
4. Formulate quality goals
5. Formulate cost targets
6. Construct and test prototypes
7. Document specifications
8. Translate product and service specifications into *process* specifications

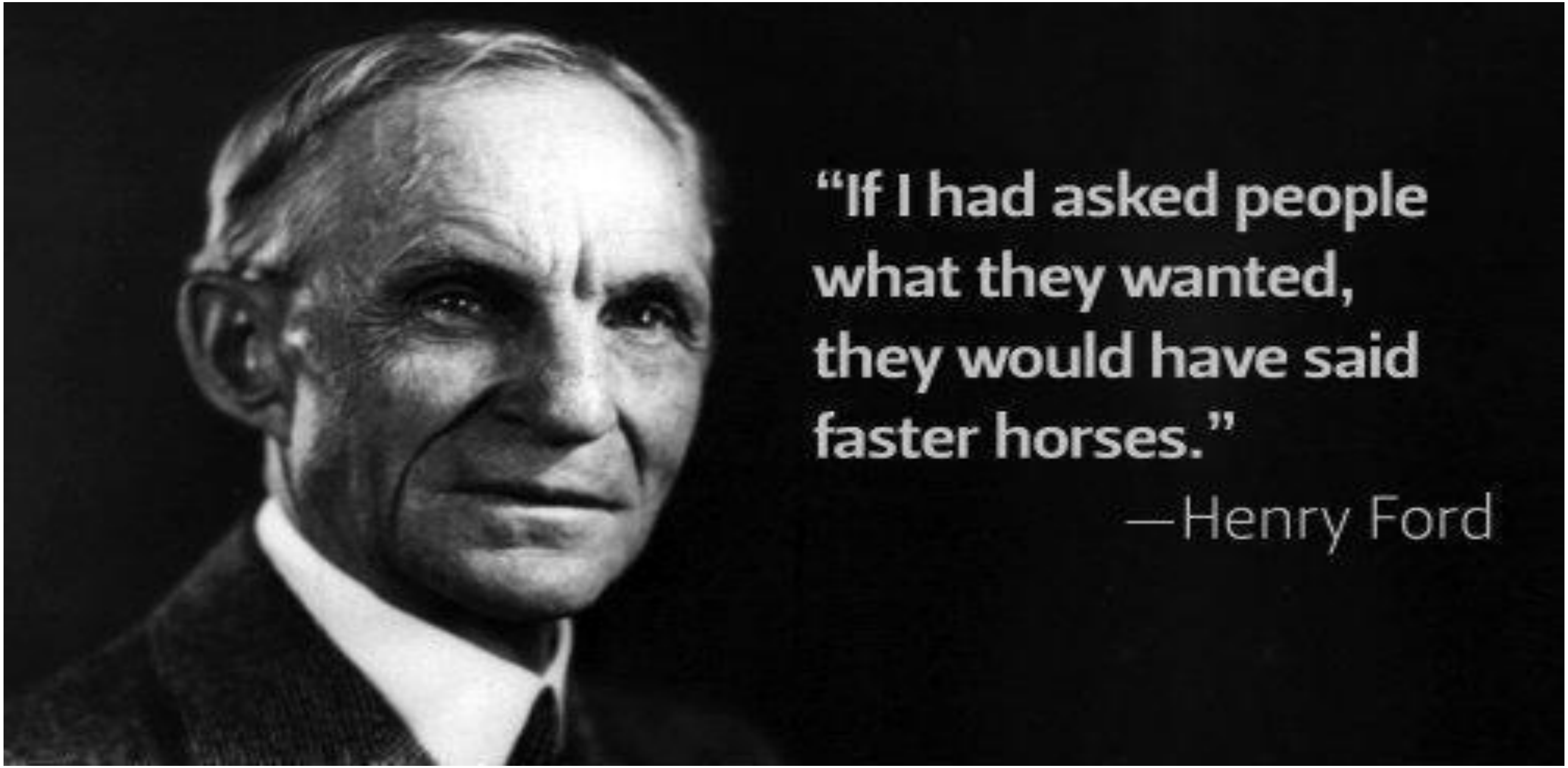
Involve Inter-functional Collaboration

What user’s want?

- Conduct user interviews (Surveys) to understand the problems

- Observe the users as much as possible

**Don’t ask for the solutions.


"If I had asked people what they wanted, they would have said faster horses."
—Henry Ford

Design Process

- Effective design can provide a competitive edge
  - **matches** product or service characteristics with customer requirements
  - ensures that customer requirements are met in the **simplest and least costly** manner
  - **reduces time** required to design a new product or service
  - **minimizes revisions** necessary to make a design workable

Reasons to Design or Re-Design

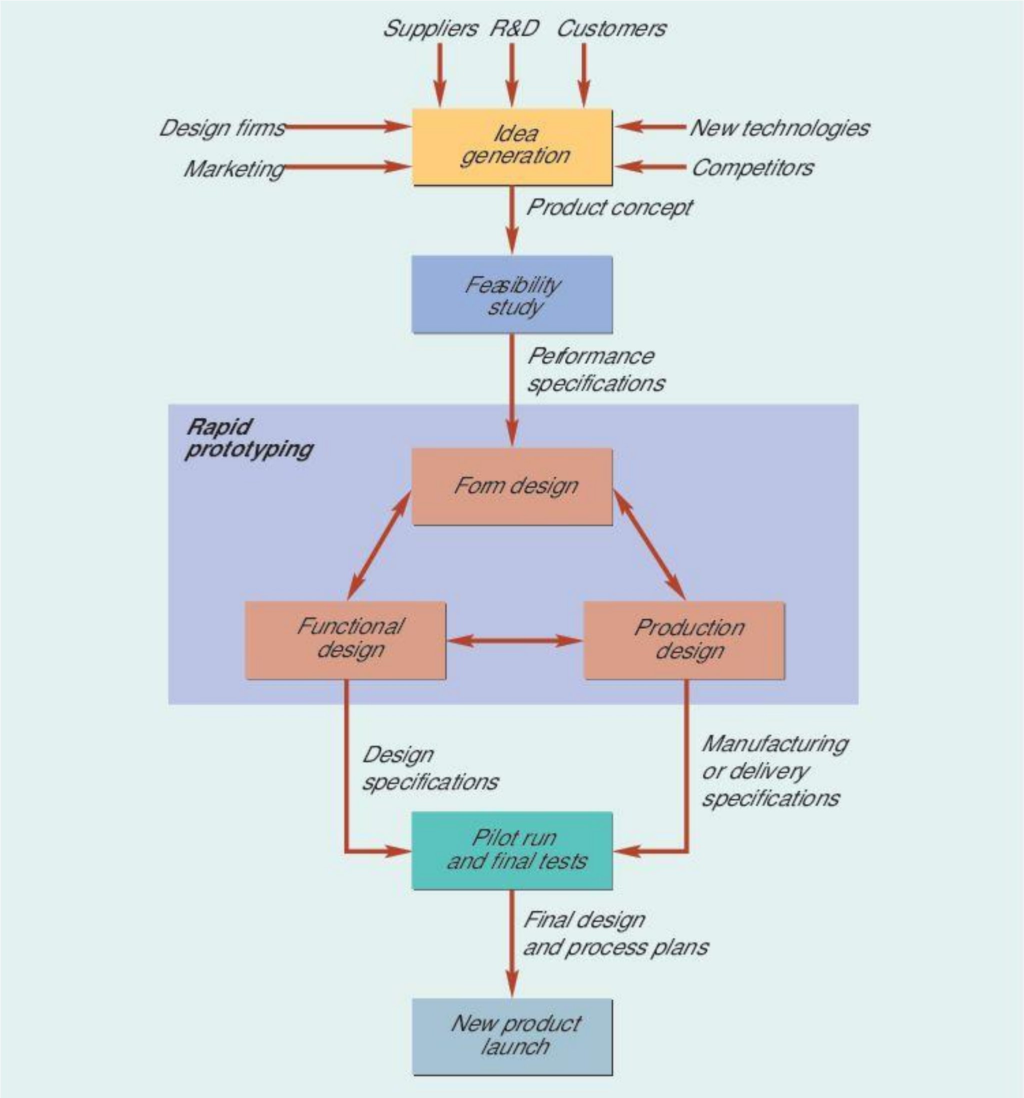
- The driving forces for product and service design or redesign are market opportunities or threats:
  - Economic
  - Social and Demographic
  - Political, Liability, or Legal
  - Competitive
  - Cost or Availability
  - Technological

Designing a product

- What constitutes a good product?
  - Train coaches: they differ across service categories
    - Have space for bikes
    - In the seating cars have separate seats for kids
- Experience at a restaurant
  - Waiting time
  - Quality of food

- Implications for
  - Selection and rejection of
    - Raw material suppliers
    - Processes

Design Process



Idea Generation

1. Supply-chain based
2. Competitor based
3. Research based

Idea Generation

- Company's own R&D department
- Customer complaints or suggestions
- Marketing research
- Suppliers
- Salespersons in the field
- Factory workers
- New technological developments
- Competitors

Idea Generation

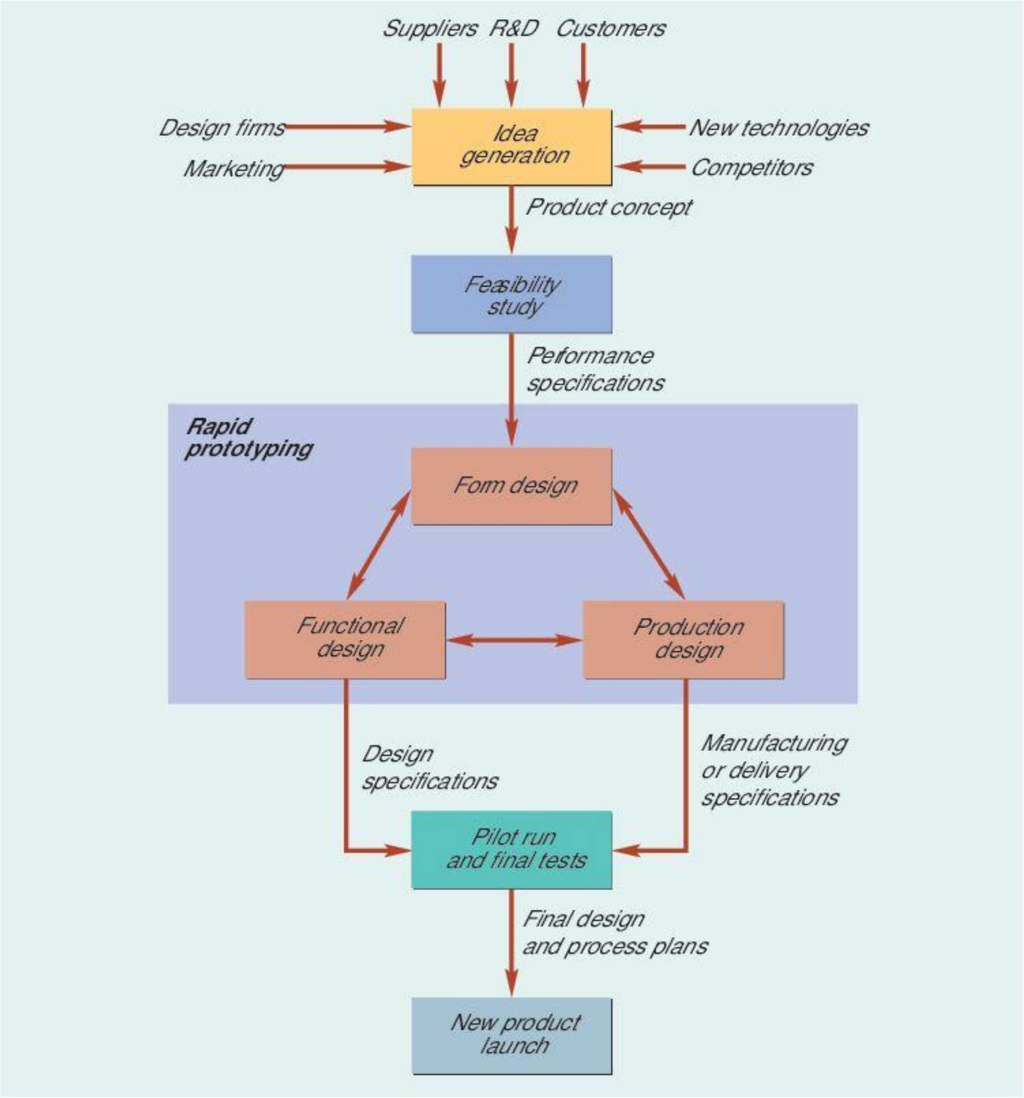
- Perceptual Maps
  - visual comparison of customer perceptions

- Benchmarking
  - comparing product/process against best-in-class

- Reverse engineering
  - dismantling competitor’s product to improve your own product

Perceptual Map of Breakfast Cereals

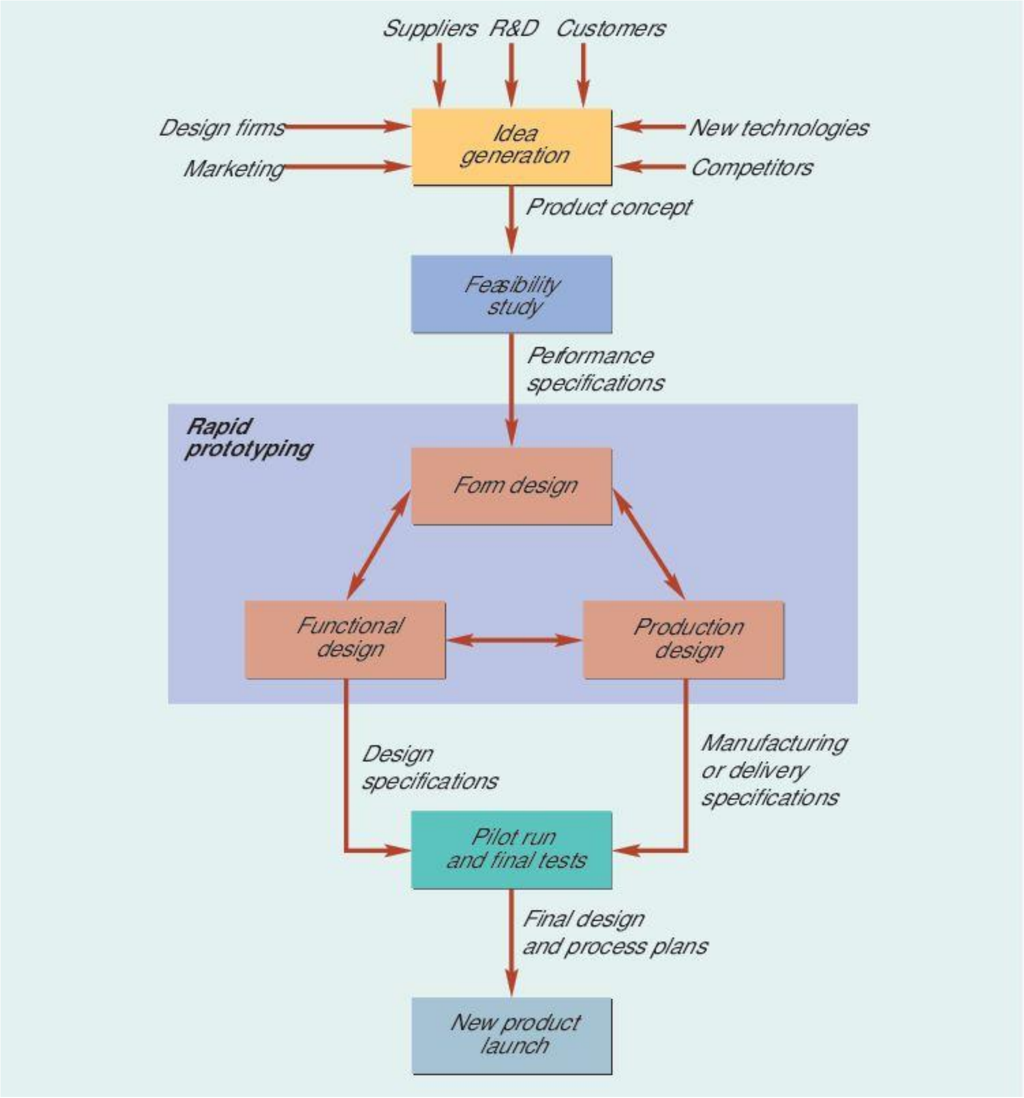
Design Process



Feasibility Study

- Market analysis
- Economic analysis
- Technical/strategic analyses
- Performance specifications

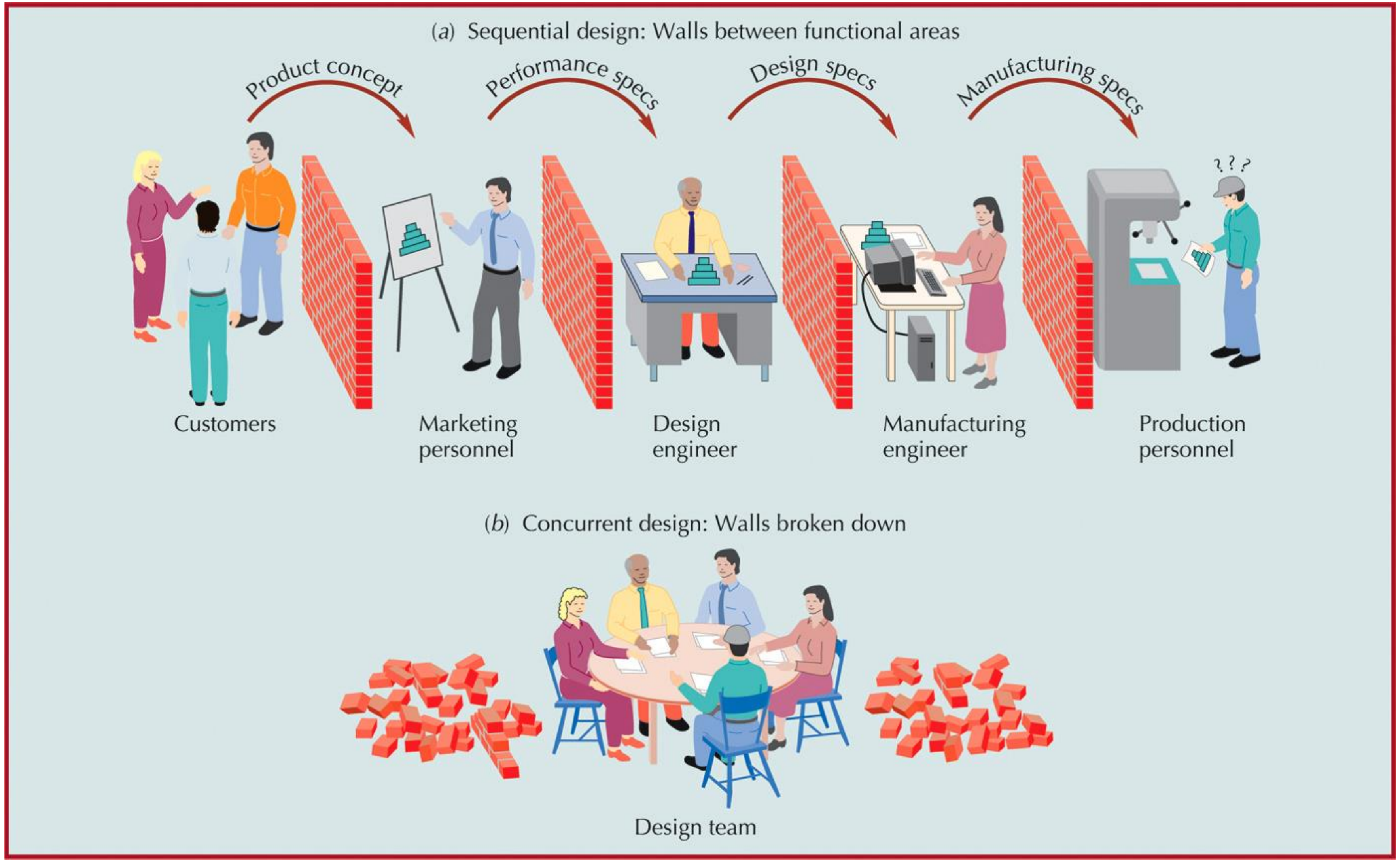
Design Process



Rapid Prototyping and Concurrent Design

- Testing and revising a preliminary design model
- Build a prototype
  - form design
  - functional design
  - production design
- Test prototype
- Revise design
- Retest

Concurrent Design



Form and Functional Design

- Form Design
  - how product will look?

- Functional Design
  - how product will perform?
    - reliability
    - maintainability
    - usability

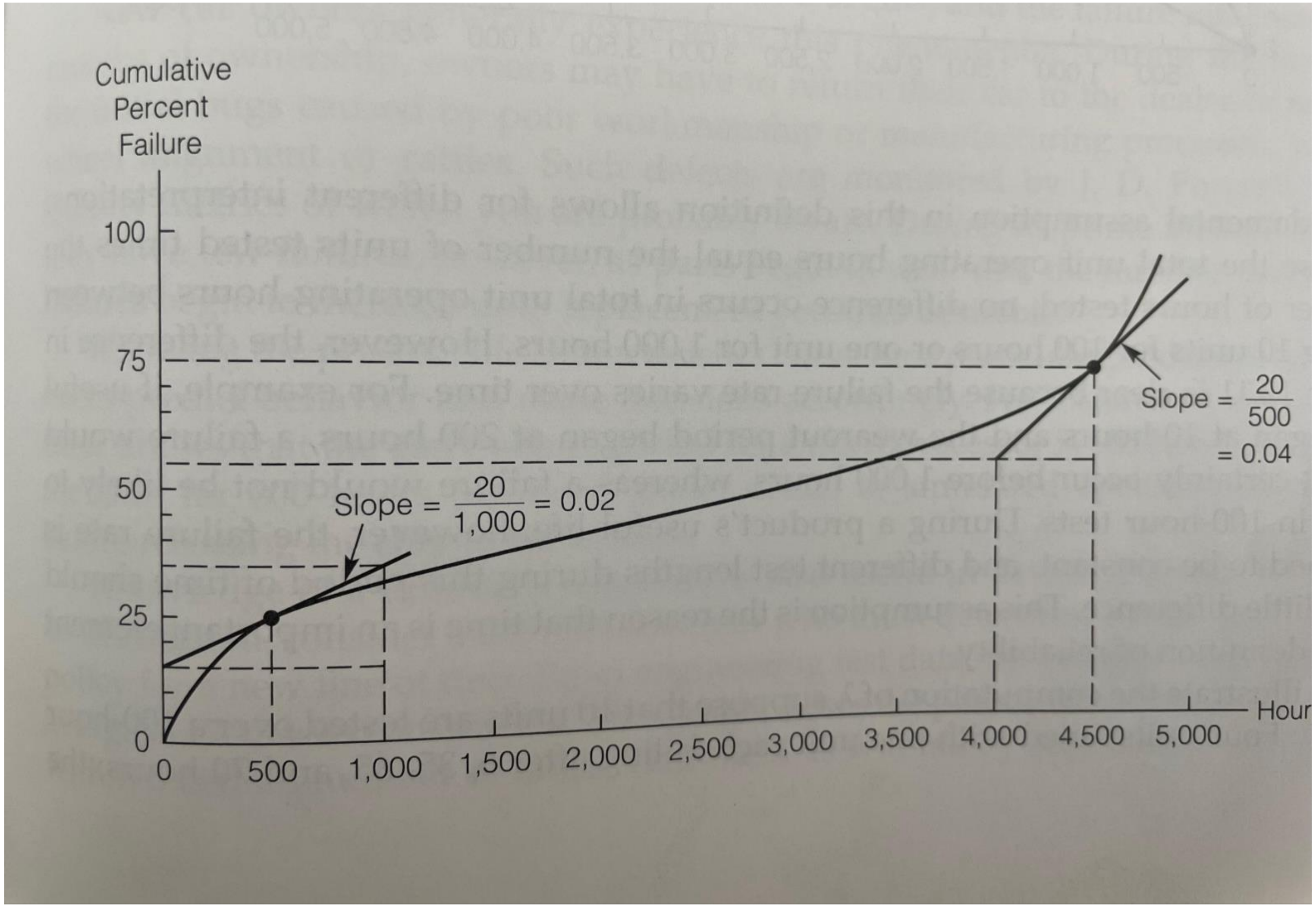
Reliability

- **Reliability**
  - The ability of a product, part, or system to perform its intended function under a prescribed set of conditions
  - Reliability is expressed as a probability:
    - The probability that the product or system will function when activated
    - The probability that the product or system will function for a given length of time

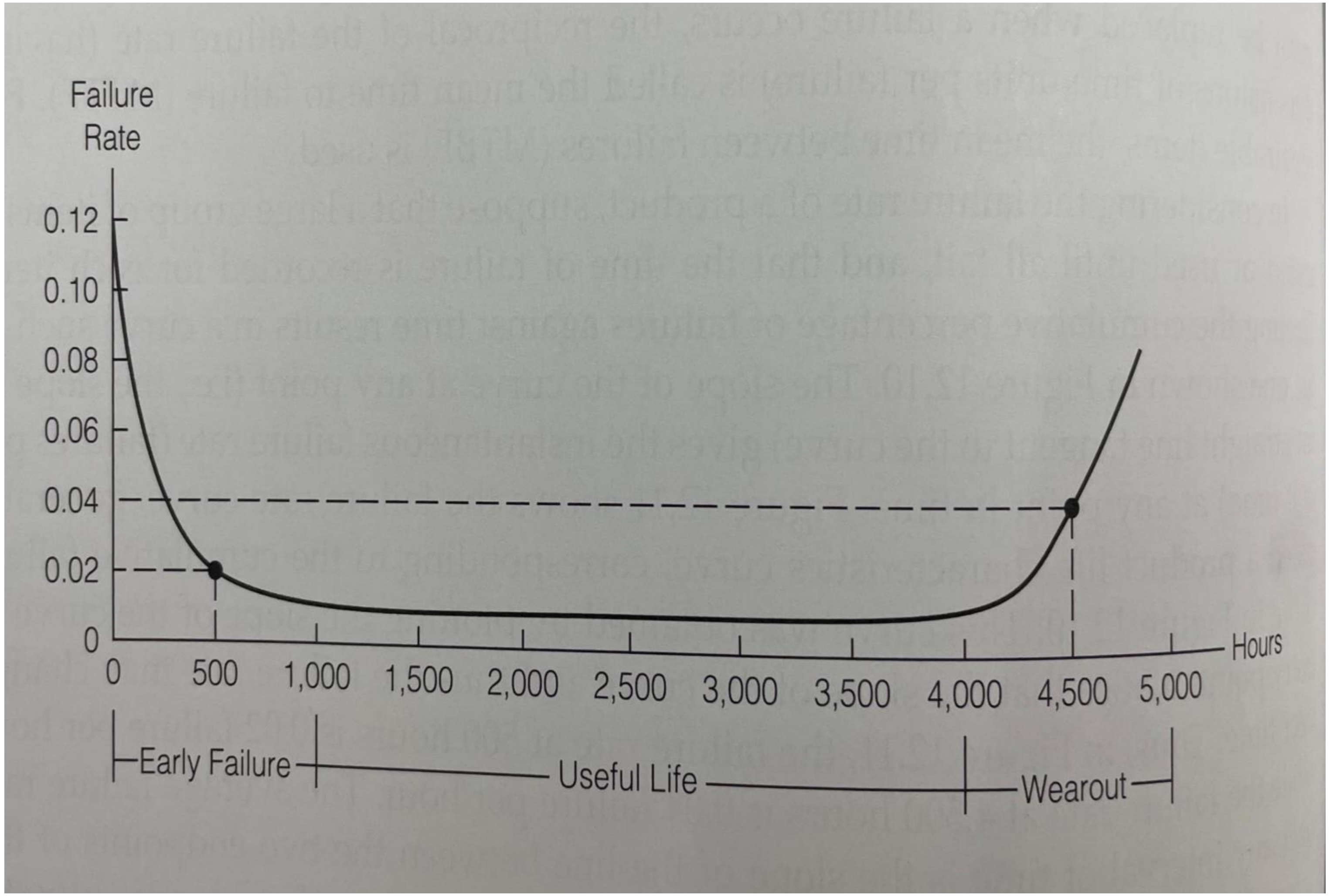
Reliability – Over Time

- In this case, reliabilities are determined relative to a specified length of time.
- This is a common approach to viewing reliability when establishing warranty periods

Cumulative failure curve over time



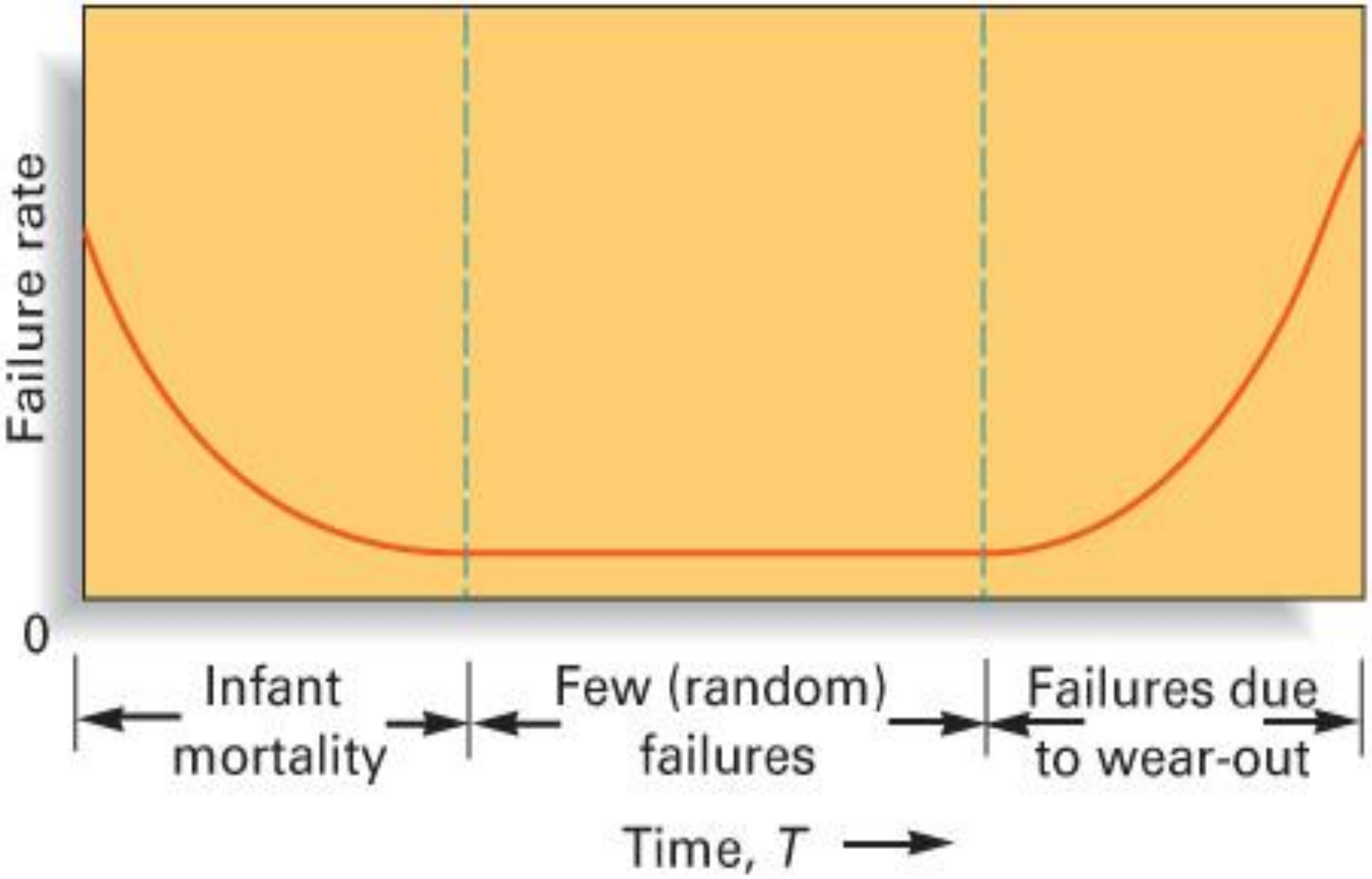
Failure rate curve



Failure rate (λ) = number of failures/Total unit operating hours

= number of failures/(Units tested * number of hours tested)

The Bathtub Curve



Distribution and Length of Phase

- To properly identify the distribution and length of each phase requires collecting and analyzing historical data
- The mean time between failures (MTBF) in the infant mortality phase can often be modeled using the negative exponential distribution

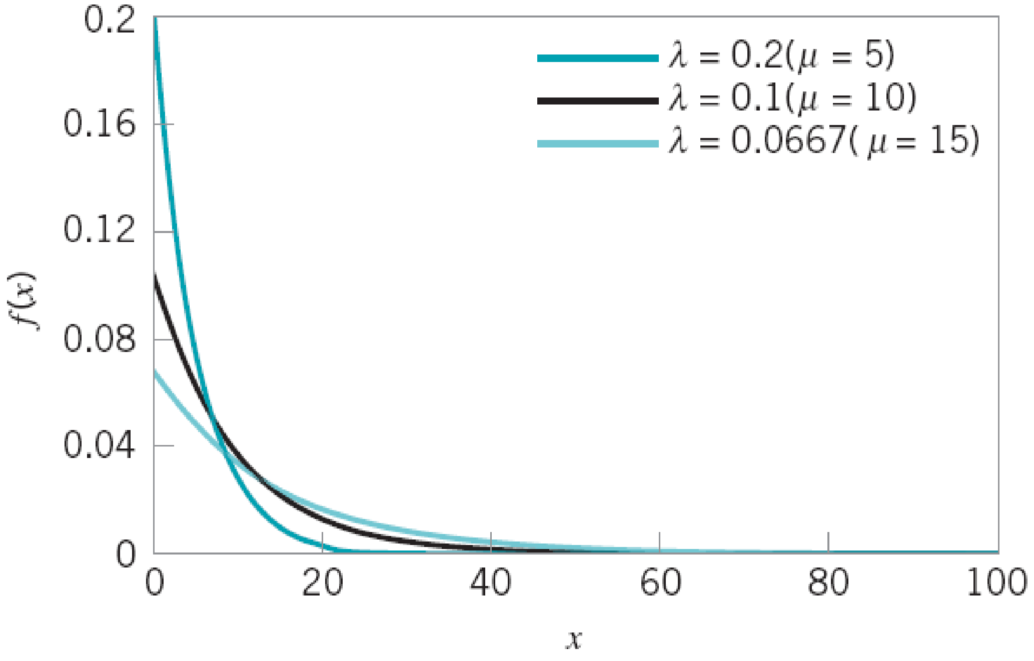


FIGURE 3.21 Exponential distributions for selected values of λ.

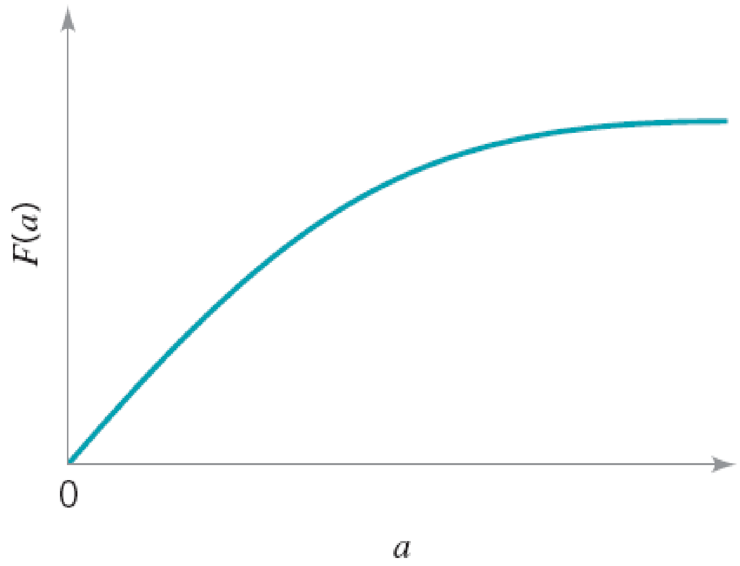
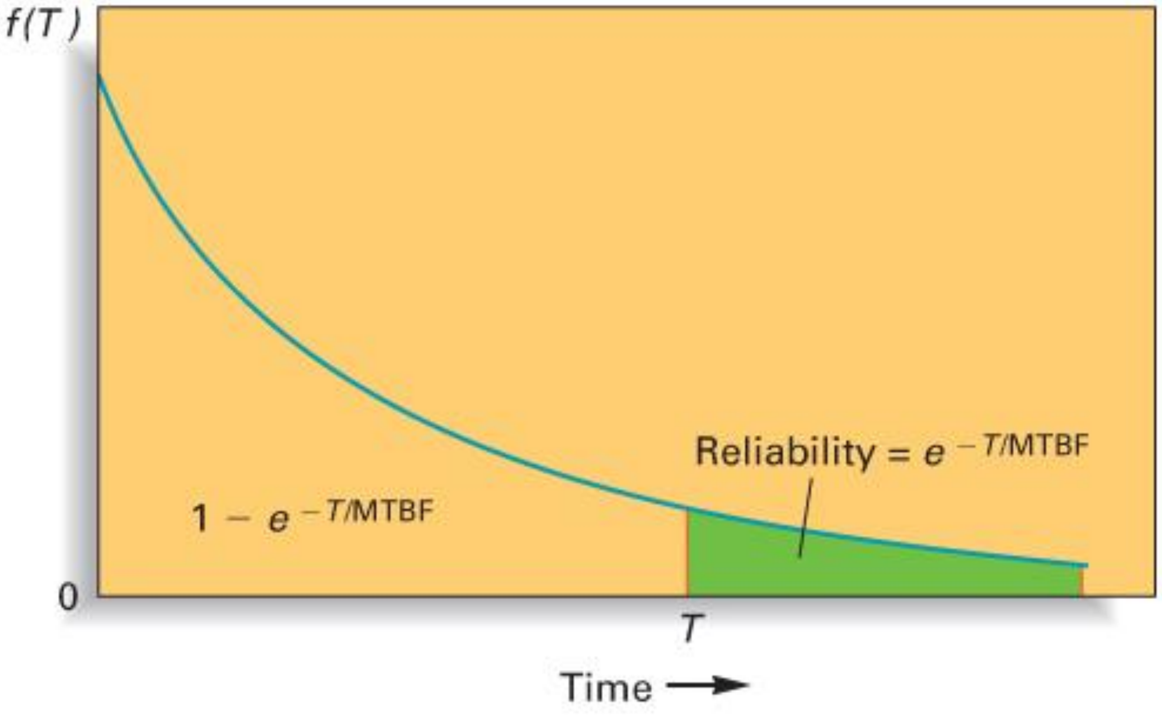


FIGURE 3.22 The cumulative exponential distribution function.

Exponential Distribution



Exponential Distribution – Formulae

$$P(\text{no failure before } T) = e^{-T/MTBF}$$

where

$$e = 2.7183...$$

$$T = \text{Length of service before failure}$$

$$\text{MTBF} = \text{Mean time between failures}$$

Example – Exponential Distribution

- A light bulb manufacturer has determined that its 150 watt bulbs have an exponentially distributed mean time between failures of 2,000 hours. What is the probability that one of these bulbs will fail before 2,000 hours have passed?

Example – Exponential Distribution

- A light bulb manufacturer has determined that its 150 watt bulbs have an exponentially distributed mean time between failures of 2,000 hours. What is the probability that one of these bulbs will fail before 2,000 hours have passed?

$$e^{-2000/2000} = e^{-1}$$

$e^{-1} = .3679$

So, the probability one of these bulbs will fail before 2,000 hours is 1 - .3679 = .6321

Consider an item having a reliability of 0.97 for 100 hours of normal use. Determine the failure rate.

Failure rate = 0.0003 failure/hour

Cumulative fraction failing and surviving

Time, T	Failures, F(T)	Survivors, R(T)
10	0.003	0.997
20	0.006	0.994
30	0.009	0.991
40	0.012	0.988
50	0.015	0.985
60	0.018	0.982
70	0.021	0.979
80	0.024	0.976
90	0.027	0.973
100	0.030	0.970

Availability

- **Availability**
  - The fraction of time a piece of equipment is expected to be available for operation

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTR}}$$

where

$$\text{MTBF} = \text{Mean time between failures}$$

$$\text{MTR} = \text{Mean time to repair}$$

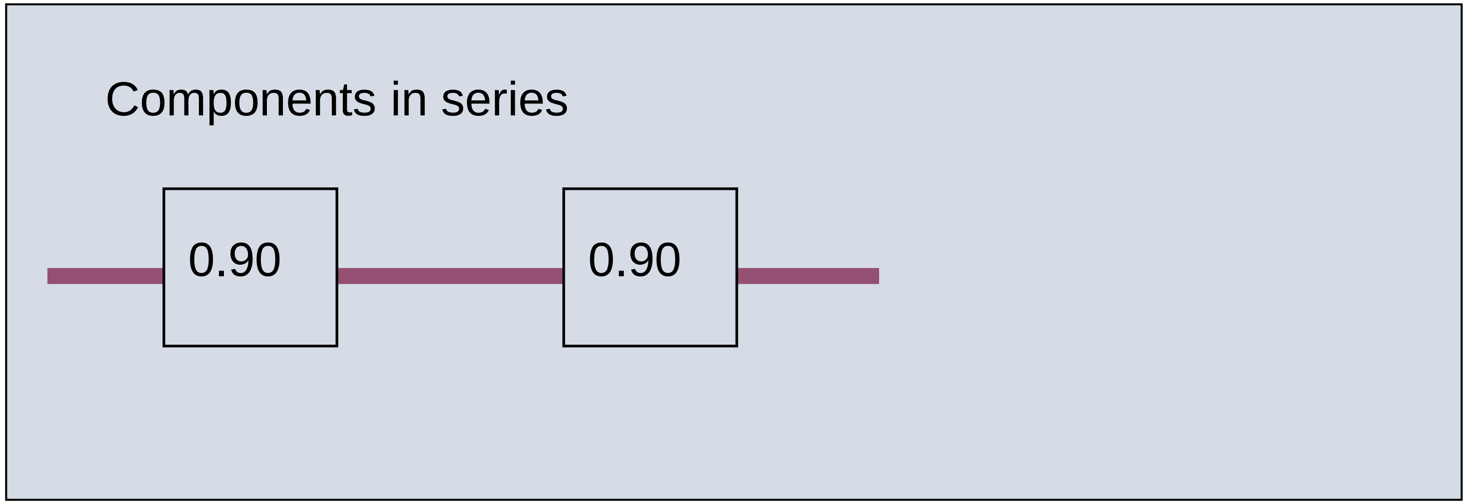
Reliability

- **Reliability**
  - The ability of a product, part, or system to perform its intended function under a prescribed set of conditions
  - Reliability is expressed as a probability:
    - The probability that the product or system will function when activated
    - The probability that the product or system will function for a given length of time

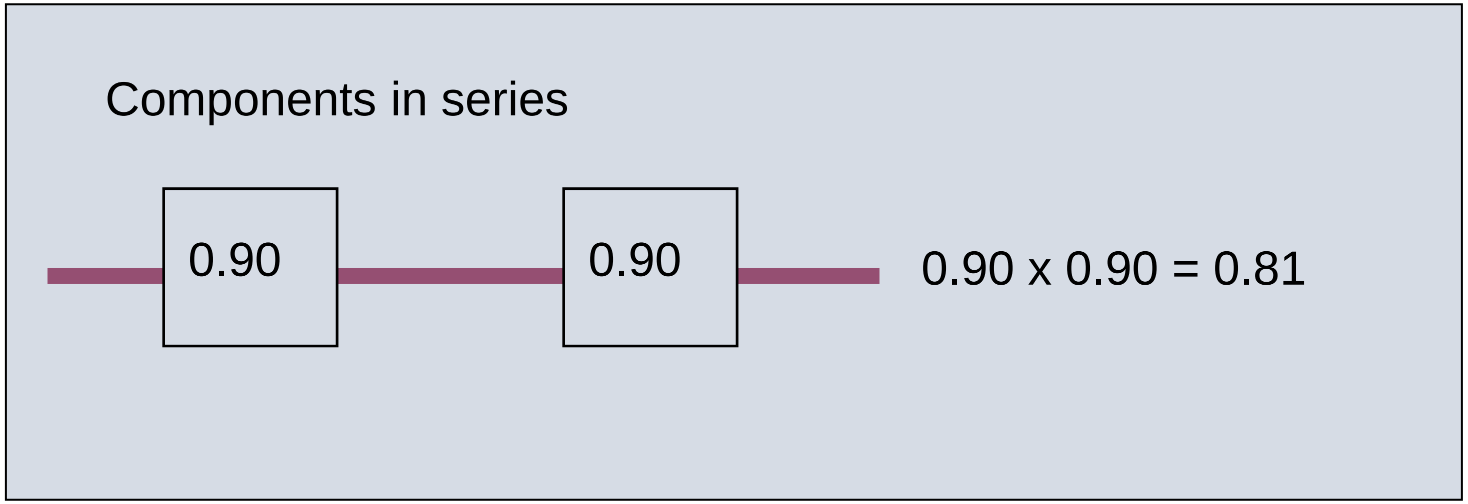
Predicting System Reliability

Rule 1

If two or more events are independent and *success* is defined as the probability that all of the events occur, then the probability of success is equal to the product of the probabilities of the events



Computing Reliability



- Suppose that a two-component series system has failure rates of 0.004 and 0.001 per hour. Then the probability of survival for 100 hours would be?

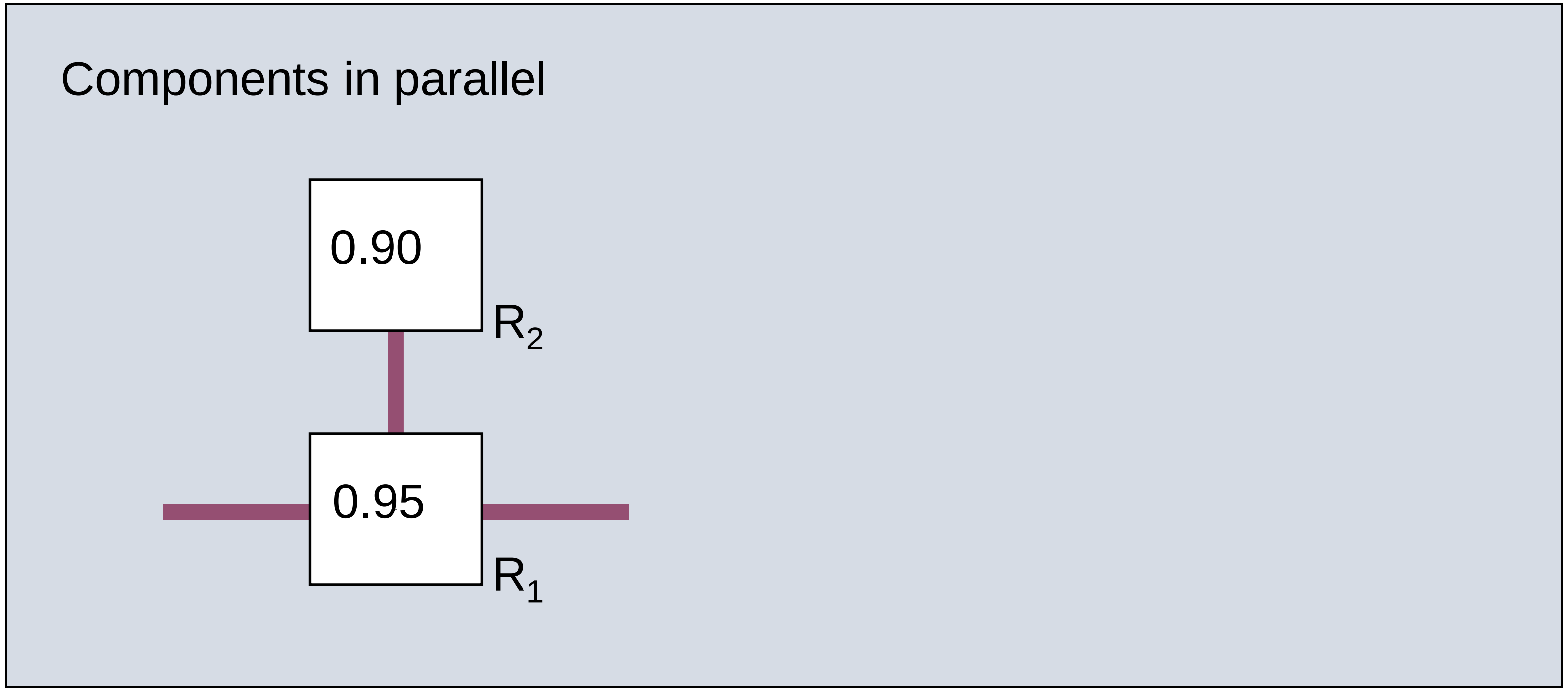
- Suppose that a two-component series system has failure rates of 0.004 and 0.001 per hour. Then the probability of survival for 100 hours would be?

0.6065

Predicting Reliability

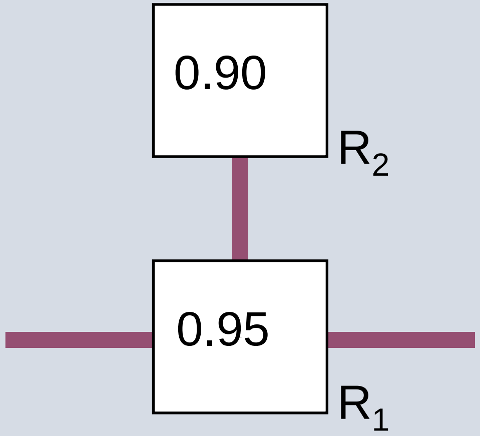
Rule 2

If two events are independent and *success* is defined as the probability that *at least one* of the events will occur, the probability of success is equal to the probability of either one plus 1.00 minus that probability multiplied by the other probability



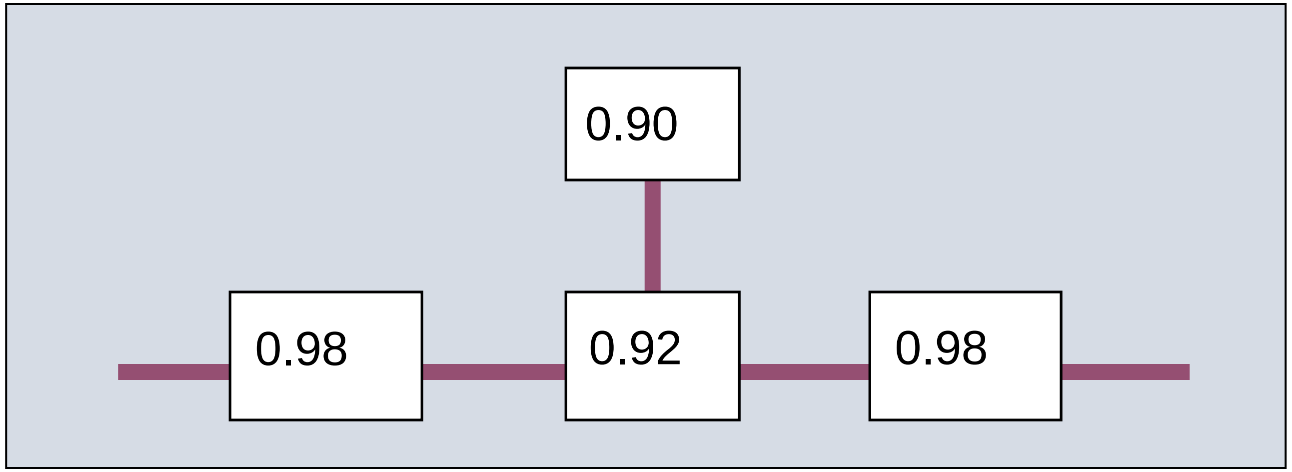
Computing Reliability

Components in parallel

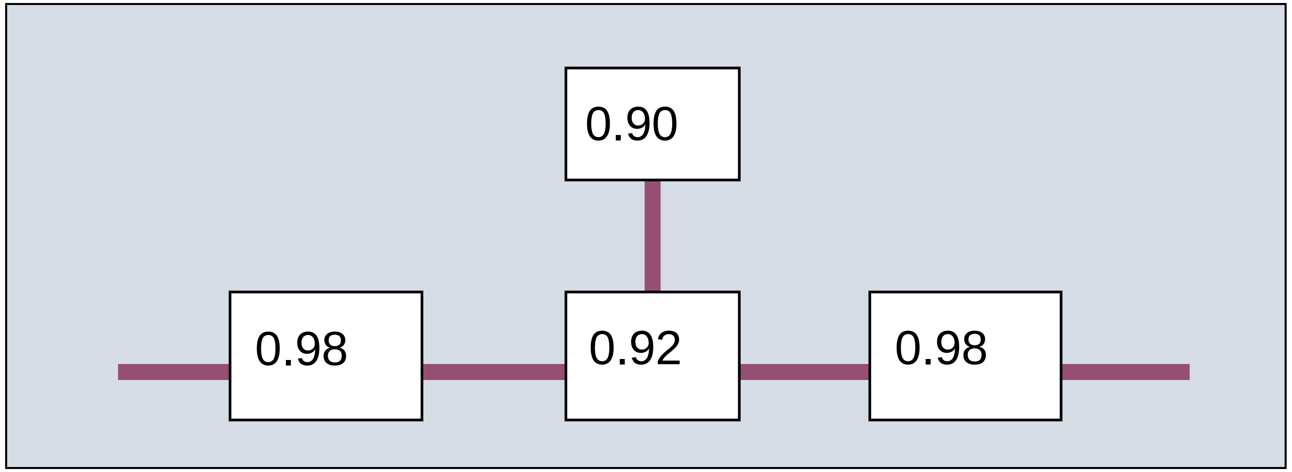


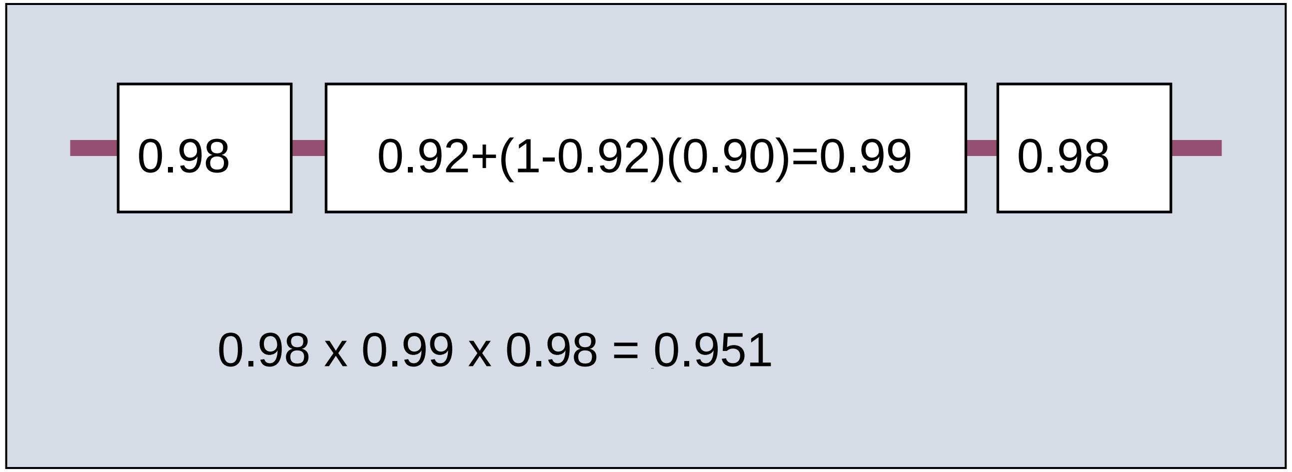
$0.95 + 0.90(1-0.95) = 0.995$

System Reliability



System Reliability





Computing reliability

- **Rule 3**
  - If two or more events are involved and success is defined as the probability that at least one of them occurs, the probability of success is 1 - *P*(all fail).

- A student takes three calculators (with reliabilities of .85, .80, and .75) to her exam. Only one of them needs to function for her to be able to finish the exam. What is the probability that she will have a functioning calculator to use when taking her exam?

Computing reliability

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$$
\begin{aligned}
P(\text{any Calc.}) &= 1-[(1-P(\text{Calc.}1)\times(1-P(\text{Calc.}2)\times(1-P(\text{Calc.}3)] \\
&= 1-[(1-.85)(1-.80)(1-.75)] \\
&= .9925
\end{aligned}
$$

System Availability

PROVIDER	MTBF (HR)	MTTR (HR)
A	60	4.0
B	36	2.0
C	24	1.0

SA_A =

SA_B =

SA_C =

System Availability (SA)

$$SA = \frac{MTBF}{MTBF + MTTR}$$

where:

MTBF = mean time between failures

MTTR = mean time to repair

System Availability

PROVIDER	MTBF (HR)	MTTR (HR)
A	60	4.0
B	36	2.0
C	24	1.0

SA_A = 60 / (60 + 4) = .9375 or 94%

SA_B = 36 / (36 + 2) = .9473 or 95%

SA_C = 24 / (24 + 1) = .96 or 96%

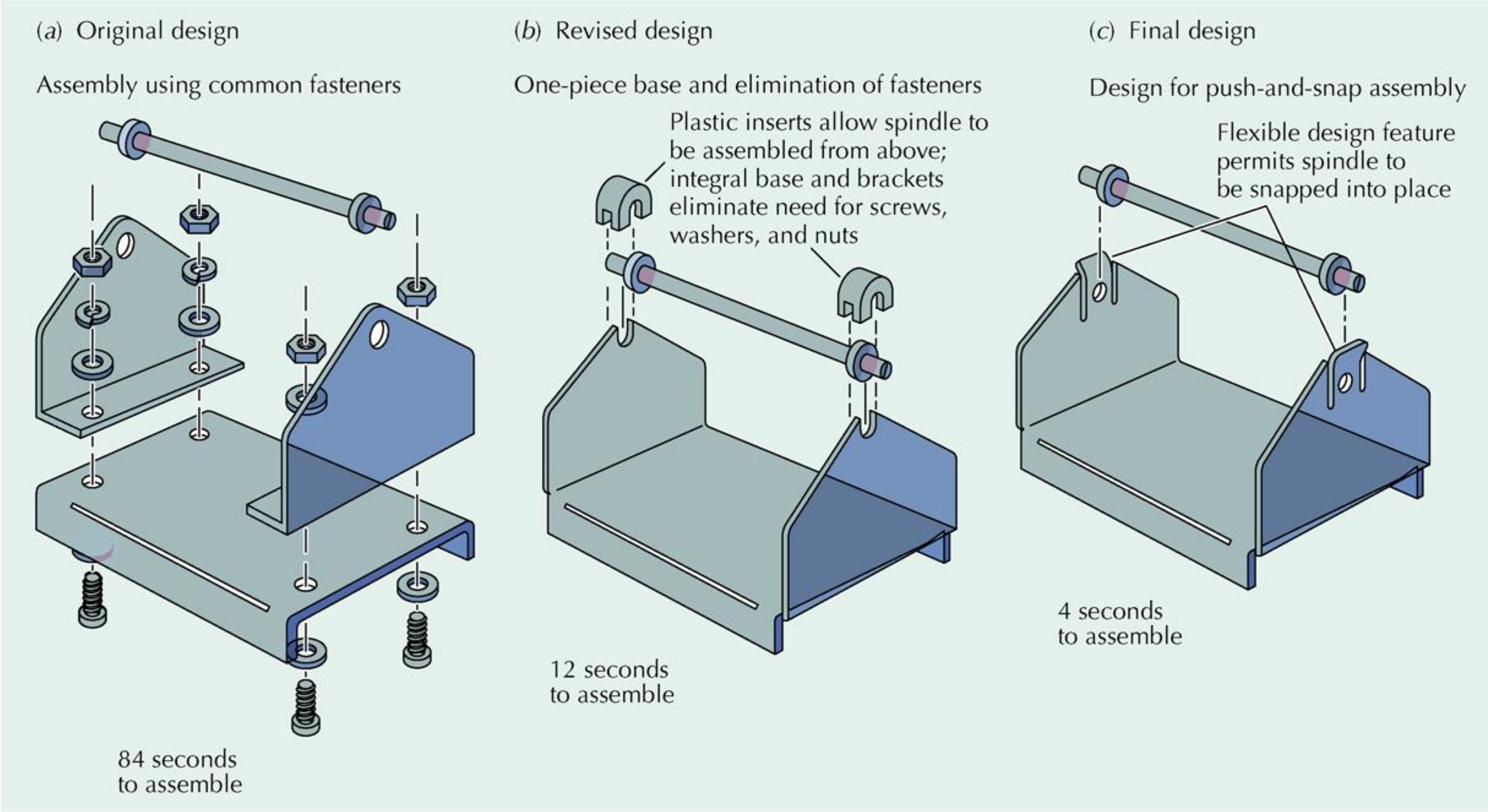
Usability

- Ease of use of a product or service
  - ease of learning
  - ease of use
  - ease of remembering how to use
  - frequency and severity of errors
  - user satisfaction with experience

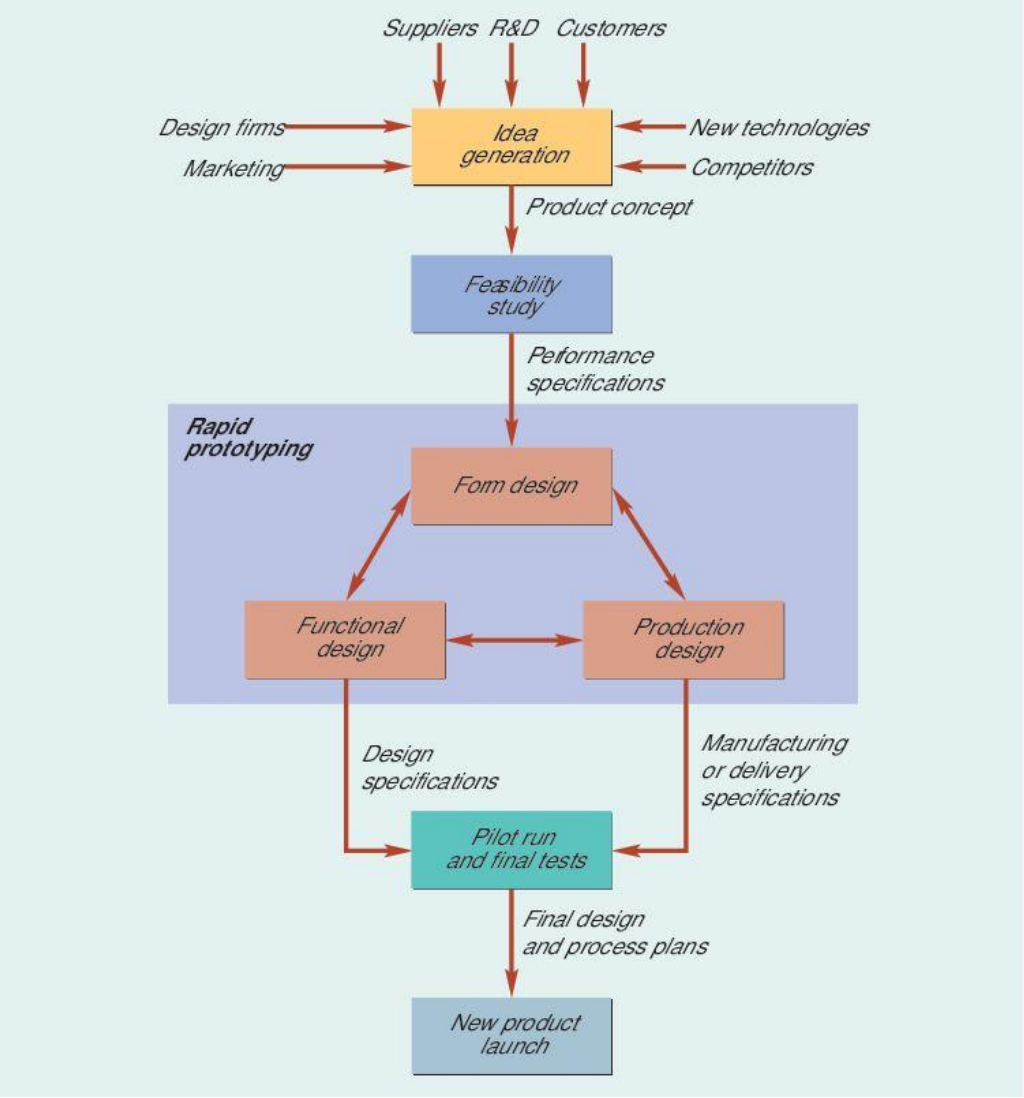
Production Design

- How the product will be made
  - Simplification
    - reducing number of parts, assemblies, or options in a product
  - Standardization
    - using commonly available and interchangeable parts
  - Modular Design
    - combining standardized building blocks, or modules, to create unique finished products
  - Design for Manufacture (DFM)
    - Designing a product so that it can be produced easily and economically

Design Simplification



Design Process



Final Design and Process Plans

- Final design
  - detailed drawings and specifications for new product or service
- Process plans
  - workable instructions
    - necessary equipment and tooling
    - component sourcing recommendations
    - job descriptions and procedures
    - computer programs for automated machines

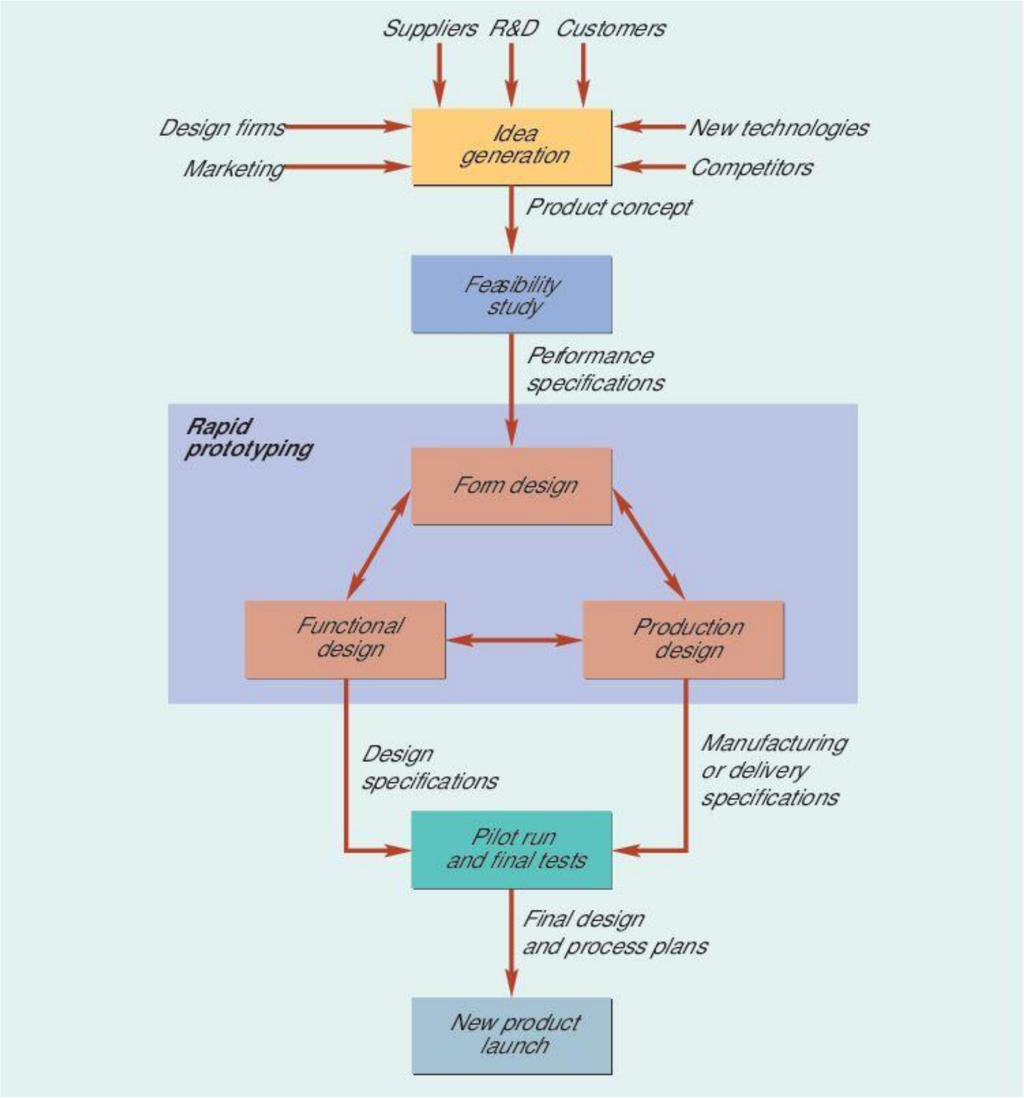
Technology in Design

- Computer Aided Design (CAD)
  - assists in creation, modification, and analysis of a design
  - computer-aided engineering (CAE)
    - tests and analyzes designs on computer screen
  - computer-aided manufacturing (CAD/CAM)
    - ultimate design-to-manufacture connection
  - product life cycle management (PLM)
    - managing entire lifecycle of a product
  - collaborative product design (CPD)

Collaborative Product Design (CPD)

- A software system for collaborative design and development among trading partners
- With PLM, manages product data, sets up project workspaces, and follows life cycle of the product
- Accelerates product development, helps to resolve product launch issues, and improves quality of design
- Designers can
  - conduct virtual review sessions
  - test “what if” scenarios
  - assign and track design issues
  - communicate with multiple tiers of suppliers
  - create, store, and manage project documents

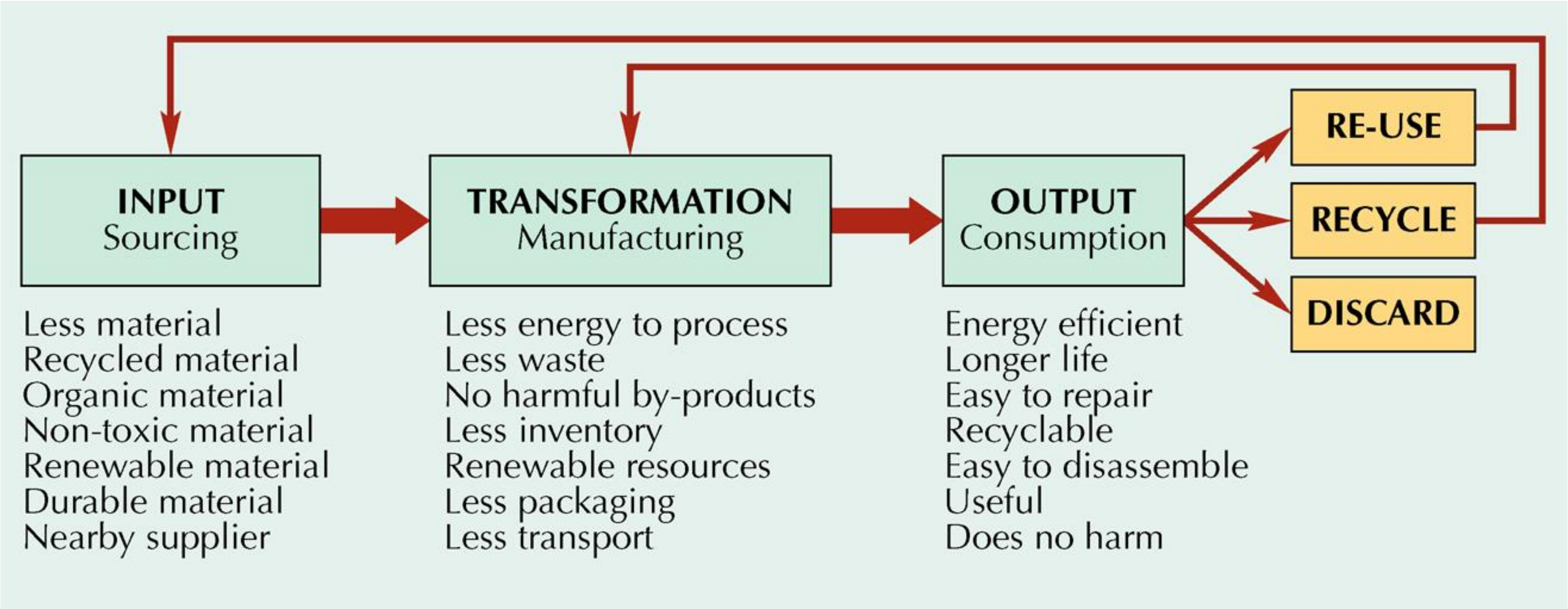
Design Process



Design for Environment and Extended Producer Responsibility

- Design for environment
  - designing a product from material that can be recycled
  - design from recycled material
  - design for ease of repair
  - minimize packaging
  - minimize material and energy used during manufacture, consumption and disposal
- Extended producer responsibility
  - holds companies responsible for their product even after its useful life

Design for Environment



Designing for Mass Customization

- **Mass customization**
  - A strategy of producing basically standardized goods or services, but incorporating some degree of customization in the final product or service
  - Facilitating Techniques
    - Delayed differentiation
    - Modular design

Delayed Differentiation

- **Delayed Differentiation**
  - The process of producing, but not quite completing, a product or service until customer preferences are known
  - It is a postponement tactic
    - Produce a piece of furniture, but do not stain it; the customer chooses the stain

Modular Design

- **Modular Design**
  - A form of standardization in which component parts are grouped into modules that are easily replaced or interchanged
    - Advantages
      - easier diagnosis and remedy of failures
      - easier repair and replacement
      - simplification of manufacturing and assembly
      - training costs are relatively low
    - Disadvantages
      - Limited number of possible product configurations
      - Limited ability to repair a faulty module; the entire module must often be scrapped

Design for Robustness

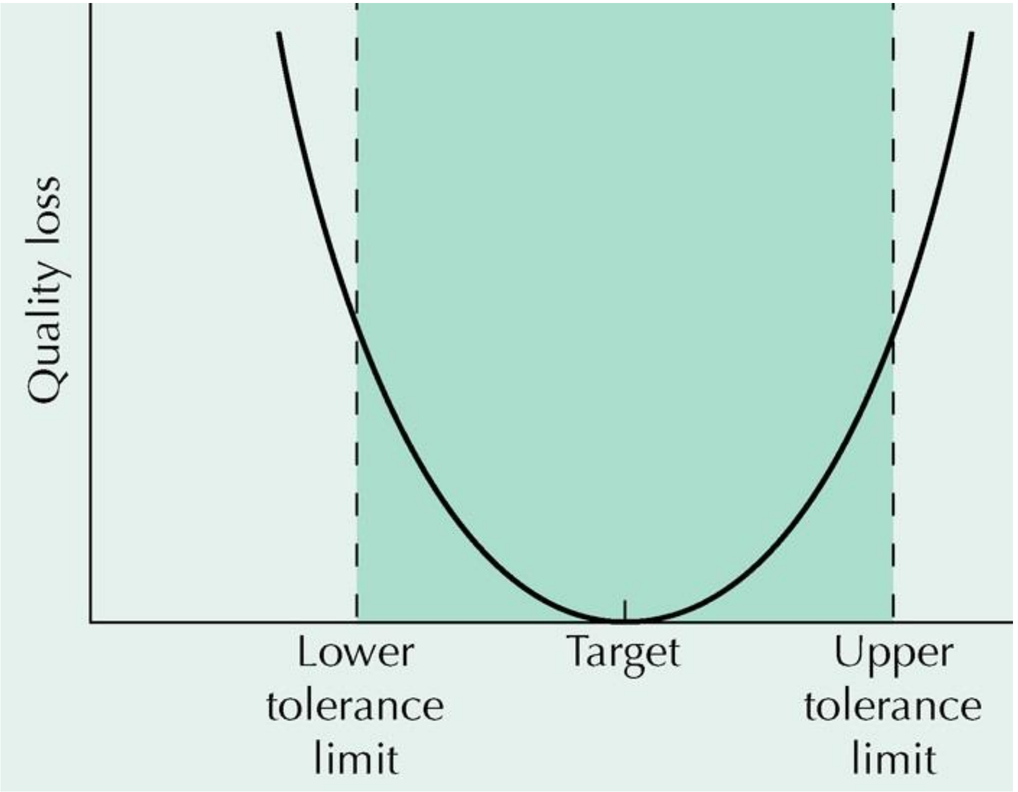
- Robust product
  - designed to withstand variations in environmental and operating conditions
- Robust design
  - yields a product or service designed to withstand variations
- Controllable factors
  - design parameters such as material used, dimensions, and form of processing
- Uncontrollable factors
  - user's control (length of use, maintenance, settings, etc.)

Design for Robustness

- Tolerance
  - allowable ranges of variation in the dimension of a part
- Consistency
  - consistent errors are easier to correct than random errors
  - parts within tolerances may yield assemblies that are not within limits
  - consumers prefer product characteristics near their ideal values

Taguchi's Quality Loss Function

- Quantifies customer preferences toward quality
- Emphasizes that customer preferences are strongly oriented toward consistency
- Design for Six Sigma (DFSS)



- Quadratic loss function

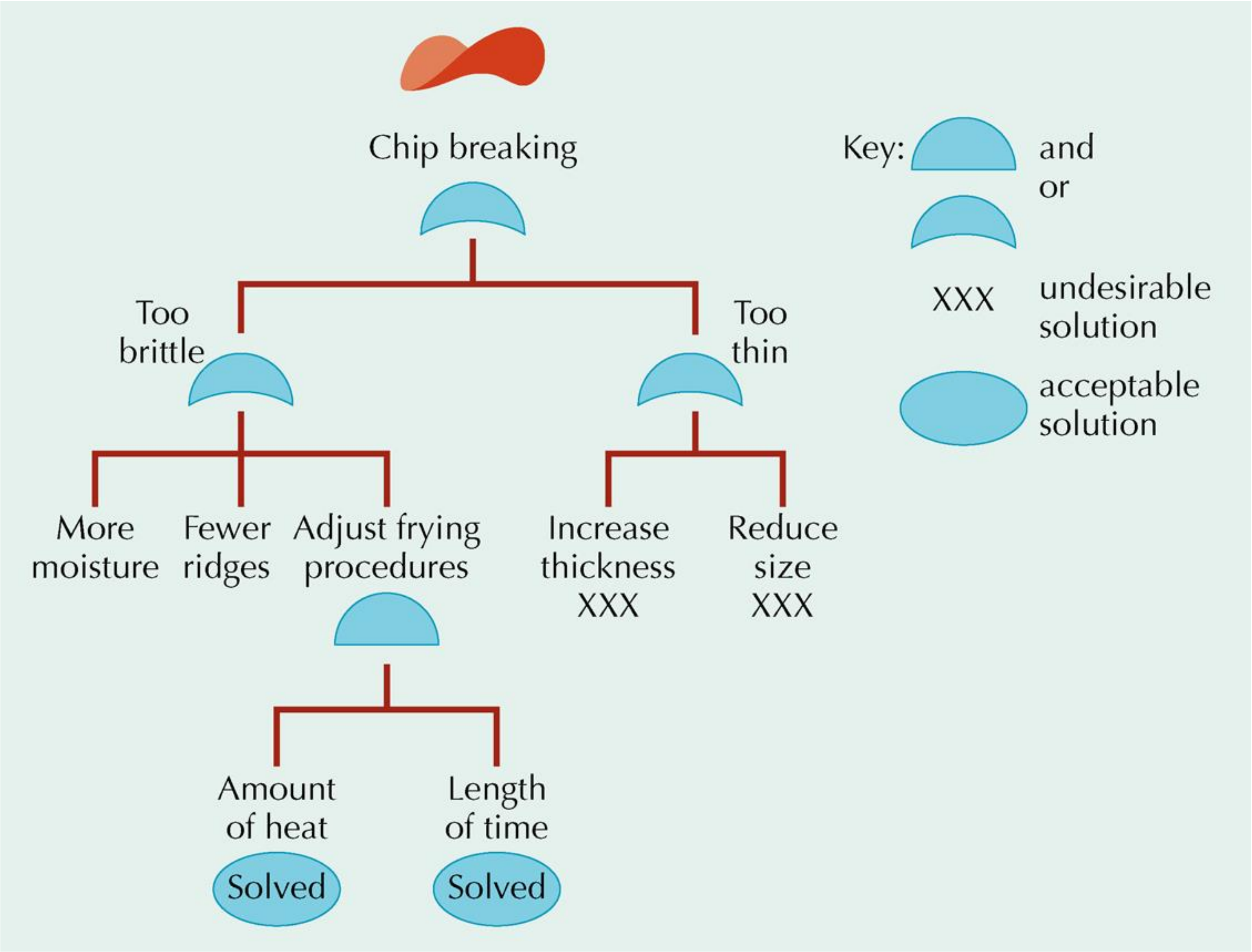
Design Quality Review

- Review designs to prevent failures and ensure value
  - Failure mode and effects analysis (FMEA)
    - a systematic method of analyzing product failures
  - Fault tree analysis (FTA)
    - a visual method for analyzing interrelationships among failures
  - Value analysis (VA)
    - helps eliminate unnecessary features and functions

FMEA for Potato Chips

Failure Mode	Cause of Failure	Effect of Failure	Corrective Action
Stale	◆low moisture content ◆expired shelf life ◆poor packaging	◆tastes bad ◆won’t crunch ◆thrown out ◆lost sales	◆add moisture ◆ cure longer ◆better package seal ◆shorter shelf life
Broken	◆too thin ◆too brittle ◆rough handling ◆rough use ◆poor packaging	◆can’t dip ◆poor display ◆injures mouth ◆chocking ◆perceived as old ◆lost sales	◆change recipe ◆change process ◆change packaging
Too Salty	◆outdated recipe ◆process not in control ◆uneven distribution of salt	◆eat less ◆drink more ◆health hazard ◆lost sales	◆experiment with recipe ◆experiment with process ◆introduce low salt version

Fault Tree Analysis (FTA)



Value Analysis (VA)

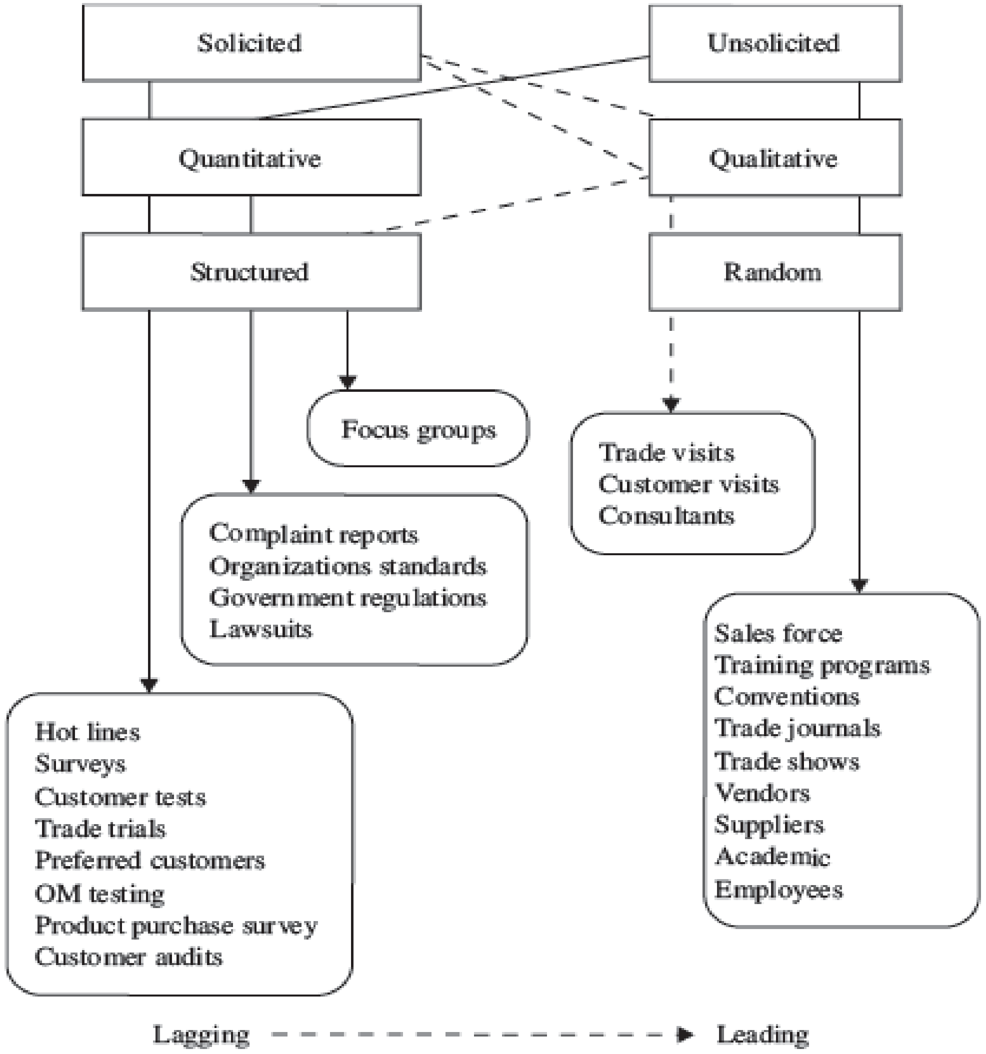
- Eliminate unnecessary features and functions
- Used by multifunctional design teams

- Define essential functions of an item
- Determine the value of the functions
- Determine the cost of providing the functions
- Compute Value/Cost ratio
- Design team works to increase the ratio

Quality Function Deployment (QFD)

- Translates voice of customer into technical design requirements
- Displays requirements in matrix diagrams
  - first matrix called “house of quality”
  - series of connected houses

Voice of Customer



Types of Customer Information and How to Collect It

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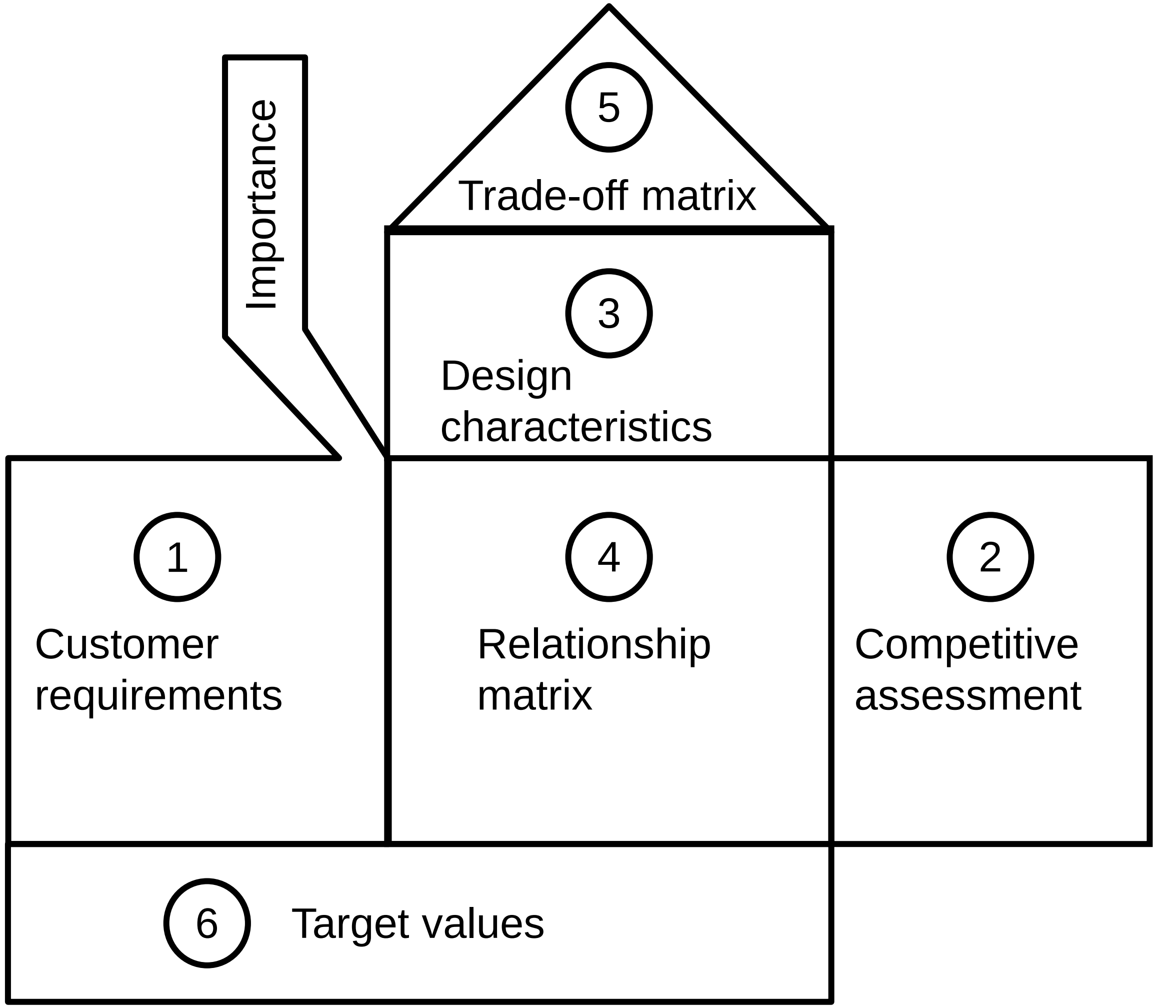
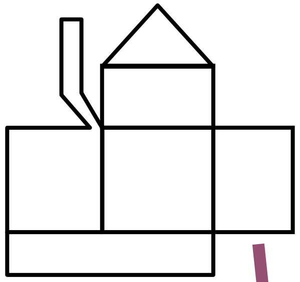
House of Quality

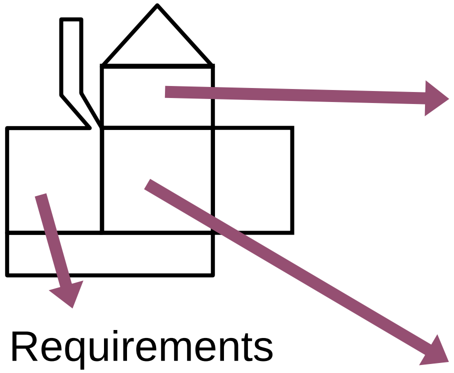


Competitive Assessment of Customer Requirements



	Customer Requirements		Competitive Assessment 1	2	3	4	5
Irons well	Presses quickly	9		B A		X	
	Removes wrinkles	8		AB		X	
	Doesn't stick to fabric	6		X		BA	
	Provides enough steam	8			AB		X
	Doesn't spot fabric	6			X AB		
	Doesn't scorch fabric	9			A XB		
Easy and safe to use	Heats quickly	6		X	B	A	
	Automatic shut-off	3					ABX
	Quick cool-down	3		X	A B		
	Doesn't break when dropped	5		AB		X	
	Doesn't burn when touched	5		AB X			
	Not too heavy	8		X		A	B

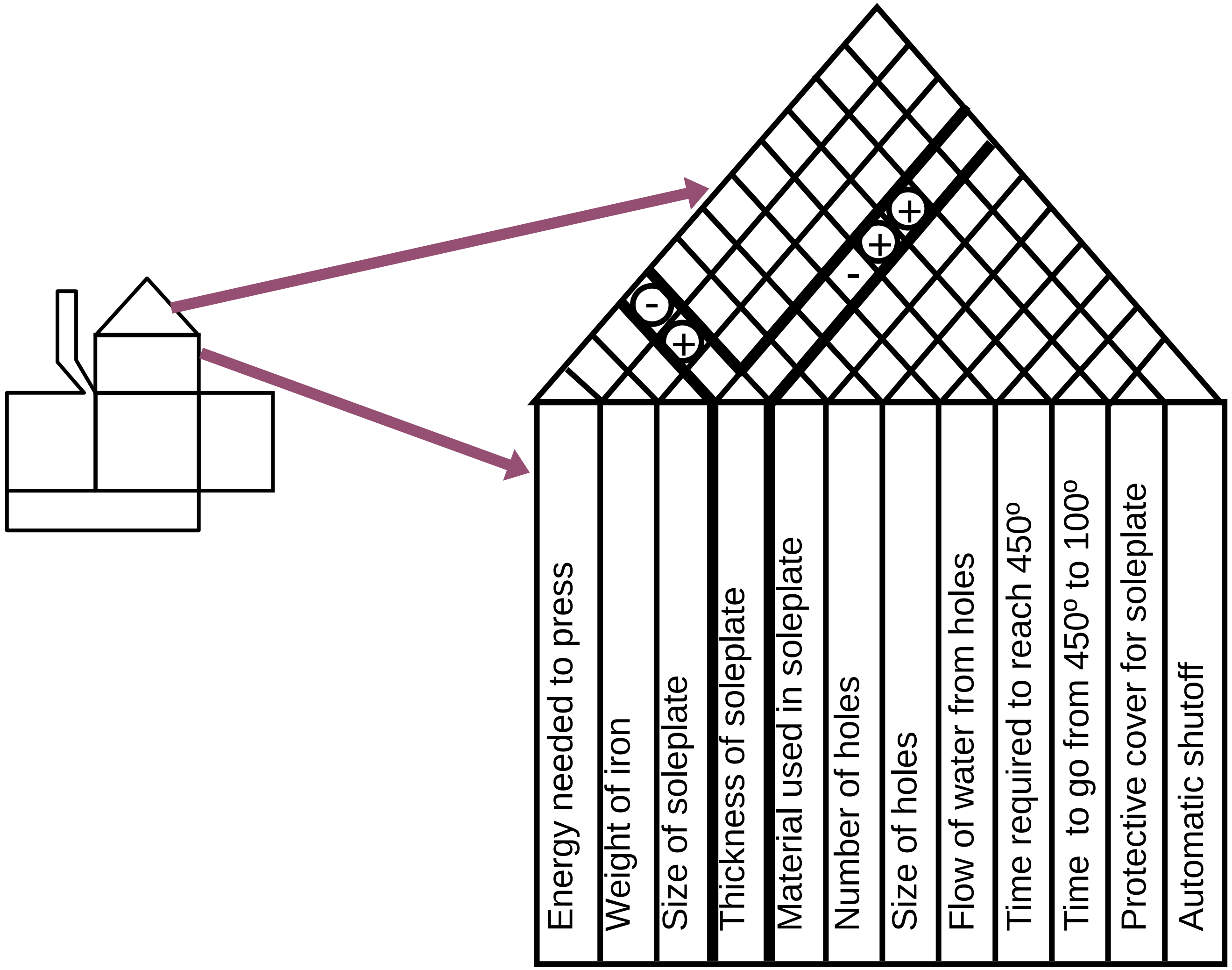
From Customer Requirements to Design Characteristics



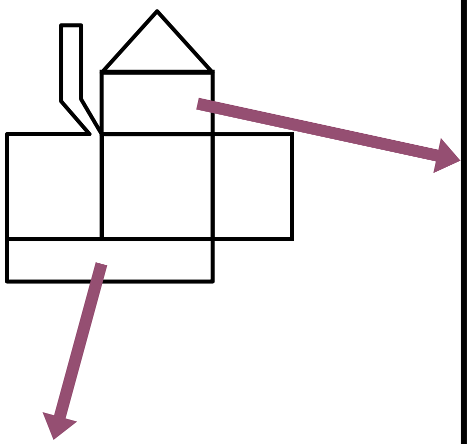
Customer Requirements

	Customer Requirements	Energy needed to press	Weight of iron	Size of soleplate	Thickness of soleplate	Material used in soleplate	Number of holes	Size of holes	Flow of water from holes	Time required to reach 450º F	Time to go from 450º to 100º	Protective cover for soleplate	Automatic shutoff
Irons well	Presses quickly	-	-	+	+	+				-			
	Removes wrinkles		+		+		+	+	+				
	Doesn't stick to fabric		-			+			+		+	+	
	Provides enough steam			+			+	+	+				
	Doesn't spot fabric					+	-	-	-				
	Doesn't scorch fabric				+	+			+	-	+		
Easy and safe to use	Heats quickly			-	-					+		-	
	Automatic shut-off												+
	Quick cool-down			-	-	+					+		
	Doesn't break when dropped		+	+	+							+	
	Doesn't burn when touched				+						+	+	+
	Not too heavy	+	-	-	-	+						-	

Tradeoff Matrix

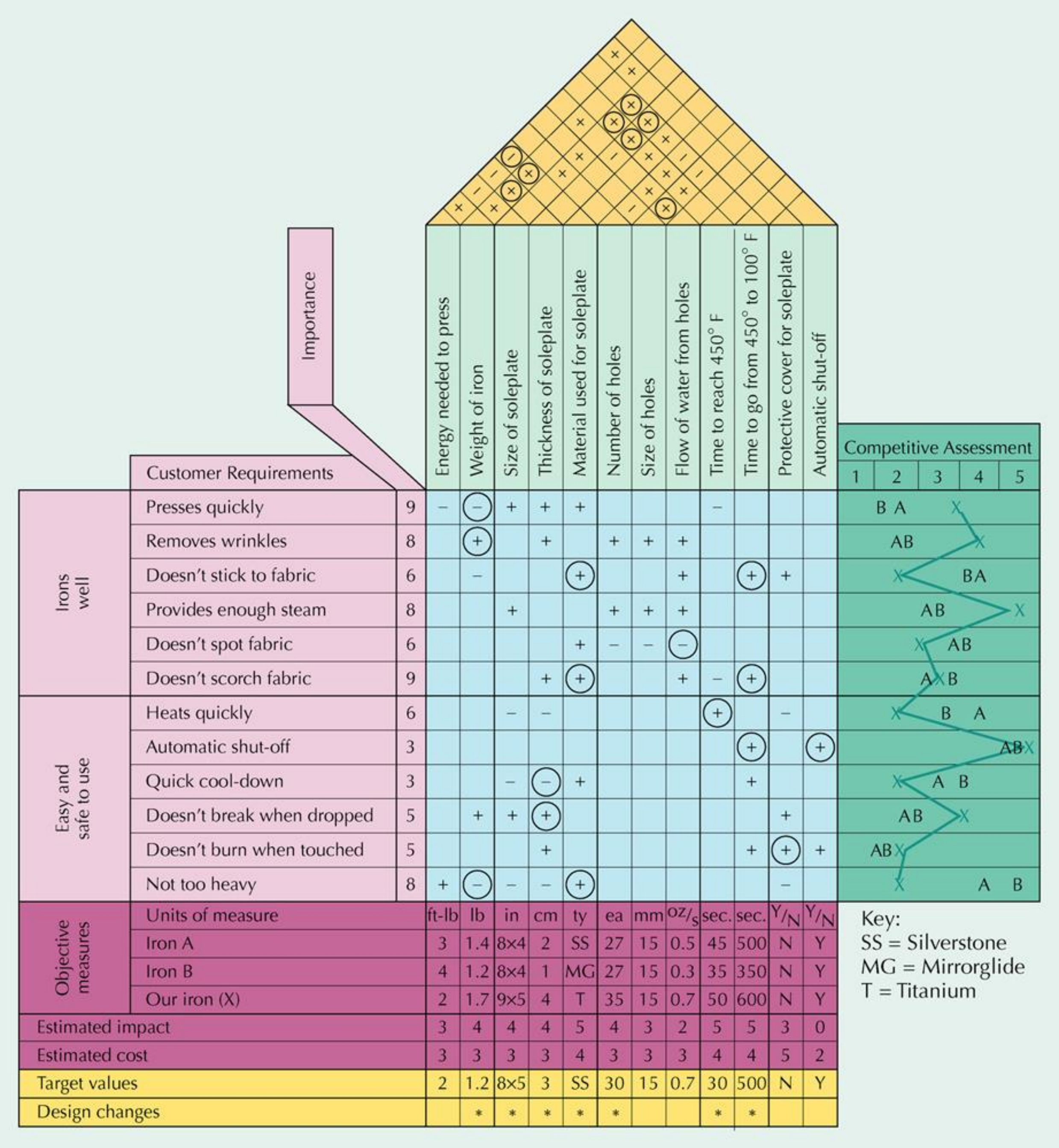


Targeted Changes in Design

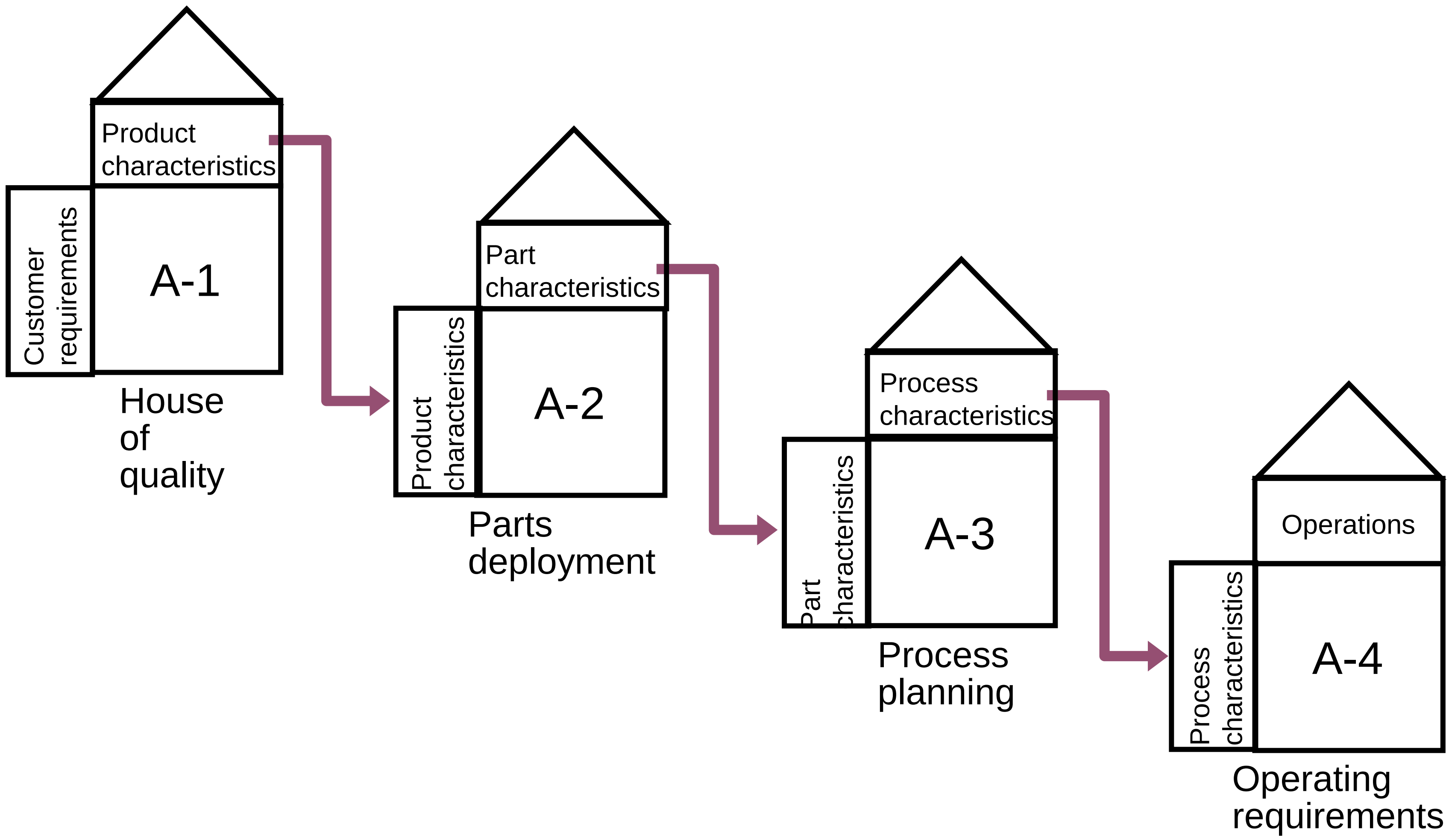


		Energy needed to press	Weight of iron	Size of soleplate	Thickness of soleplate	Material used in soleplate	Number of holes	Size of holes	Flow of water from holes	Time required to reach 450º	Time to go from 450º to 100º	Protective cover for soleplate	Automatic shutoff
Objective measures	Units of measure	ft-lb	lb	in.	cm	ty	ea	mm	oz/s	sec	sec	Y/N	Y/N
	Iron A	3	1.4	8x4	2	SS	27	15	0.5	45	500	N	Y
	Iron B	4	1.2	8x4	1	MG	27	15	0.3	35	350	N	Y
	Our Iron (X)	2	1.7	9x5	4	T	35	15	0.7	50	600	N	Y
Estimated impact		3	4	4	4	5	4	3	2	5	5	3	0
Estimated cost		3	3	3	3	4	3	3	3	4	4	5	2
Target values				1.2	8x5	3	SS	30			30	500	
Design changes			*	*	*	*	*			*	*		

Completed House of Quality



A Series of Connected QFD Houses



Quality Function Deployment (QFD)

- Translates voice of customer into technical design requirements
- Displays requirements in matrix diagrams
  - first matrix called “house of quality”
  - series of connected houses

Benefits of QFD

- Promotes
  - better understanding of customer demands
  - better understanding of design interactions
- Involves manufacturing in design process
- Provides documentation of design process